

LUXEMBOURG'S NATIONAL INVENTORY REPORT 1990-2019

ADMINISTRATION DE L'ENVIRONNEMENT

D'ËMWELTVERWALTUNG

Am Déngscht vu Mënsch an Ëmwelt

ENVIRONMENT AGENCY



LE GOUVERNEMENT
DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de l'Environnement, du Climat
et du Développement durable

Submission under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol.

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The authors of this report want to express their thanks to all experts from other institutions involved in the preparation of the Greenhouse Gas Inventory of Luxembourg for their contribution to the continuous improvement of the inventory.

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Executive Summary

ES.1. Background information on greenhouse gas (GHG) inventories and climate change

ES.1.1. Background information on climate change

Climate as such is the totality of all atmospheric conditions at a particular location. It undergoes natural variability. Since industrialisation started some 150 years ago, mankind has been influencing the climate via the emission of greenhouse gases. In 1994, by setting up the United Nations Framework Convention on Climate Change (UNFCCC), the nations of the world came together to start a process to prevent dangerous effects of climate change. However, the Convention did not include binding commitments. To go this step further, the Kyoto Protocol was adopted in 1997 and sets binding targets for 37 industrialized countries for the period 2008-2012. The so-called Doha Agreement extends the Kyoto Protocol until 2020, however it has not yet been set into force.

ES.1.2. Background information on greenhouse gas (GHG) inventories

In order to evaluate the trend of greenhouse gas emissions and the progress in achieving the reduction target, it is necessary to regularly compile an emissions inventory. The compilation of these inventories follows rules as set up by the UNFCCC and the Kyoto Protocol.

ES.2. Summary of National Emission and Removal related Trends

ES.2.1. Greenhouse Gas (GHG) Inventory

In 2019, Luxembourg's greenhouse gas emissions amounted to a total of 10.743 million tonnes calculated in CO₂ equivalents (CO₂ eq) – excluding land-use, land-use change and forestry (LULUCF). Table 0-1 splits the total GHG emissions of Luxembourg into the different greenhouse gases reported in the inventory. Carbon dioxide (CO₂) was the main source of greenhouse gases (GHG) in Luxembourg. This source counted for 90.78% of the total GHG emissions (excluding LULUCF). The second source of GHG was methane (CH₄) with 5.42% of the total emissions excluding LULUCF. Nitrous oxide (N₂O) was the third source with 3.13%. Fluorinated gases (F-gases) only accounted for 0.67% of the total emissions excluding LULUCF, with hydrofluorocarbons (HFCs) representing 0.57%, and sulphur hexafluoride (SF₆) representing 0.10% of the national total (excl. LULUCF).

In 2019, total GHG emissions increased by 1.68% compared to 2018 and are currently 15.59% below their base year level¹. For the different GHG, trends over the period 1990-2019 (and 2018-2019) were as follows:

¹ The base year for CO₂, CH₄ and N₂O is 1990. For the F-gases, the base year is 1995.

- CO₂: -17.52% (+1.92%)
- CH₄: -0.35% (-1.47%)
- N₂O: +5.69% (+1.71%)
- F-gases: +324.72%² (-4.16%)

Carbon dioxide emissions, over the period 1990-2019, are characterised by a V-shape evolution driven by changes in the sources of emissions: declining emissions in industry due to technological changes in the iron and steel production, increasing emissions from transport and natural gas fired power plants. The last emission peak was attained in 2005 and, since then, the emissions seem to be continuously decreasing until 2009. This decrease was interrupted in 2010, where emissions increased by 5.4% compared to 2009. However, since 2005 emissions have decreased by 19.3%.

Total methane emissions have remained fairly stable over the period 1990-2019. In 2019, reduced methane emissions were observed in waste management (-32.70%) as compared to 1990, and increasing emissions in agriculture (+6.47%) and in energy use (+5.55%), the latter being mainly due to an upward trend for fugitive emissions from natural gas distribution and use and, to a lesser extent, to a downward trend of combustion related emissions in the energy production industries and the commercial and residential sectors.

Nitrous oxide emissions development between 1990 and 2019 is closely linked to an increase of liquid fuels related emissions from combustion activities (+153.02% in the Energy sector) and to emissions from the waste sector (+99.36%) that could not be balanced by declining emissions from the agriculture (-13.14%) and industrial products and product use sectors (-48.68%). Total N₂O emissions (excl. LULUCF) have increased by 5.69% since 1990.

With regard to F-gases, HFCs emissions increased by 304.94% in 2019 compared to the base year (1995) mainly due to the increasing use of mobile and stationary cooling equipment. Likewise, SF₆ emissions showed a 495.90% increase between 1995 and 2019 due to, in large parts, the increasing use of high-voltage electrical devices and noise reduction windows.

Finally, when including emissions and removals from land use, land use change and forestry (LULUCF), Luxembourg's greenhouse gas emissions amounted to a total of 10430.41 million tonnes CO₂ eq. (incl. LULUCF) in 2019. Net removals from the LULUCF sector amounted to 312.39 Gg CO₂ eq. Since 1990, net emissions have decreased by 468.22% per cent (the sector was a source of net emissions in 1990 (84.84 Gg CO₂ eq.) and a source of net removals in 1991-2019).

ES.2.2. KP-LULUCF activities

In 2019, Article 3.3 activities were a net sink in Luxembourg and net CO₂ removals amounted to 127 Gg CO₂ eq. Removals from afforestation/reforestation amounted to 161 Gg CO₂. About 4/5 of these gains were caused by the C stock increases in living biomass, 1/5 was due to increases in soil carbon and litter at the afforestation/reforestation (AR) areas. In the same year, emissions from deforestation amounted to 34 Gg CO₂. About 1/2 were due to biomass losses, and 1/2 due to C stock losses in litter and soil.

Under Article 3.4, CO₂ removals from the activity forest management amounted to 215 Gg CO₂ eq. By taking into account the FMRL of 418 Gg CO₂ eq and a technical correction of 21.07 Gg CO₂ eq, the activity forest management becomes a net source of 141.38 Gg CO₂ eq. Due to a lack of reliable data, emissions or sinks due to HWP could not be estimated.

2 The trend indicated here corresponds to the period 1995 to 2019, as the base year for F-gases is 1995.

ES.3. Overview of Source and Sink Category Emission Estimates and Trends

ES.3.1. Greenhouse Gas Inventory

Table 0-2 splits the total GHG emissions of Luxembourg into the five CRF sectors included in the inventory. In 2019, the energy sector accounted for 86.36% of the total GHG emissions, excluding LULUCF. Two sectors represented between 6% and 7% of the total emissions, excluding LULUCF: industrial processes and product use (6.28%) and agriculture (6.63%). The remaining sectors³ (LULUCF (-2.91%), waste⁴ (0.73%) and other (NO)) were each below 5.0% of the total GHG emitted in Luxembourg in 2019.

For the different sectors, trends over the period 1990-2019 (and 2018-2019) were as follows:

- Energy: -9.94% (+1.82%)
- Industrial processes & product use: -58.04% (+2.70%)
- Agriculture: +0.14% (-0.20%)
- LULUCF: -468.22% (+64.05%)
- Waste: -26.14% (-5.53%)
- Other: NA (NA)

Since 1990, emission reductions were observed in all sectors except for agriculture, especially for energy use and production related emissions whose contributions to the total GHG emissions, excluding LULUCF, ranged from 80.94% to 86.36% over the period 1990 to 2019. Within the energy sector, the fastest growing sub-sectors were energy industries (1A1) and transportation (1A3): +557.01% and +135.62%, respectively between 1990 and 2019 (+1.19% and +2.31% from 2018 to 2019). For the other sub-sectors, the observed trends between 1990 and 2019 are -81.21% for manufacturing industries (1A2), +22.57% for the other sectors (1A4), -96.23% for Other (1A5), and +59.11% for fugitive emissions from fuels (1B).⁵

Trends in agriculture, which was the second largest sector in 2019 in terms of GHG emissions, were overall stable between 1990 and 2019: declining GHG emissions were observed for agricultural soils (-13.42%), whereas enteric fermentation increased by 3.55%, liming by 3959.77% and manure management by 14.06%. For inventory submission 2021, Luxembourg started to also compile the GHG emissions from urea application and other carbon-containing fertilizers. While no urea related emissions were occurring in the agriculture sector prior to 2005, the GHG emissions from carbon-containing fertilizers show a decrease of 30.94% in 2019 compared to 1990 levels.

The third largest sector in Luxembourg with regard to 2019 GHG emissions, i.e. industrial processes and product use, shows a declining trend between 1990 and 1998, then a relative stabilisation. This evolution was mainly driven by process changes that occurred in the steel industry (recorded under 2C1), which moved from blast to electric arc furnaces between 1994 and 1998. As a consequence, GHG emissions of the iron and steel industry decreased by 89.24% since 1990. Compared to 2018, emissions from industrial processes and product use increased by 2.70% in 2019, which is mainly due to an increase in the category 2.A - Mineral industry.

³ The sector "other" is not reported for Luxembourg.

⁴ The waste sector covers only landfilled waste, wastewater handling and composting activities. Waste incineration, which is the main treatment method for municipal waste in Luxembourg, is carried out in the sole incinerator of the country where energy is recovered. Consequently, waste incineration related emissions are accounted for in CRF sector 1 – Energy (details in Chapters 3 and 8 respectively).

⁵ Fugitive emission growth is closely linked to natural gas use in Luxembourg.

In the waste sector, the main source of GHG was solid waste disposal on land (5A), but its weight decreased over the period 1990-2019 due to the combination of reduced amounts of landfilled waste and increased emissions arising from composting activities (5B). GHG emission reductions for solid waste disposal on land (-50.21% between 1990 and 2019) still drove a reduction for the overall waste sector despite rising emissions from composting. Wastewater handling emissions (5D) decreased by 44.82% over the same period.



From this analysis, it is obvious that the biggest challenge Luxembourg is facing, with regard to GHG emissions reduction, is the limitation of emissions from the energy sector, and more particularly from the transportation sector. Detailed explanations on the very high shares of CO₂ from the energy sector will be provided in Chapter 2, when analysing trends in Luxembourg's GHG emissions. Also, specific national circumstances are to be kept in mind when appreciating GHG emissions trends and composition in Luxembourg. These circumstances will be exposed in Chapter 2 as well.

ES.3.2. KP-LULUCF activities

In 2019, Article 3.3 activities were a net sink in Luxembourg and net CO₂ removals amounted to 127 Gg CO₂ eq. Removals from afforestation/reforestation amounted to 161 Gg CO₂. About 4/5 of these gains were caused by the C stock increases in living biomass, 1/5 was due to increases in soil carbon and litter at the afforestation/reforestation (AR) areas. In the same year, emissions from deforestation amounted to 34 Gg CO₂. About 1/2 were due to biomass losses, and 1/2 due to C stock losses in litter and soil.

Under Article 3.4, CO₂ removals from the activity forest management amounted to 215 Gg CO₂ eq. By taking into account the FMRL of 418 Gg CO₂ eq and a technical correction of 21.07 Gg CO₂ eq, the activity forest management becomes a net source of 141.38 Gg CO₂ eq. Due to a lack of reliable data, emissions or sinks due to HWP could not be estimated.

ES.4. Other information: Emission Estimates and Trends of Indirect GHG and SO₂

Some indirect GHG – NO_x, CO, NMVOCs – and SO₂ emissions are recorded and reported in the inventory. The emissions of these air pollutants are estimated and reported under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). For more details on the emissions of these pollutants please refer to Luxembourg's Air Pollutant Emission Inventory and its related Informative Inventory report, which are both published on the Center on Emission Inventories and Projections website:

http://www.ceip.at/ms/ceip_home1/ceip_home/status_reporting

Table 0-1– Luxembourg’s GHG emissions and removals (excl. LULUCF) – overview by main gases: 1990-2019. Percentages are relative to the total GHG emissions excluding LULUCF.

Gg (1000 t) CO ₂ eq	1990 (base year)	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CO₂	11823.34	12443.14	12209.70	12354.74	11542.46	9151.71	9201.61	8553.96	7675.93	8127.85	8709.92	9207.45	9983.58	10458.92	11828.91	12087.02	11919.75	11316.96	11183.69	10638.34	11207.25	11102.38	10866.20	10320.57	9836.04	9347.99	9092.74	9261.34	9568.44	9752.16
excl. LULUCF	92.90%	93.06%	92.96%	92.99%	92.65%	90.75%	90.67%	90.08%	89.10%	89.52%	90.18%	90.70%	91.35%	91.96%	92.67%	92.94%	92.86%	92.35%	92.11%	91.74%	92.04%	92.11%	92.03%	91.57%	91.01%	90.54%	90.21%	90.57%	90.78%	
CH₄ (1)	584.29	597.16	581.58	586.44	574.08	589.23	598.55	593.62	591.42	596.69	588.19	593.86	594.15	583.56	579.29	577.94	574.17	583.35	593.50	594.63	594.28	569.59	561.70	566.09	579.21	585.26	589.46	596.93	590.94	582.25
	4.59%	4.47%	4.43%	4.41%	4.61%	5.94%	5.90%	6.25%	6.87%	6.57%	6.09%	5.85%	5.44%	5.13%	4.54%	4.44%	4.47%	4.76%	4.89%	5.13%	4.88%	4.73%	4.76%	5.02%	5.36%	5.67%	5.85%	5.81%	5.59%	5.42%
N₂O (2)	318.47	329.37	336.49	330.53	325.72	326.24	329.17	325.86	322.31	326.67	326.63	309.15	305.94	284.89	310.29	294.31	293.64	299.68	307.34	305.04	313.92	316.50	312.49	312.77	316.46	315.09	325.81	330.23	330.94	336.60
excl. LULUCF	2.50%	2.46%	2.56%	2.49%	2.61%	3.24%	3.24%	3.43%	3.74%	3.60%	3.38%	3.05%	2.80%	2.50%	2.43%	2.26%	2.29%	2.45%	2.53%	2.63%	2.58%	2.63%	2.78%	2.93%	3.05%	3.23%	3.22%	3.13%	3.13%	
HFCs (3)	0.00	0.00	0.49	12.94	14.19	15.15	17.33	20.10	22.96	26.21	31.08	38.25	41.51	41.75	41.93	40.47	43.37	47.76	50.25	51.40	53.67	56.55	58.91	62.45	66.64	66.73	65.17	68.57	64.70	61.36
	0.00%	0.00%	0.04%	0.10%	0.11%	0.15%	0.17%	0.21%	0.27%	0.29%	0.32%	0.38%	0.38%	0.37%	0.33%	0.31%	0.34%	0.39%	0.41%	0.44%	0.44%	0.47%	0.50%	0.55%	0.62%	0.65%	0.65%	0.67%	0.61%	0.57%
PF₆s (3)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SF₆ (3)	1.28	1.37	1.47	1.57	1.68	1.75	1.94	2.10	2.16	2.24	2.36	2.97	3.58	4.17	4.73	5.31	5.73	6.17	6.58	6.99	7.29	7.75	8.14	8.51	8.90	9.37	9.72	9.90	10.20	10.43
	0.01%	0.01%	0.01%	0.01%	0.01%	0.02%	0.02%	0.02%	0.03%	0.02%	0.03%	0.03%	0.04%	0.04%	0.04%	0.04%	0.04%	0.05%	0.05%	0.06%	0.06%	0.06%	0.07%	0.08%	0.08%	0.09%	0.10%	0.10%	0.10%	0.10%
Total GHG excluding LULUCF	12727.38	13371.04	13134.73	13286.22	12458.12	10084.08	10148.60	9495.63	8614.78	9079.66	9658.18	10151.68	10928.76	11373.29	12765.15	13005.05	12836.66	12253.91	12141.35	11596.40	12176.42	12052.77	11807.44	11270.40	10807.26	10324.43	10082.90	10266.98	10565.23	10742.80
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: Environment Agency

Note:

- (1) The methane emissions are converted in CO₂ equivalents by multiplying the emissions by 25, i.e. the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon.
- (2) The nitrous oxide emissions are converted in CO₂ equivalents by multiplying the emissions by 298, i.e. the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.
- (3) The F-gases are those not covered by the Montreal Protocol, i.e. HFCs, PFCs and SF₆, expressed in CO₂ equivalents using the global warming potential (GWP) values based on the effects of GHG over a 100-year time horizon.

Table 0-2– Luxembourg’s GHG emissions and removals – overview by main CRF Sectors: 1990-2019. Percentages are relative to the total GHG emissions excluding LULUCF.

Gg (1000 t) CO ₂ eq	1990 (base year)	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1. Energy	10301.39	11006.02	10846.21	11010.85	10295.26	8260.38	8368.24	7830.97	7111.27	7529.84	8088.92	8645.01	9417.09	9946.49	11267.14	11550.84	11335.99	10740.04	10660.82	10184.63	10740.47	10621.83	10421.94	9891.46	9401.60	8918.88	8641.00	8803.94	9111.46	9277.24
	80.94%	82.31%	82.58%	82.87%	82.64%	81.92%	82.46%	82.47%	82.55%	82.93%	83.75%	85.16%	86.17%	87.45%	88.26%	88.82%	88.31%	87.65%	87.81%	87.83%	88.21%	88.13%	88.27%	87.77%	86.99%	86.39%	85.70%	85.75%	86.24%	86.36%
2. Industrial Processes	1608.85	1531.70	1465.57	1455.31	1360.52	1004.21	950.60	842.68	685.17	724.36	753.46	706.72	727.20	675.27	731.19	702.50	756.78	752.98	703.63	633.58	658.31	670.07	639.37	622.17	632.63	624.02	646.32	656.72	657.31	675.07
	12.64%	11.46%	11.16%	10.95%	10.92%	9.96%	9.37%	8.87%	7.95%	7.98%	7.80%	6.96%	6.65%	5.94%	5.73%	5.40%	5.90%	6.14%	5.80%	5.46%	5.41%	5.56%	5.42%	5.52%	5.85%	6.04%	6.41%	6.40%	6.22%	6.28%
3. Agriculture	711.34	725.43	714.38	710.01	700.23	717.98	725.90	715.51	710.00	717.73	710.66	694.57	677.78	640.72	661.97	646.51	638.55	653.88	668.91	671.76	682.22	669.74	656.16	666.46	681.95	695.76	711.51	721.56	713.75	712.35
	5.59%	5.43%	5.44%	5.34%	5.62%	7.12%	7.19%	7.54%	8.24%	7.90%	7.36%	6.84%	6.20%	5.63%	5.19%	4.97%	4.97%	5.34%	5.51%	5.79%	5.60%	5.56%	5.56%	5.91%	6.31%	6.74%	7.06%	7.03%	6.76%	6.63%
4. Land use, land-use change and forestry	84.84	-210.46	-560.70	-664.50	-464.70	-584.58	-630.55	-722.39	-605.17	-699.02	-722.13	-704.15	-700.78	-655.60	-675.41	-620.65	-524.51	-432.36	-448.01	-429.10	-118.08	-289.53	-380.31	-557.83	-470.84	-420.10	-507.87	-374.74	-190.42	-312.39
	0.67%	-1.57%	-4.27%	-5.00%	-3.73%	-5.80%	-6.21%	-7.61%	-7.02%	-7.70%	-7.48%	-6.94%	-6.41%	-5.76%	-5.29%	-4.77%	-4.09%	-3.53%	-3.69%	-3.70%	-0.97%	-2.40%	-3.22%	-4.95%	-4.36%	-4.07%	-5.04%	-3.65%	-1.80%	-2.91%
5. Waste	105.80	107.89	108.58	110.04	102.11	101.50	103.86	106.47	108.34	107.73	105.15	105.38	106.69	110.81	104.85	105.21	105.34	107.00	107.98	106.42	95.42	91.13	89.97	90.30	91.08	85.77	84.06	84.77	82.71	78.14
	0.83%	0.81%	0.83%	0.83%	0.82%	1.01%	1.02%	1.12%	1.26%	1.19%	1.09%	1.04%	0.98%	0.97%	0.82%	0.82%	0.87%	0.85%	0.92%	0.78%	0.78%	0.76%	0.76%	0.80%	0.84%	0.83%	0.83%	0.83%	0.78%	0.73%
6. Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total GHG including LULUCF	12812.22	13160.58	12574.03	12621.71	11993.43	9499.50	9518.05	8773.25	8009.61	8380.64	8936.05	9447.54	10227.99	10717.69	12089.74	12384.40	12312.16	11821.55	11693.34	11167.30	12058.34	11763.24	11427.13	10712.56	10336.42	9904.34	9575.03	9892.24	10374.80	10430.41
Total GHG excluding LULUCF	12727.38	13371.04	13134.73	13286.22	12458.12	10084.08	10148.60	9495.63	8614.78	9079.66	9658.18	10151.68	10928.76	11373.29																

1 Introduction

1.1 Background information on greenhouse gas inventories and climate change

1.1.1 Background information on climate change

1.1.1.1 Global Warming

Global warming is the increase in the average temperature of Earth's near-surface air and oceans since the mid-20th century and its projected continuation. Global surface temperature increased 0.74 ± 0.18 °C between the start and the end of the 20th century (IPCC, 2007). The Intergovernmental Panel on Climate Change (IPCC) concludes that most of the observed temperature increases since the middle of the 20th century was very likely caused by increasing concentrations of greenhouse gases resulting from human activity such as fossil fuel burning and deforestation. The IPCC also concludes that variations in natural phenomena such as solar radiation and volcanic eruptions had a small cooling effect after 1950.

Climate model projections summarized in the latest IPCC report indicate that the global surface temperature is likely to rise a further 1.1 to 6.4 °C during the 21st century. The uncertainty on this estimate arises from the use of models with differing sensitivity to greenhouse gas concentrations and the use of differing estimates of future greenhouse gas emissions. Most studies focus on the period leading up to the year 2100. However, warming is expected to continue beyond 2100 even if emissions stop, because of the large heat capacity of the oceans and the long lifetime of carbon dioxide in the atmosphere.

An increase in global temperature will cause sea levels to rise and will change the amount and pattern of precipitation, probably including expansion of subtropical deserts. Warming is expected to be strongest in the Arctic and would be associated with continuing retreat of glaciers, permafrost and sea ice. Other likely effects include changes in the frequency and intensity of extreme weather events, species extinctions, and changes in agricultural yields. Warming and related changes will vary from region to region around the globe, though the nature of these regional variations is uncertain.

1.1.1.2 Climate Change in Luxembourg

Annual mean temperatures for Luxembourg-City are nowadays usually above the 30 years averages of the last century. Indeed, the 1951-1980, the 1961-1990 or the 1971-2000 mean yearly temperatures for the capital city – around 9°C – are nowadays regularly exceeded: since the turn of the 21st century, annual mean temperatures are comprised between 9.3°C (2001) and 11.3°C (2007), 9.9°C in 2016. The variation of yearly averages is mainly driven by variations in air temperatures during winter seasons. Other meteorological stations disseminated throughout the country show similar results. With regard to other meteorological parameters – rainfalls, sunshine hours, relative humidity – no clear trends can be identified yet, probably because the very small size of the country (2 586 km²) limits the identification of such changes.

Climate change effects are also witnessed by increasing frost-free periods, earlier blooming seasons and higher flood frequencies over the last 20 years. For the future, higher average yearly temperatures are anticipated with consequences on public health (heat waves), floods (higher frequency and intensity), vegetation cycles (longer periods with frost risks after early blooming) and forests (degradation of its phytosanitary state).

More details are provided in Section 2.1.2 of this NIR.

1.1.1.3 The Convention, the Kyoto Protocol and its flexible mechanisms

In 1992, Luxembourg signed the United Nations Framework Convention on Climate Change (UNFCCC) which sets an ultimate objective of stabilizing atmospheric concentrations of greenhouse gases at levels that would prevent “dangerous” human interference with the climate system. Such levels, which the Convention does not quantify, should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

The UNFCCC covers all greenhouse gases not covered by the Montreal protocol: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) as well as hydrogenated fluorocarbons (HFCs), perfluorated halocarbons (PFCs), sulphur hexafluoride (SF₆) and nitrogen trifluoride (NF₃).

Five years after adoption of the Climate Change Convention in 1997, governments took a further step forward and adopted the Kyoto Protocol (KP). Building on the Convention, the Kyoto Protocol sets out legally binding constraints on greenhouse gas emissions and “mechanisms” aimed at cutting the cost of curbing emissions. Under the terms of the Protocol, the industrialised parties – known as Annex 1 countries – pledged to reduce their greenhouse gas (GHG) emissions by 5% below the 1990 levels by the period 2008–2012. The European Union is also a Party to the Convention and the KP and agreed on a reduction target of 8% below 1990 levels during the five-year commitment period from 2008 to 2012. The EU and its Member States decided to achieve this goal jointly, for Luxembourg an emission target of minus 28% was set.

During an extensive review process in 2007, the so called Pre-commitment period review, the percentual reduction commitments of the Annex 1 countries were converted and fixed to absolute emission values, the so called assigned amounts.

Luxembourg signed the KP on 29th April 1998, and ratified the protocol on 31st May 2002. The KP entered into force on 16 February 2005, triggered by Russia’s ratification in November 2004 which fulfilled the requirement that at least 55 Parties to the Convention ratified the Protocol.

The Protocol sets out three ‘flexible mechanisms’ to help countries meet their obligations to cut emissions.

Emission Trading: Article 17 of the Kyoto Protocol allows Annex I Parties (basically, the industrialised nations) to purchase the rights to emit GHG from other Annex I countries which have reduced their GHG emissions below their assigned amounts. Trading can be carried out by intergovernmental emission trading, or entity-source trading where assigned amounts are allocated to sub-national entities.

Joint Implementation: Article 6 allows an Annex I Party to gain a credit (converted to Assigned Amounts) by investing in another Annex I country in a project which reduces GHG emissions.

Clean Development Mechanism: Article 12 allows an Annex I country (or companies in an Annex 1 country) which funds projects in developing countries (non-Annex I Party) to get credits for certified emission reductions providing that “benefits” accrue for the host country.

Tradable emission permits tie the emissions to a fixed ceiling, the costs of emission reduction being as low as possible.

The final assessment on compliance with the goals of the first commitment period of the KP will be made in the true up process after finalization of the last review reports in 2015.

The so called Doha Agreement extends the Kyoto Protocol until 2020, establishing a second commitment period. However, it has not yet been set into force as by the end of 2014 only 23 Parties have deposited their instruments of acceptance (144 are needed).

Independently of the setting into force of the Doha Agreement, the European Community has fixed its goal in the so called Effort Sharing Decision (Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020), with the goal of a 20% cut of emissions below the 1990 emission level by 2020. The ESD Directive also sets national emission targets for the member states, Luxembourg's target is -20% related to 2005 (not considering the sectors/sources regulated by the EU ETS).

1.1.2 Background information on greenhouse gas inventories

As a Party to the UNFCCC, Luxembourg is required to produce and regularly update national greenhouse gas emission inventory. To date, GHG inventories have been produced for the years 1990 to 2019. Furthermore Parties shall submit a National Inventory Report (NIR) containing detailed and complete information on their inventories, in order to ensure the transparency of the inventory.

Responsible for the preparation of Luxembourg's National Greenhouse Gas Inventory as well as the preparation of the NIR is the Unité surveillance et évaluation de l'environnement of the Environment Agency, under the political responsibility of the Ministry for the Environment, Climate and Sustainable Development.

The present NIR documents Luxembourg's GHG emission inventory in accordance with the updated UNFCCC reporting guidelines on annual inventories. It is aimed at complying with decisions 11/CP.4, 3/CP.5, 18/CP.8, 14/CP.11, 15/CP.17 and 24/CP.19 of the COP and with European Parliament and Council Decision 280/2004/EC as amended by Regulation 525/2013 concerning a mechanism for monitoring Community GHG emissions and for implementing the Kyoto Protocol. It includes a description of the methodologies and data sources used for estimating emissions by sources and removals by sinks, a discussion of these estimates and their trends (including an analysis of the key source categories), and information on recalculation, uncertainties, quality assessment and quality control.

This report is an update of the previous NIR submitted in 2020.⁶ It is based on data submitted to the UNFCCC in the Common Reporting Format (CRF) on 15th April 2021: submission 2021v1.⁷ Besides being a submission under the UNFCCC, submission 2021v1 is also a mandatory submission under the Kyoto Protocol.

6 Luxembourg's National Inventory Report dated 15 April 2020 (covering inventory years 1990 to 2018)

7 Submission 2020v1 can be downloaded from:

a) The Central Data Repository of the European Environment Information and Observation Network (EIONET) of the European Environment Agency (EEA): http://cdr.eionet.europa.eu/lu/eu/mmr/art07_inventory/ghg_inventory/envxmtk_q/

b) The UNFCCC web site: <https://unfccc.int/ghg-inventories-annex-i-parties/2020>

The structure of this NIR follows, as much as possible, the outlines as set out in the updated UNFCCC reporting guidelines on annual inventories following incorporation of the provisions of decision 24/CP.19 (see document FCCC/CP/2013/10/Add.3)⁸, as well as the annotated outline of the NIR that can be found on the UNFCCC website.⁹

This report was compiled by Dr Nora Becker (Environment Agency) and Dr Marc Schuman (Environment Agency). Specific responsibilities for this 2021 NIR have been as follows:

Executive Summary:	Marc Schuman, Nora Becker, Max Wolter, Tim Mirgain
Chapter 1:	Marc Schuman, Nora Becker (key category analysis & uncertainties)
Chapter 2:	Max Wolter, Nora Becker, Marc Schuman
Chapter 3:	Marc Schuman, Nora Becker, Max Wolter
Chapter 4:	Ermin Hadzic, Pierre Dornseiffer
Chapter 5:	Marie-Josée Mangen
Chapter 6:	Tim Mirgain with the help of Georges Kugener, Willibald Croi and Peter Weiss (UBA Vienna);
Chapter 7:	Tim Mirgain, Fabien Wahl, Dominique Manetta, Tom Bechet
Chapters 8 & 9:	Marc Schuman
Chapter 10:	Marc Schuman, Nora Becker
Chapter 11:	Tim Mirgain with the help of Willibald Croi and Peter Weiss (UBA Vienna);
Chapter 12:	Martine Kemmer, Nora Becker, Tim Mirgain
Chapter 13:	Marc Schuman
Chapter 14:	Martine Kemmer, Nora Becker
Chapter 15 & 16:	Marc Schuman
Layout:	Nora Schintgen

The GHG inventory reviewed in the present NIR covers the period 1990-2019 and contains information on anthropogenic emissions by sources and removals by sinks for direct GHG (CO₂, CH₄, N₂O, HFCs, PFCs, SF₆ and NF₃). With regard to indirect greenhouse gases (CO, NO_x, NMVOCs) and SO₂, though also recorded in this inventory, they are derived from the air pollutant emission inventory Luxembourg is compiling for the United Nations Economic Commission for Europe's Convention on Long-Range Transboundary Air Pollution (UN-

⁸ <http://unfccc.int/resource/docs/2006/sbsta/eng/09.pdf>

⁹ Annotated outline of the National Inventory Report including reporting elements under the Kyoto Protocol:
http://unfccc.int/files/national_reports/annex_i_ghg_inventories/reporting_requirements/application/pdf/annotated_nir_outline.pdf

ECE CLRTAP). Consequently, indirect GHG and SO₂ emissions are not discussed in this NIR. For more details on the emissions of these pollutants please refer to Luxembourg's Air Pollutant Emission Inventory and its related Informative Inventory report, which are both published on the Center on Emission Inventories and Projections website¹⁰.

1.1.3 Background information on supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol

Besides the information that Parties to the Convention have to report annually, Parties to the Kyoto Protocol are additionally required to report supplementary information necessary to determine compliance with the regulations of the Protocol. This information is generally referred to as "supplementary information under Article 7, paragraph 1 of the Kyoto Protocol". Main elements of this information are the reporting on Kyoto Protocol 3.3 and 3.4 activities and reporting on national registries and Kyoto Protocol units:

1.1.3.1 Article 3.3 and 3.4 activities

Luxembourg reports only the mandatory Art. 3.3 and Art. 3.4 activities. They include emissions/removals from human-induced Afforestation/Reforestation/Deforestation activities since 1990 (Art. 3.3) and forest management (Art. 3.4). In addition, Parties may elect to include emissions/removals from any of the following human-induced activities since 1990 (Art. 3.4): Cropland management, Grazing land management and Revegetation. Luxembourg has not elected Article 3.4 activities such as Cropland management, Grazing land management and Revegetation due to the lack of reliable data allowing producing realistic estimates of the activities covered under Article 3.4.¹¹

Furthermore, Parties had to elect the accounting frequency for 3.3 and 3.4 activities: annual or at the end of the Commitment Period (for all other sectors the accounting frequency is annually). For the mandatory art. 3.3 and art. 3.4 activities Luxembourg has chosen accounting at the end of the Commitment Period.

1.1.3.2 National registry and Kyoto Protocol Units

Each Party to the Kyoto Protocol has to operate a national registry following the standards as defined in the Data Exchange Standards for Registry Systems under the Kyoto Protocol. The registry is an electronic database for the administration of Kyoto units that are used to account for greenhouse gas emissions under the commitments of the Kyoto Protocol. Like banks recording balances and transactions of money in accounts belonging to individuals or other entities, registries record balances of units of greenhouse gas emissions, so called Kyoto units, which are allocated to countries or other entities. The registry ensures the precise tracking of holdings, issuances, transfers, cancellations and retirements of allowances and Kyoto units.

¹⁰ http://www.ceip.at/ms/ceip_home1/ceip_home/status_reporting

¹¹ Luxembourg's initial report under the Kyoto Protocol for the second commitment period (2013-2020) is available at http://unfccc.int/national_reports/initial_reports_under_the_kyoto_protocol/second_commitment_period_2013-2020/items/9499.php.

Different types of Kyoto units exist, e.g. depending on the source of emissions/removals:

- Assigned Amount Units (AAUs) are the tradable units of the Assigned Amount (AA), which a country with a reduction commitment (Annex B country) gets allocated.
- Removal Units (RMUs) are Kyoto units which Annex B Parties can generate e.g. through national afforestation and other sink projects.
- Emissions Reduction Units (ERUs) are generated by Joint Implementation projects.
- Certified Emissions Reductions (CERs) are generated from Clean Development Projects.

Additionally, registries of EC and EEA countries administrate the European Emissions Trading Scheme, the traded units are EU Allowances (EUAs).

For more information on the National Registry and Kyoto Protocol Units, please refer to chapters 12 and 14.

1.2 A Description of the national inventory arrangements

1.2.1 Institutional, legal and procedural arrangements

1.2.1.1 Overview of Luxembourg's obligations

Some obligations are directly linked with GHG emission reporting:

- Annual obligations under Regulation 525/2013/EC of the European Parliament and of the Council of 21 May 2013 on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change (known as Monitoring Mechanism Regulation, MMR) and repealing Decision 280/2004/EC of the European Parliament and of the Council of 11 February 2004 concerning a mechanism for monitoring Community GHG emissions and for implementing the Kyoto Protocol and Commission Decision 2005/166/EC of 10 February 2005 laying down rules implementing Decision 280/2004/EC;
- Obligations under the UNFCCC. Relevant COP Decisions and Guidelines are:
 - Decision 3/CP.5 – Guidelines for the preparation of National Communications by Parties included in Annex I to the Convention, Part I: UNFCCC Reporting Guidelines on Annual Inventories (referring to Document FCCC/CP/1999/7) revised with Decision 18/CP.8 (referring to Document FCCC/CP/2002/8);
 - Decision 4/CP.5 – Guidelines for the preparation of National Communications by Parties included in Annex I to the Convention, Part II: UNFCCC Reporting Guidelines on National Communications (referring to Document FCCC/CP/1999/7) revised with Decision 19/CP.8 (referring to Document FCCC/CP/2002/8);
 - Document FCCC/CP/1999/7 – Review of the Implementation of Commitments and of other Provisions of the Convention – UNFCCC Guidelines on Reporting and Review revised with Document FCCC/CP/2002/8;
 - Decision 11/CP.4 – National communications from Parties included in Annex I to the Convention;
 - Document FCCC/CP/2001/13/Add.3 – Report of the Conference of the Parties on its seventh session, held at Marrakech from 29 October to 10 November 2001, Addendum, Part two: Action taken by the Conference of the Parties, Volume III (Decision 20/CP.7: Guidelines for national systems under Article 5, paragraph 1, of the Kyoto Protocol; Decision 21/CP.7: Good practice guidance and adjustments under Article 5, paragraph 2, of the Kyoto Protocol; Decision 22/C.7: Guidance for the preparation of the information required under Article 7 of the Kyoto Protocol; Decision 23/CP.7: Guidelines for review under Article 8 of the Kyoto Protocol).
 - Decision 24/CP.19 - Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention – introducing the 2006 IPCC Guidelines.

Some provide, indirectly, information that can be used to produce GHG inventories:

- Annual obligations under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) and its Protocols comprising the annual reporting of national emission data on SO₂, NO_x, NMVOCs, NH₃, CO, TSP, PM₁₀, and PM_{2.5} as well as on the heavy metals Pb, Cd and Hg and persistent organic hydrocarbons (PAHs), dioxins and furans and hexachlorobenzene (HCB);
- Annual obligations under Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants, (known as the “NEC Directive”) comprising the annual reporting of national emission data on SO₂, NO_x, NMVOCs and NH₃;
- Obligations under the European Pollutant Emission Register (EPER), which was the first Europe-wide register for emissions from industrial facilities both into air and water. The legal basis of EPER is Article 15 of the IPPC Directive (EPER Decision 2000/479/EU), which stipulates that information on environmental pollution has to be provided to the public. The reporting years under EPER were 2001 or 2002 and 2004. EPER was replaced by the European Pollutant Release and Transfer Register (E-PRTR) in 2007, which was established by the E-PRTR Regulation No 166/2006.
- Obligations under the framework of the European Union Emission Trading Scheme (EU-ETS) established by Directive 2003/87/EC of the European Parliament. It includes heavy energy-consuming installations in power generation and manufacturing. The activities covered are energy activities, the production and processing of ferrous metals, the mineral industry and some other production activities. From 2012 onwards, CO₂ emissions from aviation have also been included. For the trading period 2013–2020 the scope of the EU ETS has been further extended to include additional installations from the metal and chemical industry and compressor stations.

1.2.1.2 Luxembourg’s National Inventory System

A new Grand-Ducal Regulation (GDR, 04/2017)- hereafter the “Regulation” – of April 2017 designates a **Single National Entity**, the **National Inventory Compiler** and the **National GHG Inventory Focal Point**. It also defines and allocates specific responsibilities for the realization of the GHG inventories both within the Single National Entity and within the other administrations and/or services that will be involved in the inventory preparation in the future. This Regulation also sets up a system for reporting on emissions of certain atmospheric pollutants under Directive (EU) 2016/2284, and more largely under the UNECE LRTAP Convention (CLRTAP). Consequently, the system put in place aims at reporting under both the UNFCCC and CLRTAP. Moreover, the Regulation proposes a national system for reporting on policies and measures and for reporting on projections of anthropogenic GHG emissions by sources and removals by sinks as required by Article 12 of the MMR Regulation (Regulation 525/2013/EC). This new Regulation of April 2017 repealed the one from 1st August 2007.

1.2.1.2.1 Single National Entity and other cross-cutting roles

The Grand-Ducal Regulation designates the Minister having environment in his or her attributions as the “**Single National Entity**” (SNE). The SNE designates both the UNFCCC and CLRTAP **National Focal Points** (NFPs), but also the **Inventory and Projections Focal Points as well as the Inventory and Projections Sectoral Experts**. With regard to GHG inventory reporting under the UNFCCC and the MMR Regulation, the overall management of the SNE is assigned to the **Inventory Focal Point** that is presently located at the Environment Agency – *Unité surveillance et évaluation de l’environnement* – and which also acts as **National Inventory Compiler** (NIC) compiling and checking the information and GHG emission estimates coming from sector experts working in other administrations or services (Figure 1-1). The Inventory Focal Point and the NIC are actually the same person.¹²

12 Luxembourg being a small country, its administrations and public services are small too. Hence, it is frequent that its staff members wear different hats. Nevertheless, this conjunction of responsibilities makes sense.

The Environment Agency is also the Inventory Focal Point for reporting under the CLRTAP and Directive (EU) 2016/2284.

The Environment Agency has therefore the “technical” knowledge and responsibility for the GHG inventories, but the “political” responsibility is staying with the Ministry for the Environment, Climate and Sustainable Development – hereafter designated as MECDD – acting as UNFCCC **National Focal Point** (NFP). Thus, it is the Department that officially submits the inventories and their related reports to the UNFCCC Secretariat and to the EC (see Article 11 of the Regulation).

Thus, Luxembourg has adopted an **integrated approach** to avoid redundant and overlapping activities in different administrative services. This concentration of air emissions reporting in one department also allows an improved consistency between different reporting schemes. As an ex-ample, indirect GHG and SO₂ emissions that are to be recorded in the GHG inventory are extracted and adapted from the CLRTAP/NEC reporting schemes.

With regard to inputs for the monitoring of GHG emissions, having E-PRTR managed by the *Unité surveillance et évaluation de l’environnement* of the Environment Agency (and EU ETS also within the Environment Agency) ensures easy access to facilities’ reported fuel and/or emissions that are subsequently integrated in GHG emissions calculations. The Environment Agency also gathers information from establishments and installations subordinated to operational permits to carry out certain activities, the so-called “*établissements classés*”. There, too, valuable information for the inventories is found. More details on these AD and, sometimes, EF sources are presented in Section 1.4.

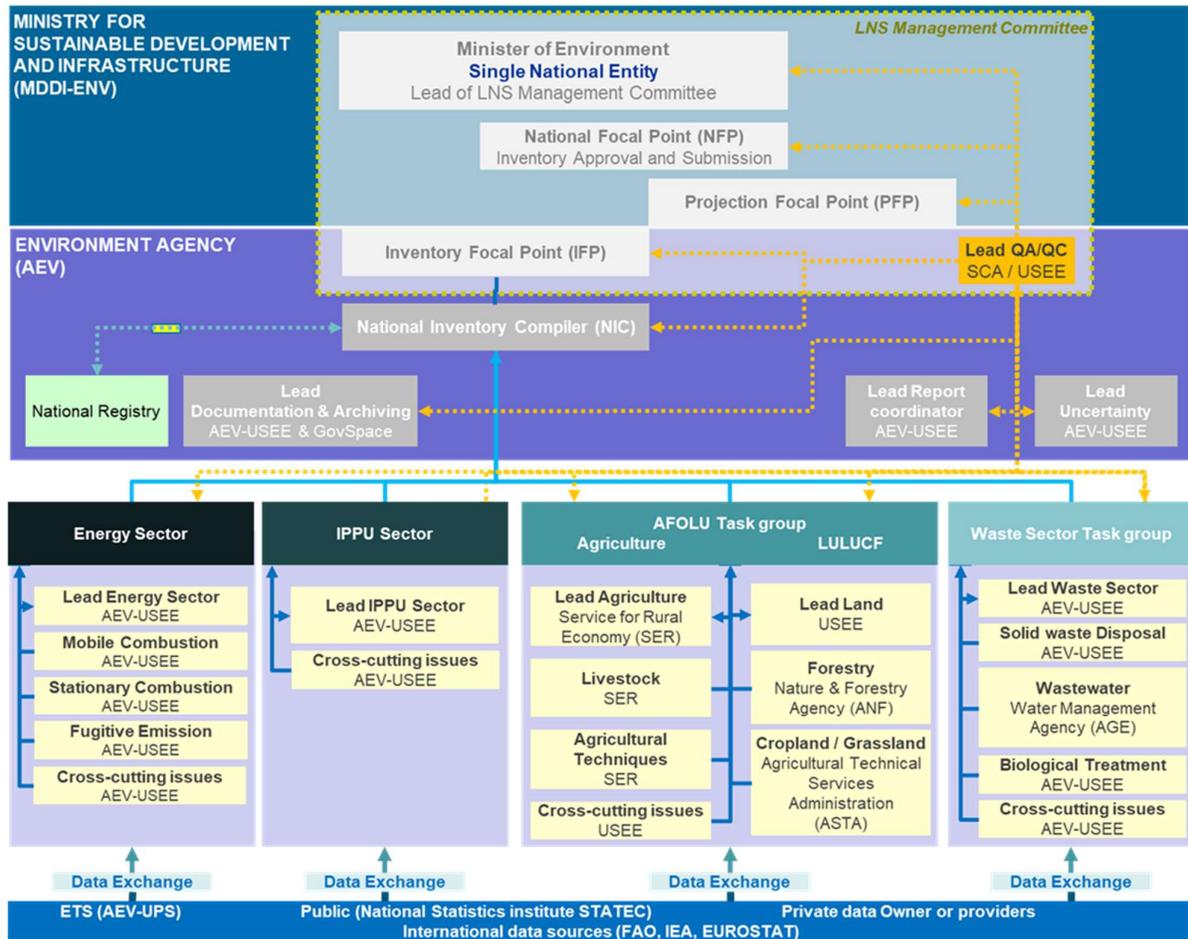
With regards to outputs from the *Unité surveillance et évaluation de l’environnement*, not only are they used for the various inventory reporting obligations (GHG, CLRTAP, NEC), but also for other reporting activities, such as those linked to Spatial Data Information (such as the EC INSPIRE Directive¹³) and under the Shared Environmental Information System.¹⁴ Of course, these are also used for various national publications, as well as, for defining policies and measures (PaMs).

Figure 1-1 **summarizes the organisation** of the GHG reporting in Luxembourg in accordance with the national Regulation for setting-up a National Inventory System (NIS), as well as the data flow process that is implied by the setting-up of the NIS. The *Unité surveillance et évaluation de l’environnement* of the Environment Agency not only collects and validates AD, EFs, parameters and emission estimates from sector experts, but also produces emission estimates. This flexibility is introduced in Luxembourg’s system to ensure a better quality for the reporting of GHG emissions.

13 <http://inspire.jrc.it/>.

14 <http://ec.europa.eu/environment/seis/index.htm>.

Figure 1-1- Luxembourg's NIS and data flow process according to the regulation of April 2017



1.2.1.2.2 Specific responsibilities for the GHG Inventory compilation and development process

Article 4 of the Regulation indicates that the Single National Entity designates sectoral experts. Articles 6 and 8 describe the tasks of the Inventory Focal Point and of the Sectoral Experts. In a few words, the Inventory Focal Point – i.e. the Environment Agency – provides sector experts for all the IPCC Sectors except Agriculture, LULUCF and Wastewater Handling (Figure 1-1). It is also the Agency that:

- manages the NIS and coordinates the work on GHG Inventories by informing the experts of any changes and evolutions in the Guidelines;
- as National Inventory Compiler (NIC), compiles the GHG emissions estimates produced by sector experts;
- prepares the NIR (notably on the basis of chapters received from the sector experts), including the Key Category Analysis (KCA) and the calculation of the uncertainties;
- prepares and defines work plans to secure timely data supply;
- assists sector experts in their assignments and their training;
- defines and approves, together with sector experts, activity/background data (AD), emission factors (EF), methods to estimate GHG emissions;
- archives the relevant information on the inventories and the NIS;

- implements recommendations from the quality assurance/quality control (QA/QC) annual exercise (section 1.6).

Article 8 describes the tasks that fall to sector experts, among others:

- choice of the best methods to evaluate GHG emissions, using IPCC Guidelines (these methods have to be approved by the Single National Entity as indicated above);
- collection of the necessary AD and EFs;
- calculation of emission estimates;
- recalculation of emission estimates when possible and desirable: new AD sources, new parameters, new methods, etc.;
- proceeding with first quality checks (using, inter alia, tools embedded in CRF Reporter that allow to verify completeness and consistency);
- preparation of the NIR relevant chapters.

Finally, Article 10 indicates that activity/background data providers have to transmit quality AD using formats, and respecting the deadlines, defined by the Single National Entity.

Table 1-1– CRF sector responsibilities within the NIS

CRF Sector	AD	Choice of EFs	Emissions estimation methods
Energy, excl. road transportation – CRF 1 except 1A3b	AEV – STATEC	AEV	AEV
Road transportation – CRF 1A3b	AEV – STATEC – SNCT	AEV	AEV
Industrial Processes – CRF 2	AEV	AEV	AEV
Agriculture – CRF 3	ASTA – SER	ASTA – SER	ASTA – SER
LULUCF – CRF 4	ANF – SER – ASTA – AEV	ANF – SER – ASTA – AEV	ANF – SER – ASTA – AEV
Waste – CRF 5A, 5B & 5D	AEV	AEV	AEV
Wastewater Handling – CRF 5B	AGE	AGE	AGE

Abbreviations:

Ministry of Agriculture:

ASTA = Agriculture Technical Services Administration (*Administration des Services Techniques de l’Agriculture*): <http://www.asta.etat.lu/>

SER = Agriculture Economic Service (*Service d’Economie Rurale*): <http://www.ser.public.lu/>

Ministry of Economic Affairs & External Trade:

STATEC = National Statistical Institute: <http://www.statec.public.lu/fr/index.html>

Ministry for the Environment, Climate and Sustainable Development: <http://www.emwelt.lu/>:

ANF = Nature & Forestry Administration (*Administration de la Nature et des Forêts*)

AEV = Environment Agency (*Administration de l’Environnement*)

AGE = Water Management Administration (*Administration de la Gestion de l’Eau*): <http://www.eau.public.lu/>

Ministry for Mobility and Public Works:

SNCT = Technical Vehicle Inspection Administration (*Société Nationale de Contrôle Technique*): <http://www.snct.lu/>

1.2.1.2.3 Luxembourg's emissions trading registry

Luxembourg's emissions trading registry has been operational since 2005 and serves both as registry for the EU Emissions Trading Scheme, and as the national registry for Luxembourg as a Party of the Kyoto Protocol.

Since July 2013, Luxembourg's national registry was migrated to a European based consolidated system operated by the European Commission. Please refer to Chapter 14 for more information on the consolidated system.

1.2.2 Overview of inventory planning, preparation and management

The main planning of Luxembourg's GHG inventory is performed once a year during summer at the so called Decision Making Body meeting: a meeting between the Director of the Environment Agency, the head of the Unité surveillance et évaluation de l'environnement, the quality manager, and the national inventory compiler.

During the meeting, the quality manager and the national inventory compiler present an overview of the activities, during the previous reporting year, including information on audits and fulfilments of last year's improvement plan. On the basis of this report, the quality management system (QMS) is judged by the director and the head of the Unité surveillance et évaluation de l'environnement, in collaboration with the quality manager and the national inventory compiler. If required, measures to optimize the QMS are defined. Finally, the improvement plan is elaborated on the basis of the previously conducted discussions. It consists of two parts:

Quality management improvement plan: bases on findings of internal and external audits; it also includes a training plan for sector experts.

Inventory improvement plan: bases on particular findings of reviews of the GHG inventory.

The decision making body prioritises the recommended improvements (including a timeline and responsibilities) and cares for associated resources.

Table 1-2 gives an overview on the tasks of inventory preparation together with a typical timeline.

Table 1-2– Inventory preparation timeline

Task	Description	Deadline
Decision making body meeting	Evaluation of the fulfilment of the previous improvement plan Preparation of a plan for QMS and inventory improvement, i.a. based on audit and review findings.	Summer
Kick-Off	Meeting of sector experts, quality manager and national inventory compiler; definition of a work plan	Summer
Activity data collection	Collection of activity data, including contracting out studies.	November 1st
Inventory preparation	Estimation of emissions for all sources, including collection of background data.	December 1st
Compilation of national inventory	Stocking the database and transfer to CRF reporter ; key category analysis and uncertainty assessment	December 31
Quality checks	Tier 1 and Tier 2 QA/QC activities	December
Compilation of report (Short-NIR)	Compilation of an inventory report “Short NIR” and submission to the European Commission (Decision 280/2004/EC)	January 15
Preparation of NIR	Compilation of the National Inventory Report	January - March
EU Submission NIR	Submission of the National Inventory Report to the EC	March 15
UNFCCC Submission NIR	Submission of the National Inventory Report to the UNFCCC	April 15
Archive submission	All relevant calculation and documentation files as well as the NIR are archived on Sharepoint	May

Table 1-3 gives an overview on the registry related tasks for providing the supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol including a timeline.

Table 1-3– Timeline for registry related tasks

Task	Description	Deadline
Standard Electronic Format (SEF)	Compilation of the SEF for the previous year	January 15
Information on changes in the national registry	Preparation of the chapter on the changes in the national registry, which is part of the NIR	March 15
Information on accounting of Kyoto Protocol units	Preparation of the chapter on information on the accounting of Kyoto Protocol units, which is part of the NIR. Compilation of the files for the Standard Independent Assessment Report (SIAR), which are submitted together with the NIR.	March 15

Finally, an official approval process has been established between the Single National Entity (SNE, Environment Agency) and the UNFCCC National Focal Point (NFP, MECDD). Thus, the SNE notifies the NFP, in writing, that the inventory has been compiled according to the rules established by the UNFCCC and uploads the submission onto the Sharepoint data archive (see Section 1.3). The NFP informs the Minister in charge of environmental affairs accordingly. Upon acceptance, the NFP uploads the submission from the Sharepoint archive onto the UNFCCC submission portal and onto the European central data repository hosted by the EEA.

1.3 Inventory preparation, and data collection, processing and storage

1.3.1 GHG Inventory and KP-LULUCF inventory

Luxembourg's greenhouse gas inventory for the period 1990 to 2019 was compiled according to the recommendations for inventories set out in the revised UNFCCC reporting guidelines according to Decision 24/CP.19. IPCC Guidelines have been applied as much as possible. These Guidelines are:

- the 2006 IPCC Guidelines for National Greenhouse Gas Inventories¹⁵;
- the 2013 Revised Supplementary Methods and Good Practice Guidance arising from the Kyoto Protocol.

During the inventory preparation process, sector experts collect activity data, emission factors and all relevant information needed for estimating the emissions. The sector experts also have specific responsibilities regarding the choice of methods, data processing and archiving and for contracting studies, if needed. As part of the quality management system, the national inventory compiler approves the methodological choices. Sector experts are also responsible for performing Quality Control (QC) activities that are incorporated in the Quality Management System (QMS). All data collected together with emission estimates are archived on a central archiving system (see below), together with the well documented data sources in order to be able to perform future reconstructions of the inventory.

Supplementary information required under Article 7 of the Kyoto Protocol regarding KP-LULUCF is prepared by the same sector experts as for UNFCCC-LULUCF. Other Article 7 supplementary information is requested from Luxembourg's Emission Trading Registry, which is also located at the Environment Agency.

Data collection, processing and storage, including for KP-LULUCF inventory

For estimating GHG emissions, Luxembourg mostly used Microsoft Excel™ spreadsheets (Table 1-4).

Table 1-4 – Programs and software used for generating emission estimates

CRF Sector	Emissions calculated using ...
Energy – CRF 1 – stationary combustion, fugitive emissions	MS Excel 2016
Energy – CRF 1 – mobile combustion	NEMO 5.0.1 and MS Excel 2016
Industrial Processes – CRF 2	MS Excel 2016
Agriculture – CRF 3	MS Excel 2016 and the add-in software Palisade @Risk 7.5 I
LULUCF – CRF 4	MS Excel 2016
Waste – CRF 5	MS Excel 2016

This way of proceeding offers a very flexible system that can be easily adjusted to new requirements. It is only for the estimation of road transportation emissions, where a dedicated model is used:

NEMO 5.0.1 is a Microsoft Windows™ software tool for the calculation of emissions from road transport. The emissions calculated include all major pollutants (CO₂, CO, CH₄, NO_x, VOC, and PM) and several more (N₂O, NH₃, SO₂...). Data produced is then transformed

15 <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm>

using MS Excel spreadsheets into the UNFCCC common reporting format, according to the IPCC Guidelines, to comply with the reporting obligations under the UNFCCC.

GHG emission estimates produced by the sector experts are then being centralized and verified by the Single National Entity (i.e. the National Inventory Compiler (Environment Agency)).

A centralised data management and archiving system (Sharepoint) has been implemented. This system is hosted by the National IT Administration, and access is password protected. This system enables sector experts to quickly and easily exchange and store data between administrations, which are not connected through a single network. The data stored on this system are backed up daily for the needs of data security. Furthermore, as part of the QMS, backups of the entire inventory information are made regularly on write-protected DVDs. This ensures the necessary documentation and archiving for future reconstruction of the inventory and for the timely response to requests during the review process.

For the generation of the CRF tables and the XML submission file, Luxembourg used the latest version of the UNFCCC's CRF-Reporter, i.e. version 6.0.8. As a large number of GHG source categories are not occurring in Luxembourg, only around a hundred values per inventory year – other than notation keys – need to be transferred to the CRF-Reporter. This is why, so far, CRF Reporter has been “manually” populated by having recourse to “copy-paste” from Microsoft Excel™ inventory work files.

However, with the increasing number of LULUCF data, which needs to be transferred to the CRF-Reporter, this manual data transfer becomes prone to errors. Therefore, it is foreseen to centralise the emission estimates (and all the associated data such as EFs, AD, Documentation, etc) in a centralised database. Specific software tools embedded in this database would then allow the automatic data transfer into the CRF-reporter software, without the need of the “copy-paste” procedure. Currently, Luxembourg is in the process of switching to the centralised database, and it is expected that the automatic transfer will be used for the next submission. Nevertheless, this is not an absolute “must do” for Luxembourg since, as underlined above, yearly data to be included in CRF Reporter are not numerous. Furthermore, “manually” populating CRF Reporter offers concrete advantages compared to automated operations: mistakes and missing values can be directly identified, recalculations cross-checked, explanations for notation keys or recalculations not forgotten and documentation boxes filled accordingly when needed.

1.3.2 Quality assurance/quality control (QA/QC) procedures and extensive review of GHG inventory and KP-LULUCF inventory

QA/QC procedures are performed as defined in the QMS plan (see Chapter 1.6).

Quality assurance, control and plausibility assessments of the estimates are being performed through internal audits covering all sectors, by the SNE in collaboration with Umweltbundesamt Wien. In addition, various checking procedures, included in the CRF-Reporter software are undertaken.

The NIR is circulated after publication to experts that are involved in the estimation on greenhouse gas emissions in Luxembourg as identified by the National Inventory Compiler and the QA/QC manager.

Comments received from experts are considered for the inventory improvement plan.

1.4 Methodologies and Data Sources Used

1.4.1 GHG inventory

The following table briefly presents the activity data (AD) sources, the types of emission factors (EF) used, as well as the methods applied for estimating GHG emissions reported in this submission. A more detailed listing can be found in CRF table Summary 3.

Table 1-5 – Methodologies, data sources and EFs used by Luxembourg – main CRF Sectors

CRF Sector	CO ₂			CH ₄			N ₂ O		
	Method applied	AD	EF	Method applied	AD	EF	Method applied	AD	EF
Energy – CRF 1 – stationary combustion, fugitive emissions	Tier 1 Tier 2	NS PS Q TÜV	D CS PS	Tier 1	NS PS Q TÜV	D CS	Tier 1	NS PS Q TÜV	D
Energy – CRF 1 – mobile combustion	CIV CS	NS SNCT	CS	CIV	NS SNCT	OTH D	CIV	NS SNCT	OTH
Industrial Processes – CRF 2	Tier 2 CS	NS PS	CS PS	NA	NO	NA	NA	NO	NA
Agriculture – CRF 3	Tier 1	EJ NS	D	Tier 1 Tier 2	EJ NS	CS D OTH	Tier 1 Tier 2	EJ NS	CS D
LULUCF – CRF 4	Tier 1 Tier 2	NS EJ	CS D	NA	NA	NA	Tier 1	NS EJ	D
Waste – CRF 5	NA	NA	NA	Tier 1	NS Q PS	CS D	Tier 1	NS Q PS	PS D

Note: for F-gases (IPCC Category 2F) methods applied = CS; AD = NS & Q; EF = CS.

Abbreviations:

CS = Country Specific

CIV = NEMO

D = IPCC Default

EJ = Expert Judgement

NS = National Statistics

OTH = Other

PS = Plant Specific Data

Q = Specific Questionnaire/Survey/Annual Reports

TÜV = TÜV Rheinland, *Emissionskataster für das Großherzogtum*

Luxemburg, Köln, 1990

Detailed information on data sources for activity and emission data, as well as for EFs used by sector, can be found in the methodological chapters of this report (chapter 3 to 7). A few general comments are, however, presented in the next sub-sections.

1.4.1.1 Activity and background data

Data used to produce the annual air emission (including GHG) inventories are mainly:

- taken from official statistics published by the National Statistical Institute (STATEC). Concerning energy data (energy balance), STATEC has recently developed a new system for data collection, treatment, checking and compilation. This new system was implemented in such a way to ensure that both the needs of public administrations dealing with energy questions and the reporting obligations to the European regulation 1099/2008/EC on energy statistics and to the IEA (IEA Joint Questionnaires¹⁶), are fulfilled. The data sources and methodologies for preparing Luxembourg's energy balance as well as the new compilation system are described in STATEC 08_2010¹⁷;
- extracted from statistical information received by other ministries and public administrations;
- coming from information supplied directly by facilities (annual reports, emission measurement reports);
- on occasion, from specific surveys or questionnaires and from expert judgements.

For large point sources – and after careful assessment of data plausibility – activity data that are reported by facilities are preferably used. Indeed, these data usually reflect the actual consumptions better than aggregated national statistics data, because the facility is supposed having the best information about its own emissions. Such plant specific data have been used for CRF sectors 1 and 2.

Besides plant specific data collected under EU legal requirements, national obligations are also a source of activity and emission data for single facilities. This is the case under the law for “établissements classés”¹⁸ that imposes regular reporting obligations to those units – the “établissements classés” – which, by their activities, could represent a risk with regards to security, public health and convenience for both the citizens and the workers occupied in these units, as well as regards the environment.¹⁹ These “établissements classés” could be public or private industrial or commercial establishments and craft industries, as well as single specific equipments or processes within an installation.

Most of the plant specific data, whether they are collected for European or national obligations, are actually transmitted and managed by the Environment Agency which eases a more systematic use of data provided directly by facilities. In particular, it is investigated whether it will be feasible, both technically and legally, that facilities would report only once for various purposes – such as EU-ETS, E-PRTR, permitting activities, etc. – in order to avoid extra and unnecessary burden for them.

16 The energy balance is based on several databases mainly prepared by:

- Ministère de l'Economie et du Commerce Extérieur
- Ministère du développement durable et des infrastructures (département de l'environnement, département du transport)
- Administration de l'environnement: *Unité surveillance et évaluation de l'environnement, Unité permis et subsides, Registre des quotas d'émissions à effet de gaz de serre (ETS)*;
- Administration des Douanes et Accises (Ministère des Finances);
- Service Central de la Statistique et des Etudes Economiques (STATEC);
- Société Nationale des Chemins de fer Luxembourgeois (CFL)
- all relevant fuel importers and distributors;
- plant operators;

The methodology used to compile the energy balance follows the International Energy Agency (IEA) and Eurostat conventions. The aggregated balances are harmonised with the IEA tables.

17 <http://www.statistiques.public.lu/catalogue-publications/bulletin-Statec/2010/PDF-Bulletin-8-2010.pdf>

18 See http://www.environnement.public.lu/etablissements_classes/index.html (in French).

19 “Permitting activities”, i.e. activities subordinated to a permit.

1.4.1.2 Emission factors

For EFs, besides country-specific and plant specific factors derived from emission data transmitted by facilities (see above), it is also made use of default IPCC values published in the 2006 IPCC Guidelines, as well as in the 2013 KP Supplement for LULUCF. Other sources for EFs are the EMEP/EEA air pollutant emission inventory guidebook — 2019²⁰ and national / international studies or calculations leading to country-specific EFs.

1.4.2 KP-LULUCF inventory

Land use and land use change data are based on commercial satellite imagery, land cover maps held by the Nature and Forestry Administration and on information on agricultural practices from the Service of Rural Economics. These two institutions are the main data providers for the greenhouse gas reporting in the frame of the KP-LULUCF inventory.

Accordingly, the area of forest land reported for Afforestation/Reforestation and Deforestation (ARD) under the Kyoto Protocol has the same basis as the area reported for Land use changes from and to forests in the UNFCCC greenhouse gas inventory taking the different time frame (ARD areas starting with 1990) as well as the permanence of ARD areas into account.

Furthermore the methods used to estimate emissions/removals from ARD activities are of the same Tier method as those used for the UNFCCC reporting. These are described in detail in Chapter 11.

20 <https://www.eea.europa.eu/publications/emep-eea-guidebook-2019>

1.5 Brief description of key categories

The identification of key categories is described in Chapter 4 of the 2006 IPCC Guidelines. It stipulates that a key category is one that is prioritised within the National System because its estimate has a considerable influence on a country's total inventory of GHG in terms of the absolute level of emissions or removals, the trend in emissions or removals, or both. Any category meeting the 95% threshold in any year of the Level Assessment (LA) or in the Trend Assessment (TA) is considered a key category. Then, whenever a method used for the estimation of emissions/removals of a key category is not consistent with the requirements of the 2006 IPCC Guidelines, the method will have to be improved to reduce uncertainty, which is considered in the emission inventory improvement programme (see Chapter 10.4).

All notations, descriptions of identification and results for key categories included in this section are based on the 2006 IPCC Guidelines. The identification includes all reported GHG CO₂, CH₄, N₂O, HFC, PFC and SF₆, and all IPCC categories.

The key category analysis was performed using the Tier 1 approach based on submission 2021v1. It comprises a level assessment for all years between 1990 and 2019, as well as a trend assessment for the trend of the year 2019 with respect to base year emissions, i.e. 1990 (1995 for F-gases). Key categories have been identified excluding LULUCF categories and also for the full inventory including LULUCF.

1.5.1 GHG inventory (including and excluding LULUCF)

1.5.1.1 Level Assessment (Tier 1)

The key categories (LA) identified for 2019 are listed in Table 1-6 (excl. LULUCF) and Table 1-8 (incl. LULUCF). The 15 key categories without LULUCF comprise 10234.61 Gg CO₂e in 2019, which is a share of 95.27% of Luxembourg's total GHG emissions, excluding LULUCF.

Table 1-6 – 2019 key categories (Tier 1, LA) excluding LULUCF based on emission data reported in submission 2021v1

IPCC category	Category name	Fuel	Gas	2019 emissions in Gg CO ₂ e	Share in 2019 national total GHG emissions (excl. LULUCF)
1A1	Fuel combustion - Energy industries	gaseous	CO ₂	114.67	1.07%
1A1	Fuel combustion - Energy industries	other	CO ₂	108.07	1.01%
1A2	Fuel combustion - Manufacturing Industries and Construction	liquid	CO ₂	241.77	2.25%
1A2	Fuel combustion - Manufacturing Industries and Construction	solid	CO ₂	167.40	1.56%
1A2	Fuel combustion - Manufacturing Industries and Construction	gaseous	CO ₂	666.82	6.21%
1A2	Fuel combustion - Manufacturing Industries and Construction	other	CO ₂	89.88	0.84%
1A3b	Road Transportation	gasoline	CO ₂	1044.28	9.72%
1A3b	Road Transportation	Diesel oil	CO ₂	5023.89	46.77%
1A4	Fuel combustion – Other sectors	Liquid	CO ₂	825.39	7.68%
1A4	Fuel combustion – Other sectors	gaseous	CO ₂	826.51	7.69%
2A1	Cement production		CO ₂	394.79	3.67%
2A3	Glass production		CO ₂	63.98	0.60%
2C1	Iron & steel production		CO ₂	103.70	0.97%
3A	Enteric fermentation		CH ₄	401.55	3.74%
3D1	Direct N ₂ O emissions from managed soils		N ₂ O	161.90	1.51%
All	Sum of all 2019 key categories	all	all	10234.61	95.27%

Table 1-7 specifies for which years any source category has been identified as key category (LA) for from 1990 to 2019 (excl. LULUCF).

Table 1-7 – Key categories (Tier 1, LA) excluding LULUCF of submission 2021v1: 1990-2019

IPCC source category	gas	fuel	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	
1A1	CO ₂	gaseous						X			X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
1A1	CO ₂	other									X											X		X	X	X	X	X	X	X	X	X	
1A2	CO ₂	liquid	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A2	CO ₂	solid	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A2	CO ₂	gaseous	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A2	CO ₂	other																								X			X	X	X	X	
1A3b	CO ₂	gasoline	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A3b	CO ₂	diesel oil	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A4	CO ₂	liquid	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A4	CO ₂	gaseous	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A5	CO ₂	liquid											X																				
2A1	CO ₂		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2A3	CO ₂								X				X										X	X	X	X	X	X	X	X	X	X	
2C1	CO ₂		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2F1	F-gases																										X	X					
3A	CH ₄		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3B	CH ₄									X	X	X	X	X	X																X		
3D1	N ₂ O		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5A	CH ₄							X	X	X	X	X	X	X	X	X	X			X	X	X											

Table 1-8 indicates which source categories – including LULUCF - have been identified as key categories (LA) for 2019. The key categories comprise 10748.94 Gg CO₂e in the year 2019, which is a share of 95.45% of Luxembourg's 2019 total GHG emissions, including LULUCF.

Table 1-8 – 2019 key categories (Tier 1, LA) including LULUCF based on emission data recorded in submission 2021v1

IPCC	IPCC source category	Fuel	Gas	2019 emissions in Gg CO ₂ e	Share in 2019 national total GHG emissions (incl. LULUCF)
1A1	Fuel combustion - Energy industries	gaseous	CO ₂	114.67	1.02%
1A1	Fuel combustion - Energy industries	other	CO ₂	108.07	0.96%
1A2	Fuel combustion – Manufacturing industries and construction	liquid	CO ₂	241.77	2.15%
1A2	Fuel combustion – Manufacturing industries and construction	solid	CO ₂	167.40	1.49%
1A2	Fuel combustion – Manufacturing industries and construction	gaseous	CO ₂	666.82	5.92%
1A2	Fuel combustion – Manufacturing industries and construction	other	CO ₂	89.88	0.80%
1A3b	Fuel combustion – Transport - Road transportation	gasoline	CO ₂	1044.28	9.27%
1A3b	Fuel combustion – Transport - Road transportation	diesel oil	CO ₂	5023.89	44.61%
1A3b	Fuel combustion – Transport - Road transportation	diesel oil	N ₂ O	60.53	0.54%
1A4	Fuel combustion – Other sectors	liquid	CO ₂	825.39	7.33%
1A4	Fuel combustion – Other sectors	gaseous	CO ₂	826.51	7.34%
2A1	Cement production		CO ₂	394.79	3.51%
2A3	Glass production		CO ₂	63.98	0.57%
2C1	Iron and steel production		CO ₂	103.70	0.92%
3A	Enteric fermentation		CH ₄	401.55	3.57%
3B	Manure management		CH ₄	62.12	0.55%
3D1	Direct N ₂ O emissions from managed soils		N ₂ O	161.90	1.44%
4A1	Forest Land remaining Forest Land		CO ₂	334.77	2.97%
4E2	Land converted to settlements		CO ₂ , N ₂ O	56.91	0.51%
all	Sum of all 2019 key categories	all	all	10748.94	95.45%

Table 1-9 specifies for which years any source category has been identified as key category (LA) for from 1990 to 2019 (incl. LULUCF).

The key category with the highest contribution to the national total emissions in 2019 is *1A3b Road Transportation – diesel oil (CO₂)*. The contribution to the national total emissions in the base year was 9.97%, whereas in 2019 this contribution has increased to 46.77%.²¹ This strong increase is due to the general increase of road performance, but also due to a shift from gasoline to diesel driven vehicles. Category *1A3b Road Transportation – diesel oil (CO₂)* is the most important category in terms of emission trends and, since 1990 emissions have increased by 296%.

The second most important source of greenhouse gas emissions in 2019 in Luxembourg is *1A3b Road Transportation – gasoline (CO₂)*. Its contribution to national total emissions is 9.72% for 2019 compared to 10.07% in the base year, followed by *1A4 – Other sectors – liquid fuels (CO₂)* with a contribution of 7.69% in 2019 (7.68% in 1990).

The key category with the highest contribution to national removals is *4.A.1 Forest land remaining forest land (CO₂)*. In the key category analysis including LULUCF it is the 8th largest category in the level assessment (2.97%) in 2019 and is also a key category in the trend assessment.

1.5.1.2 Trend Assessment (Tier 1)

Table 1-10 presents the key categories (excluding and including LULUCF) according to the trend assessment for the year 2019.

²¹ The percentages given here are those obtained by the level assessment excluding LULUCF.

Table 1-9 – Key categories (Tier 1, LA) including LULUCF based on emission data recorded in submission 2021v1: 1990-2019

IPCC source category	gas	fuel	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1A1	CO ₂	gaseous					X			X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A1	CO ₂	other								X						X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A2	CO ₂	liquid	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A2	CO ₂	solid	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A2	CO ₂	gaseous	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A2	CO ₂	other																							X			X	X	X	X	
1A3b	CO ₂	gasoline	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A3b	CO ₂	diesel oil	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A3b	N ₂ O	diesel oil																												X	X	
1A4	CO ₂	liquid	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A4	CO ₂	gaseous	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1A5	CO ₂	liquid										X																				
2A1	CO ₂		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2A3	CO ₂							X				X	X										X	X	X		X	X	X	X	X	
2C1	CO ₂		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2F1	F-gases																										X	X				
3A	CH ₄		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3B	CH ₄									X	X	X	X	X													X	X	X	X	X	X
3D1	N ₂ O		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4A1	CO ₂		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4A2	CO ₂		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4B2	CO ₂						X	X	X	X	X																					
4C2	CO ₂ , N ₂ O											X	X	X	X						X	X	X									
4E2	CO ₂ , N ₂ O		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5A	CH ₄						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X						

Table 1-10 –Key categories (excluding and including LULUCF) according to the trend assessment for 2019.

IPCC Category	Category Name	Fuel	GHG	TA excl. LULUCF	TA incl. LULUCF
1A1	Energy Industries	other	CO ₂	X	X
1A2	Manufacturing Industries and Construction	gaseous	CO ₂	X	X
1A2	Manufacturing Industries and Construction	solid	CO ₂	X	X
1A3b	Road Transportation	diesel oil	CO ₂	X	X
1A4	Other Sectors	gaseous	CO ₂	X	X
2C1	Iron & Steel Production		CO ₂	X	X
3A	Enteric Fermentation		CH ₄	X	X
4A1	Forest Land remaining FL		CO ₂		X
4A2	Land converted to FL		CO ₂		X
4E2	Land Converted to Settlements		CO ₂ , N ₂ O		X
<u>Source:</u> Environment Agency					

1.5.2 KP-LULUCF inventory

According to the IPCC GPG for LULUCF, the key categories for Kyoto Protocol activities can be derived from the identified key categories in the UNFCCC inventory as follows: Whenever a category is identified as key in the UNFCCC inventory, the associated activity under the Kyoto-Protocol can be considered as key in reporting under the Kyoto-Protocol²².

In the case of Luxembourg, **Afforestation and Reforestation, Deforestation, and Forest Management should be considered key categories** according to this quantitative analysis (level assessment). This result is confirmed by “Table NIR.3” extracted from the CRF Reporter (Table 1-11).

The key category analysis was performed using the Tier 1 approach on the basis of submission 2021v1. It comprises a level assessment for all years between 1990 and 2019, as well as a trend assessment for the trend of the year 2019 with respect to base year emissions, *i.e.* 1990. As stipulated in the IPCC-GPG-LULUCF, key categories have been identified, for the full inventory, including LULUCF categories (Table 1-8).

Table 1-11 – Table NIR.3 extracted from the CRF Reporter.

Table NIR 3. SUMMARY OVERVIEW FOR KEY CATEGORIES FOR LAND USE, LAND-USE CHANGE AND ACTIVITIES UNDER THE KYOTO PROTOCOL

KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	CRITERIA USED FOR KEY CATEGORY IDENTIFICATION			Comments ⁽⁴⁾
		Associated category in UNFCCC inventory ⁽¹⁾ is key (indicate which category)	Category contribution is greater than the smallest category considered key in the UNFCCC inventory ⁽²⁾ (including LULUCF)	Other ⁽³⁾	
Specify key categories according to the national level of disaggregation used ⁽¹⁾					
Afforestation and Reforestation					
CO2	CO2	Land converted to forest land	Yes	none	no comments
Deforestation					
CO2	CO2	Land converted to cropland, Land converted to grassland, Land converted to other land, Land converted to settlements, Land converted to wetlands	Yes	none	no comments
Forest Management					
CO2	CO2	Forest land remaining forest land	Yes	none	no comments

(1) See section 2.3.6 of the 2013 Revised Supplementary Methods and Good Practice Guidance arising from the Kyoto Protocol.

(2) If the emissions or removals of the category exceed the emissions of the smallest category identified as key in the UNFCCC inventory (including LULUCF).

(3) This should include qualitative assessment as per section 4.3.3 of the 2006 IPCC Guidelines or any other criteria.

(4) Indicate the criteria (level, trend of both) identifying the category as key.

²² IPCC Good Practice Guidance for LULUCF, Section 5.4.2. and Table 5.4.1.

Comparison with the key category analysis from CRF Table 7

The results of the automatic key category analysis in the CRF Reporter (CRF Table 7) are shown in **Table 1-12**. Cells shaded in grey refer to categories which have not been identified as key category for 2019 by Luxembourg's key category analysis. These differences are due to a different level of aggregation of the the sub-categories, for example, the category 1A3b was considered as a whole in the CRF reporter key category analysis, while Luxembourg's key category analysis splits 13Ab into 5 sub-categories corresponding to the fuel types (diesel oi, gasoline, LPG, biomass, and other fossil fuels).

Table 1-12 - Results of the automatic key category from the CRF Reporter (Table 7) for the year 2019. Cells shaded in grey refer to categories which have not been identified as key category for 2019 by Luxembourg's key category analysis.

KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Criteria used for key source identification		Key category excluding LULUCF	Key category including LULUCF
		L	T		
1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CO2	X	X	X	X
1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	CO2	X	X	X	X
1.A.2 Fuel combustion - Manufacturing I	CO2	X		X	X
1.A.2 Fuel combustion - Manufacturing I	CO2	X	X	X	X
1.A.2 Fuel combustion - Manufacturing I	CO2	X	X	X	X
1.A.2 Fuel combustion - Manufacturing I	CO2	X	X	X	X
1.A.3.b Road Transportation	CO2	X	X	X	X
1.A.3.b Road Transportation	N2O	X		X	X
1.A.4 Other Sectors - Liquid Fuels	CO2	X		X	X
1.A.4 Other Sectors - Gaseous Fuels	CO2	X	X	X	X
2.A.1 Cement Production	CO2	X		X	X
2.A.3 Glass Production	CO2	X			X
2.C.1 Iron and Steel Production	CO2	X	X	X	X
3.A Enteric Fermentation	CH4	X	X	X	X
3.B Manure Management	CH4	X			X
3.D.1 Direct N2O Emissions From Managed Soils	N2O	X		X	X
4.A.1 Forest Land Remaining Forest Land	CO2	X	X		X
4.A.2 Land Converted to Forest Land	CO2		X		X
4.C.2 Land Converted to Grassland	CO2		X		X
4.E.2 Land Converted to Settlements	CO2		X		X

1.6 Information on the QA/QC plan including verification and treatment of confidentiality issues where relevant

The overall responsibility for the establishment and existence of a Quality Management System (QMS), in order to prepare the national inventory of greenhouse gases and air pollutants, lies with the Environment Agency (Administration de l'environnement, AEV).

Being designated by a grand-ducal regulation (GDR, 08/2007) as the single national entity (SNE), the AEV, has the overall technical responsibility for the national GHG Inventory. Political responsibility lies with the Ministry for the Environment, Climate and Sustainable Development (MECDD). Within the AEV, the Unité surveillance et évaluation de l'environnement is responsible for the following tasks:

The National Inventory Compiler (NIC):

- supervises the inventory preparation process for various obligations as outlined below;
- is the national inventory focal point to the Ministry (MECDD).

The national, European and international obligations are:

- UNECE Convention on Long Range Transboundary Air Pollution and its protocols
- UNFCCC & Kyoto Protocol
- European Union:
 - EU GHG Monitoring Mechanism (525/2013/EC (repealing 280/2004/EC) & 2005/166/EC)
 - NEC Directive (2001/81/EC)
 - Ambient Air Quality Directive (2008/50/EC).

1.6.1 Quality Policy

The quality policy is the central aspect of a Quality Management System. It defines the understanding of quality in relation to all topics of inventory preparation and specifies its basic principles.

The single national entity has:

- to establish and maintain the quality policy and quality objectives regarding GHG Inventories;
- to promote the quality policy and quality objectives regarding GHG Inventories throughout the organisation to increase awareness, motivation and involvement;
- to ensure focus on the fulfilment of the Kyoto Protocol and the requirements of the IPCC GPG Chapter 8 QA/QC;
- to ensure that appropriate processes are implemented to enable requirements of the IPCC GPG Chapter 8 QA/QC (and other interested parties) to be fulfilled and quality objectives to be achieved;
- to ensure that an effective and efficient QMS is established, implemented and maintained in order to achieve these quality objectives;
- to ensure the availability of necessary resources;
- to review the Quality Management System periodically;
- to decide on actions regarding the quality policy and quality objectives regarding GHG Inventories;
- to decide on actions for the improvement of the Quality Management System;
- to decide on actions for the improvement of national GHG inventories.

1.6.2 Quality Management System Build-up

The build-up of the Quality Management System (QMS) of the GHG emission reporting was outsourced and supervised by SEG Umwelt-Service GmbH until 2018²³. Since 2018, the QMS has been internalized within AEV in collaboration with Umweltbundesamt Wien.

Luxembourg's QMS follows a Plan-Do-Check-Act-Cycle (PDCA-cycle) ²⁴, which is an accepted model for pursuing a continual improvement of performance according to international standards and is in line with procedures described in decision 19/CMP.1 and in the IPCC Good Practice Guidance.

Due to Luxembourg's clear extent, its QMS deals with a manageable quantity of documents. Following are the specifications of Luxembourg's Quality Management System:

- firm build-up with a quality manual consisting of a chart with all relevant documents, handling instructions and deadlines for check (Figure 1-2);
- good manageability (instead of a complex system);
- usable and effective quality control procedures (user-friendly, clearly arranged).

Since the QMS has been implemented in the year 2008, it has evolved continuously and many improvements have already been realised.

The QMS shall ensure and continuously improve the quality (measured by transparency, accuracy consistency, comparability, completeness (TACCC) and timeliness) of Luxembourg's GHG Inventory in order to fulfil the party's obligations according to articles 3, 5 and 7 of the Kyoto Protocol. The QMS therefore supplies procedures to:

- check integrity, correctness and completeness of data;
- identify errors and omissions;
- reduce uncertainties of emission estimates;
- document and archive inventory calculation sheets and background data.

²³ SEG Umwelt-Service GmbH, Auf der Haardt 2, D – 66693 Mettlach, <http://www.seg-online.de>

²⁴ <http://www.asq.org/learn-about-quality/project-planning-tools/overview/pdsa-cycle.html>

1.6.3 QMS Structure

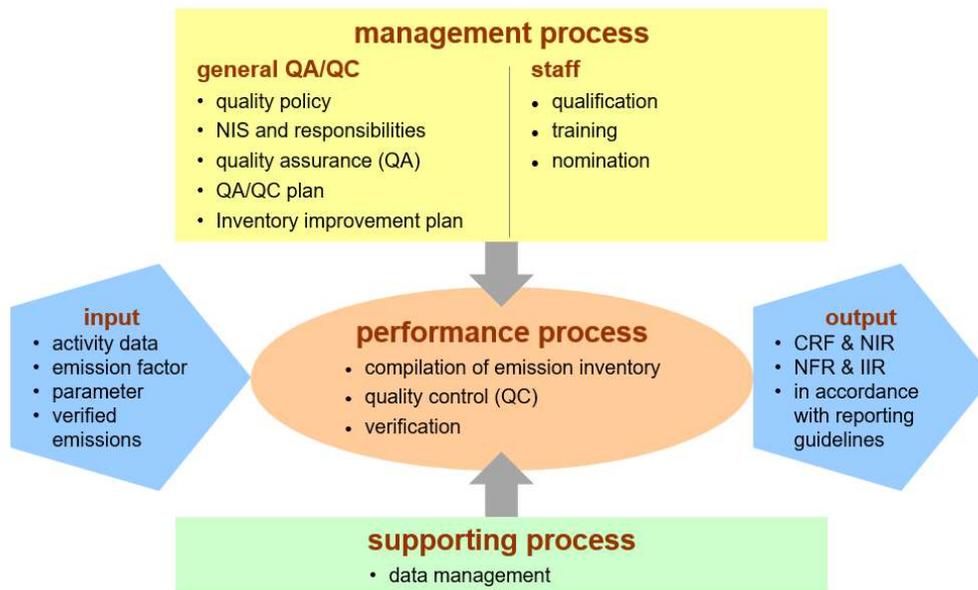
Luxembourg's Quality Management System (QMS) of the GHG Inventory is organised in three layers (Figure 1-2):

Performance processes: Performance processes directly concern the compilation of the GHG Inventory. They comprise input data, data acquisition, calculations, and generation of CRF tables and NIR as well as quality control checks and the outcomes of the NIR and CRF-tables.

Management processes: Management processes control the system's performance by defining quality objectives, responsibilities, quality assurance procedures, improvement plans and the personnel's qualifications and obligations.

Supporting processes: Supporting processes assist the system's performance by providing technical requirements and standards.

Figure 1-2 – QMS structure



1.6.4 Quality Manual

The applied quality manual adopts the structure of the QMS and is divided in management, performance and supporting processes.

For each process, a list of related documents exists with information on content, handling, interval of document check and planned improvement. An extract of the quality manual is given below (Figure 1-3).

Figure 1-3 – Extract of QA/QC Manual

	QA/QC procedure	purpose	document	content	handling	interval of document check
management processes	quality policy	basis of the implemented quality management system	quality policy	obligation to prepare and improve the emission inventory according to the demands resulting from <ul style="list-style-type: none"> • UNFCCC, Kyoto protocol, Paris Agreement • EU MMR • UNECE/LRTAP and its protocols & amendments, • EU NECD 	the head of administration, National Focal Point (NFP), Inventory Focal Point (IFP/NIC), (former National Inventory Compiler (NIC)) and Quality Manager (QM) <ul style="list-style-type: none"> -> check validity of quality policy -> adjustment if necessary -> announcement 	yearly before kick-off meeting
	general QA/QC	organisation of inventory work	definitions and list of abbreviations	explanation of important terms and abbreviations that are used	Inventory Focal Point (IFP/NIC) and Quality Manager (QM) <ul style="list-style-type: none"> -> check validity -> adjustment if necessary 	yearly before kick-off meeting
			Luxembourg's National Inventory System	organisation of Luxembourg's National System, organigram, position of QA/QC within the organisation, handling of submission	"Règlement grand-ducal du 24 avril 2017 relatif à la mise en place d'un système national pour la surveillance, l'évaluation et la déclaration des émissions de gaz à effet de serre et des polluants atmosphériques et la déclaration d'autres informations ayant trait au changement climatique et à la pollution atmosphérique." RGD dictates handling of submission <ul style="list-style-type: none"> • AEV -> EIONET, • MEV -> UNFCCC • MEV oder AEV -> UNECE/LRTAP Inventory Focal Point (IFP/NIC) and Quality Manager (QM) <ul style="list-style-type: none"> -> check validity -> adjustment if necessary -> announcement 	yearly before kick-off meeting
	personnel		responsibilities	personnel involved in inventory work (collection of activity data, selection of emission factors and methods, calculation of emissions, data compilation, uncertainties, recalculations, identification of key categories, etc.)	nomination of sector experts and data suppliers according RGD; IFP/NIC and quality manager check validity <ul style="list-style-type: none"> -> adjustment if necessary -> announcement 	yearly before kick-off meeting
			nomination	nomination of sector experts and data suppliers according RGD	nomination by minister of environment; IFP/NIC and quality manager check validity <ul style="list-style-type: none"> -> information of ministry if necessary -> nomination proposed by IFP/NIC 	yearly before kick-off meeting or in case of staff changing the function/unit/division, etc.
	quality assurance	to support and complete quality control measures check of formal aspects check of applicability & comparisons	personal file	proof of sector expert's qualification	sector experts complete their personal file	regular
			Checklist for internal audit	checklist for performance of internal reviews (conformity with IPCC Guidelines, target-performance comparison)	internal audit of general aspects by quality manager, of sector specific aspects by IFP/NIC <ul style="list-style-type: none"> -> internal audit report -> QA/QC plan 	yearly before kick-off meeting
			internal audit report	audited sectors, observations, proposed improvements	report prepared by quality manager and IFP/NIC <ul style="list-style-type: none"> -> generation of QA/QC plan 	yearly before kick-off meeting
			external audit report	audited sectors, observations, proposed improvements	report prepared by external persons or organisations <ul style="list-style-type: none"> -> generation of QA/QC plan 	obligatory
			audit list	date, audit character, audited sectors, auditors, hence prepared audit reports and QA/QC plans	auditlist completed by IFP/NIC and quality manager	regular
	improvement plan	list of objectives and proposed actions in order to improve inventory's quality	inconsistencies	procedure for handling of inconsistencies (that are detected during compilation of inventory, in internal or external audits)	documenting and archiving of indication of inconsistency (audit report, annotation) <ul style="list-style-type: none"> -> informing of IFP/NIC and quality manager -> entry of proposals for improvement in QA/QC plan 	yearly before kick-off meeting
			improvement plan	QAQC plan, inventory improvement plan, priority list	result of internal and external audits; documenting of detected inconsistencies or possibilities for improvement in QA/QC plan by IFP/NIC and quality manager <ul style="list-style-type: none"> -> definition of deadlines -> check if objectives have been achieved during the following audits 	regular
Criteria for the prioritization of the QAQC plan		Criteria for the prioritization of the QAQC plan	criteria for the prioritization of the QAQC plan	QAQC plan is set up according to the criteria for the prioritization;	yearly before kick-off meeting	
		inventory		inventory timetable'	timetable for inventory planning and preparation, sector specific timetable for inventory planning and preparation, QAQC timetable, submission deadlines	IFP/NIC, quality manager and sector experts check validity <ul style="list-style-type: none"> -> adjustment if necessary -> announcement per mail
calculation sheets	calculated emissions; information on activity data, data suppliers (QA/QC), emission factors, calculation methods and special events; information on completeness, revisions and planned improvements of emission data	sector experts complete their calculation sheets <ul style="list-style-type: none"> -> transfer to IFP/NIC before deadline; check of document by IFP/NIC and quality manager; check of data content by sector expert 		yearly before kick-off meeting		
NIR and CRF-tables	national greenhouse gas inventory	sector experts submit calculation sheets to IFP/NIC before deadline <ul style="list-style-type: none"> -> IFP/NIC generates CRF-tables and compiles NIR -> submission of crf-tables and NIR to EU and UNFCCC 		regular according to the deadlines		
IIR and NFR-tables	national air pollutant emission inventory	sector experts submit calculation sheets to IFP/NIC before deadline <ul style="list-style-type: none"> -> IFP/NIC generates NFR-tables and compiles IIR -> submission of NFR-tables and IIR to EU and UNECE/LRTAP 		regular according to the deadlines		
quality control	activities to assess and maintain the quality of the inventory being compiled	sector specific QA/QC Checklist	Accuracy checks on data acquisition and calculations, verification of activity data, emission factors and methods	performance by sector experts before submission; completion of checklists; archiving of checks; transmission of completed checklists in common with NIR data to IFP/NIC	yearly before kick-off meeting	
		checklist data supplier	validation of data that are submitted by plant operators and other organisations	performance by data supporter before submission; check and archiving by sector expert	yearly before kick-off meeting	

supporting	data management	definition of data naming and archiving	data flow	cooperation between the competent authorities and organisations; exchange and archiving of data and information	sector experts calculate emissions and perform data validation checks -> submission of calculations to IFP/NIC -> IFP/NIC validates methods, activity data and emission factors, generates crf-tables and compiles NIR; IFP/NIC and quality manager perform internal audit on NIR compilation -> generation of a QA/QC plan including proposed improvements -> information of sector experts and implementation of improvements	yearly before kick-off meeting
			data management on CTIE	instruction for data naming and archiving	IFP/NIC designates access authorisation	yearly before kick-off meeting

Sources: SEG Umwelt-Service GmbH and Environment Agency.

1.6.5 Inventory Timetable

The inventory timetable gives several schedules to control the performance of inventory compilation, quality control and quality assurance procedures, implementation of inventory improvements and inventory publication (see Table 1-2 in Section 1.2.2).

In addition, there are summaries of deadlines regarding EU and UNFCCC submissions.

1.6.5.1 Timetable for inventory planning and preparation

This schedule refers to general inventory work:

- Yearly meetings of the inventory work group and the decision making body
- Key category analysis
- Uncertainty analysis
- Generation of CRF-tables
- NIR preparation and finalisation
- NIR and CRF submission
- Publication and archiving of NIR
- Consideration and implementation of EU review recommendations
- Consideration and implementation of UNFCCC review recommendations
- Internal and external training
- Documentation and archiving

1.6.5.2 Sector specific timetable for inventory planning and preparation

This schedule refers to sector specific compilation work and quality control checks:

- Collection of activity data, emission factors and other parameters
- Calculation of emissions and removals
- Quality check of data, comparison with previous years, documentation of calculations and assumptions
- Uncertainty analysis
- Completion of checklists and other QC activities
- Documentation and archiving

1.6.5.3 QA/QC timetable

This schedule especially refers to QA procedures:

- Internal audit
- Implementation of internal review recommendations
- Yearly meetings of the inventory work group and the decision making body
- QA/QC training for the National Inventory Compiler and the sector experts.

1.6.6 Quality Control and Quality Assurance procedures

The first steps to implement quality control and quality assurance procedures have already been undertaken but need further improvement. The current status and planned improvements are described in the following sub-sections.

Figure 1-4 – QA/QC Procedures

Does NOT require knowledge of the emission source category	Requires knowledge of the emission source category
general	source specific
QC procedures	
Sector experts (1 st party) performed throughout preparation of inventory	
TIER 1	TIER 2
Data validation, calculation sheet (check of formal aspects)	Preparation of NIR, comparison with Guidelines (check of applicability, comparisons)
QA procedures	
Quality manager (2 nd or 3 rd party; staff not directly involved, preferably independent) performed after inventory work was finished	
TIER 1	
Basic, before submission	
	Internal audit /EU 'initial check' (Expert Peer Review)
	Evaluate if TIER 2 QC is effectively performed (check if methodologies are applicable)
TIER 2	
extensive	
System audit by Umweltbundesamt (Audit)	ICR by UNFCCC (Expert Peer Review)
Evaluate if TIER 2 QC is effectively performed	Evaluate if TIER 2 QC is effectively performed (Check if methodologies are applicable)

Sources: Umweltbundesamt Austria, SEG Umwelt-Service GmbH and Environment Agency.

1.6.6.1 Quality Control procedures

The following Quality Control procedures are conducted:

- Yearly meeting of the decision making body (the decision making body consists of the head of the AEV, the National Inventory Compiler and the quality manager) in order to appoint responsibilities, priorities and schedules for inventory work.
- Checklists for data supplier that have to be completed by external suppliers of input data in order to assure the reliability of reported data.
- Checklists for validation of data that have to be completed by sector experts until data are transmitted to the National Inventory Compiler. An example of a data validation checklist is given in Figure 1-5.

Figure 1-5 – Data Validation Checklist

Data:		1990 - 2xxx																							
Source:		CRF			XXX			Snap			XX XX			Emission factor			check done			Emissions			check done		
Greenhouse gas		CO2	CH4	N2O	Remarks	Date	Person	CO2	CH4	N2O	Remarks	Date	Person	CO2	CH4	N2O	Remarks	Date	Person						
Content check																									
Trend checks																									
For each category, current inventory estimates should be compared to previous estimates, if available. If there are significant changes or departures from expected trends, re-check estimates and explain any differences																									
Data plausible in comparison to other references																									
Check time series consistency																									
For each category check input data for temporal consistency in time series																									
Check methodological and data changes resulting in recalculations																									
Check that the effects of mitigation activities have been appropriately reflected in time series calculations																									
Check completeness																									
Confirm that estimates are reported for all categories and for all years from the appropriate base year to the period of the current inventory																									
For subcategories, confirm that entire category is being covered																									
Provide clear definition of "Other" type categories																									
Check that known data gaps that result in incomplete estimates are documented, including a qualitative evaluation of the importance of the estimate in relation to total emissions																									
Uncertainty estimation of data existent																									
data relying on a legal reporting commitment																									
Formal check																									
Collection of data is understandable																									
Check that assumptions and criteria for the selection of data are documented																									
Assumptions and criteria for the selection of data are documented																									
Cross-check descriptions of activity data, emission factors and other estimation parameters with information on categories and ensure that these are properly recorded and archived																									
Check for transcription errors in data input and reference																									
data correctly entered and transcribed																									
Confirm that bibliographical data references are properly cited in the internal documentation																									
Cross-check a sample of data from each source category (either measurements or parameters used in calculations) for transcription errors																									
Accurate data aggregation and correctness of calculations																									
Parameters and units are correctly recorded																									
Data fields are properly labelled																									
Data transmission of intermediate result is correct																									
Check that parameters and units are correctly recorded and that appropriate conversion factors are used																									
Units are properly labelled and correctly carried through from beginning to end of calculations																									
Conversion factors respectively temporal and spatial adjustment factors are correct																									
Data path and data coherence are understandable																									
Consistency given for the multiple use of data																									
Archiving of data and records ensured																									
Emissions complete																									
Uncertainty estimation of emissions existent																									
emission measurements in compliance with international accredited standards																									
Greenhouse gas		Uncertainties			check done																				
		CO2	CH4	N2O	Remarks	Date	Person																		
Content check																									
Check that uncertainties in emissions and removals are estimated and calculated correctly																									
Check that qualifications of individuals providing expert judgement for uncertainty estimates are appropriate																									
Check that qualifications, assumptions and expert judgements are recorded																									
Formal check																									
Designation of uncertainties is understandable																									
Uncertainties complete																									
documentation of fundamental assumption concerning expert judgement																									
Archiving of data and records ensured																									

Sources: Umweltbundesamt Austria, SEG Umwelt-Service GmbH and Environment Agency.

Checks for validation of data include:

- Checks of activity data (trend checks, time series consistency, completeness, check of assumptions and criteria for activity data, check for transcription errors in data input and reference)
- Checks of emission factors (trend checks, time series consistency, completeness, check of correct recording of units and the use of appropriate conversion factors, check of documentation of assumptions and criteria for the selection of emission factors, check for transcription errors in data input and reference)
- Checks of emissions (trend checks, time series consistency, completeness, check of documentation of assumptions and criteria for emissions, check for transcription errors in data input and reference, check of correct recording of units and the use of appropriate conversion factors)
- Check of uncertainties (check of correct calculation and estimation of uncertainties in emissions and removals).

Checklists for verification of methods, activity data and emission factors that have to be completed by sector experts.

Checklist for the monitoring of internal and external reviews that has to be completed by the quality manager.

1.6.6.2 Quality Assurance procedures

The following Quality Assurance procedures are conducted:

- Internal audit during NIR preparation time performed by the quality manager, the National Inventory Compiler and a consultant from the "Umweltbundesamt Wien". The internal review analyses every sector as well as the QMS system and checks:
 - whether inventory work and the inventory comply with IPCC 2006 Guidelines, Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories and Good Practice Guidance for Land Use, Land Use Change and Forestry
 - whether data acquisition, calculation, referencing and archiving is handled according to the defined methods
 - whether there are enough resources for inventory work
 - whether relevant data are available and if the reliability of external data is guaranteed
 - whether the QMS system needs improvement
 - whether recommendations of EU reviews, UNFCCC reviews and previous internal audits have been considered and implemented.
- QA/QC training for the sector experts and the National Inventory Compiler during execution of the internal audit.
- Support by inventory experts from the "Umweltbundesamt Wien".
- External audits conducted by experts who provide support for inventory work, EU or UNFCCC.

1.6.6.3 Improvement plan

The results from internal and external audits are merged in the improvement plan. This plan lists the relevant sector, recommendations for improvement, priorities, responsibilities, deadlines and gives opportunity for attest.

The improvement plan is segmented in a QA/QC plan, that contains recommendations for the improvement of the QMS and an inventory improvement plan that contains recommendations for inventory improvement.

The decision making body prioritises the recommended improvements and cares for associated resources.

1.6.6.4 Planned improvements

The following QMS improvements shall be implemented in the following years:

- Strengthening the implementation of the QMS in general
- Improvement of QC procedures in the LULUCF sector
- Strengthening the implementation of QA/QC procedures in KP-LULUCF
- Development of the four-eyes principle in inventory work
- Continuance in QA/QC training of NIC and sector experts
- Internalization of all QA/QC procedures within AEV is ongoing through 2021

1.6.7 Archiving and documentation

Within the inventory system, a system for transparent documentation of inventory data and related information (special circumstances, assumptions etc.) is implemented. Archiving takes place on the Sharepoint server, where the data is secure for at least fifteen years.

As a principle every file shall be named clearly, shall be write/delete protected and supply relevant information concerning validity in the footer.

1.6.8 Treatment of confidentiality issues

In this submission, data is reported using the notation key C (confidential) in categories 2.C.7 - Metal Industry - Other (secondary aluminium production) and 2.G.4 Other – Manufacture Solvents.

1.7 General uncertainty evaluation, including data on the overall uncertainty for the inventory totals

Uncertainty estimates are an essential element of a complete inventory of greenhouse gas emissions and removals and requires a detailed understanding of the uncertainties of the respective input parameters. They should be derived for both the national level and the trend estimate, as well as for the component parts such as emission factors, activity data and other estimation parameters for each category.²⁵ Principally, two different TIER for the estimation of combined uncertainties are presented in the IPCC GPG: TIER 1 uses simple error propagation equations, while TIER 2 uses Monte Carlo.

TIER 1 is based upon error propagation and is used to estimate uncertainty in individual categories, in the inventory as a whole, and in trends between a year of interest and a base year. The key assumptions, requirements, and procedures are described here. TIER 1 should be implemented using Table 3.2 of the IPCC Guidelines for National Greenhouse Gas Inventories (2006).

The TIER 2 is based on a Monte Carlo analysis, which is suitable for detailed category-by-category assessment of uncertainty, particularly where uncertainties are large, distribution is non-normal, the algorithms are complex functions and/or there are correlations between some of the activity sets, emissions factors, or both.

1.7.1 GHG inventory

For submission 2021v1, only a Tier 1 uncertainty analysis has been carried out. A new Tier 2 uncertainty analysis will only be carried out if important methodological changes have occurred.

1.7.1.1 Results using the Tier 1 (error propagation) approach

The input parameters and the results (level and trend uncertainties, with and without LULUCF) of the error propagation approach are presented in Table 1-13. A detailed uncertainty of the agriculture sector is provided in Annex 3B.

The overall level uncertainty as well as trend uncertainty is being derived as the square root of the squares of the respective contributions.

The TIER 1 approach including LULUCF suggests an overall level uncertainty of 4.51% and a trend uncertainty of 5.49%, and the TIER 1 approach excluding LULUCF suggests an overall level uncertainty of 3.99% and a trend uncertainty of 4.86% (Table 1-13).

Compared to the results of other countries, level and trend uncertainties in Luxembourg are on the lower end of the range. This is plausible, as the situation in Luxembourg is characterized by high energy consumption and emission density, compared to other countries. With respect to GHG emissions, energy data are among the best known, and also CO₂ emission factors are much better understood (can be derived from material balances) than emission factors of CH₄ or N₂O. The fact that at the same time, in the total inventory, N₂O and CH₄ emissions are less important, leads to a structurally lower uncertainty.

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1.7.1.2 Tier 2 approach

The TIER 2 method is based on a Monte Carlo analysis, which is suitable for detailed category-by-category assessment of uncertainty, particularly where uncertainties are large, distribution is non-normal, the algorithms are complex functions and/or there are correlations between some of the activity sets, emissions factors, or both.

A study from 2011 on the uncertainty assessment of Luxembourg's GHG inventory also covers a Tier 2 analysis. A full description of the Tier 2 uncertainty evaluation from 2011, including the required tables, can be provided upon request.

1.7.1.3 Scope for improvement

Compared to other countries, the uncertainty of the Luxembourg GHG inventory is quite small already. Still the potential exists to even further improve, as the share of (well understood) emissions from combustion sources is particularly large in the case of Luxembourg, and thus the highly uncertain area-related contributors to GHG inventories play a less important role.

Nevertheless, for Luxembourg like for many other countries where these features have been investigated, the emissions of N₂O from soils and the uptake/release of CO₂ from LULUCF are dominant factors to the uncertainty of the national GHG inventory. It is thus useful to focus on these parameters in an evaluation of possible improvements.

Opportunities may actually exist to provide the improvements needed to just these sectors which have been identified the major contributors to uncertainty. In the case of LULUCF, national activities that provide an update to the national forest inventory should be utilized also for the GHG inventory in order to remove major obstacles to data quality also affecting uncertainty. Moreover, close observation should be given to developments on validation of the currently used soil N₂O emission factors. Such validation exercises might provide a closure of the error margins.

Table 1-13 – Input parameters and results of the Tier 1 uncertainty analysis (2021v1).

IPCC category/group	Gas	Base year emissions or removals	Year 2019 emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to variance by category in year x	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions	Comments (optional)
		Gg CO2 equivalent	Gg CO2 equivalent	%	%								
		input data	input data	input data Note A	input data Note A			Note B		I*F Note C	J*E*sqrt(2) Note D	K^2 + L^2	
1A - Stationary Combustion - Gaseous Fuels	CO2	1035.80	1608.00	2%	0.5%	0.0206	0.0000	0.0557	0.1254	0.0003	0.0035	1.26E-05	
1A - Stationary Combustion - Gaseous Fuels	CH4	1.04	2.19	2%	50%	0.5004	0.0000	0.0001	0.0002	0.0001	0.0000	2.58E-09	
1A - Stationary Combustion - Gaseous Fuels	N2O	0.53	0.85	2%	50%	0.5004	0.0000	0.0000	0.0001	0.0000	0.0000	2.39E-10	
1A - Stationary Combustion - Liquid Fuels	CO2	1166.05	866.48	2%	0.5%	0.0206	0.0000	0.0108	0.0675	0.0001	0.0019	3.65E-06	
1A - Stationary Combustion - Liquid Fuels	CH4	3.34	2.72	2%	50%	0.5004	0.0000	0.0000	0.0002	0.0000	0.0000	7.39E-11	
1A - Stationary Combustion - Liquid Fuels	N2O	2.68	2.04	2%	50%	0.5004	0.0000	0.0000	0.0002	0.0000	0.0000	1.31E-10	
1A - Stationary Combustion - Other Fuels	CO2	33.48	197.30	8%	20%	0.2154	0.0000	0.0131	0.0154	0.0026	0.0017	9.92E-06	
1A - Stationary Combustion - Other Fuels	CH4	0.25	1.69	8%	50%	0.5064	0.0000	0.0001	0.0001	0.0001	0.0000	3.54E-09	
1A - Stationary Combustion - Other Fuels	N2O	0.39	2.69	8%	50%	0.5064	0.0000	0.0002	0.0002	0.0001	0.0000	8.93E-09	
1A - Stationary Combustion - Biomass	CH4	5.50	8.74	7%	50%	0.5049	0.0000	0.0003	0.0007	0.0002	0.0001	2.88E-08	
1A - Stationary Combustion - Biomass	N2O	1.82	6.91	7%	60%	0.6041	0.0000	0.0004	0.0005	0.0002	0.0001	6.53E-08	
1A - Stationary Combustion - Solid Fuels	CO2	5317.44	168.42	1%	3%	0.0316	0.0000	0.3427	0.0131	0.0103	0.0002	1.06E-04	
1A - Stationary Combustion - Solid Fuels	CH4	5.40	0.52	1%	50%	0.5001	0.0000	0.0003	0.0000	0.0002	0.0000	2.60E-08	
1A - Stationary Combustion - Solid Fuels	N2O	5.94	0.79	1%	50%	0.5001	0.0000	0.0003	0.0001	0.0002	0.0000	2.84E-08	
1A3a - Transport - Civil Aviation	CO2	0.21	0.51	10%	5%	0.1118	0.0000	0.0000	0.0000	0.0000	0.0000	3.28E-11	
1A3a - Transport - Civil Aviation	CH4	0.00	0.00	10%	100%	1.0050	0.0000	0.0000	0.0000	0.0000	0.0000	2.10E-17	
1A3a - Transport - Civil Aviation	N2O	0.00	0.00	10%	150%	1.5033	0.0000	0.0000	0.0000	0.0000	0.0000	1.05E-13	
1A3b - Road Transportation - Diesel Oil	CO2	1269.24	5023.89	2%	2%	0.0283	0.0002	0.3061	0.3916	0.0061	0.0111	1.60E-04	
1A3b - Road Transportation - Diesel Oil	CH4	0.68	2.39	2%	20%	0.2010	0.0000	0.0001	0.0002	0.0000	0.0000	8.26E-10	
1A3b - Road Transportation - Diesel Oil	N2O	2.53	60.53	2%	20%	0.2010	0.0000	0.0045	0.0047	0.0009	0.0001	8.45E-07	

IPCC category/Group	Gas	Base year emissions or removals	Year 2019 emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to variance by category in year x	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions	Comments (optional)
		Gg CO2 equivalent	Gg CO2 equivalent	%	%								
		input data	input data	input data Note A	input data Note A			Note B		I*F Note C	J*E*sqrt(2) Note D	K^2 + L^2	
1A3b - Road Transportation - Gasoline	CO2	1282.06	1044.28	2%	2%	0.0283	0.0000	0.0047	0.0814	0.0001	0.0023	5.31E-06	
1A3b - Road Transportation - Gasoline	CH4	11.67	1.07	2%	20%	0.2010	0.0000	0.0007	0.0001	0.0001	0.0000	1.96E-08	
1A3b - Road Transportation - Gasoline	N2O	12.79	1.68	2%	20%	0.2010	0.0000	0.0007	0.0001	0.0001	0.0000	2.12E-08	
1A3b - Road Transportation - LPG	CO2	11.34	0.88	2%	2%	0.0283	0.0000	0.0007	0.0001	0.0000	0.0000	1.96E-10	
1A3b - Road Transportation - LPG	CH4	0.10	0.00	2%	40%	0.4005	0.0000	0.0000	0.0000	0.0000	0.0000	6.59E-12	
1A3b - Road Transportation - LPG	N2O	0.13	0.00	2%	100%	1.0002	0.0000	0.0000	0.0000	0.0000	0.0000	7.01E-11	
1A3b - Road Transportation - biomass	CH4	0.00	0.21	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	1.13E-11	
1A3b - Road Transportation - biomass	N2O	0.00	4.30	2%	20%	0.2010	0.0000	0.0003	0.0003	0.0001	0.0000	4.57E-09	
1A3b - Road Transportation - other fossil fuels	CO2	0.00	18.67	20%	2%	0.2010	0.0000	0.0015	0.0015	0.0000	0.0004	1.70E-07	
1A3b - Road Transportation - other fossil fuels	CH4	0.00	0.01	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	5.87E-14	
1A3b - Road Transportation - other fossil fuels	N2O	0.00	0.23	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	3.75E-11	
1A3c - Railways - liquid fuels	CO2	24.82	6.74	2%	2%	0.0283	0.0000	0.0011	0.0005	0.0000	0.0000	7.43E-10	
1A3c - Railways - liquid fuels	CH4	0.05	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	3.41E-13	
1A3c - Railways - liquid fuels	N2O	0.04	0.01	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	1.45E-13	
1A3c - Railways - biomass	CH4	0.00	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	2.45E-17	
1A3c - Railways - biomass	N2O	0.00	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	5.51E-17	
1A3c - Railways - other fossil fuels	CO2	0.00	0.03	20%	2%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	3.07E-13	
1A3c - Railways - other fossil fuels	CH4	0.00	0.00	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	2.25E-19	
1A3c - Railways - other fossil fuels	N2O	0.00	0.00	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	5.07E-19	
1A3d - Navigation - liquid fuels	CO2	1.30	0.97	2%	2%	0.0283	0.0000	0.0000	0.0001	0.0000	0.0000	4.65E-12	
1A3d - Navigation - liquid fuels	CH4	0.03	0.01	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	9.34E-14	
1A3d - Navigation - liquid fuels	N2O	0.11	0.06	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	3.16E-13	
1A3d - Navigation - biomass	CH4	0.00	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	3.65E-17	
1A3d - Navigation - biomass	N2O	0.00	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	4.00E-15	
1A3d - Navigation - other fossil fuels	CO2	0.00	0.00	20%	2%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	4.91E-15	
1A3d - Navigation - other fossil fuels	CH4	0.00	0.00	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	3.97E-21	
1A3d - Navigation - other fossil fuels	N2O	0.00	0.00	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	3.65E-17	

IPCC category/Group	Gas	Base Year emissions or removals	Year 2019 emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to variance by category in year x	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions	Comments (optional)
		Gg CO2 equivalent	Gg CO2 equivalent	%	%								
		input data	input data	input data Note A	input data Note A			Note B		I*F Note C	J*E*sqrt(2) Note D	K^2 + L^2	
1A - other mobile machinery - liquid fuels	CO2	76.89	202.09	2%	2%	0.0283	0.0000	0.0106	0.0158	0.0002	0.0004	2.43E-07	1A2gvi, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - liquid fuels	CH4	0.61	0.19	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	2.72E-11	1A2gvi, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - liquid fuels	N2O	7.53	6.73	2%	20%	0.2010	0.0000	0.0000	0.0005	0.0000	0.0000	2.33E-10	1A2gvi, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - biomass	CH4	0.00	0.01	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	2.28E-14	1A2gvi, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - biomass	N2O	0.00	0.45	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	5.03E-11	1A2gvi, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - other fossil fuels	CO2	0.00	0.73	20%	2%	0.2010	0.0000	0.0001	0.0001	0.0000	0.0000	2.62E-10	1A2gvi, 1A4cii, 1A5b
1A - other mobile machinery - other fossil fuels	CH4	0.00	0.00	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	1.66E-18	1A2gvi, 1A4cii, 1A5b
1A - other mobile machinery - other fossil fuels	N2O	0.00	0.03	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	4.60E-13	1A2gvi, 1A4cii, 1A5b
1B2 - Fugitive Emission from Natural Gas	CO2	0.03	0.04	2%	100%	1.0002	0.0000	0.0000	0.0000	0.0000	0.0000	2.12E-12	
1B2 - Fugitive Emission from Natural Gas	CH4	19.57	31.14	2%	100%	1.0002	0.0000	0.0011	0.0024	0.0011	0.0001	1.24E-06	
2A1 - Cement Production	CO2	539.36	394.79	1%	3%	0.0269	0.0000	0.0055	0.0308	0.0001	0.0004	2.08E-07	
2A3 - Glass Production	CO2	53.57	63.98	2%	5%	0.0539	0.0000	0.0014	0.0050	0.0001	0.0001	2.47E-08	
2C1 - Iron & Steel Production	CO2	984.91	103.70	5%	5%	0.0707	0.0000	0.0580	0.0081	0.0029	0.0006	8.75E-06	
2C7 - Other Metal Industry	CO2	0.00	2.28	0.4%	50%	0.5000	0.0000	0.0002	0.0002	0.0001	0.0000	7.92E-09	
2D1 - Lubricant use	CO2	6.20	4.69	5%	50%	0.5025	0.0000	0.0001	0.0004	0.0000	0.0000	1.33E-09	
2D2 - Paraffin wax use	CO2	0.21	2.62	5%	100%	1.0012	0.0000	0.0002	0.0002	0.0002	0.0000	3.63E-08	
2D3 - solvent use	CO2	14.13	12.93	50%	50%	0.7071	0.0000	0.0001	0.0010	0.0000	0.0007	5.09E-07	
2D3 - urea-based catalysts	CO2	0.00	13.57	20%	5%	0.2062	0.0000	0.0011	0.0011	0.0001	0.0003	9.24E-08	

IPCC category/Group	Gas	Base year emissions or removals	Year 2019 emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to variance by category in year x	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions	Comments (optional)
		Gg CO2 equivalent	Gg CO2 equivalent	%	%								
		input data	input data	input data Note A	input data Note A			Note B		I*F Note C	J*E*sqrt(2) Note D	K^2 + L^2	
2F1a - Commercial refrigeration	F-gases	0.13	3.95	25%	25%	0.3536	0.0000	0.0003	0.0003	0.0001	0.0001	1.74E-08	
2F1b - Domestic refrigeration	F-gases	0.00	0.00	1%	1%	0.0141	0.0000	0.0000	0.0000	0.0000	0.0000	1.36E-18	
2F1d - Transport refrigeration	F-gases	0.45	1.56	2%	25%	0.2508	0.0000	0.0001	0.0001	0.0000	0.0000	5.31E-10	
2F1e - Mobile air-conditioning	F-gases	2.65	47.22	2%	25%	0.2508	0.0000	0.0035	0.0037	0.0009	0.0001	7.78E-07	
2F1f - Stationary air-conditioning	F-gases	0.05	1.66	25%	25%	0.3536	0.0000	0.0001	0.0001	0.0000	0.0000	3.11E-09	
2F2 - Foam blowing agents	F-gases	10.22	2.22	25%	5%	0.2550	0.0000	0.0005	0.0002	0.0000	0.0001	4.40E-09	
2F4a - Meter dose inhalers	F-gases	0.00	0.92	25%	0%	0.2500	0.0000	0.0001	0.0001	0.0000	0.0000	6.40E-10	
2F4b - Other	F-gases	1.65	1.95	25%	0%	0.2500	0.0000	0.0000	0.0002	0.0000	0.0001	2.88E-09	
2G - Other Product Manufacture and Use	F-gases	1.75	12.31	7%	0%	0.0660	0.0000	0.0008	0.0010	0.0000	0.0001	8.02E-09	
2G - Other Product Manufacture and Use	N2O	9.19	4.71	20%	20%	0.2828	0.0000	0.0002	0.0004	0.0000	0.0001	1.33E-08	
3A - Enteric fermentation	CH4	387.78	401.55	15%	0%	0.1500	0.0000	0.0052	0.0313	0.0000	0.0066	4.41E-05	total subcategory uncertainty
3Ba - Manure management	CH4	47.73	62.12	25%	0%	0.2500	0.0000	0.0016	0.0048	0.0000	0.0017	2.93E-06	total subcategory uncertainty
3Bb - Manure management	N2O	30.74	27.37	165%	0%	1.6500	0.0000	0.0001	0.0021	0.0000	0.0050	2.48E-05	total subcategory uncertainty
3D - Agricultural soils	N2O	238.80	206.75	195%	0%	1.9500	0.0013	0.0001	0.0161	0.0000	0.0444	1.98E-03	total subcategory uncertainty
3G - Liming	CO2	0.26	10.38	30%	0%	0.3000	0.0000	0.0008	0.0008	0.0000	0.0003	1.18E-07	total subcategory uncertainty
3H - Urea application	CO2	0.00	0.00	15%	0%	0.1500	0.0000	0.0000	0.0000	0.0000	0.0000	9.57E-19	total subcategory uncertainty
3I - Other Carbon-containing Fertilizers	CO2	6.04	4.17	30%	0%	0.3000	0.0000	0.0001	0.0003	0.0000	0.0001	1.90E-08	total subcategory uncertainty
4 - Land Use, Land-Use Change and Forestry	CO2, N2O	84.84	312.39	74%	0%	0.7400	0.0004	0.0187	0.0244	0.0000	0.0255	6.49E-04	total sector uncertainty
5A - Solid Waste disposal on Land	CH4	92.98	46.30	8%	42%	0.4276	0.0000	0.0026	0.0036	0.0011	0.0004	1.39E-06	
5B1 - Composting	CH4	0.00	7.75	5%	100%	1.0012	0.0000	0.0006	0.0006	0.0006	0.0000	3.67E-07	
5B1 - Composting	N2O	0.00	5.54	5%	100%	1.0012	0.0000	0.0004	0.0004	0.0004	0.0000	1.88E-07	
5B2 - Anaerobic Digestion at Biogas Facilities	CH4	0.00	11.48	7%	68%	0.6836	0.0000	0.0009	0.0009	0.0006	0.0001	3.78E-07	
5D - Wastewater treatment and discharge	CH4	7.58	2.15	10%	50%	0.5099	0.0000	0.0003	0.0002	0.0002	0.0000	2.97E-08	
5D - Wastewater treatment and discharge	N2O	5.25	4.92	10%	50%	0.5099	0.0000	0.0000	0.0004	0.0000	0.0001	3.19E-09	
						Inventory Uncertainty including LULUCF	4.51%				Trend uncertainty incl. LULUCF	5.49%	
						Total Inventory Uncertainty excluding	3.99%				Trend uncertainty exd. LULUCF	4.86%	

1.7.1.4 KP-LULUCF inventory

Please refer to sections 0 and 11.2.7.5 for uncertainties of emissions/removals of the ARD units.

1.8 General assessment of completeness

1.8.1 GHG inventory

CRF table 9 on completeness has been filled for every reported year 1990 to 2019. It is expected that this table recapitulates all the explanations given for the notation keys reported in Luxembourg's GHG inventory for a given year since all the checks included in CRF Reporter were passed successfully by submission 2021v1. Hence, if missing information is encountered in CRF table 9 for some years, this is not due to a lack of explanations from the side of Luxembourg, but well due to conversion problems in CRF Reporter when the CRF tables are created.

A completeness overview by CRF category and by gas is presented in Table 1-14. In this section, some additional information is presented. An assessment of completeness for each CRF sector is given in the sector overview part of each of the sector chapters.

Table 1-14 - Completeness overview for submission 2021v1.

GHG source & sink categories (CRF nomenclature)	CO ₂	CH ₄	N ₂ O	HFCs	PFCs	SF ₆	NF ₃
1. ENERGY	X	X	X				
A. Fuel Combustion	X	X	X				
1. Energy Industries	X	X	X				
a. public electricity & heat production	X	X	X				
b. petroleum refining	NO	NO	NO				
c. manufacture of solid fuels and other energy industries	NO	NO	NO				
2. Manufacturing industries & construction	X	X	X				
a. iron & steel	X	X	X				
b. non-ferrous metals	X	X	X				
c. chemicals	X	X	X				
d. pulp, paper & print	X (2000-2019)	X (2000-2019)	X (2000-2019)				
e. food processing, beverages & tobacco	X	X	X				
f. non-metallic minerals	X	X	X				
g. other	X	X	X				
3. Transport	X	X	X				
a. civil aviation	X	X	X				
b. road transportation	X	X	X				
c. railways	X	X	X				
d. navigation	X	X	X				
e. other transportation	NO	NO	NO				
4. Other sectors	X	X	X				
a. commercial/institutional	X	X	X				
b. residential	X	X	X				
c. agriculture/forestry/fish farms	X	X	X				
5. Other non-specified	X	X	X				
a. stationary	X (1990-2003)	X (1990-2003)	X (1990-2003)				
b. mobile	X	X	X				
B. Fugitive Emissions from Fuels	X	X	NO				
1. solid fuels	NO	NO	NO				
a. coal mining & handling	NO	NO	NO				
b. solid fuel transformation	NO	NO	NO				
c. other	NO	NO	NO				
2. oil & natural gas	NA	NA	NO				
a. oil	NA	NA	NO				
b. natural gas	X	X					
c. venting & flaring	X	X	NO				
d. other	NA	NA	NA				
C. CO₂ transport and storage	NO						
2. Industrial Processes and Product Use	X	NO	X	X	NO	X	NO

GHG source & sink categories (CRF nomenclature)	CO ₂	CH ₄	N ₂ O	HFCs	PFCs	SF ₆	NF ₃
A. mineral products	X						
1. cement production	X						
2. lime production	NO						
3. glass production	X						
4. other process uses of carbonates	NO						
B. chemical industry	NO	NO	NO	NO	NO	NO	NO
1. ammonia production	NO	NO	NO				
2. nitric acid production			NO				
3. adipic acid production	NO		NO				
4. caprolactam, glyoxal and glyoxylic acid production	NO		NO				
5. carbide production	NO	NO					
6. titanium dioxide production	NO						
7. soda ash production	NO						
8. petrochemical and carbon black production	NO	NO					
9. fluorochemical production				NO	NO	NO	NO
10. other	NO	NO	NO	NO	NO	NO	NO
C. metal production	X	NO	NO	NO	NO	NO	NO
1. iron and steel production	X	NO					
2. ferroalloys production	NO	NO					
3. aluminium production	NO				NO	NO	
4. magnesium production	NO			NO	NO	NO	
5. lead production	NO						
6. zinc production	NO						
7. other	X (2016-2019)	NO	NO	NO	NO	NO	NO
D. non-energy products from fuels and solvent use	X						
1. lubricant use	X	NO	NO				
2. paraffin wax use	X	NO	NO				
3. other (solvent use & urea based catalysts)	X	NO	NO				
E. Electronics industry				NO	NO	NO	NO
1. integrated circuit or semiconductor				NO	NO	NO	NO
2. TFT flat panel display				NO	NO	NO	NO
3. photovoltaics				NO	NO	NO	NO
4. heat transfer fluid				NO	NO	NO	NO
5. other				NO	NO	NO	NO
F. Product uses as substitutes for ODS				X	NO	X	NO
1. refrigeration and air conditioning				X	NO	NO	NO
2. foam blowing agents				X	NO	NO	NO
3. fire protection				NO	NO	NO	NO
4. aerosols				X (1992-2019)	NO	NO	NO
5. solvents				NO	NO	NO	NO
6. other applications				NO	NO	NO	NO
G. other product manufacture and use	NO	NO	X	NO	NO	X	NO

GHG source & sink categories (CRF nomenclature)	CO ₂	CH ₄	N ₂ O	HFCs	PFCs	SF ₆	NF ₃
1. electrical equipment				NO	NO	X	NO
2. SF6 and PFCs from other product use				NO	NO	X	NO
3. N2O from product uses			X				
4. other	NO	NO	NO	X (2013-2019)	NO	NO	NO
H. Other	NO	NO	NO	NO	NO	NO	NO
3. Agriculture	X	X	X				
A. Enteric Fermentation		X					
1. cattle		X					
2. sheep		X					
3. swine		X					
4. other livestock (poultry, horses, deer, mules and asses, goats, other)		X					
B. Manure Management		X	X				
1. CH ₄ emissions		X					
1. cattle		X					
2. sheep		X					
3. swine		X					
4. other livestock (poultry, horses, deer, mules and asses, goats, other)		X					
2. N ₂ O and NMVOC emissions			X				
1. cattle			X				
2. sheep			X				
3. swine			X				
4. other livestock (poultry, horses, deer, mules and asses, goats, other)			X				
5. indirect N ₂ O emissions			X				
C. Rice Cultivation		NO					
D. Agricultural Soils			X				
1. direct emissions from managed soils			X				
2. indirect emissions from managed soils			X				
E. Prescribed Burning of Savannas		NO	NO				
F. Field Burning of Agricultural Residues		NO	NO				
G. Liming	X						
H. Urea Application	x						
I. Other Carbon-containing Fertilisers	x						
J. Other	NO						
4. Land Use, Land-Use Change and Forestry	X	NO	X				
A. Forest Land	X	NO	NO				
1. forest land remaining forest land	X	NO	NO				
2. land converted to forest land	X	NO	NO				
B. Cropland	X	NO	X				
1. cropland remaining cropland	X	NO	X				
2. land converted to cropland	X	NO	X				
C. Grassland	X	NO	X				

GHG source & sink categories (CRF nomenclature)	CO ₂	CH ₄	N ₂ O	HFCs	PFCs	SF ₆	NF ₃
1. grassland remaining grassland	NO	NO	NO				
2. land converted to grassland	X	NO	X				
D. Wetlands	X	NO	X				
1. wetlands remaining wetlands	NE,NO	NO	NO				
2. land converted to wetlands	X	NO	X				
E. Settlements	X	NO	X				
1. settlements remaining settlements	NO	NO	NO				
2. land converted to settlements	X	NO	X				
F. Other Land	X	NO	X				
1. other land remaining other land							
2. land converted to other land	X	NO	X				
G. Harvested Wood Products	NO						
H. Other	NO	NO	NO				
5. Waste	NO, IE	X	X				
A. Solid Waste Disposal	NO	X					
1. Managed waste disposal sites	NO	X					
2. Unmanaged waste disposal sites	NO	NO					
3. Uncategorized waste disposal sites	NO	NO					
B. Biological Treatment of Solid Waste		X	X				
1. Composting		X (1993-2019)	X (1993-2019)				
2. Anaerobic digestion at biogas facilities		X (1992-2019)	NE				
C. Incineration and Open Burning of Waste	IE	IE	IE				
1. Waste incineration	IE	IE	IE				
2. Open burning of waste	NO	NO	NO				
D. Wastewater Treatment and Discharge		X	X				
1. Domestic wastewater		X	X				
2. Industrial wastewater		NO	X				
3. Other		NO	NO				
E. Other	NO	NO	NO				
6. Other	NO	NO	NO	NO	NO	NO	NO
Memo Items	X	X	X				
International Bunkers	X	X	X				
aviation	X	X	X				
marine	X	X	X				
Multilateral Operations	NA	NA	NA				
CO₂ emissions from biomass	X						
CO₂ captured	NO						

Note: an X indicates that emissions from this sub-category have been estimated, the grey shaded cells are those also shaded in the CRF tables.

1.8.1.1 Sources and sinks

All sources and sinks included in the IPCC Guidelines are covered.

1.8.1.2 Gases

Both direct GHGs and indirect GHGs – NO_x, CO, NMVOCs – and SO₂ are covered by Luxembourg's inventory.

1.8.1.3 Geographic coverage

The geographic coverage is complete. There is no part of the national territory not covered by the inventory.

1.8.1.4 Notation keys

The sources and sinks not considered in the inventory, but included in the IPCC Guidelines, are clearly indicated. The reasons for such exclusions are explained. In addition, the notation keys presented below are used to fill in the blanks in all the CRF tables.

Notation keys used in the NIR are consistent with those reported in the CRF tables. Notation keys used are those described on page 12 of document FCCC/CP/2013/10/Add.3 dated 22nd November 2013.

Allocations to categories may differ from Party to Party. The main reasons for different category allocations are different allocations in national statistics, insufficient information in national statistics and/or national methods, and the impossibility to disaggregate emission declarations.

IE (included elsewhere)

The notation key IE is used for emissions by sources and removals by sinks of GHG that have been estimated but included elsewhere in the inventory instead of the expected source/sink category. Where IE is used in the inventory, CRF table 9 indicates where (in the inventory) these emissions or removals have been included. Such deviation from the expected category is also explained.

NE (not estimated)

The notation key NE is used for existing emissions by sources and removals by sinks of GHG which have not been estimated. Where NE is used in an inventory for emissions or removals, CRF table 9 indicates why emissions or removals have not been estimated.

NA (not applicable)

The notation key NA is used for activities or processes in a given source/sink category that do not produce emissions or lead to removals of a specific gas.

NO (not occurring)

The notation key NO is used for activities or processes in a given source/sink category that do not occur within Luxembourg.

C (confidential)

The notation key C is used for emissions which could lead to the disclosure of confidential information if reported at the most disaggregated level. In this case, a minimum of aggregation is required to protect business information.

1.8.1.5 Transparency and completeness indexes

In Table 1-15, transparency and completeness of submission 2021v1 is presented. The exercise focuses on the inventory year 2019 and the sectoral report tables only. The level of detail for CRF sources and categories is up to 4 digits for the energy sector (e.g. IPCC Subcategory 1A1a) and 3 digits for the other sectors (e.g. IPCC Sub-category 4D3). Finally, only the 6 GHGs are covered by this exercise. The total number of estimates (including IE, NE, NA, NO, and empty cells in the CRF reporting tables) for each CRF sector is counted as well as the numbers reported as 'not estimated' and 'included elsewhere'.

Transparency and completeness indexes are calculated as follows:

- Transparency (TR) [%] = $[1 - (\text{number of IE}/\text{number of estimates})] * 100$
- Completeness (CP) [%] = $[1 - (\text{number of NE}/\text{number of estimates})] * 100$

Table 1-15 - Transparency and completeness indexes for submission 2021v1.

CRF Sector	Submission 2021v1				
	# estimates	IE	NE	TR	CP
Energy (sectoral approach) – CRF 1	90	0	0	100%	100%
Industrial Processes – CRF 2	144	0	0	100%	100%
Agriculture – CRF 3	57	3	0	95%	100%
LULUCF – CRF 4	66	0	1	100%	98%
Waste – CRF 5 (*)	60	3	1	95%	98%
Total	417	6	2	99%	100%

(*) IE from Waste includes waste incineration that is reported under IPCC Sub-category 1A1a since the energy produced while burning waste is recovered.

1.8.2 KP-LULUCF inventory

All mandatory activities according to Article 3.3 and Article 3.4 of the Kyoto Protocol are estimated. Luxembourg did not elect Article 3.4 activities, such as Cropland Management, Grazing land Management, Revegetation, Wetland Drainage and Rewetting. Forest management activities were estimated, as these are mandatory for the second commitment period.

2 Trends in Greenhouse Gas Emissions

According to the Kyoto Protocol, Luxembourg's GHG emissions had to be 8% below base year emissions during the five-year commitment period from 2008 to 2012. The European Community and its Member States also had a common reduction target of 8%, which they decided to achieve jointly. In April 2002, the Council of the European Union has adopted a decision, the so-called "burden sharing agreement", which includes reduction targets for each Member State. Luxembourg agreed to reduce its GHG emissions for 2008–2012 by 28% compared to the base year emissions level. The second commitment period bridges the gap between the end of the 1st Kyoto period and the start of the new global agreement in 2020. Luxembourg, together with 27 other EU member states and Iceland, has agreed to make further cuts by 20% of GHG emissions compared to 1990 (Doha Agreement).

When estimating GHG emission composition and trends in Luxembourg, one should keep in mind that the IPCC methodology used for compiling GHG inventories is raising some peculiar issues for small countries, in particular because of the "territory" or "origin" principle underpinning it. Therefore, in Section 2.1, specific national circumstances are examined. These specific conditions are relating to socio-economic characteristics that have significant effects on Luxembourg's GHG total emissions when applying IPCC accounting rules. This first section is complemented by a discussion of how both the UNFCCC and the Kyoto Protocol are challenging Luxembourg's action with regard to climate change (Section 2.2) and by a general overview of the national circumstances (Section 2.3). Section 2.4 concludes this chapter with an overview of the main developments of and drivers to GHG emissions in Luxembourg since 1990.

2.1 National Circumstances

2.1.1 The Grand-Duchy of Luxembourg

The Grand-Duchy of Luxembourg has been an independent sovereign state since the Treaty of London was signed on 19 April 1839. The country is a **parliamentary democracy** in the form of a **constitutional monarchy** and is the second smallest Member State of the EU-28, after Malta. For many years, it has been characterized by **high economic and demographic growth rates**. The country is **located in the heart of North-Western Europe** and has direct borders with Belgium, Germany and France (Figure 2-1). It is therefore a crossroads for international trade and related transport flows, the most dynamic source of its GHG emissions.

Luxembourg has a territory of 2 586 km². The maximum distance from North to South is some 82 km and from West to East about 57 km (Figure 2-2). In 2019, 84.8% of the total area of Luxembourg was agricultural land and land under forest – with around 47.6% for agriculture and 37.2% for forests. The built-up areas occupied 9.8% of the total surface while land covered by water and transport infrastructure covered about 5.1% (Table 2-1 & Figure 2-3).

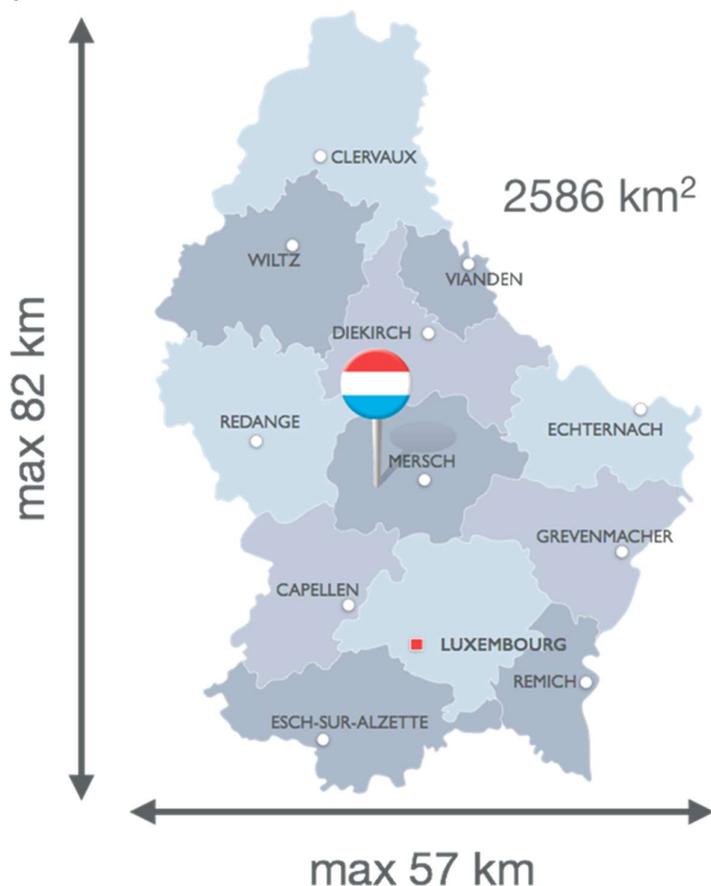
The North of Luxembourg is a part of the Ardennes and is called "Ösling". Its altitude is at an average of 400 to 500 meters above sea level. The "Ösling" landscape is affected by hills and deep river valleys, as for instance the Sure (Sauer) river. With 560 m, the highest elevation is called the "Kneiff" in Wilwerdange. In the South of Luxembourg lies the rank "Gutland", which belongs to the "Lothringer Stufenland". This area has higher population and industrial densities than "Ösling". The lowest point in the country, called "Spatz" (129 m above sea level), is located at the confluence of the Moselle and the Sure rivers in Wasserbillig. The most important rivers are the Moselle, the Sure, the Our – all three delimiting the border with Germany – and the Alzette.

Figure 2-1 – GEOGRAPHIC LOCATION OF LUXEMBOURG



Source: Google Maps.

Figure 2-2 – LUXEMBOURG SIZE



Source: Google Maps.

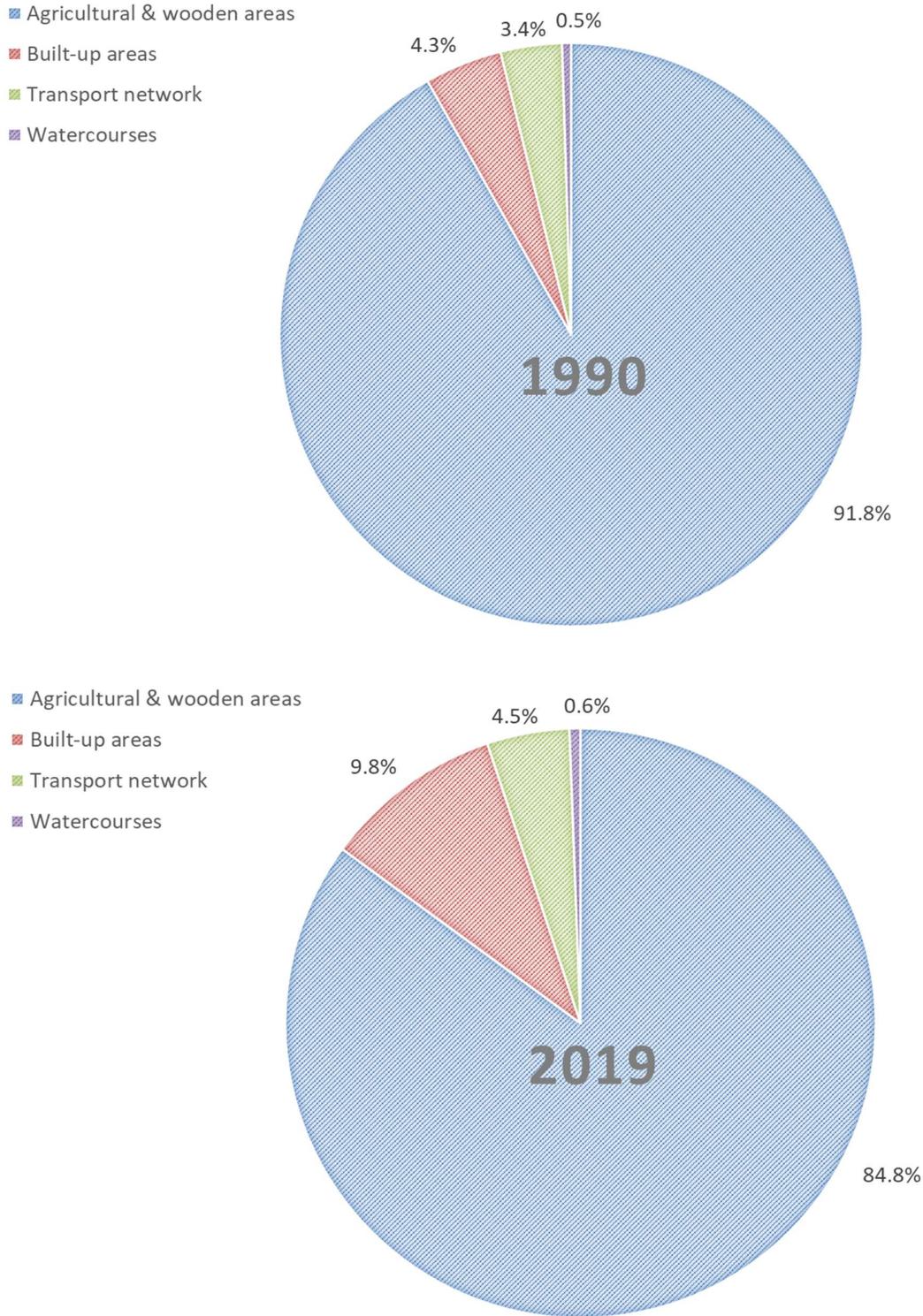
Table 2-1 – Land use in Luxembourg: 1972-2019

Percentages	1972	1990	2000	2010	2015	2016	2017	2018	2019
Total land	100	100	100	100	100	100	100	100	100
Agriculture & wooded area	93.2	91.8	87.4	85.7	85.3	85.1	85.1	85.2	84.8
Built-up area	3.1	4.3	8.1	9.3	9.7	9.8	9.8	9.7	9.8
of which industrial area & other	NA	NA	2.7	3.0	3.0	3.1	3.1	3.0	3.1
Transport network & sheets of water	3.2	3.4	3.9	4.4	4.4	4.5	4.5	4.5	4.5
Watercourses	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6

Source: STATEC, Statistical Yearbook, Table A.1101 (updated 11 February 2021):

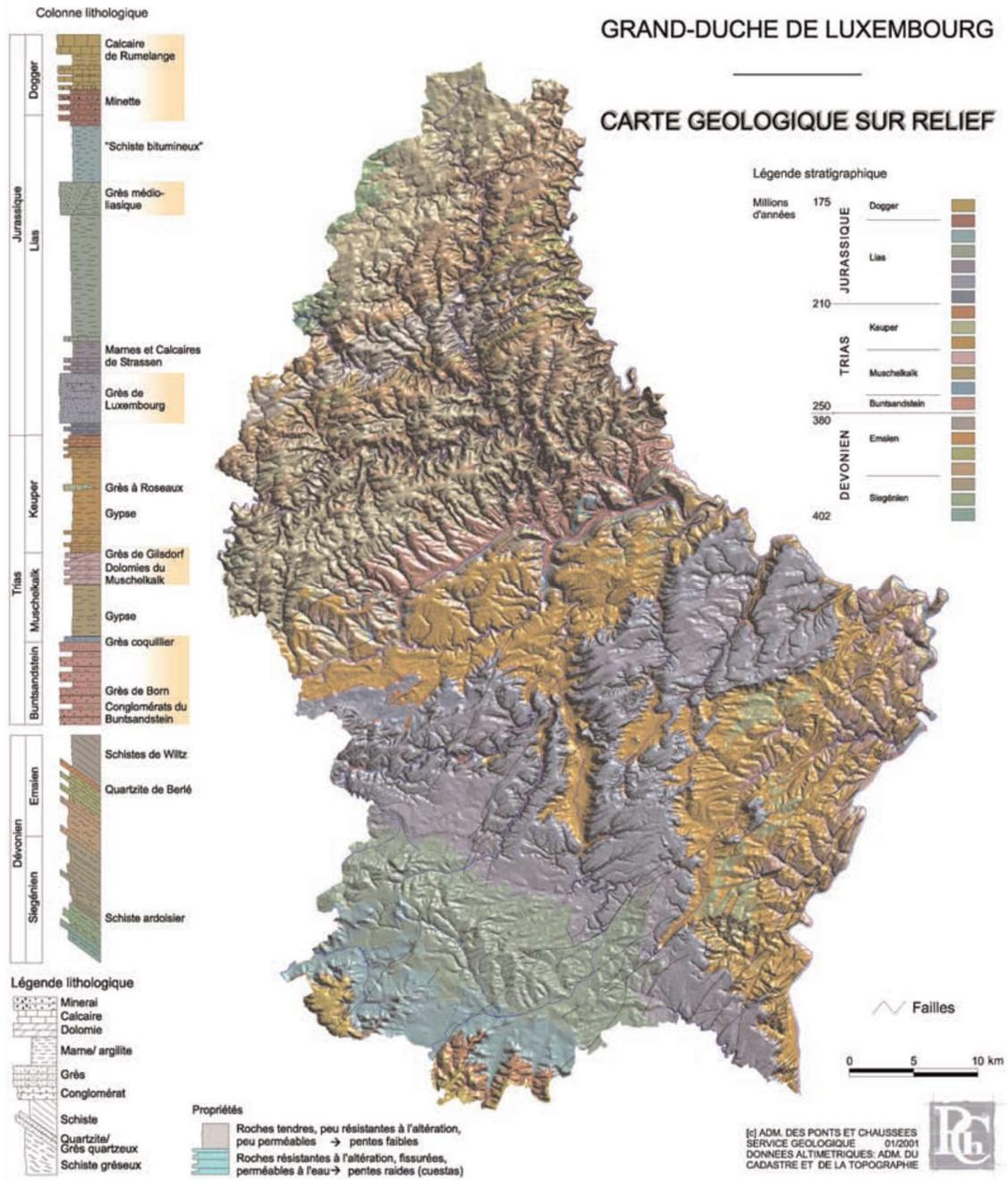
http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12695&IF_Language=fra&MainTheme=1&FldrName=1

Figure 2-3 – Land use: 1990 & 2019



Source: STATEC, Statistical Yearbook, Table A.1101 (updated 11 February 2021):
http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12695&IF_Language=fra&MainTheme=1&FldrName=1

Figure 2-4 – Geological map of Luxembourg's territory



Source: STATEC, *Annuaire statistique du Luxembourg 2012*, page 39: <http://www.statistiques.public.lu/fr/publications/series/annuaire-stat-lux/index.html>.

2.1.2 Climate ²⁶

2.1.2.1 Present climate: increasing average air temperatures and high variability in precipitation patterns during the last decades

The climate in Luxembourg can be characterized as a **moderate oceanic Western European climate** with mild winters and comfortable summers (Goergen, Beersma, Hoffmann, & Junk, 2013).

As shown by the long-term annual means (WMO reference period from 1961-1990 and 1981-2010) measured at the Findel-Airport meteorological station WMO 06590 (Table 2-2), temperatures have an unimodal distribution, with the lowest long-term mean values occurring during January (0.0°C for the period 1961-1990) and the highest air temperature in July (16.9°C for the period 1961-1990). Absolute minimum and maximum air temperatures ever recorded at Findel station until 31 December 2016 were -20.2°C (2 February 1956) and 37.9°C (8 and 12 August 2003)²⁷.

Table 2-2: Long-term mean values (1961-1990 & 1981-2010) of air temperature and precipitation for Findel-Airport station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean air temperature [°C]	0.0 0.8	1.1 1.6	4.0 5.2	7.5 8.7	11.8 13.0	14.9 15.9	16.9 18.2	16.4 17.7	13.4 13.9	9.1 9.5	3.8 4.7	1.0 1.8	8.3 9.3
Mean minimum air temperature [°C]	-2.3 -1.6	-1.8 -1.3	0.6 1.6	3.3 4.4	7.1 8.4	10.2 11.1	12.0 13.3	11.8 13.0	9.3 10.0	5.7 6.3	1.2 2.2	-1.3 -0.5	4.7 5.6
Mean maximum air temperature [°C]	2.3 3.1	4.2 4.7	7.9 9.1	12.1 13.3	16.8 17.8	20.0 20.7	22.0 23.2	21.6 22.8	18.2 18.4	13.0 13.1	6.6 7.3	3.3 3.9	12.3 13.1
Mean monthly precipitation sum [mm]	71.1 76.6	61.7 62.5	70.1 69.1	61.0 58.2	81.2 78.5	81.5 79.9	68.4 71.0	72.2 75.4	69.8 76.3	74.7 86.8	83.1 76.0	79.6 86.7	874.4 896.9

Sources: 1961-1990–MeteoLux

(http://meteolux.lu/filedownload/73/2016_Informations_sur_le_climat_au_Luxembourg_en_2016_Anglais.pdf)

1981-2010 –MeteoLux (<http://meteolux.lu/fr/climat/normales-et-extremes/>).

According to definitions for GHG reporting, **Luxembourg is situated in a cool climate region** since its annual average air temperature is below 15°C: 8.3°C for the reference period 1961-1990 (Table 2-2) and 9.3°C for the reference period 1981-2010.

A regional analysis of different stations operated by the Agriculture Technical Services Administration (Administration des Services Techniques de l’Agriculture – ASTA) throughout Luxembourg, shows that temperatures in the North of the country (Ösling) are on average up to 1°C lower than at Findel airport, whereas in the Moselle valley they are on average nearly 1°C higher (Table 2-3 to Table 2-5).

Table 2-3: Long-term mean values (1981-2010) of mean air temperature for different ASTA stations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Asselborn	0.3	0.7	4.0	7.5	11.9	14.8	17.0	16.3	12.6	8.7	4.0	1.2	8.3
Clemency	1.0	1.5	5.0	8.5	13.1	16.2	18.2	17.4	13.4	9.4	4.7	2.0	9.2
Grevenmacher	1.7	2.5	5.9	9.5	13.9	17.0	19.1	18.2	14.1	10.1	5.5	2.7	10.0
Remich	1.6	2.5	6.2	9.8	14.2	17.1	19.3	18.5	14.5	10.3	5.5	2.7	10.2

²⁶ The text of this Section has been prepared by Junk, J., Trebs, I., Hoffmann, L. of the Luxembourg Institute of Science and Technology (LIST), Department Environmental Research and Innovation (ERIN), with additions by Andrew Ferrone of the Administration des services techniques de l’agriculture (ASTA), Meteorological Service.

²⁷ <http://meteolux.lu/fr/climat/normales-et-extremes/>.

Table 2-4: Long-term mean values (1981-2010) of maximum air temperature for different ASTA stations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Asselborn	2.7	3.9	7.9	12.2	16.7	19.5	21.9	21.5	17.3	12.5	6.6	3.2	12.2
Clemency	3.4	5.0	9.3	13.5	18.0	20.9	23.4	23.0	18.6	13.5	7.5	4.2	13.4
Grevenmacher	4.3	6.1	10.7	15.2	19.7	22.6	25.1	24.6	20.2	14.6	8.6	5.3	14.7
Remich	4.1	6.0	10.6	14.9	19.3	22.3	24.6	24.2	19.7	14.4	8.3	5.1	14.5

Table 2-5: Long-term mean values (1981-2010) of minimum air temperature for different ASTA stations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Asselborn	-1.8	-2.0	0.6	2.9	6.9	9.5	11.6	11.0	8.4	5.5	1.8	-0.5	4.5
Clemency	-1.5	-1.5	1.2	3.2	7.4	10.1	12.1	11.6	8.7	5.8	2.3	-0.3	4.9
Grevenmacher	-0.8	-0.8	1.9	4.1	8.1	11.0	13.0	12.4	9.6	6.8	2.8	0.6	5.7
Remich	-0.7	-0.4	2.4	4.8	8.8	11.5	13.6	13.0	10.0	6.8	3.0	0.5	6.1

Source: ASTA, Agrimeteo (<http://asta.public.lu/meteorologie/meteo.html>).

The regional distribution of precipitation (Table 2-6) shows higher regional variability. A general gradient from the North-West to the South-East of the country can be noted, with highest annual average values recorded in Arsdorf (1055 mm) and lowest values in Remich (725 mm).

Table 2-6: Long-term mean values (1981-2010) of precipitation for different ASTA stations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Altrier, Hersdorf	72	56	60	51	62	65	65	61	63	69	70	81	775
Arsdorf	120	84	88	69	75	75	74	78	76	100	96	120	1055
Asselborn	81	64	69	58	68	71	68	74	69	75	75	84	856
Berdorf	73	59	63	50	63	65	68	60	68	73	68	82	791
Beringen	76	58	61	53	64	63	59	64	64	69	66	85	781
Bettborn, Pratz	90	67	69	55	66	65	60	67	66	81	75	96	857
Clemency	92	73	73	52	64	65	62	63	64	78	77	94	856
Ermsdorf	78	62	64	55	68	66	73	70	66	76	68	83	830
Fourhen	77	56	62	51	61	61	64	62	63	72	68	82	780
Grevenmacher	66	53	54	46	58	67	61	61	60	69	63	73	729
Holler	86	69	79	59	73	73	76	74	73	76	76	89	903
Hosingen	93	71	78	67	72	67	73	70	75	84	83	97	930
Kehmen	102	75	78	65	73	67	67	74	71	86	86	106	951
Koerich	88	70	69	54	62	65	56	63	62	78	76	95	834
Lorentzweiler	83	67	66	55	68	70	64	66	66	75	72	90	843
Mamer	85	68	68	54	70	68	64	64	65	79	74	94	852
Mullendorf	84	66	67	54	65	69	60	63	66	77	73	93	837
Remerschen	70	56	58	51	63	67	71	60	64	75	65	78	779
Remich	63	51	55	47	58	68	61	59	62	70	60	71	725
Saeul	93	65	68	55	67	65	60	61	64	80	75	98	852
Troine, Wincrange	92	73	80	67	76	76	74	78	76	84	83	100	959

Source: ASTA, Agrimeteo (<http://asta.public.lu/meteorologie/meteo.html>).

Climate conditions have significant impacts on energy use for heating or cooling purposes. An increase in average air temperature in the forthcoming years could have a positive impact on energy consumption, especially in the residential, commercial and institutional sectors. However, in case of a substantial increase of air temperatures, an increase in energy consumption related to a more frequent use of air conditioning systems could also be expected.

As shown by measurements at the Findel-Airport meteorological station (Table 2-7), two conclusions can be drawn: firstly, an increase in average air temperature is observed over the last decades (Figure 2-5 and Figure 2-6); secondly, annual precipitation does not show such clear trends (Figure 2-7 and Figure 2-8). Similar observations have been obtained in scientific studies on the climate in Luxembourg, notably in (Goergen, Beersma, Hoffmann, & Junk, 2013), Lokys et al. (2016) and Junk et al. (2016). From 1990 onwards, annual mean air temperatures for the Findel-Airport station started to increase rather sharply to systematically exceed the 1961-1990 mean value (Figure 2-5). Temperature maxima have mostly been observed during the last 25 years (Figure 2-6). Further analysis of the data suggests that the average air temperature in Luxembourg has increased mainly during the winter seasons, coupled with longer frost-free periods (Molitor, et al., 2014).

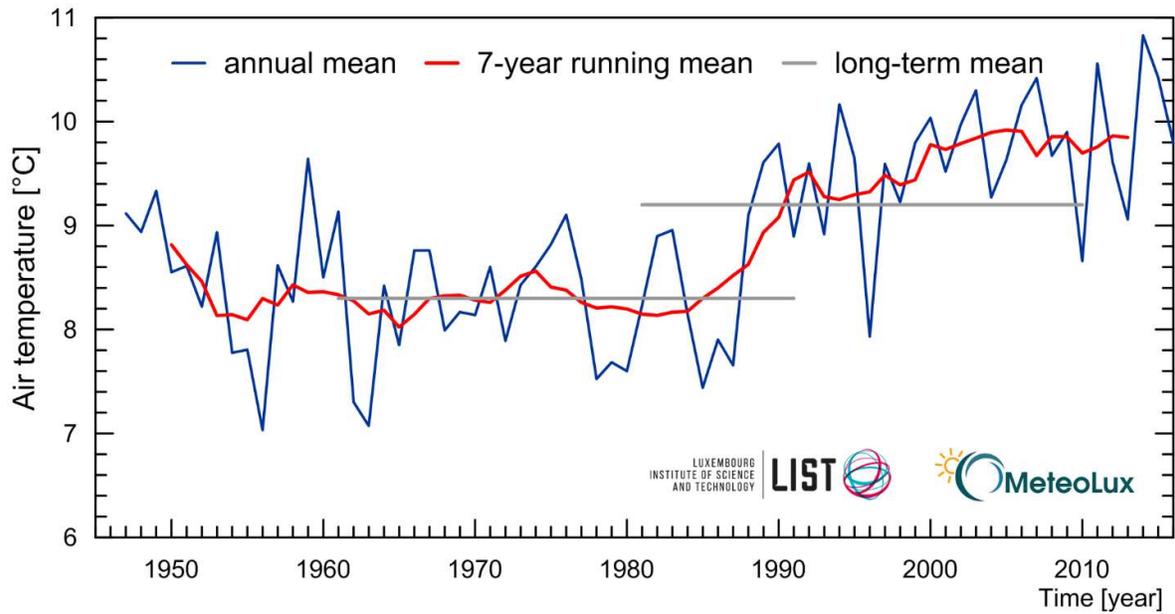
Further analysis of the data suggests that the average air temperature in Luxembourg has increased during the winter seasons, coupled with longer frost-free periods.

Table 2-7: Mean values of air temperature (daily mean, maximum & minimum) and precipitation for the Findel-Airport station for different time spans and individual years.

	1961-1990	1981-2010	2005	2010	2015	2016
Mean air temperature [°C]	8.3	9.3	9.6	8.7	10.4	9.8
Mean minimum air temperature [°C]	4.7	5.6	5.9	5.1	6.6	6.1
Mean maximum air temperature [°C]	12.3	13.1	13.6	12.4	14.3	13.7
Mean yearly precipitation sum [mm]	874.4	896.9	722.5	917.2	605.9	864.6

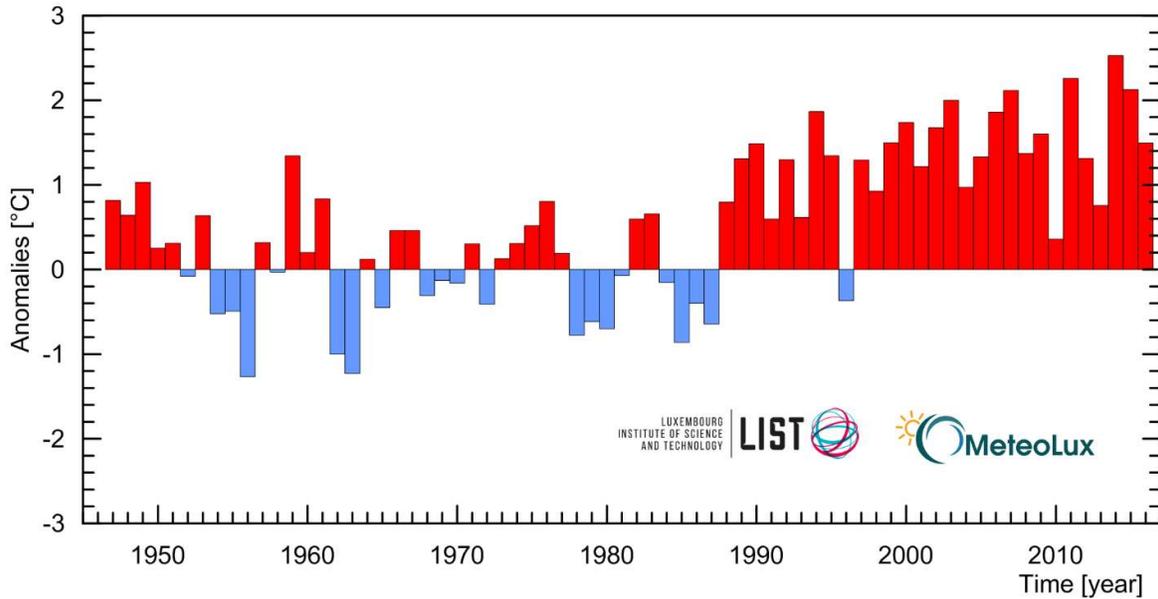
Sources: MeteoLux (http://meteolux.lu/filedownload/73/2016_Informations_sur_le_climat_au_Luxembourg_en_2016_Anglais.pdf)

Figure 2-5: Average annual air temperature (blue line), 7-year running mean (red line) and long-term annual mean 1961-1990 and 1981-2010 (grey lines) for the Findel-Airport station: 1947-2016



Sources: Findel-Airport station (MeteoLux) and Luxembourg Institute of Science and Technology (LIST). unpublished.

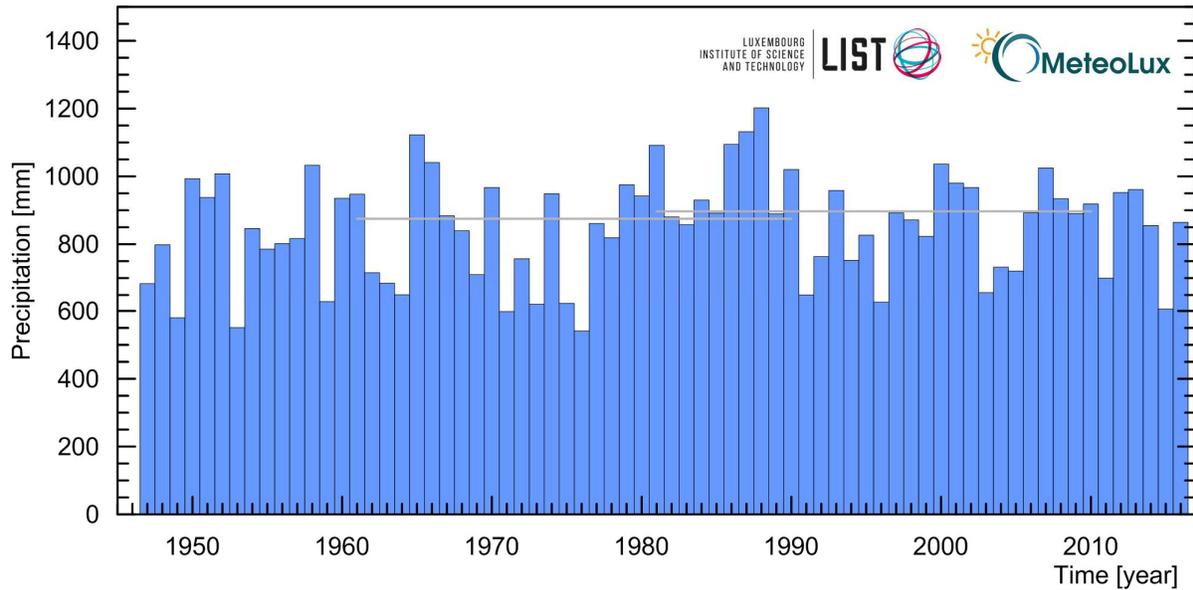
Figure 2-6: Anomalies of annual air temperature from the reference period 1961-1990 for the Findel-Airport station: 1947-2016



Sources: Findel-Airport station (MeteoLux) and Luxembourg Institute of Science and Technology (LIST). unpublished.

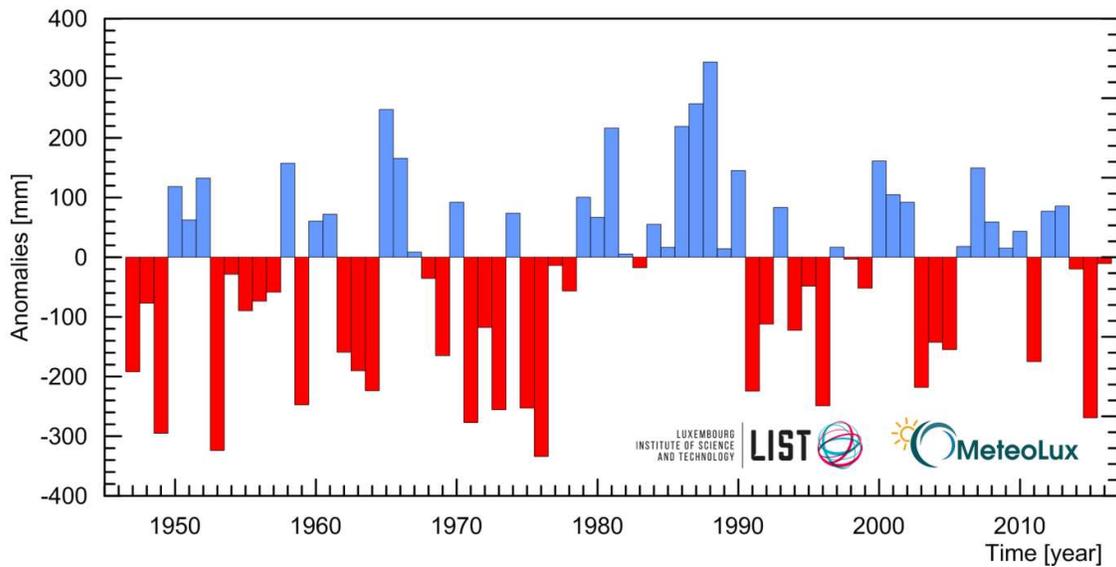
Note: anomalies from the reference period 1961 until 1990: long-term mean: 8.3°C.

Figure 2-7: Annual precipitation totals (blue columns) and long-term annual mean 1961-1990 and 1981-2010 (grey lines) for the Findel-Airport station: 1947-2016



Sources: Findel-Airport station (MeteoLux) and Luxembourg Institute of Science and Technology (LIST). unpublished.

Figure 2-8: Anomalies of annual precipitation totals from the reference period 1961-1990 for the Findel-Airport station: 1947-2016



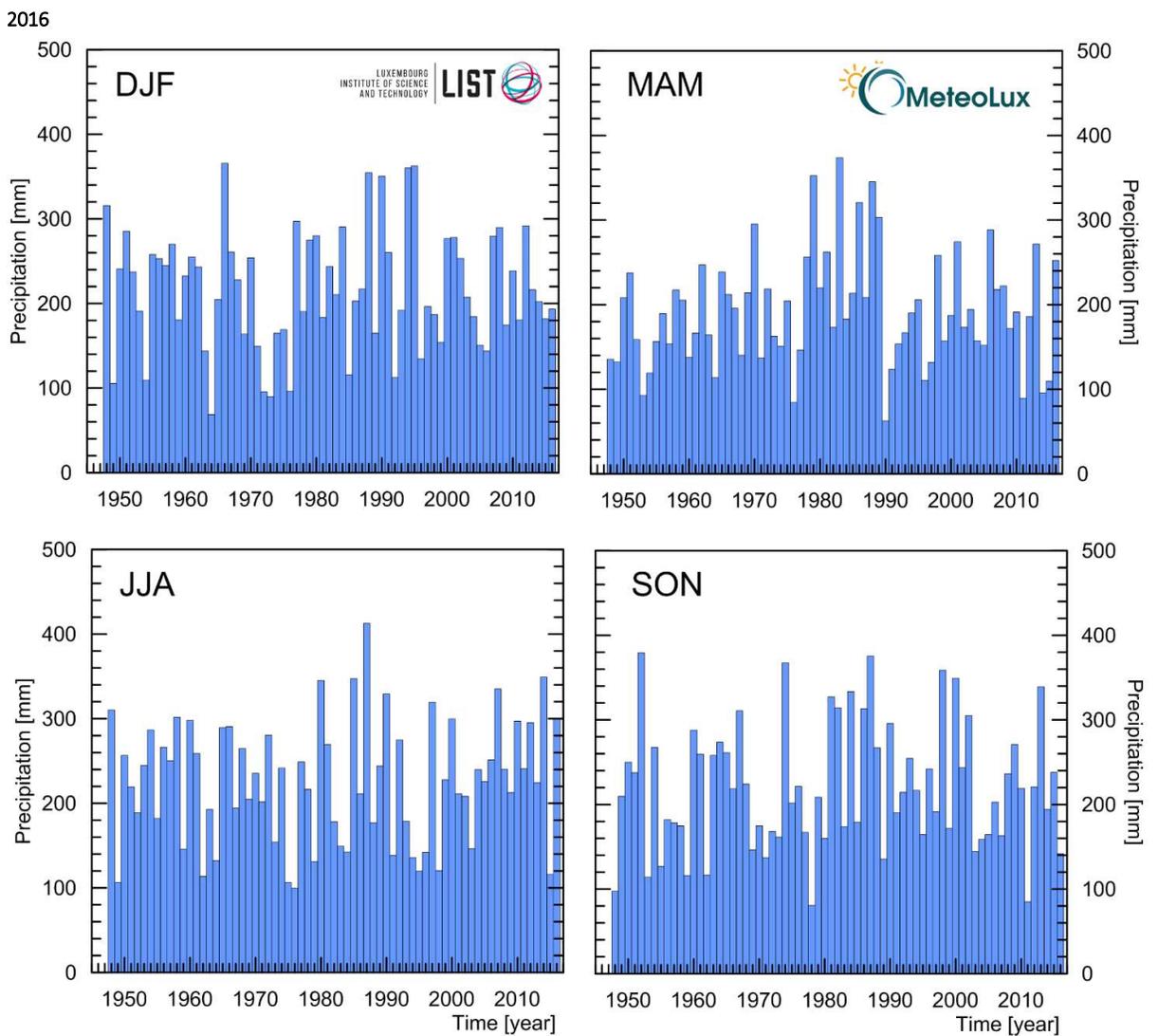
Sources: Findel-Airport station (MeteoLux) and Luxembourg Institute of Science and Technology (LIST). unpublished.

Note: anomalies from the reference period 1961 until 1990: long-term mean: 874 mm.

With regard to annual precipitation, no clear changes can be detected from the direct measurements (Table 2-7). During the hydrological winter half-year (October / November to March / April) evaporation is rather unimportant, which means that the precipitation falling during this period is almost completely discharged or stored underground. The most part of the precipitations falling during the summer half year evaporates and is very important for the development of the vegetation. However, the seasonal distribution of precipitation totals has shown substantial variability through the past 70 years (Figure 2-9).

Most of this variability can be attributed to changes in the large-scale atmospheric circulation patterns. An increase in westerly atmospheric fluxes during winter months was shown by Buchholz et al. (2010) for the past years. In combination with higher air temperatures, this has led to higher flood frequencies in most national river basins (Pfister, Hoffmann, & Humbert, 2000) (Pfister, et al., 2004).

Figure 2-9: Seasonal precipitation totals (DJF = winter; MAM = spring; JJA = summer; SON = autumn) for the Findel-Airport station: 1947-2016

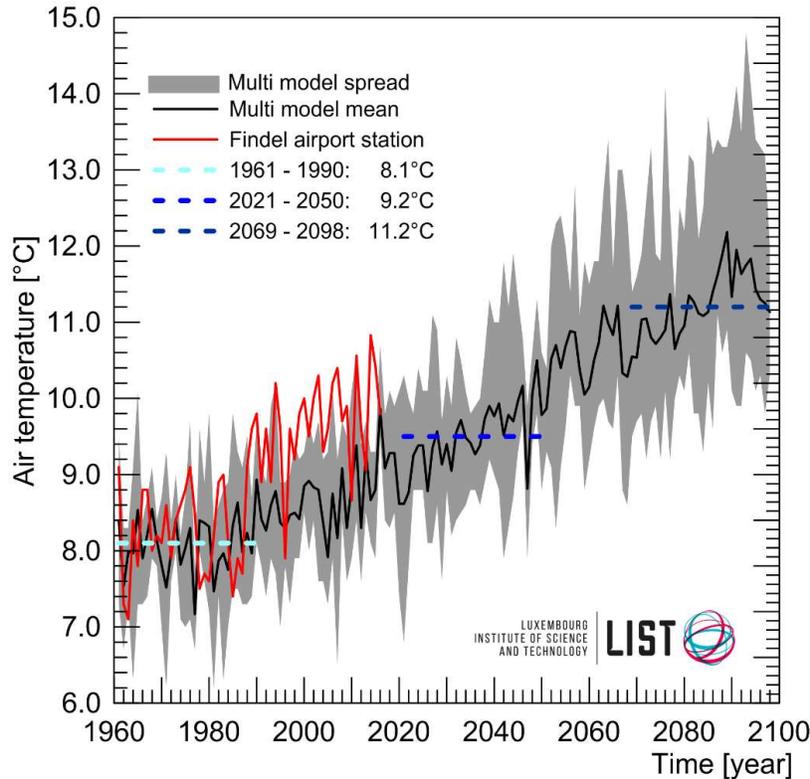


Sources: Findel-Airport station (MeteoLux) and Luxembourg Institute of Science and Technology (LIST). unpublished.

2.1.2.2 Climate projections for air temperature and precipitation

Results of a research project (FNR-CLIMPACT) show an increase in mean air temperature for the Grand Duchy of Luxembourg. Based on selected results of the FP₆ ENSEMBLES project climate change projections²⁸, mean annual temperatures are expected to reach up to 11.6°C for the period 2071 until 2100. This value refers to the GHG emission scenario A1B (Figure 2-10).²⁹

Figure 2-10: Projections of mean annual temperature.



Source: Luxembourg Institute of Science and Technology (LIST). unpublished.

Notes: (1) based on selected ENSEMBLES data sets. A1B emission scenario.

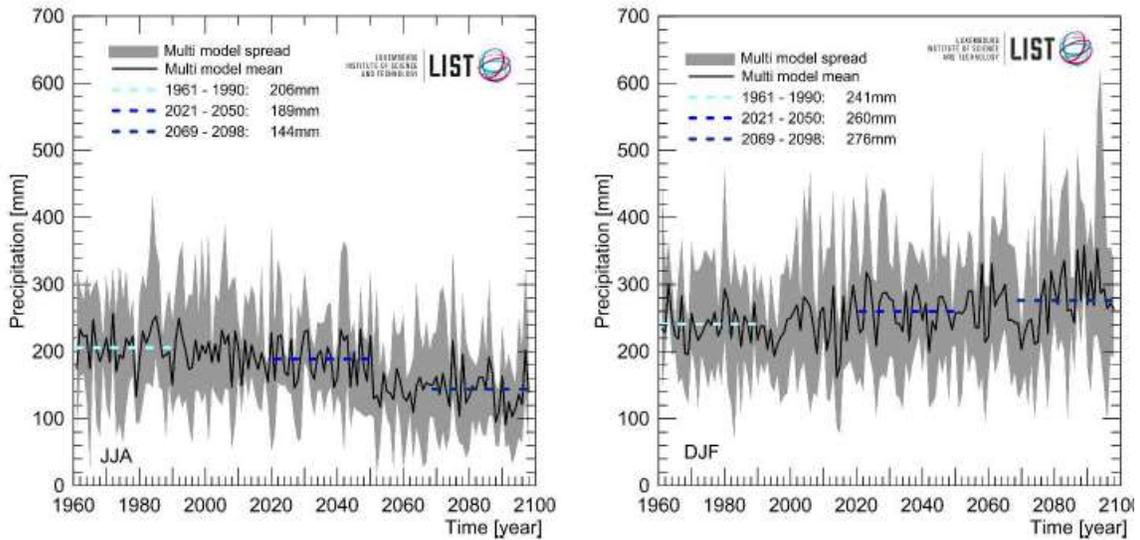
(2) anomalies from the reference period 1961 until 1990: long-term mean: 8.9°C.

The results concerning changes in precipitation suggest a relative stability in annual totals until 2100 (Figure 2-11). However, a substantial redistribution of seasonal precipitation totals can be expected in the second half of the 21st century, with a decrease in summer rainfall and an increase in winter precipitation (Figure 2-12). It is also likely that there will be an increase in heavy rain events, especially during the summer months. In addition, the winter precipitation will probably fall more often as rain and less often as snow, whereby the risk for floods will increase especially during the winter months and spring.

²⁸ More details on ENSEMBLE are provided in Box VI.1-1 in Section V.1.1. see also <http://ensembles-eu.metoffice.com>.

²⁹ Results were published in a series of peer reviewed papers e.g.: (Eickermann, Beyer, Goergen, Hoffmann, & Junk, 2014); (Goergen, Beersma, Hoffmann, & Junk, 2013); Junk et al. (2014); Junk et al. (2016); (Matzarakis, Rammelberg, & Junk, 2013); (Molitor, Junk, Evers, Hoffmann, & Beyer, 2013); (Molitor, et al., 2014)

Figure 2-11: Projections of precipitation sums for the meteorological winter and summer seasons.

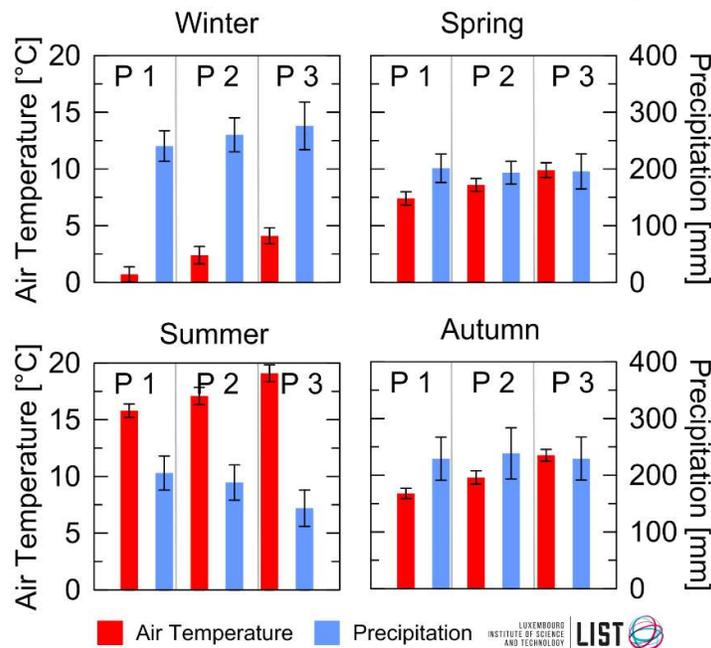


Source: Luxembourg Institute of Science and Technology (LIST). Unpublished.

Notes: (1) based on selected ENSEMBLES data sets. A1B emission scenario.

(2) JJA = meteorological summer season (June-July-August); DJF= meteorological winter season (December – January – February).

Figure 2-12: Projections of mean annual air temperature and precipitation sums for the meteorological seasons.



Source: Luxembourg Institute of Science and Technology (LIST). Georgen et al. (2013).

Notes: (1) based on selected ENSEMBLES data sets. A1B emission scenario.

(2) periods: P1 = 1961-1990 // P2 = 2021-2050 // P3 = 2069-2098.

2.1.2.3 Expected impacts of climate change in Luxembourg: vegetation and water in the forefront

According to a report published in 2016 by the EEA [European Environment Agency (2016)], Luxembourg is part of the biogeographical “Continental Region” area as defined under the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) – see Map ES.1, p. 25 of the aforementioned report. The threats identified for this peculiar region are:

- increase in heat extremes;
- decrease in summer precipitation;
- increasing risks of river floods;
- increasing risk of forest fire;
- decrease in economic value of forests;
- increase in energy demand for cooling.

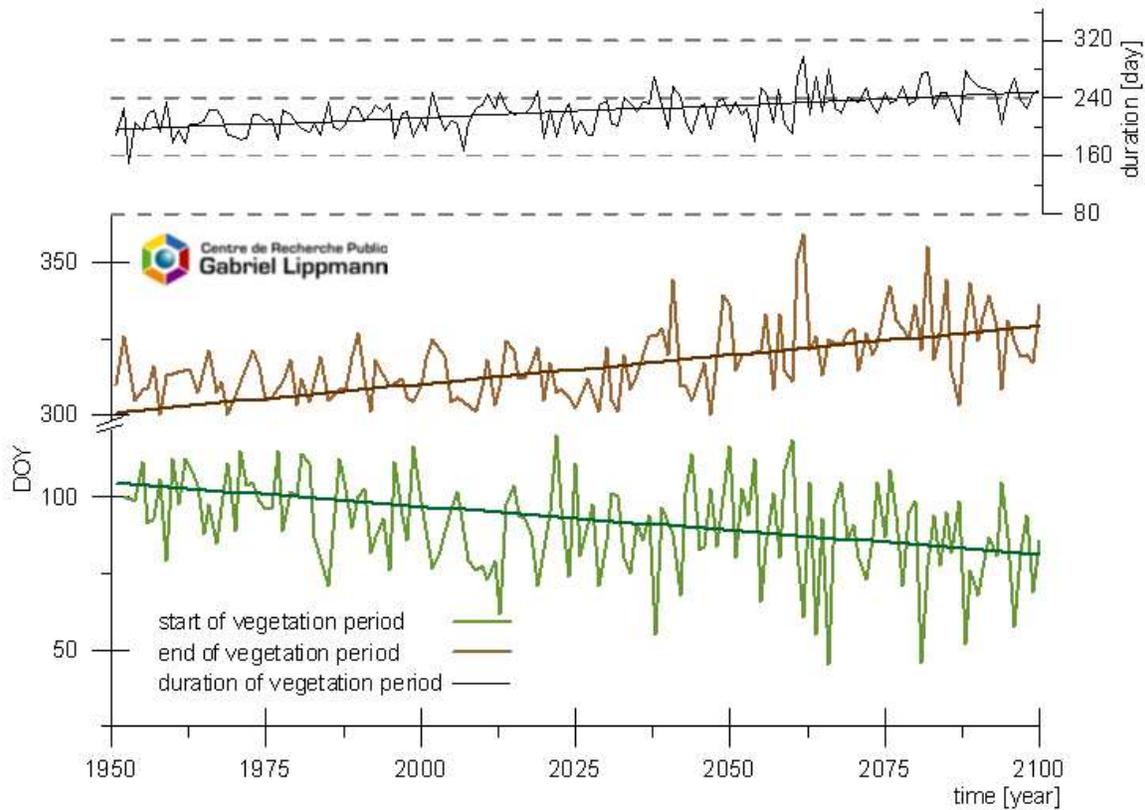
Two of these threats are of main concern for Luxembourg, **those relating to forests. Temperature extremes** and **summer precipitation reduction** are also causes for concern due to their impacts on human health, especially of the most fragile persons and the elderly (heat, air quality), and impacts on water quality in summer when rivers flows are usually at their lowest.

According to the researchers of the Luxembourg Institute of Science and Technology (LIST), the projected changes in air temperature (section 2.1.2.2) are likely to induce a modification of the vegetation period in Luxembourg. The start of the vegetation period is defined as the exceedance of the 5°C daily mean temperature threshold in spring for at least 5 successive days; the end of the vegetation period corresponds to the undershooting of this threshold until the end of the year (Chmielewski & Rötzer, 2001).

In Luxembourg, the vegetation period is expected to be initiated earlier in spring and to last longer into autumn (Figure 2-13). During the early stages of the vegetation period this might cause an increased risk of frost damages to vegetation (Goergen, Beersma, Hoffmann, & Junk, 2013).

The increase of temperatures, especially during the winter period (section 2.1.2.1), already has significant impacts on the phenology of plants (earlier flowering dates) and animals (e.g. earlier breeding dates of birds, advancement of life cycle of insects (Junk, Eickermann, Goergen, Beyer, & Hoffmann, 2012); (Eickermann, Beyer, Goergen, Hoffmann, & Junk, 2014), three instead of two yearly cycles), but also on the migratory behaviour of birds and insects (i.e. species now winter in Luxembourg that in former times migrated to Spain or northern Africa). Furthermore, the temperature changes have an impact on the bio-geography of plants and animals, with new species with a Mediterranean distribution, formerly unknown in Luxembourg, which recently appeared in the country fauna (e.g. *Nomophila noctuella*, *Udea ferrugalis*, *Brenthis daphne*) and flora (some moss species). Bio-climatic approaches also indicate that some relict species of the last glaciation period (e.g. *Lycaena helle*) will disappear from Luxembourg with the expected temperature increase.

Figure 2-13 - Start, end and duration of the vegetation period



Source: Luxembourg Institute of Science and Technology, unpublished.

Notes: (1) based on selected ENSEMBLES data sets, A1B emission scenario.

(2) End and duration of the vegetation period as defined by (Chmielewski & Rötzer, 2001)

(3) DOY = day(s) of year.

The climate projections for the second half of this century will also have significant impacts on the **bio-meteorological conditions** in Luxembourg. The higher air temperatures, especially stressful for humans during night in their recreation time, also increase the likelihood of extreme heat events such as the one that struck Europe in August 2003. Besides impact on the **human health**, this will also lead to more frequent and more stringent stress conditions for **agricultural plants and forestry**, most severely impacting perennial forest trees. Observations on the phytosanitary state of Luxembourg forest – a rather “old” forest – show a sharp degradation – which seems to have stabilised nowadays – resulting, among other factors, from climate change. The ageing of the forest also increases the risk of outbreak of diseases and of infestation by insects as well as other parasites that could proliferate if more mild winters and overall general temperatures are recorded in Luxembourg.

With regard to **water**, the most analysed phenomena so far are floods. It is known that; due to major redistributions of winter rainfalls, essentially, a higher inundation frequency is being recorded since the river systems have reacted to these changes with a statistically significant increase of maximum daily runoff during winter. (Pfister, Drogue, Poirier, & Hoffmann, 2005) this is why an observation hydro-climatic network (réseau d’observation hydro-climatologique) has been put in place in the mid-1990s.³⁰ Its main functions

30 <http://www.hydroclimato.lu>.

consist in continuously (24/7) monitoring Luxembourg’s water courses, and in the realization and the updating of an atlas of areas of the national territory subjected to swellings and floods. The network also suggests anti-flooding measures and participates to renaturation projects aiming at re-creating natural areas which have been used as natural reservoirs containing rising waters.³¹

2.1.3 Population and Workforce

2.1.3.1 A strong population growth driven by immigration

At the end of 2019, the **population of Luxembourg** was estimated to 613 894 inhabitants. Since 1960, the residential population has grown by some 299 000 inhabitants or about 95% – or 60% since 1990 (

Table 2-8). The average annual growth rate of the resident population of Luxembourg is elevated compared to the rates of its neighbouring regions: between 1990 and 2015, the average annual growth rate for Luxembourg (1.54%) was about 4 times higher than its equivalent for the Grande Région.³² It even reached 1.78% p. a. since 2000 (Figure 2-15).

Demographic growth in Luxembourg is actually dominated by **immigration**. Nationals themselves saw their number stagnating, and without immigrants taking the citizenship of Luxembourg they would even have fallen. At the end of 2019, 47.5% of the residential population did not have the citizenship of Luxembourg. This percentage was only around 30% in 1990, as depicted in Figure 2-14. The main driver behind these demographic trends is the economic restructuring and development of the country towards the tertiary sector coupled with attractive wages, which is presented in Section 0.

Since population projections are based on scenarios derived from past statistical data, population forecasts a continuation of the demographic trend in Luxembourg. Projections calculated by STATEC in 2017 forecast, under the assumption of a 3% annual gross domestic product increase, that almost 980 000 inhabitants could be living in Luxembourg by 2050 (Figure 2-15).³³ As it is the case for any forecasts, these predictions should be treated with caution because they cannot predict radical changes in the economic structure or demographics of a country, especially a small one whose economy relies heavily on a few economic sectors. However, since population growth is one of the key drivers for domestic energy use, mainly in the housing and transportation sector, these forecasts illustrate the scale of one of the many challenges Luxembourg is facing in the definition of measures aiming at reducing its GHG emissions.

Table 2-8 – Population: 1960-2019

Calculated on 31 st December	1960	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
Resident population (x 1000)	314.9	384.4	411.6	439.0	469.1	511.8	576.2	590.7	602.0	613.9	626.1

Source: STATEC, Statistical Yearbook, Table B.1100 (updated 12 February 2020): http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12856&IF_Language=fra&MainTheme=2&FldrName=1

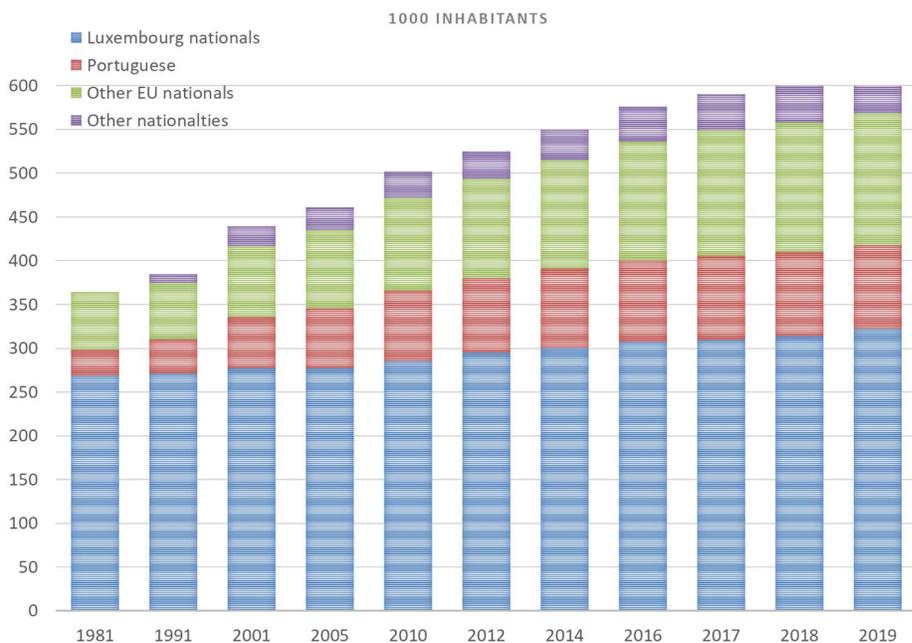
31 For an example, look at <http://www.luxnatur.lu/alzrena1.htm>.

32 Refer to Box 2-1 for a presentation of the Grande Région.

33 For details, see STATEC (2017), Projections macroéconomiques et démographiques de long terme : 2017-2060, Bulletin du STATEC N° 3-17, Luxembourg, page 31

(<https://statistiques.public.lu/catalogue-publications/bulletin-Statec/2017/PDF-Bulletin3-2017.pdf>). Other projections, which are a bit lower than STATEC’s baseline scenario, are also produced in the framework of the European Commission Ageing Working Group: http://europa.eu/epc/working_groups/ageing_en.htm and http://europa.eu/epc/pdf/2012_ageing_report_en.pdf, as well as http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Population_projections.

Figure 2-14 – Population structure on 31st December: 1981-2019

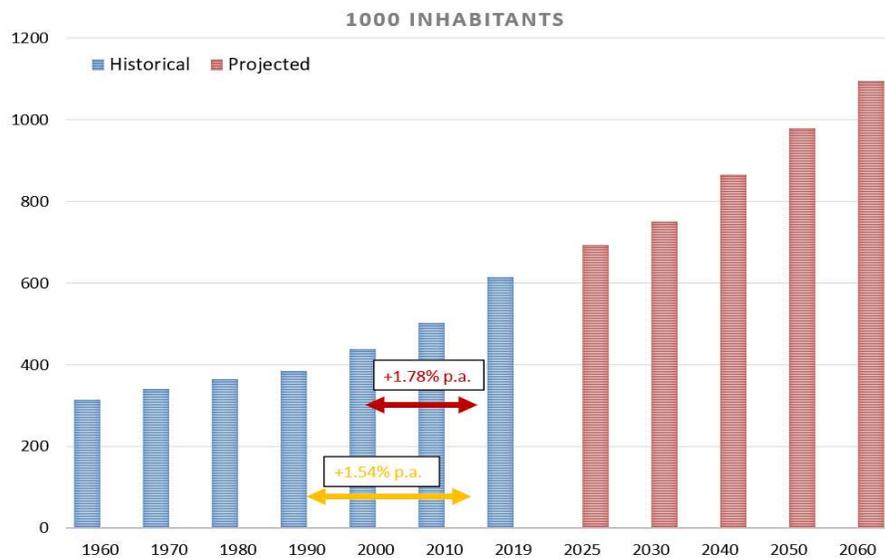


Source: STATEC, Statistical Yearbook, Table B.1101 (updated 12 February 2021):

https://statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12853&IF_Language=fra&MainTheme=2&FldrName=1.

Note: 1981, 1991, 2001 and 2011 data are coming from population censuses held every decade, other years are calculated by STATEC.

Figure 2-15 – Population growth on 31st December: 1960-2060 assuming a 3% annual increase of the gross domestic product



Sources: STATEC, Statistical Yearbook, Table B.1101 (updated 12.02.2021):

http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12856&IF_Language=fra&MainTheme=2&FldrName=1.

STATEC, Projections macroéconomiques et démographiques de long terme: 2017-2060:

<https://statistiques.public.lu/catalogue-publications/bulletin-Statec/2017/PDF-Bulletin3-2017.pdf>.

Box 2-1 – The *Grande Région*

The *Grande Région* is the geographic unit that includes Luxembourg, the Region of Wallonia in Belgium, Lorraine in France and two German *Länder*: Saarland and Rheinland-Pfalz.

Today, this structure is more a cooperative space than an effective integrated region defining and modelling its own policies and development. This is the result of the diversity of the territories constituting the *Grande Région*, of its dimension and of the barriers created by institutional and administrative structures in each country. De facto, being a sovereign state amongst country regions, Luxembourg has a special status in this cooperative space: it is the main driving force behind the *Grande Région*, a position re-enforced by its demographic and economic development as shown by the figures in the table below.

<i>Grande Région</i> entity	Population change (1st January) % 1990-2015	Population annual average growth rate (1st January) % 1990-2015	GDP at current price annual average growth rate % 1990-2015	Total employment in 2015 1990=100
BE-Wallonia	10.67%	0.41%	3.57%	116
DE-Rheinland-Pfalz	8.37%	0.32%	2.35%	117
DE-Saarland	-7.12%	-0.29%	2.48%	116
FR-Lorraine	1.51%	0.06%	2.06%	102
Luxembourg	48.42%	1.59%	7.23%	201

More information on the *Grande Région* can be found on line:

<http://www.granderegion.net/fr/index.html>

<http://www.grande-region.lu/eportal/pages/HomeTemplate.aspx>

2.1.3.2 Workforce: the importance of cross-border commuters

The economic restructuring and development of Luxembourg led to a doubling of the workforce in the last 20 years. The resident population of Luxembourg nationality was unable to meet this increasing demand for labour. How, therefore, could this urgent economic need be satisfied? The initial response was to resort to **immigration**. The number of foreign employees living and working in Luxembourg rose from 54 900 in 1995 to 121 837 in 2019 - but, this was not enough. So the **cross-border commuters** came into play. Between 1995 and 2019, the number of cross-border workers increased from 56 900 to 192 100 (Figure 2-16).³⁴

For 2019, among the commuters employed in Luxembourg, 52.3% came from France, 24.0% from Germany and 23.7% from Belgium. In total, the commuters accounted for 43% of the total workforce in Luxembourg and for 33% of the residential population.³⁵ The commuting flows amongst the various regions of the *Grande Région* clearly show the economic attraction of Luxembourg (Figure 2-17).

A vast majority of workers from abroad commute by car.³⁶ However, in order to alter the current modal split of home-work journeys, Luxembourg invests predominantly and jointly with the neighbouring regions into the public transport offer. Since 2020, public transportation services are free of charge in Luxembourg.

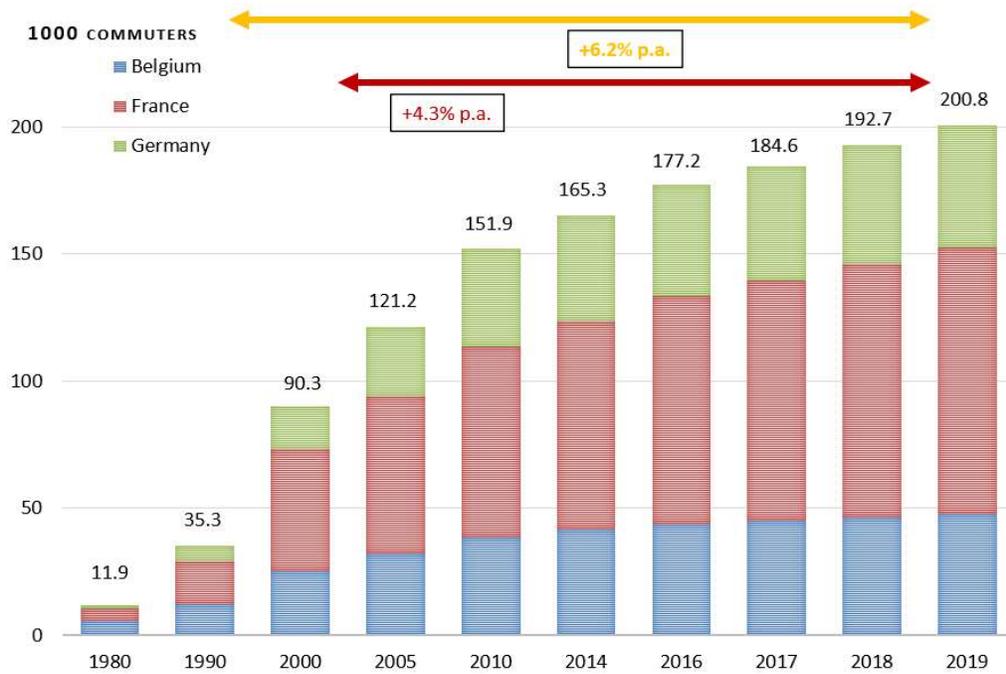
34 Figures indicated in this paragraph are annual cumulative averages.

35 Calculated from STATEC, Statistical Yearbook, Table B.3107:

http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12919&IF_Language=fra&MainTheme=2&FldrName=3&RFPath=92

36 According to a recent study, for 2010, it was estimated that 86% of the cross-border commuters were only using their car for their home-work journeys. This percentage was 91% in 2007: <http://www.ceps.lu/?type=module&id=104&tmp=1900>.

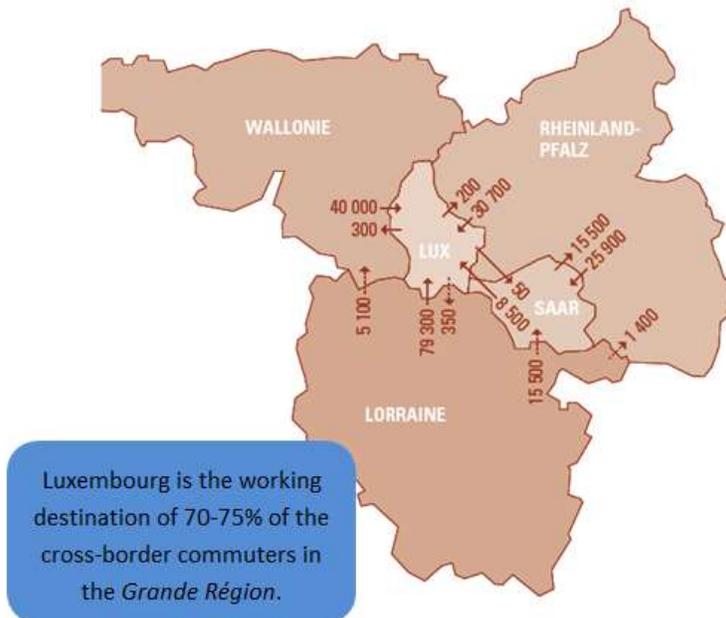
Figure 2-16 – Cross-border commuters’ growth: annual cumulative averages 1980-2019



Source: STATEC, Statistical Yearbook, Table B.3100 (updated 30.03.2020):

https://statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12951&IF_Language=fra&MainTheme=2&FldrName=3&RFPPath=92

Figure 2-17 – Commuting flows 2015



Luxembourg is the working destination of 70-75% of the cross-border commuters in the Grande Région.

Source: INSEE, IGSS, STATEC, IWEPS, Statistisches Amt Saarland, Statistisches Landesamt Rheinland-Pfalz:

http://www.statistiques.public.lu/stat/TableViewer/document.aspx?ReportId=498&IF_Language=fra&MainTheme=2&FldrName=3&RFPPath=92..

2.1.4 Economic profile

One of the main characteristics of economic growth in Luxembourg is its volatility. Generally speaking, the economic cycle in Luxembourg follows that of other European countries, but the amplitude of the GDP variations is more pronounced. This is a common feature of small economies, open to the outside world, and therefore more vulnerable to external shocks. It would however appear that over the past ten years the amplitude of GDP variations in Luxembourg has diminished, as has the gap in relation to the European cycle.

The economic restructuring and development of the country towards the tertiary sector from the 1960s-70s, led to the following economic cycles since 1990:

- up to 1992, the continuation of the exceptional growth initiated around 1985;
- the effects of the economic slowdown in Luxembourg during the period between 1992 and 1996 and the economic downturn in 2001 – as well as the less impressive growth in 2002-2004 – which is mirrored by a stagnation of the GDP level per inhabitant in Luxembourg in comparison with the EU-15;
- the good economic performance of Luxembourg between 2005 and 2008;
- the financial and economic crisis that started at the end of 2008 and that has been particularly pronounced in the first semester of 2009;
- from 2010 onwards, a very slow recovery could be observed, though it flattened quickly for the industry and commercial sectors.

Nowadays, gross value added is mainly generated in the financial intermediation (banking and insurances), real estate and services to business sector. The share of total gross value added in this branch has increased from about 39.3% in 1995 to 46.5% in 2019.³⁷ While the commercial sector has maintained a relatively constant share at about 15% to 19%, the share of the industry sector has decreased significantly from 14.9% in 1995 to 6.5% in 2019. Other service activities ranged between a share of 18% to 26% and construction kept a rather constant share in total gross value added around 6.0%. The contribution of the agricultural sector is negligible with less than 1% (Table 2-9 & Figure 2-18).

Nevertheless, GHG emissions trends in Luxembourg are not so much influenced by the economic profile of the country, but for the most part by:

- the energy-mix for both production and consumption of fuels (liquid, solid, gaseous, biomass): more on this in the next section;
- due to its size and the size of its energy and industrial sector, structural changes in these sectors that could be initiated by a single entity;
- road transportation related fuel sales: more on this in Section 2.1.6.

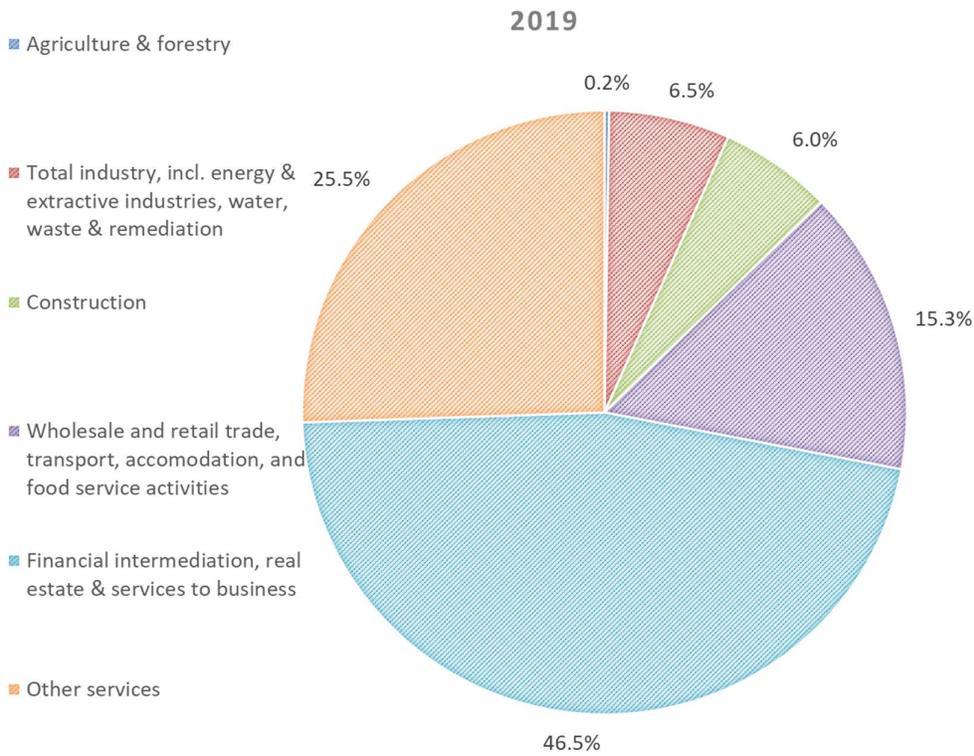
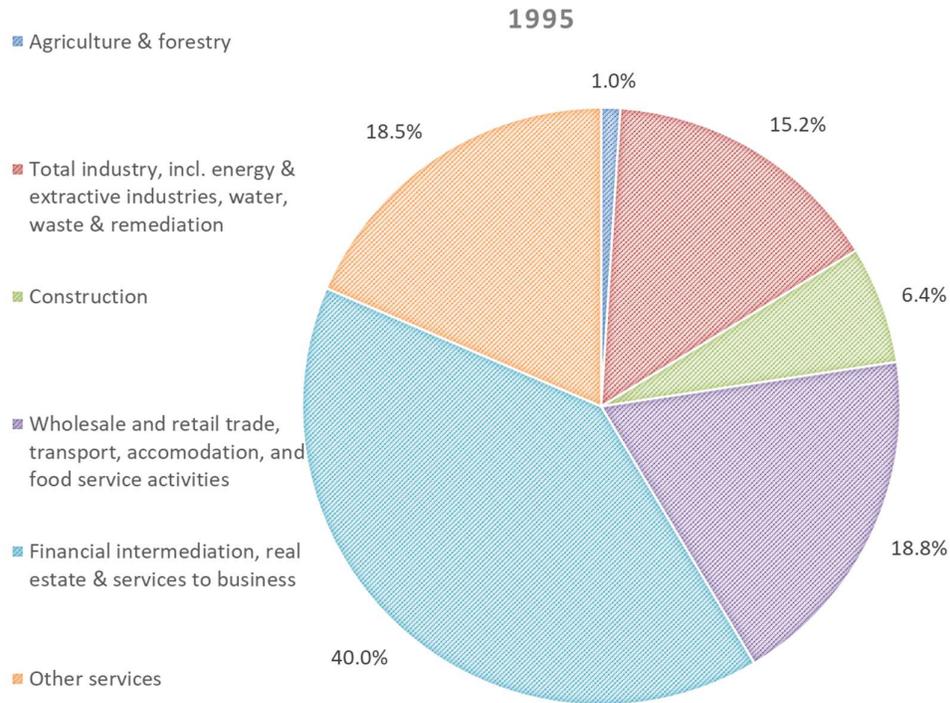
³⁷ Data prior to 1995 are and will not be translated into the new European System of Accounts (ESA).

Table 2-9 – Sectoral gross value added at current prices: 1995-2019

	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Agriculture, forestry & fishing (A)	144	144	107	115	152	119	94	99	109	159	129	145	118	117	139	136	144
%	1.0%	0.7%	0.4%	0.4%	0.5%	0.3%	0.3%	0.3%	0.3%	0.4%	0.3%	0.3%	0.3%	0.2%	0.3%	0.3%	0.2%
Total industry, including extractive industries, energy production & distribution, water supply, sewerage, waste	2131	2594	2886	2948	3885	3185	2346	2661	2706	2673	2942	2729	3176	3656	3537	3830	3722
management and remediation activities (B to E)	14.9%	12.6%	10.8%	9.7%	10.8%	9.3%	7.1%	7.4%	7.0%	6.8%	7.1%	6.1%	6.8%	7.3%	6.9%	7.0%	6.5%
Construction (F)	892	1240	1527	1663	1943	1915	1914	1931	2124	2034	2129	2511	2571	2745	2851	3239	3467
%	6.2%	6.0%	5.7%	5.5%	5.8%	5.6%	5.8%	5.3%	5.5%	5.2%	5.1%	5.7%	5.5%	5.5%	5.5%	6.0%	6.0%
Wholesale and retail trade, transport, accomodation	2636	3599	4257	4738	4910	5835	5374	6145	7261	7017	7699	8111	7634	8228	8492	8657	8808
%	18.5%	17.5%	16.0%	15.6%	14.8%	17.1%	16.2%	17.0%	18.7%	17.8%	18.5%	18.3%	16.2%	16.5%	16.5%	15.9%	15.3%
Financial and insurance activities; real estate activities; professional, scientific and technical activities;	5603	8658	11745	14238	15514	15606	15346	16738	17436	17783	18614	20366	22227	23205	24204	24808	26765
administrative and support service activities (K to N)	39.3%	42.0%	44.0%	46.9%	46.6%	45.6%	46.3%	46.3%	45.0%	45.1%	44.8%	45.9%	47.2%	46.6%	46.9%	45.6%	46.5%
Other services; information and communication; public administration, defence, education, human health and social work activities; arts, entertainment and recreation;	2593	4008	5612	6053	6564	6901	7375	7867	8355	8944	9168	9662	10490	10953	11470	12784	14705
Other service activities; activities of household (J & O to U)	18.2%	19.4%	21.0%	20.0%	19.7%	20.2%	22.3%	21.8%	21.6%	22.7%	22.1%	21.8%	22.3%	22.0%	22.2%	23.5%	25.5%
Total: all NACE rev2 branches	14270	20619	26668	30339	33276	34203	33135	36137	38739	39386	41527	44396	47057	49771	51599	54378	57611
Annual growth rate - current prices				13.8%	9.7%	2.8%	-3.1%	9.1%	7.2%	1.7%	5.4%	6.9%	5.1%	3.5%	3.9%		
Annual growth rate - constant prices in volume				5.7%	8.5%	-1.5%	-4.6%	5.0%	2.0%	-0.8%	3.6%	3.9%	4.1%	2.5%	1.7%		

Source: STATEC, Statistical Yearbook, Tables E.2304 (current prices) & E.2305 (constant prices) (updated 15 February 2021); http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=13158&IF_Language=fr&MainTheme=5&FlDrName=2&RFPPath=21

Figure 2-18 – Sectoral gross value added at current prices: 1995 & 2019



Source: STATEC, Statistical Yearbook, Table E.2304 (updated 15 February 2021): http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=13157&IF_Language=fra&MainTheme=5&FldrName=2&RFPPath=21

2.1.5 Energy

2.1.5.1 A total change in Luxembourg's energy-mix

Primary and final energy consumption in Luxembourg experienced dramatic changes since 1990. Overall **primary energy consumption** increased by 28.26% between 1990 and 2019. Whereas solid fuels and coal declined by 96.43% over the period, liquid fuels (incl. kerosene) and natural gas consumptions increased by 86.12% and 59.70% respectively (

Table 2-10 & Figure 2-19).

Table 2-10 – Primary energy consumption: 1990-2019

TJ	1990 (base year)	1991	1992	1993	1994	1995	1996	1997	1998
Solid fuels & coal	49939.83 33.23%	45812.91 28.98%	43145.01 27.20%	44770.76 27.75%	38726.29 24.76%	22010.21 15.90%	20893.02 14.78%	13306.17 9.57%	4861.42 3.57%
Liquid fuels (incl. kerosene)	66030.62 43.94%	76910.67 48.66%	79078.34 49.86%	78994.97 48.97%	78578.11 50.24%	72455.60 52.35%	74715.90 52.85%	77882.37 56.00%	82209.79 60.30%
Natural gas (1)	19925.91 13.26%	20717.94 13.11%	21593.35 13.61%	22427.07 13.90%	22593.81 14.45%	25819.65 18.65%	28324.39 20.03%	29023.46 20.87%	29305.68 21.50%
Electricity	13256.15 8.82%	13464.58 8.52%	13631.32 8.59%	14006.50 8.68%	15423.82 9.86%	17083.75 12.34%	16644.80 11.77%	17889.96 12.86%	18859.16 13.83%
Heat	NO NA	NO NA	NO NA	NO NA	NO NA	NO NA	NO NA	NO NA	NO NA
Renewable energy sources & waste Incineration (with heat recovery) (2)	1125.52 0.75%	1167.21 0.74%	1167.21 0.74%	1125.52 0.70%	1083.84 0.69%	1042.15 0.75%	808.71 0.57%	964.61 0.69%	1100.93 0.81%
Total	150278.03	158073.30	158615.20	161324.80	156405.90	138411.40	141386.80	139066.60	136337.00

TJ	1999	2000	2001	2002	2003	2004	2005	2006	2007
Solid fuels & coal	4814.73 3.33%	4594.52 2.96%	4957.84 3.02%	3083.62 1.79%	2369.15 1.31%	3328.54 1.65%	3248.87 1.58%	3876.79 1.91%	3280.32 1.65%
Liquid fuels (incl. kerosene)	87715.26 60.72%	96236.54 61.99%	102063.70 62.27%	104261.60 60.42%	111789.90 61.74%	126709.60 62.91%	130884.50 63.82%	124310.30 61.24%	121227.00 60.92%
Natural gas (1)	30397.85 21.04%	31231.01 20.12%	34718.00 21.18%	49629.00 28.76%	50238.00 27.74%	55632.00 27.62%	54720.18 26.68%	57237.24 28.20%	53426.14 26.85%
Electricity	19580.75 13.55%	21059.69 13.56%	19649.82 11.99%	12952.77 7.51%	13931.02 7.69%	12698.58 6.30%	12323.47 6.01%	13490.64 6.65%	14981.85 7.53%
Heat	NO NA	0.03 0.00%	1.21 0.00%	4.04 0.00%	6.43 0.00%	8.86 0.00%	11.54 0.01%	14.48 0.01%	19.65 0.01%
Renewable energy sources & waste Incineration (with heat recovery) (2)	1946.32 1.35%	2128.82 1.37%	2520.68 1.54%	2630.06 1.52%	2736.22 1.51%	3041.45 1.51%	3883.23 1.89%	4049.26 1.99%	6063.63 3.05%
Total	144454.90	155250.60	163911.20	172561.10	181070.70	201419.00	205071.80	202978.70	198998.60

TJ	2008	2009	2010	2011	2012	2013	2014	2015	2016
Solid fuels & coal	3136.57 1.57%	2801.27 1.48%	2806.63 1.40%	2443.45 1.25%	2249.59 1.18%	2005.86 1.08%	2235.46 1.24%	2057.27 1.15%	2193.19 1.23%
Liquid fuels (incl. kerosene)	122653.40 61.51%	114781.90 60.83%	120101.40 60.06%	122553.60 62.58%	118269.70 61.78%	116297.50 62.72%	112052.90 62.09%	110128.90 61.78%	109970.50 61.59%
Natural gas (1)	50856.70 25.51%	51751.75 27.43%	55665.22 27.84%	48021.10 24.52%	48894.89 25.54%	41398.28 22.33%	39223.62 21.74%	35770.96 20.07%	32988.07 18.47%
Electricity	16412.67 8.23%	12987.43 6.88%	15290.40 7.65%	16677.00 8.52%	15567.70 8.13%	18791.88 10.13%	18634.28 10.33%	21238.39 11.91%	23821.51 13.34%
Heat	26.29 0.01%	36.03 0.02%	48.71 0.02%	61.46 0.03%	76.02 0.04%	91.98 0.05%	101.66 0.06%	113.51 0.06%	124.63 0.07%
Renewable energy sources & waste Incineration (with heat recovery) (2)	6310.98 3.17%	6320.76 3.35%	6052.85 3.03%	6067.60 3.10%	6363.53 3.32%	6846.43 3.69%	8208.17 4.55%	8956.12 5.02%	9463.93 5.30%
Total	199396.70	188679.20	199965.20	195824.20	191421.50	185432.00	180456.10	178265.20	178561.90

TJ	2017	2018	2019
Solid fuels & coal	1897.95 1.03%	1763.93 0.92%	1784.32 0.93%
Liquid fuels (incl. kerosene)	115043.70 62.49%	121501.30 63.54%	122897.50 63.76%
Natural gas (1)	32244.57 17.52%	31802.53 16.63%	31822.35 16.51%
Electricity	23785.11 12.92%	23858.70 12.48%	23030.57 11.95%
Heat	134.44 0.07%	150.50 0.08%	160.80 0.08%
Renewable energy sources & waste Incineration (with heat recovery) (2)	10981.21 5.97%	12137.03 6.35%	13057.83 6.77%
Total	184086.90	191214.00	192753.40

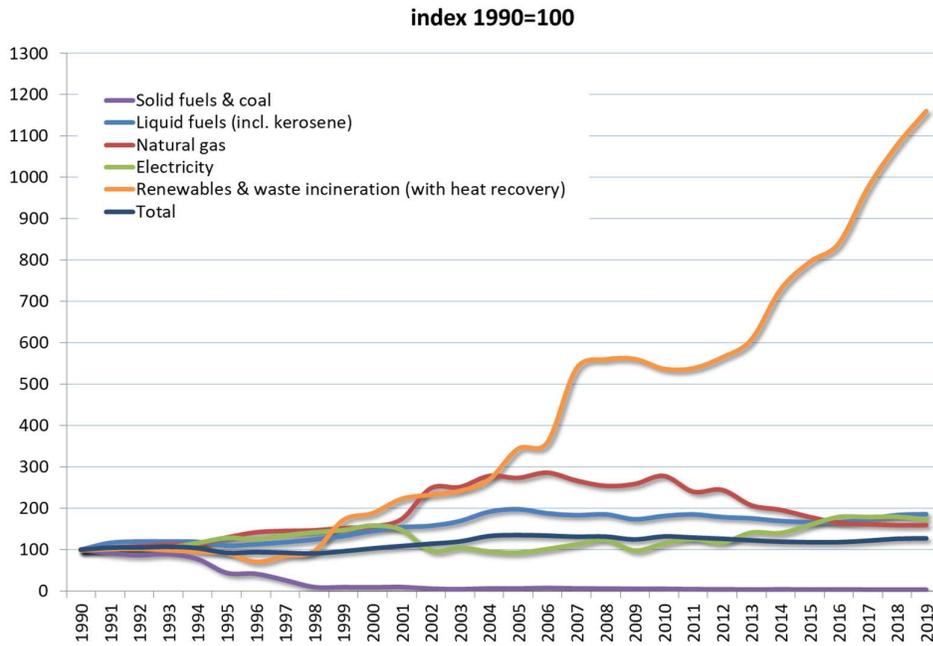
Source: STATEC, *Statistical Yearbook*, Table A.4200 (updated 15 February 2021):http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?reportId=12759&IF_Language=fr&MainTheme=1&F

[drName=4&RFPath=54](#)

Notes: (1) Natural gas is expressed in GCV;

(2) Only the organic fraction of waste is counted. The biogas included as renewable energy source is expressed in GCV that also comprises blended biofuels. There is a break in the time-series between 1999 & 2000 (II).

Figure 2-19 –Primary energy consumption: 1990-2019



Source: STATEC, Statistical Yearbook, Table A.4200 (updated 15 February 2021):

http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12759&IF_Language=fra&MainTheme=1&FI
[drName=4&RFPath=54](#)

Final energy consumption increased by 29.55% between 1990 and 2019. As for primary energy consumption, all the energy sources have seen their consumption increase over the period, except solid fuels and coal and blast furnace gases (Table 2-11 & Figure 2-20).

Over the period 1990-2019, the final energy-mix of Luxembourg changed considerably with a dropping share for solid fuels – for which the main part was used in the iron and steel industry – in favour of liquid fuels and natural gas and, to a lesser extent, to new energy sources based on biomass. Indeed, in 2019, 81.71% of the **final energy consumption** was covered by fossil fuels – 65.30% by liquid fuels including the important volume of road fuels as well as kerosene,³⁸ 15.46% by natural gas and 0.96% by solid fuels and coal. The remaining 18.29% of the consumption were either electricity (12.34%) and heat (2.00%) or renewable energy sources, including organic waste incineration with energy recovery, biogas, and biofuels (3.94%). Going back to 1990, 23.83% of the final energy consumption was stemming from solid fuels and coal, 45.95% from liquid fuels, 13.49% from natural gas, and 10.41% from electricity (Table 2-11 & Figure 2-20). The following elements caused the shift from 1990 to 2019 in terms of final energy consumption:

- Regarding **solid fuels and coal**, the important decline (-94.80%) is the result of a change in production processes in the steel industry sector: the production process was moved from blast furnaces to electric arc furnaces between 1994 and 1998 and, therefore, solid fuels (mainly imported coke, but also imported anthracite) were replaced, to a very large extent, by electricity and natural gas;
- **Liquid fuels** increase (+84.09%) was driven by road fuel sales and kerosene, but with the former being 4 to 5 times higher in quantity than the latter. It is especially the “road fuel sales to non-residents” that explains a great deal of the sharp increase in liquid fuels consumption (see Section 2.1.6);
- The 48.48% increase in **natural gas** final consumption followed the continuous extension of the natural gas network in Luxembourg so that this fuel ranked second after the consumption of liquid fuels in 2019 – and even first if “road fuel sales to non-residents” and kerosene are not considered.

38 Diesel being the first liquid fuel in terms of volumes sold. The liquid fuel consumption in Luxembourg is much lower than the level of fuel sales, because large amounts of road fuels are bought by foreign commuters and transit traffic passing through Luxembourg: see section 2.1.6 below.

Table 2-11 – Final energy consumption: 1990-2019

TJ	1990 (base year)	1991	1992	1993	1994	1995	1996	1997	1998
Solid fuels & coal	34331.76 23.83%	30814.85 20.38%	29475.07 19.46%	30689.24 19.85%	27268.21 18.05%	16035.03 11.91%	15670.77 11.35%	10422.20 7.64%	4882.65 3.60%
Liquid fuels (incl. kerosene)	66193.31 45.95%	76911.52 50.87%	78669.97 51.93%	78837.44 51.00%	78753.71 52.14%	72682.85 53.99%	74734.38 54.13%	78046.98 57.20%	82554.07 60.90%
Natural gas (1)	19426.75 13.49%	20389.72 13.49%	21227.08 14.01%	22064.44 14.27%	21989.91 14.56%	23906.63 17.76%	26251.24 19.01%	27155.58 19.90%	27436.94 20.24%
Blast furnaces gas	8'457.30 5.87%	7'234.80 4.79%	6'196.50 4.09%	6'514.20 4.21%	5'503.50 3.64%	2'731.90 2.03%	2'511.70 1.82%	1'347.31 0.99%	NO NA
Electricity	14988.74 10.41%	15198.08 10.05%	15281.82 10.09%	15826.10 10.24%	16747.20 11.09%	18045.11 13.40%	17710.16 12.83%	18254.45 13.38%	19091.81 14.08%
Heat (2)	NO NA	NO NA	NO NA	NO NA	125.60 0.08%	586.15 0.44%	547.21 0.40%	563.54 0.41%	949.98 0.70%
Renewable energy sources & waste Incineration (with heat recovery) (3)	644.77 0.45%	644.77 0.43%	644.77 0.43%	644.77 0.42%	644.77 0.43%	644.77 0.48%	644.77 0.47%	644.77 0.47%	644.77 0.48%
Total	144042.70	151193.70	151495.20	154576.20	151032.90	134632.40	138070.20	136434.80	135560.20

TJ	1999	2000	2001	2002	2003	2004	2005	2006	2007
Solid fuels & coal	4835.75 3.39%	4594.52 3.07%	4957.84 3.16%	3083.62 1.95%	2369.15 1.41%	3328.54 1.78%	3248.87 1.71%	3876.79 2.07%	3280.32 1.77%
Liquid fuels (incl. kerosene)	88082.74 61.67%	94660.74 63.27%	100748.50 64.30%	103139.20 65.18%	110837.90 65.84%	125735.20 67.37%	130190.30 68.35%	123620.40 65.86%	120557.60 65.22%
Natural gas (1)	28435.91 19.91%	28125.74 18.80%	27997.84 17.87%	28258.28 17.86%	28673.98 17.03%	29942.32 16.04%	29338.04 15.40%	30622.60 16.32%	29822.71 16.13%
Blast furnaces gas	NO NA	NO NA	NO NA	NO NA	NO NA	NO NA	NO NA	NO NA	NO NA
Electricity	19835.80 13.89%	20790.21 13.90%	21033.19 13.42%	21260.54 13.44%	22252.42 13.22%	23007.38 12.33%	22149.43 11.63%	23806.48 12.68%	24097.50 13.04%
Heat (2)	986.41 0.69%	503.93 0.34%	623.54 0.40%	1084.56 0.69%	2815.05 1.67%	3031.39 1.62%	3050.00 1.60%	3203.55 1.71%	2572.81 1.39%
Renewable energy sources & waste Incineration (with heat recovery) (3)	644.77 0.45%	929.70 0.62%	1321.31 0.84%	1405.98 0.89%	1406.76 0.84%	1586.77 0.85%	2489.86 1.31%	2562.50 1.37%	4518.54 2.44%
Total	142821.40	149604.80	156682.20	158232.10	168355.20	186631.70	190466.50	187692.30	184849.50

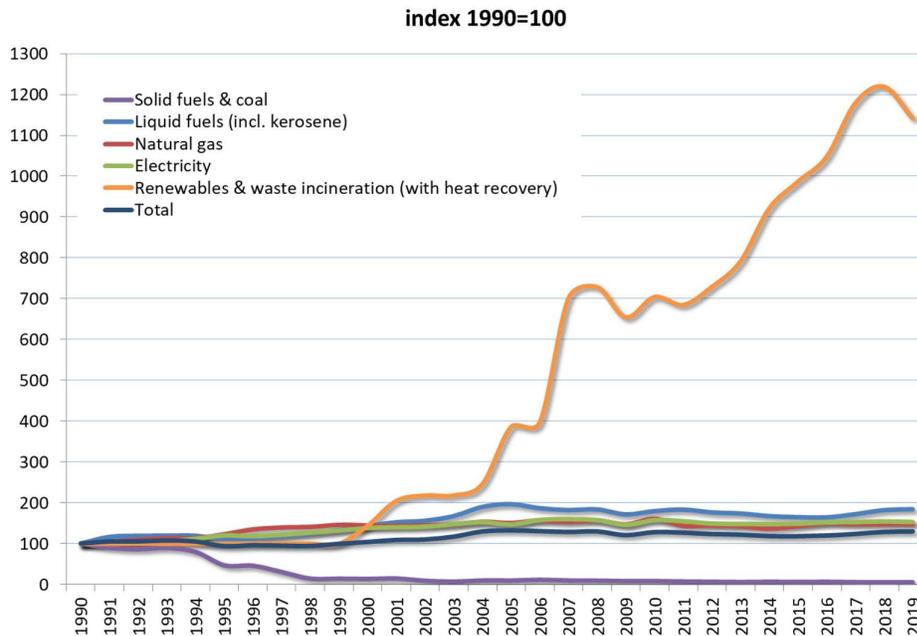
TJ	2008	2009	2010	2011	2012	2013	2014	2015	2016
Solid fuels & coal	3136.57 1.68%	2801.27 1.61%	2806.63 1.52%	2443.45 1.34%	2249.59 1.27%	2005.86 1.14%	2235.46 1.31%	2057.27 1.21%	2193.19 1.27%
Liquid fuels (incl. kerosene)	121629.30 65.13%	113546.50 65.37%	118873.20 64.48%	121286.00 66.47%	116797.00 65.82%	114981.10 65.57%	110832.80 65.11%	108960.10 64.16%	108688.60 63.11%
Natural gas (1)	30616.00 16.40%	28658.82 16.50%	31411.99 17.04%	27916.40 15.30%	28262.17 15.93%	27789.82 15.85%	26536.40 15.59%	27791.20 16.36%	29226.32 16.97%
Blast furnaces gas	NO NA								
Electricity	23750.44 12.72%	22004.89 12.67%	23734.71 12.87%	23343.11 12.79%	22449.55 12.65%	22315.52 12.73%	22256.43 13.07%	22406.96 13.19%	22922.20 13.31%
Heat (2)	2907.26 1.56%	2457.70 1.42%	3000.60 1.63%	3057.26 1.68%	2988.32 1.68%	3161.19 1.80%	2431.09 1.43%	2260.78 1.33%	2432.74 1.41%
Renewable energy sources & waste Incineration (with heat recovery) (3)	4697.03 2.52%	4219.33 2.43%	4540.66 2.46%	4414.70 2.42%	4700.15 2.65%	5103.19 2.91%	5938.32 3.49%	6360.30 3.74%	6751.66 3.92%
Total	186736.70	173688.50	184367.80	182461.00	177446.70	175356.60	170230.50	169836.60	172214.70

TJ	2017	2018	2019
Solid fuels & coal	1897.95 1.07%	1763.93 0.95%	1784.32 0.96%
Liquid fuels (incl. kerosene)	113906.30 64.07%	120411.50 65.09%	121855.90 65.30%
Natural gas (1)	28760.25 16.18%	28761.50 15.55%	28845.62 15.46%
Blast furnaces gas	NO NA	NO NA	NO NA
Electricity	23015.79 12.95%	23252.19 12.57%	23027.39 12.34%
Heat (2)	2605.87 1.47%	2955.92 1.60%	3735.96 2.00%
Renewable energy sources & waste Incineration (with heat recovery) (3)	7599.27 4.27%	7860.57 4.25%	7361.13 3.94%
Total	177785.50	185005.60	186610.30

Source: STATEC, *Statistical Yearbook*, Table A.4300 (updated 16 February 2021):
http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12771&IF_Language=fra&MainTheme=1&FdrName=4&RFPPath=51

Notes: (1) Natural gas is expressed in GCV;
 (2) from 2000 onwards, heat that is consumed by the cogeneration power plants themselves is no longer included, hence there is a break in the time series (II);
 (3) only the organic fraction of waste is counted. The biogas included as renewable energy source is expressed in GCV that also comprises blended biofuels. There is a break in the time series between 1999 & 2000 (II).

Figure 2-20 – Final energy consumption: 1990-2019



Natural gas has also become the main energy source of Luxembourg’s national electricity production capacity. In 1990, more than 90% of Luxembourg’s electric energy consumption was imported and one medium size power plant of about 70 MW was run by the iron and steel company Arbed.³⁹ That power plant was mainly run on blast furnace gas – a side product of the blast furnaces in the steel industry – and was phased out in 1998 after the last blast furnace went out of service. In the early 1990s, small combined heat-power (CHP) installations (or cogeneration) plants appeared. Their installation was encouraged financially by the Government. This development was followed later by some industrial companies which installed gas turbines to produce electricity and heat simultaneously. In mid-2002, the ultra-modern TWINerg power plant started its commercial operation. Located in Esch-sur-Alzette, TWINerg is a gas and steam turbine power station running on natural gas, with an electrical output of 376 MWel (efficiency 55.7%).⁴⁰ If almost all of these cogeneration plants run on natural gas, gas oil remains the emergency fuel in case of a natural gas supply disruption.

The impact of TWINerg on the primary energy consumption mix is clearly visible in

39 Then Arcelor and now, ArcelorMittal.

40 http://www.twinerg.lu/en_index.html, “Environment” tab and <http://www.ilr.public.lu/gaz/documents/statistiques/rapport2011.pdf>, p. 29.

Table 2-10 and its associated Figure 2-19: electricity imports dropped and natural gas primary consumption increased in 2002, while in 2015 they reverted back to similar values than in 2001. After a few years of reduced activity, the TWINerg plant was finally shut down in 2016. To complement this analysis, a balance for the electrical energy is provided (Table 2-12 & Figure 2-21).

Table 2-12 – Balance for electrical energy: 1990-2019

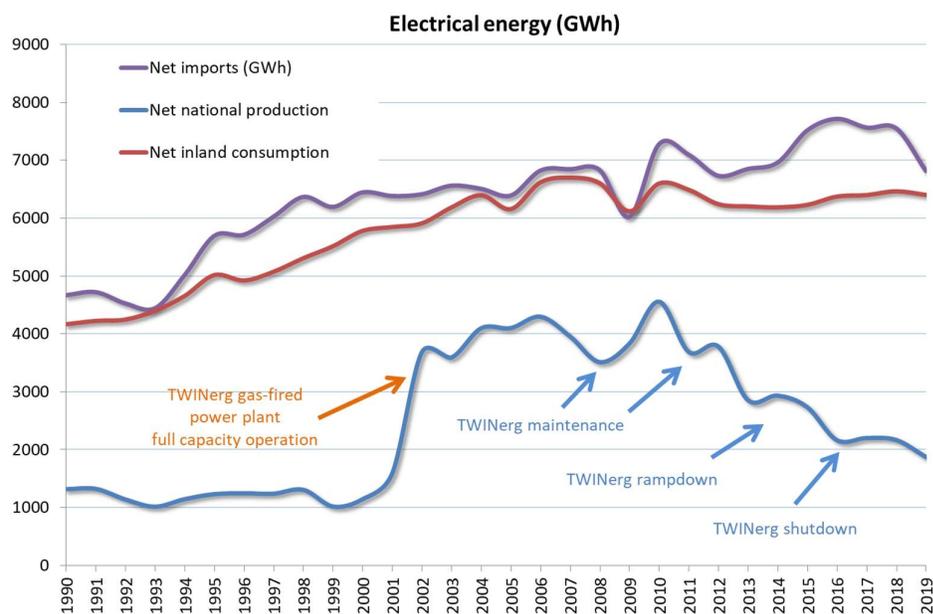
GWh	1990 (base year)	1991	1992	1993	1994	1995	1996	1997	1998
Net import	4665.46	4718.45	4523.56	4440.97	5015.24	5693.47	5712.33	6026.52	6366.60
Net national production	1322.04	1327.54	1144.30	1019.29	1150.11	1236.06	1251.78	1243.99	1311.39
Net inland consumption	4163.54	4221.69	4244.95	4396.14	4652.00	5012.53	4919.49	5070.68	5303.28

GWh	1999	2000	2001	2002	2003	2004	2005	2006	2007
Net import	6193.53	6445.38	6383.25	6413.64	6562.18	6506.31	6391.61	6823.54	6846.58
Net national production	1311.39	1022.59	1148.34	1591.96	3687.51	3597.10	4102.05	4104.41	4301.32
Net inland consumption	5509.95	5775.06	5842.55	5905.71	6181.23	6390.94	6152.62	6612.91	6693.75

GWh	2008	2009	2010	2011	2012	2013	2014	2015	2016
Net import	6829.87	6022.47	7279.51	7096.34	6732.10	6851.52	6961.18	7518.76	7718.39
Net national production	3516.43	3835.95	4560.28	3693.17	3786.31	2859.81	2937.81	2737.71	2167.69
Net inland consumption	6597.35	6112.47	6592.97	6484.20	6235.99	6198.76	6182.34	6224.16	6367.28

GWh	2017	2018	2019
Net import	7566.69	7553.01	6817.52
Net national production	2204.81	2171.38	1877.38
Net inland consumption	6393.28	6458.94	6396.50

Figure 2-21 – Balance for electrical energy: 1990-2019



Sources: Compiled by the Environment Agency on 3 March 2021 using data published by the Ministry of the Economy – Energy Department, the *Institut Luxembourgeois de Régulation* and STATEC (Tables A.4208, A.4203, A.4300).

Notes: (1) The net national production is the difference between the national production and the conversion process uses and losses.

2.1.6 Road transportation

2.1.7 Diverse inland and cross-border road transport flows

Luxembourg's location and its economic development have made it a **focal point for international road traffic**. Luxembourg is located at the heart of the main traffic axes for Western Europe (Figure 2-22) and, therefore, has traditionally had a high volume of road transit traffic for both goods (freight transport) and passengers (tourists on their way to or back from southern Europe). The latter has increased even further by the **high number of commuter journeys** observed every working day. In comparison with international traffic, domestic traffic plays only a relatively small role since it is responsible for only one quarter of the total road fuels sold in Luxembourg.

Road traffic is also the largest source of emissions in Luxembourg's GHG balance. Fuel quantities sold at Luxembourg's petrol stations, after having been converted into GHG volumes, are, according to IPCC reporting rules, totally included in the GHG balance, although around 71% of the emissions cannot be assigned to vehicles registered in Luxembourg and are actually emitted mostly abroad. This phenomenon is referred to as **"road fuel sales to non-residents"** whether they are in transit or commuting for work or leisure. Indeed, due to a policy of low taxed fuel (gasoline and diesel), Luxembourg is an attractive **"fuelling station"** for daily commuters from neighbouring countries and cross-border shoppers, but, most importantly, for international road transit traffic crossing its territory (mainly freight transport). **"Road fuel sales to non-residents"** is briefly defined in Box 2-2.

With numerous trucks transiting through Luxembourg, as well as a passenger cars market dominated by diesel vehicles in at least two of its neighbouring countries – namely Belgium and France – it is not surprising that diesel oil is the first liquid fuel in terms of volumes sold (Figure 2-23).

The allocation of fuel sales between residents (“domestic”) and non-residents (“exports”) is not made on the basis of statistics or counting, but by using the Network Emission Model (NEMO). Details are provided in Section 3.2.9.3.2.2 of this report.

Box 2-2 – Road fuel sales to non-residents

It covers fuel sales to non-residents, i.e.:

1. Road vehicles in transit: freight trucks, buses & coaches, passenger cars, that fill up in Luxembourg because of lower fuel prices;
2. Cross-border commuters who are also benefiting from the cheaper fuel prices;
3. “Fuel tourism”, known as “Tanktourismus” in Luxembourg: people driving purposefully to Luxembourg to benefit from the lower fuel prices, as well as lower prices on other commodities such as non-alcoholic & alcoholic drinks, tobacco, etc. (Luxembourg usually applies the lower taxation rates adopted at EU levels, i.e. 17%).

In the subsequent chapters & sections of this NIR, “road fuel sales to non-residents” is sometimes referred to as “(road) fuel exports”.

2.1.7.1 Effects on GHG emissions: an untypical situation

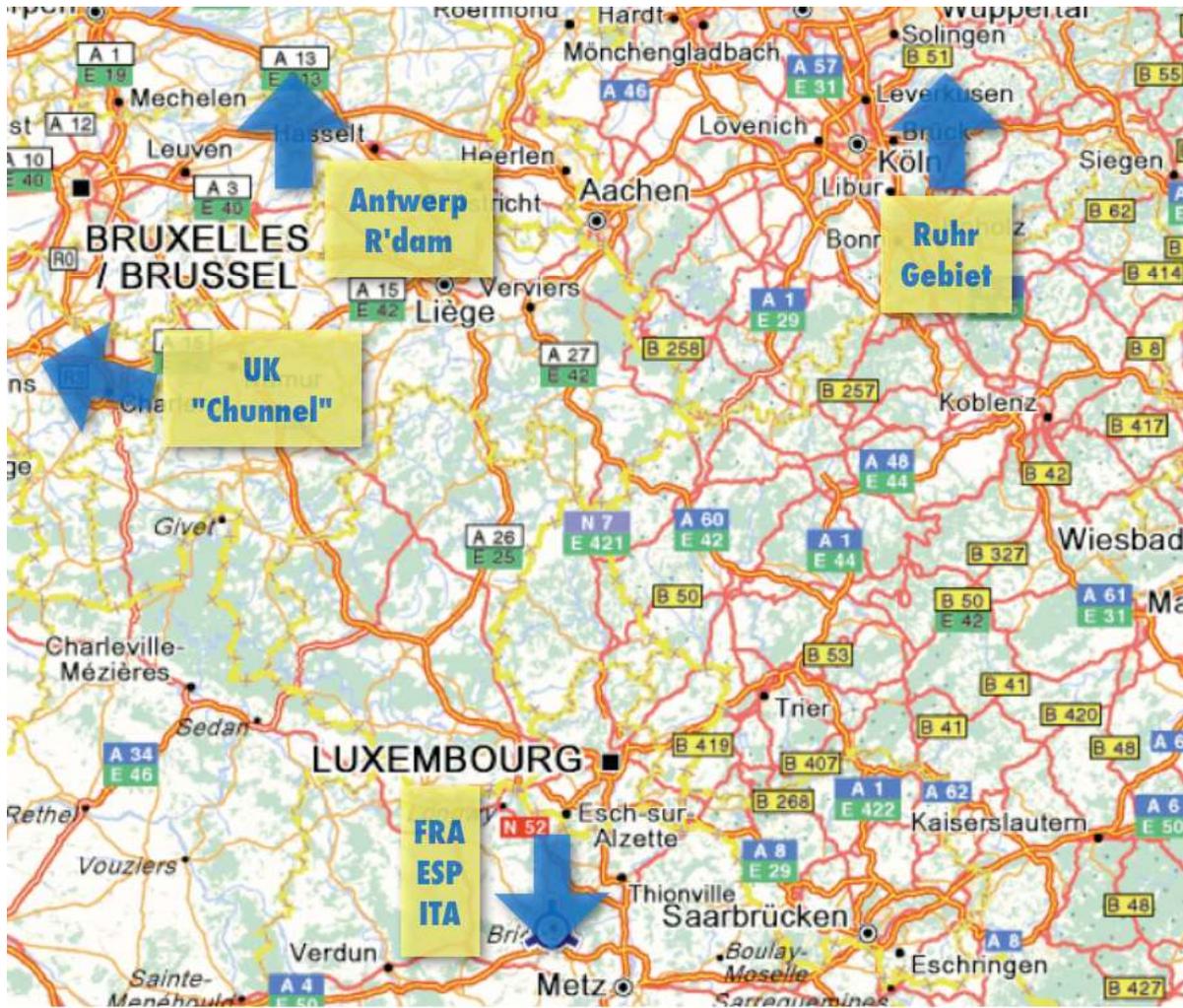
Combining the size of the country and its economy, on the one side, and lower road fuel prices that imply a disproportionate volume of road fuel sales compared to its resident population on the other side, Luxembourg presents a completely untypical and unique structural feature in its GHG emission balance. In 2019, 6.14 Mio. t CO₂eq were produced by the road transportation sector and out of these, 4.38 Mio. t CO₂eq, corresponding to 71.5%, are based on fuel sales to commuting and transiting vehicles. That last amount represented around 40.8% of the total 2019 GHG emissions for Luxembourg (excluding LULUCF) while the whole CRF sub-category 1A3b accounted for 57.3% of the total 2019 GHG emissions for Luxembourg (excluding LULUCF) (Figure 2-24).

Both the emissions generated by the national vehicles fleet and by the non-residents – “road fuel sales to non-residents” – showed dramatic increases over the 1990-2019 period: +100% and +156%, respectively.⁴¹ For the national fleet, the evolution correlates with both the population and economic activity growth. It is also explained by an increasing rate for passenger cars per inhabitants (from 499 to 676 passenger cars per 1000 inhabitants between 1990 and 2018, i.e. the highest rate within the EU⁴²). Regarding “road fuel sales to non-residents”, the rise is undoubtedly linked to the growing number of commuters crossing the borders every working day as well as to the general increase of road freight traffic in Europe.

41 Corresponding percentages were +70% and +232% in 2005, the peak year with regard to road transportation related emissions. These percentages differ slightly from those reported under Table 3-63 since the latter includes CO₂ emissions from biomass which are not counted here.

42 Data extracted from <https://ec.europa.eu> in April 2020

Figure 2-22 – MAIN ROAD FREIGHT AXES CROSSING LUXEMBOURG



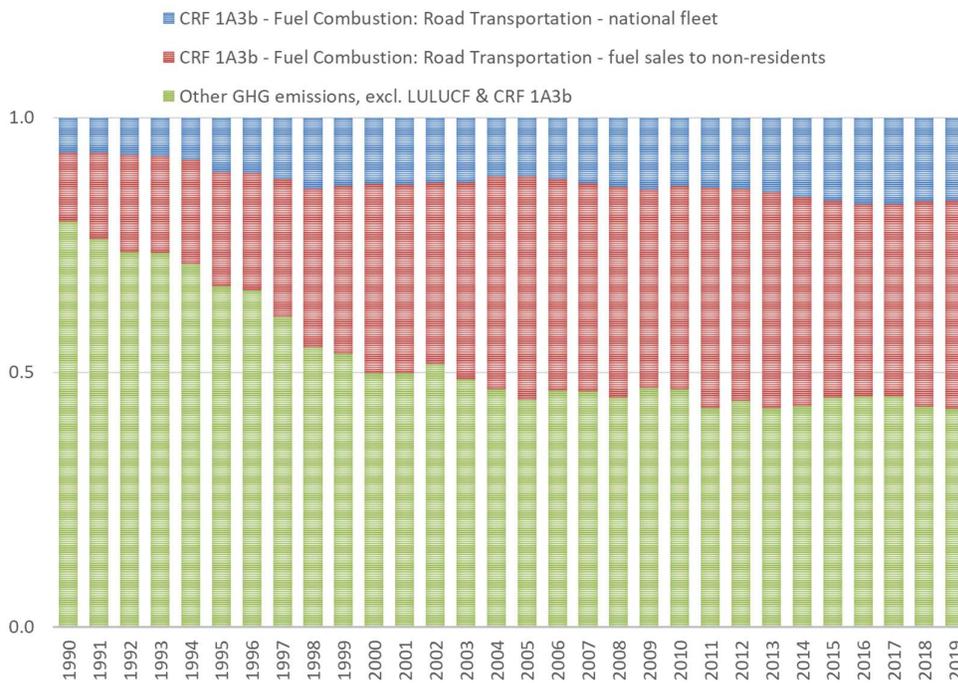
Source: ViaMichelin.

Figure 2-23 – Road blended fuel sales: 1990-2019 in tonnes



Source: based on Table 3-63 in Section 3.2.9.3.

Figure 2-24 – GHG emissions for road transportation (CRF sub-category 1A3b): 1990-2019



Source: Submission 2021v1.

Note: CO₂ emissions from biofuels are excluded, and reported as “memo item”.

2.1.8 UNFCCC and Kyoto Protocol: a demanding challenge for Luxembourg

2.1.8.1 The road transportation dilemma

Since Luxembourg is a small open economy integrated in the European internal market **where mobility of tax bases are likely to be high**, only marginal variations in the price differentials for petrol and diesel can be initiated by the authorities. Indeed, if Luxembourg's rates of taxation and prices were higher than those in the surrounding countries, it would be rather easy for any citizen of Luxembourg to avoid domestic taxation and to practise arbitrage: no location in Luxembourg is further than a maximum of 25-30 km away from a border with a neighbouring country. Lower taxation rates for certain goods – such as fuels, e.g. – have therefore always been part of Luxembourg fiscal policy and will remain crucial in the future, because of the country's geographical location and its small area. Whereas in larger neighbouring states, increasing certain tax rates would result in a slight shift in demand and in arbitrage deals at the outer fringes of their national territory – with a corresponding relatively slight reduction in tax revenues – this would not be the case for Luxembourg where such a policy may result in big losses in tax incomes. However, since road transportation, and more precisely “road fuel sales to non-residents”, is the main contributor to GHG emissions in Luxembourg, as underlined in the second national “Action Plan for reducing CO₂ emissions”⁴³, Luxembourg will use a policy mix of instruments with the aim of progressively reducing road transport related emissions.

With regard to the instrument of excise duties, Luxembourg will gradually increase road fuels excise rates following a cautious approach based on a better knowledge of the factors determining road fuel sales in Luxembourg that also takes into account the impact on the public finances of the country. Furthermore, in its programme, the actual Government that took office early December 2013 underlines that a **feasibility study on the progressive way out of “fuel tourism”** – and more generally of “road fuel sales to non-residents” – should be realized so to evaluate the economic impacts of such a decision on the medium and long terms⁴⁴. This study has been released in November 2016 (Königswinter, 2016). Its outcomes led to the setting-up of an inter-ministerial working group with the aim to inform the Government on possible venues to reduce the weight of road fuel sales in the GHG balance of Luxembourg, as well as making public finances less dependent from that source of income. In parallel, STATEC is working on evaluating price-elasticities of road fuel sales.

With regard to other instruments, the Luxembourg Government considers the organization of transport and the necessity to overcome existing problems linked to the traffic intensity as primary objectives. In this context, it promotes sustainable ways of transport consisting of public and non-motorized modes of transport. The re-organisation is intended to encompass both the national territory and the neighbouring regions of Germany, France and Belgium where many commuters come from, leading to a doubling of the workforce in Luxembourg during the day. All this is done in a conceptual way where new modes of transport such as electro-mobility and car sharing are promoted.

43 <http://www.developpement-durableinfrastructures>.

public.lu/fr/actualites/articles/2013/05/presentation_plan_action_climat/2_Nationaler-Aktionsplan-Klimaschutz.pdf

44 <http://www.gouvernement.lu/3322796/Programme-gouvernemental.pdf>

2.1.8.2 Country and economy sizes

Special attention must also be made for the **small size of the country's economy** in a different context: it is a contributory factor to the fact that, in spite of the healthy economic situation, the courses of the overall development of the country, of the demand for energy and of the emissions balance are often affected by a single plant which is starting its activities, closing them down or changing its production processes. This became particularly clear when the steel industry switch from blast furnaces to electric arc furnaces was completed during the 1990s: from 1990 to 1998, GHG emissions in Luxembourg were reduced by one third (see Section 2.4 for details).

Furthermore, the construction of a single power station, the TWINerg gas and steam plant, represents a further illustrative example as depicted in Section 2.1.5. When TWINerg started its operation in mid-2002, Luxembourg, which did not yet have any substantial electricity generating capacity, saw, at once, its GHG emissions increasing by 0.9 to 1 Mio. t CO₂e per year. To give another illustration on how this project affected the GHG emissions pattern in Luxembourg, one can underline that it represents 35% of the allocated emissions volume of the whole GHG EU Emissions Trading Scheme sector (EU-ETS) for the first commitment period under the Kyoto Protocol.

The impact that single industrial projects might have, plays also the other way round when a production unit or a plant is closed down. After a few years of reduced activity, the TWINerg power plant was finally shut down in 2016, which has a very high impact on Luxembourg's total GHG emissions. Also, a sufficiently long breakdown in one of the main industrial unit of the country could have impacts on the total GHG emissions, such as the long maintenance operations of the TWINerg plant in 2008 and 2011 demonstrated (cf. Figure 2-21).

If these issues might not be a major concern for large economies, it is for Luxembourg, as shown by the examples discussed above.

2.1.8.3 Limited GHG emissions reduction potentials

As of today, Luxembourg **does not have those significant technical potentials** which exist in other countries where residual "old-technology" industrial and power plants still operate. In Luxembourg, there were almost none, and there still is none of those GHG reduction potentials stemming from the modernisation or the replacement of existing national industrial or power plants. In fact, with the move from blast to electric arc furnaces in the steel sector during the 1990s, Luxembourg very soon exhausted its only major technical potential for GHG emissions reduction. With the process change in the steel industry – an activity which accounted for 50% of Luxembourg's total GHG emissions in 1990 (excluding LULUCF)⁴⁵ – total emissions from industry and electricity generation – i.e. largely the sectors covered by the EU-ETS – decreased to 2 Mio. t CO₂e in 2019 – about 19% of total GHG emissions (excluding LULUCF) – coming from slightly more than 7.9 Mio. t CO₂e in 1990 - or about 62% of total GHG emissions (excluding LULUCF).⁴⁶

Also, any ultramodern fossil fuel-based electricity generating plant that Luxembourg might decide to construct will automatically lead to an increase of its national GHG emissions, since there are no existing power plants which can be stopped in return. Thus, those highly efficient CHP installations and the ultramodern gas and steam power station (TWINerg, shut down in 2016) that have been promoted and are operating in Luxembourg since 1998, and that use natural gas and, sometimes, gas oil as inputs, have led to an

45 Sum of CRF sub-categories 1A2a and 2C1.

46 Sum of CRF sub-categories 1A1a, 1A2 and 2, excluding F-gases.

additional amount of up to 1.2 Mio. t CO₂e per year in the GHG balance.⁴⁷ It is therefore clear that any new fossil-fuel power generating installation that might be constructed will inevitably lead to a deterioration of Luxembourg's GHG balance. This also implies that the implementation of the EU CHP installation guidelines, which in other countries may lead to CO₂ reductions thanks to increased efficiency, is counterproductive for Luxembourg. For this reason, Luxembourg's authorities will only promote heat production from renewable energy sources, focusing mainly on biomass, wood and solar energy.⁴⁸ More precisely, CHP installations using renewable energies, biogas addition in distribution networks and the mobilization of wood resources will be favoured.

2.1.8.4 The "origin" principle of the IPCC reporting Guidelines vs. "polluter pays" principle

For the period 2002-2015, the "origin" or "territorial" principle, applied for reporting GHG emissions under the IPCC Guidelines, generates a GHG balance for Luxembourg that looks significantly less favourable than a "consumer" or "polluter pays" approach would produce (Figure 2-25). The "origin" principle is in favour of Luxembourg in that its imports of electricity are excluded from its GHG emission balance: those emissions are attributed to the electricity producing countries. But, as indicated above, "road fuel sales to non-residents" related emissions are reported in Luxembourg's GHG balance.

Now, if the "polluter pays" principle is used as a yardstick, Luxembourg's assessment reveals that GHG emissions according to the IPCC Guidelines are higher from 2002-2015 (the period during which the TWINerg power plant was operational and during which Luxembourg exported significantly greater quantities of electricity), but about 0.9 Mio. t CO₂e lower for 2019 (Figure 2-25).⁴⁹ This illustrates that the presence of a single power plant – even though it was highly efficient – has a significant impact on Luxembourg's national total GHG emissions.

Luxembourg's efforts to develop efficient, low-carbon electricity production are not rewarded in the actual reporting system for GHG emissions. Luxembourg has, for many years, promoted the construction and the development of highly efficient CHP installations and of a modern gas and steam power plant. Luxembourg has also actively supported power generation and uses based on renewable energies and, in addition to all these policies, further developments are still in the offing. The impact of these policies has been evaluated using GEMIS 4.2:⁵⁰ it has been estimated that electricity net imports – with, nowadays, an average emission factors of 0.75 (kt CO₂ per GWh) – have fallen by more than 1 200 GWh since 2001 – the last year before the TWINerg power plant operated at full capacity – and have been replaced by national electricity generation with a current average emission factor of 0.41 (kt CO₂ per GWh).

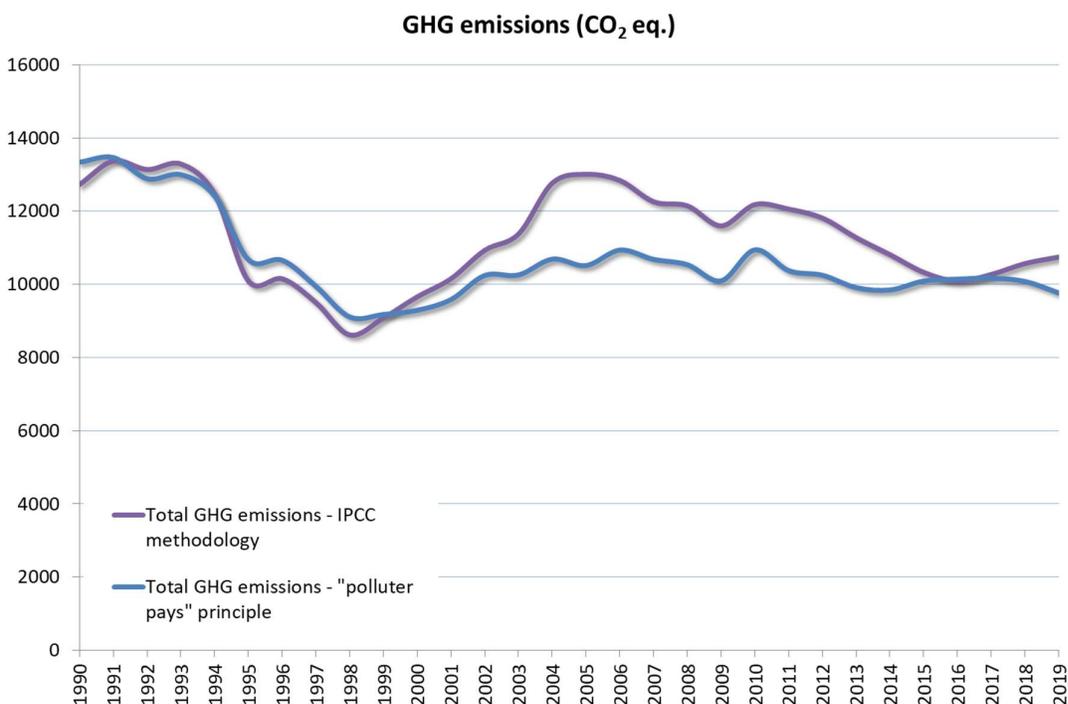
47 Max. 1 Mio. t CO₂e for the TWINerg and about 0.2 Mio. t CO₂e for CHP installations.

48 See the second Action Plan for Reducing CO₂ Emissions (http://www.environnement.public.lu/actualites/2013/05/plan_action_climat/index.html).

49 After having reached a "surplus" of 2.5 Mio. t CO₂e in 2005.

50 GEMIS stands for Global Emission Model for Integrated Systems: <http://www.iinas.org/gemis-de.html>.

Figure 2-25 – Total GHG emissions, excluding LULUCF – two approaches: 1990-2019



Sources: Environment Agency and MECDD.

Notes: The "polluter pays" principle figures have been obtained from the total GHG emission according to the IPCC methodology by excluding emissions from "road fuel sales to non-residents" and for electricity generated that is exported, and by adding an estimate for electricity production emissions generated abroad for satisfying Luxembourg consumption (i.e. emissions relating to electricity imports): Emissions "polluter pays" principle = emissions IPCC methodology – emissions "road fuel sales to non-residents" + emissions electricity net imports

So, in terms of the GHG balance, the promotion of renewable energies in the electricity sector, which is associated with major investments, is of little interest. Moreover, additional capacities based upon renewable energies cannot actually be used to replace any electricity from inefficient existing fossil-fuel plants in Luxembourg. Nor will they substitute the modern and highly efficient national production plants. In reality, they will replace the imported electricity which does not contribute to Luxembourg's GHG balance. In this sense, the existing system provides Luxembourg with the incentive not to earmark the generally scant subsidies for Europe's priority investments in renewable energies but, instead, to invest these in measures which might improve its GHG balance.

2.1.9 National circumstances: overview

Key points that play a role on GHG emissions trends in the past and in the future are:

- a country characterized by both **high demographic** and **high economic growth** in a stagnating region, hence an **attractive economic destination**;
- **strong population growth** due to immigration and that is expected to go on;
- **even stronger cross-border commuters growth** that is expected as well to continue;
- **increase of built-up areas** (housing, offices, services, infrastructures) as a consequence of the previous statements;
- location at the **heart** of the main Western Europe **transit routes** for both **goods and passengers**;
- **increase of transport flows** as a consequence of the previous statements;
- **small size** and open economy: a new industrial project, a technological change, a closure or a breakdown of a production unit might have significant impacts on the GHG emissions and increase the overall uncertainty of GHG projections;
- **limitations in taxation policies** due to short distances to neighbouring countries;
- a country that **needs to co-operate and to interact with its neighbours** since environmental issues become quickly cross-border issues;
- **limited national** GHG emissions reduction potential.

Figure 2-26, Figure 2-27 and Figure 2-28 provide a quick overview of the trends of some key variables since 1990.

Figure 2-26 – Key variables trends – 1: 1990-2019

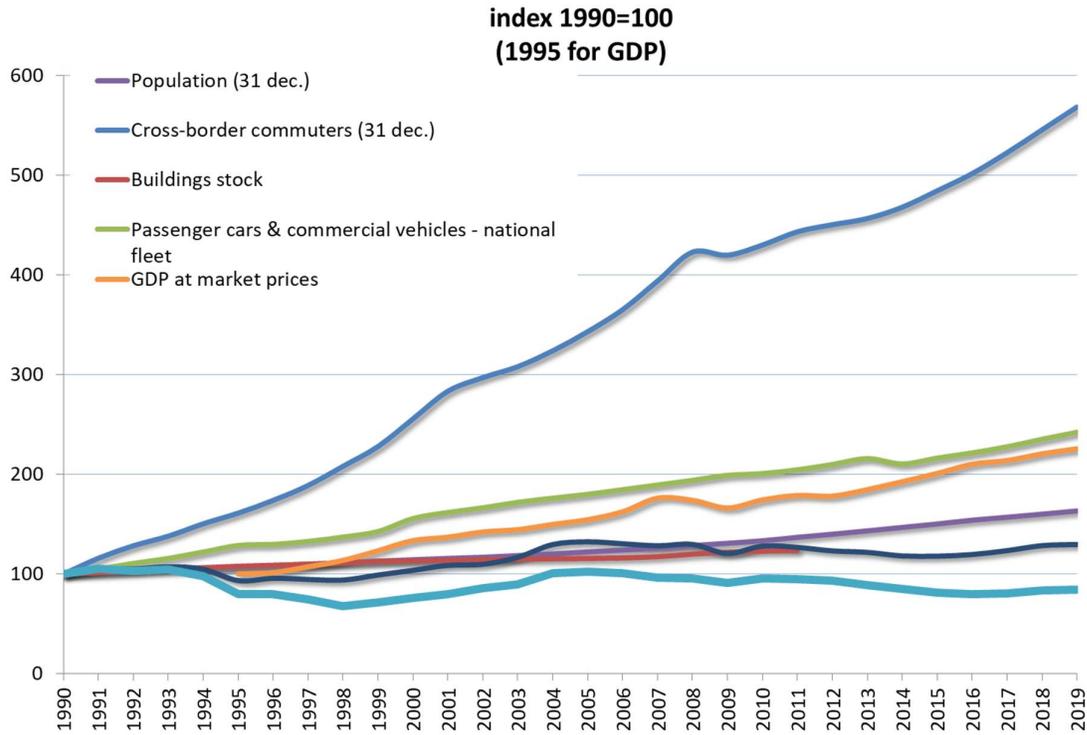


Figure 2-27 – Key variables trends – 1: 1990-2019 (excl. cross-border commuters)

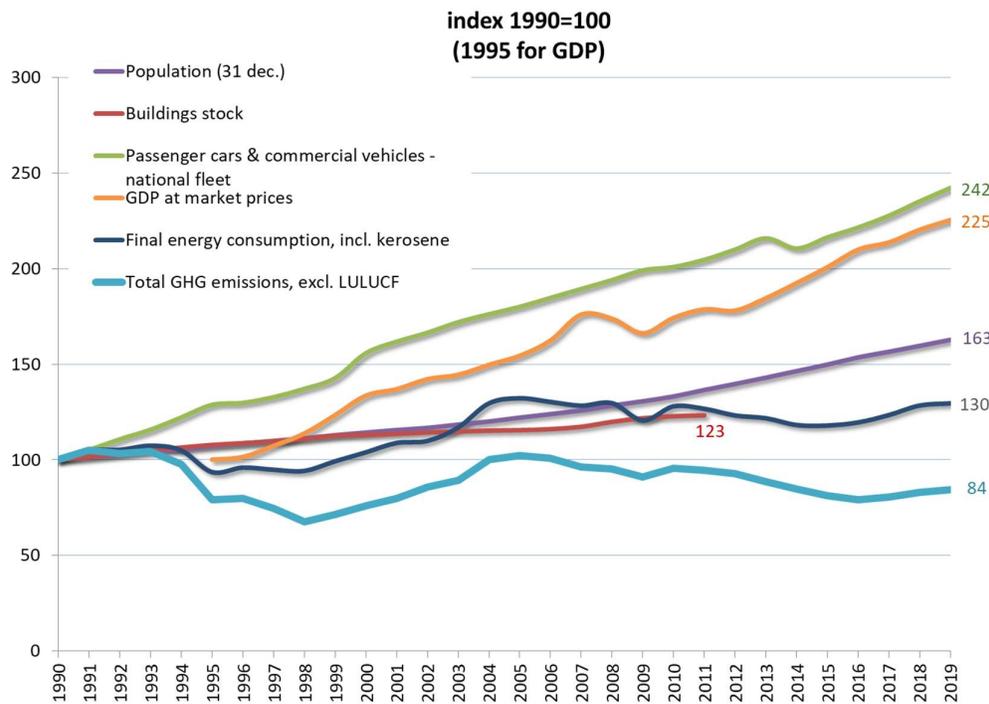
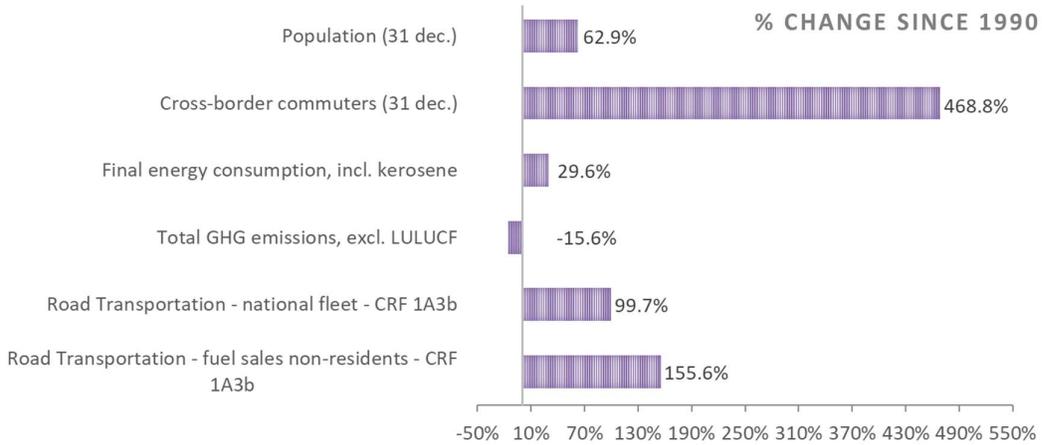


Figure 2-28 – Key variables trends – 2: 1990 & 2019



Sources: Population: STATEC, *Statistical Yearbook*, Table B.1100 (updated 4 March 2021).

http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12856&IF_Language=fra&MainTheme=2&FldrName=1

Commuters: STATEC, *Statistical Yearbook*, Table B.3107 (updated 4 March 2021).

http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12928&IF_Language=fra&MainTheme=2&FldrName=3&RFPath=92

Buildings stock: MECDD estimates on the basis of STATEC, *Statistical Yearbook*, Table D.4200 & results from the 2011 population census.

http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=13443&IF_Language=fra&MainTheme=4&FldrName=4&RFPath=35

<http://www.statistiques.public.lu/stat/tableviewer/document.aspx?ReportId=8624>

Cars & vehicles: STATEC, *Statistical Yearbook*, Table D.6102 (updated 4 March 2021).

http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=13499&IF_Language=fra&MainTheme=4&FldrName=7&RFPath=7049%2c13898

GDP: STATEC, *Statistical Yearbook*, Table E.2101 (updated 4 March 2021).

http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=13147&IF_Language=fra&MainTheme=5&FldrName=2&RFPath=23

Energy: STATEC, *Statistical Yearbook*, Table A.4300 (updated 4 March 2021).

http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12771&IF_Language=fra&MainTheme=1&FldrName=4&RFPath=51

GHG: Environment Agency and MECDD – Submission 2021v1.

Notes: (1) Energy: there is a break in time series between 1999 & 2000.

(2) Buildings stocks = stock of permanently occupied dwellings.

2.2 Description of Emission Trends for Aggregated GHG Emissions

Luxembourg ratified the United Nations Framework Convention on Climate Change in 1994, and the Kyoto Protocol in 2002. Pursuant to that Protocol and the terms of the European agreement distributing the burden among, at that time, the EU-15 Member States, Luxembourg committed itself **to reduce its GHG emissions by 28% below their 1990 level over the period 2008-12**. This is the deepest cut of any agreed by the 15 Member States. When the Act approving the Kyoto Protocol was adopted in Luxembourg (2001), its GHG emissions were down by more than 30% between 1990 and 1998 (Table 2-13). Now for the 2nd commitment period EU Member States aim to reduce GHG emissions by 20% with regard to the reference year 1990.

In 2019, carbon dioxide was the main source of GHG in Luxembourg. This source accounted for 90.78% of the total GHG emissions calculated in CO₂e – total excluding LULUCF.⁵¹ The second source of GHG was methane with 5.42% of the total GHG emissions. Nitrous oxide was the third source with 3.13%. Fluorinated gases only accounted for 0.67% of the total GHG emissions, with hydrofluorocarbons representing 0.57% of the total GHG emissions and sulphur hexafluoride representing 0.10% of the total GHG emissions.

In 2019, total GHG emissions amounted to 10.743 Mio. t CO₂e, i.e. 15.6% below their level in 1990 and 15.6% below the level retained for the base year under the Kyoto Protocol.⁵² As Figure 2-29 shows, several phases can clearly be distinguished over the period 1990 to 2019:

- from base year up to 1993, Luxembourg’s emissions remained rather stable;
- then, between 1994 and 1998, they started to decrease significantly to reach their lowest value in 1998, when they were down by more than 30%;
- from 1999 up to 2004, emissions augmented recurrently;
- from 2004 to 2006, a stabilisation peaking around 13 Mio. t CO₂e is observed;
- a decrease occurred between 2006 and 2007 followed by a period of two years impacted by the financial and economic crisis;
- Following the financial and economic crisis, the emissions fell steadily until 2016, after which they picked up again.

The evolution during those 29 years can essentially be explained by **changes in production techniques**, as well as by **changes in the final “energy-mix” consumption**. Of course, **increasing or decreasing activities** for certain source categories also played a crucial role in Luxembourg’s GHG emissions trend. During the years 2008-2010, **the financial and economic crisis and its aftermaths** also played a part. The decreasing trend in emissions since 2012 is mainly due to the progressive shutdown of the TWINerg power plant and slowly declining sales volumes of road fuels. The recent increases of GHG emissions are due to steadily increasing sales volumes of road fuels.

51 In Section 2.2, “total (GHG) emissions” means “total GHG emissions excluding LULUCF”. Reference is made to total emissions excluding LULUCF since this is the one that counts for the reduction target under the Kyoto Protocol.

52 The level of emissions considered for the base year is 12.727 Mio. t CO₂e. The base year for CO₂, CH₄ and N₂O is 1990. For the F-gases, the base year is 1995. When the assigned amount under the Kyoto Protocol was determined, F-gases emissions were equal in 1990 and 1995 due to a lack of background data and methods at that time. Now, as Table 2-13 shows, F-gases emissions are no longer the same in 1990 and 1995.

Table 2-13 – Luxembourg’s GHG emissions and removals – overview by main gases and CRF Sectors: 1990-2019

Gg (1000 t) CO ₂ equivalent	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
CO₂ emissions, incl. net CO₂ from LULUCF (1)	11886.85 92.78%	12211.35 92.79%	11627.68 92.47%	11668.92 92.45%	11056.44 92.19%	8545.81 89.96%	8549.74 89.83%	7810.25 89.02%	7049.44 88.01%	7407.51 88.39%	7966.78 89.15%	8482.61 89.79%	9262.43 90.56%	9783.26 91.28%	11133.76 92.09%
CO₂ emissions, excl. net CO₂ from LULUCF	11823.34 92.90%	12443.14 93.06%	12209.70 92.96%	12354.74 92.99%	11542.46 92.65%	9151.71 90.75%	9201.61 90.67%	8553.96 90.08%	7675.93 89.10%	8127.85 89.52%	8709.92 90.18%	9207.45 90.70%	9983.58 91.35%	10458.92 91.96%	11828.91 92.67%
CH₄ (2) emissions, incl. net CH₄ from LULUCF (1)	584.29 4.56%	597.16 4.54%	581.58 4.63%	586.44 4.65%	574.08 4.79%	589.23 6.20%	598.55 6.29%	593.62 6.77%	591.42 7.38%	596.69 7.12%	588.19 6.58%	593.86 6.29%	594.15 5.81%	583.56 5.44%	579.29 4.79%
CH₄ (2) emissions, excl. net CH₄ from LULUCF	584.29 4.59%	597.16 4.47%	581.58 4.43%	586.44 4.41%	574.08 4.61%	589.23 5.84%	598.55 5.90%	593.62 6.25%	591.42 6.87%	596.69 6.57%	588.19 6.09%	593.86 5.85%	594.15 5.44%	583.56 5.13%	579.29 4.54%
N₂O (3) emissions, incl. net N₂O from LULUCF (1)	339.79 2.65%	350.70 2.66%	357.81 2.85%	351.85 2.79%	347.04 2.89%	347.56 3.66%	350.49 3.68%	347.18 3.96%	343.63 4.29%	347.99 4.15%	347.64 3.89%	329.84 3.49%	326.31 3.19%	304.94 2.85%	330.03 2.73%
N₂O (3) emissions, excl. net N₂O from LULUCF	318.47 2.50%	329.37 2.46%	336.49 2.56%	330.53 2.49%	325.72 2.61%	326.24 3.24%	329.17 3.24%	325.86 3.43%	322.31 3.74%	326.67 3.60%	326.63 3.38%	309.15 3.05%	305.94 2.80%	284.89 2.50%	310.29 2.43%
HFCs (4)	0.00 0.00%	0.00 0.00%	5.49 0.04%	12.94 0.10%	14.19 0.11%	15.15 0.15%	17.33 0.17%	20.10 0.21%	22.96 0.27%	26.21 0.29%	31.08 0.32%	38.25 0.38%	41.51 0.38%	41.75 0.37%	41.93 0.33%
PFCs (4)	NO NA	NO NA	NO NA	NO NA	NO NA	NO NA	NO NA	NO NA	NO NA						
SF₆ (4)	1.28 0.01%	1.37 0.01%	1.47 0.01%	1.57 0.01%	1.68 0.01%	1.75 0.02%	1.94 0.02%	2.10 0.02%	2.16 0.03%	2.24 0.02%	2.36 0.02%	2.97 0.03%	3.58 0.03%	4.17 0.04%	4.73 0.04%
1. Energy	10301.39 80.94%	11006.02 82.31%	10846.21 82.58%	11010.85 82.87%	10295.26 82.64%	8260.38 81.92%	8368.24 82.46%	7830.97 82.47%	7111.27 82.55%	7529.84 82.93%	8088.92 83.75%	8645.01 85.16%	9417.09 86.17%	9946.49 87.45%	11267.14 88.26%
2. Industrial Processes	1608.85 12.64%	1531.70 11.46%	1465.57 11.16%	1455.31 10.95%	1360.52 10.92%	1004.21 9.96%	950.60 9.37%	842.68 8.87%	685.17 7.95%	724.36 7.98%	753.46 7.80%	706.72 6.96%	727.20 6.65%	675.27 5.94%	731.19 5.73%
3. Agriculture	711.34 5.59%	725.43 5.43%	714.38 5.44%	710.01 5.34%	700.23 5.62%	717.98 7.12%	725.90 7.15%	715.51 7.54%	710.00 8.24%	717.73 7.90%	710.66 7.36%	694.57 6.84%	677.78 6.20%	640.72 5.63%	661.97 5.19%
4. LULUCF	84.84 0.66%	-210.46 -1.60%	-560.70 -4.46%	-664.50 -5.26%	-464.70 -3.87%	-584.58 -6.15%	-630.55 -6.62%	-722.39 -8.23%	-605.17 -7.56%	-699.02 -8.34%	-722.13 -8.08%	-704.15 -7.45%	-700.78 -6.85%	-655.60 -6.12%	-675.41 -5.59%
5. Waste	105.80 0.83%	107.89 0.81%	108.58 0.83%	110.04 0.83%	102.11 0.82%	101.50 1.01%	103.86 1.02%	106.47 1.12%	108.34 1.26%	107.73 1.19%	105.15 1.09%	105.38 1.04%	106.69 0.98%	110.81 0.97%	104.85 0.82%
6. Other	NA 0.00%	NA 0.00%	NA 0.00%	NA 0.00%	NA 0.00%	NA 0.00%	NA 0.00%	NA 0.00%	NA 0.00%						
Total GHG including LULUCF	12812.22 100.00%	13160.58 100.00%	12574.03 100.00%	12621.71 100.00%	11993.43 100.00%	9499.50 100.00%	9518.05 100.00%	8773.25 100.00%	8009.61 100.00%	8380.64 100.00%	8936.05 100.00%	9447.54 100.00%	10227.99 100.00%	10717.69 100.00%	12089.74 100.00%
Total GHG excluding LULUCF	12727.38 100.00%	13371.04 100.00%	13134.73 100.00%	13286.22 100.00%	12458.12 100.00%	10084.08 100.00%	10148.60 100.00%	9495.63 100.00%	8614.78 100.00%	9079.66 100.00%	9658.18 100.00%	10151.68 100.00%	10928.76 100.00%	11373.29 100.00%	12765.15 100.00%

Gg (1000 t) CO ₂ equivalent	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CO ₂ emissions, incl. net CO ₂ from LULUCF (1)	11446.95 92.43%	11376.14 92.40%	10865.81 91.92%	10717.60 91.66%	10191.87 91.27%	11072.47 91.82%	10796.84 91.78%	10470.57 91.63%	9748.16 91.00%	9351.39 90.47%	8914.86 90.01%	8572.63 89.53%	8875.08 89.72%	9367.22 90.29%	9429.70 90.41%
CO ₂ emissions, excl. net CO ₂ from LULUCF	12087.02 92.94%	11919.75 92.86%	11316.96 92.35%	11183.69 92.11%	10638.34 91.74%	11207.25 92.04%	11102.38 92.11%	10866.20 92.03%	10320.57 91.57%	9836.04 91.01%	9347.99 90.54%	9092.74 90.18%	9261.34 90.21%	9568.44 90.57%	9752.16 90.78%
CH ₄ (2) emissions, incl. net CH ₄ from LULUCF (1)	577.94 4.67%	574.17 4.66%	583.35 4.93%	593.50 5.08%	594.63 5.32%	594.28 4.93%	569.59 4.84%	561.70 4.92%	566.09 5.28%	579.21 5.60%	585.26 5.91%	589.46 6.16%	596.93 6.03%	590.94 5.70%	582.25 5.58%
CH ₄ (2) emissions, excl. net CH ₄ from LULUCF	577.94 4.44%	574.17 4.47%	583.35 4.76%	593.50 4.89%	594.63 5.13%	594.28 4.88%	569.59 4.73%	561.70 4.76%	566.09 5.02%	579.21 5.36%	585.26 5.67%	589.46 5.85%	596.93 5.81%	590.94 5.59%	582.25 5.42%
N ₂ O (3) emissions, incl. net N ₂ O from LULUCF (1)	313.73 2.53%	312.75 2.54%	318.47 2.69%	325.41 2.78%	322.40 2.89%	330.63 2.74%	332.51 2.83%	327.82 2.87%	327.35 3.06%	330.27 3.20%	328.12 3.31%	338.05 3.53%	341.75 3.45%	341.74 3.29%	346.67 3.32%
N ₂ O (3) emissions, excl. net N ₂ O from LULUCF	294.31 2.26%	293.64 2.29%	299.68 2.45%	307.34 2.53%	305.04 2.63%	313.92 2.58%	316.50 2.63%	312.49 2.65%	312.77 2.78%	316.46 2.93%	315.09 3.05%	325.81 3.23%	330.23 3.22%	330.94 3.13%	336.60 3.13%
HFCs (4)	40.47 0.31%	43.37 0.34%	47.76 0.39%	50.25 0.41%	51.40 0.44%	53.67 0.44%	56.55 0.47%	58.91 0.50%	62.45 0.55%	66.64 0.62%	66.73 0.65%	65.17 0.65%	68.57 0.67%	64.70 0.61%	61.36 0.57%
PFCs (4)	NO NA														
SF ₆ (4)	5.31 0.04%	5.73 0.04%	6.17 0.05%	6.58 0.05%	6.99 0.06%	7.29 0.06%	7.75 0.06%	8.14 0.07%	8.51 0.08%	8.90 0.08%	9.37 0.09%	9.72 0.10%	9.90 0.10%	10.20 0.10%	10.43 0.10%
1. Energy	11550.84 88.82%	11335.99 88.31%	10740.04 87.65%	10660.82 87.81%	10184.63 87.83%	10740.47 88.21%	10621.83 88.13%	10421.94 88.27%	9891.46 87.77%	9401.60 86.99%	8918.88 86.39%	8641.00 85.70%	8803.94 85.75%	9111.46 86.24%	9277.24 86.36%
2. Industrial Processes	702.50 5.40%	756.78 5.90%	752.98 6.14%	703.63 5.80%	633.58 5.46%	658.31 5.41%	670.07 5.56%	639.37 5.42%	622.17 5.52%	632.63 5.85%	624.02 6.04%	646.32 6.41%	656.72 6.40%	657.31 6.22%	675.07 6.28%
3. Agriculture	646.51 4.97%	638.55 4.97%	653.88 5.34%	668.91 5.51%	671.76 5.79%	682.22 5.60%	669.74 5.56%	656.16 5.56%	666.46 5.91%	681.95 6.31%	695.76 6.74%	711.51 7.06%	721.56 7.03%	713.75 6.76%	712.35 6.63%
4. LULUCF	-620.65 -5.01%	-524.51 -4.26%	-432.36 -3.66%	-448.01 -3.83%	-429.10 -3.84%	-118.08 -0.98%	-289.53 -2.46%	-380.31 -3.33%	-557.83 -5.21%	-470.84 -4.56%	-420.10 -4.24%	-507.87 -5.30%	-374.74 -3.79%	-190.42 -1.84%	-312.39 -2.99%
5. Waste	105.21 0.81%	105.34 0.82%	107.00 0.87%	107.98 0.89%	106.42 0.92%	95.42 0.78%	91.13 0.76%	89.97 0.76%	90.30 0.80%	91.08 0.84%	85.77 0.83%	84.06 0.83%	84.77 0.83%	82.71 0.78%	78.14 0.73%
6. Other	NA 0.00%														
Total GHG including LULUCF	12384.40 100.00%	12312.16 100.00%	11821.55 100.00%	11693.34 100.00%	11167.30 100.00%	12058.34 100.00%	11763.24 100.00%	11427.13 100.00%	10712.56 100.00%	10336.42 100.00%	9904.34 100.00%	9575.03 100.00%	9892.24 100.00%	10374.80 100.00%	10430.41 100.00%
Total GHG excluding LULUCF	13005.05 100.00%	12836.66 100.00%	12253.91 100.00%	12141.35 100.00%	11596.40 100.00%	12176.42 100.00%	12052.77 100.00%	11807.44 100.00%	11270.40 100.00%	10807.26 100.00%	10324.43 100.00%	10082.90 100.00%	10266.98 100.00%	10565.23 100.00%	10742.80 100.00%

Source: Environment Agency and MECDD.

Notes:(1) These percentages are relative to the total GHG emissions, including LULUCF.

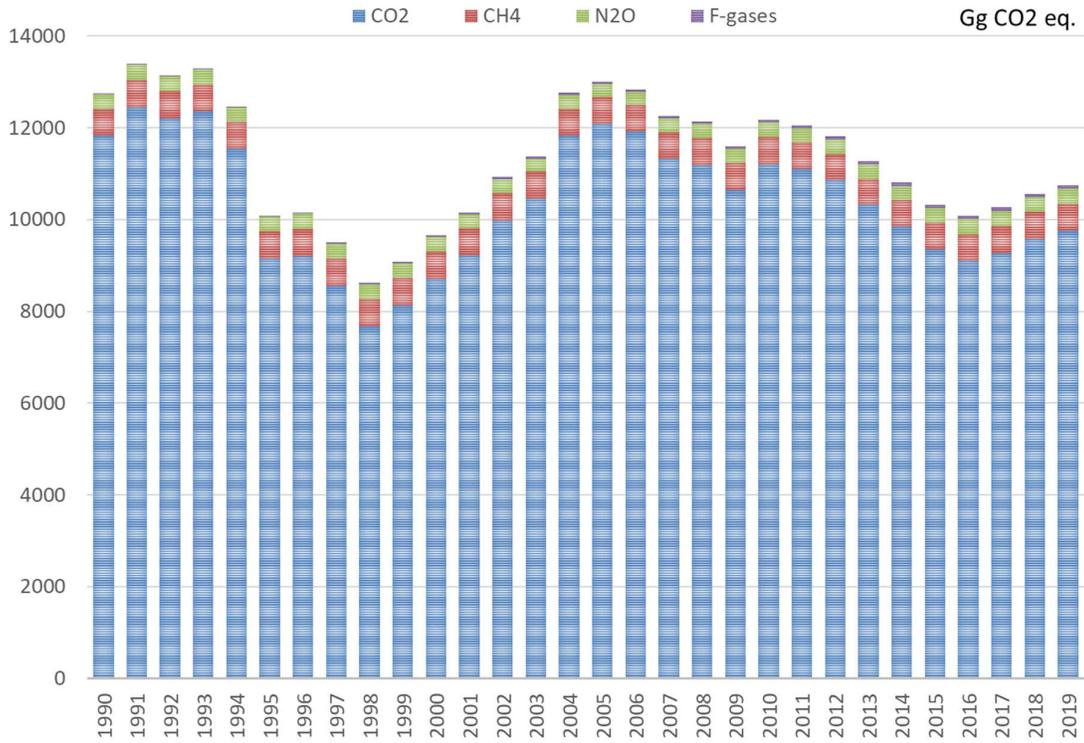
(2) The methane emissions are converted into CO₂ equivalents by multiplying the emissions by 25, *i.e.* the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon.

(3) The nitrous oxide emissions are converted into CO₂ equivalents by multiplying the emissions by 298, *i.e.* the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

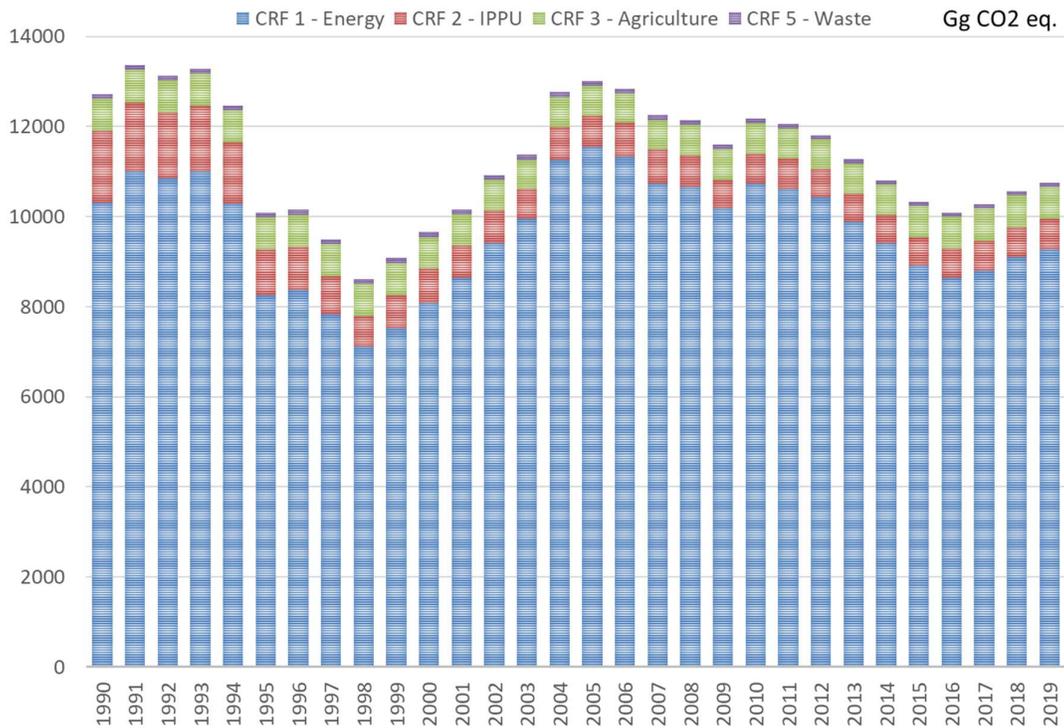
(4) The F-gases are those not covered by the Montreal Protocol, *i.e.* the HFCs, PFCs and SF₆ expressed in CO₂ equivalents using the global warming potential (GWP) values based on the effects of GHG over a 100-year time horizon.

Figure 2-29 – Luxembourg’s GHG emissions (excl. LULUCF) – absolute values: 1990-2019

GHG



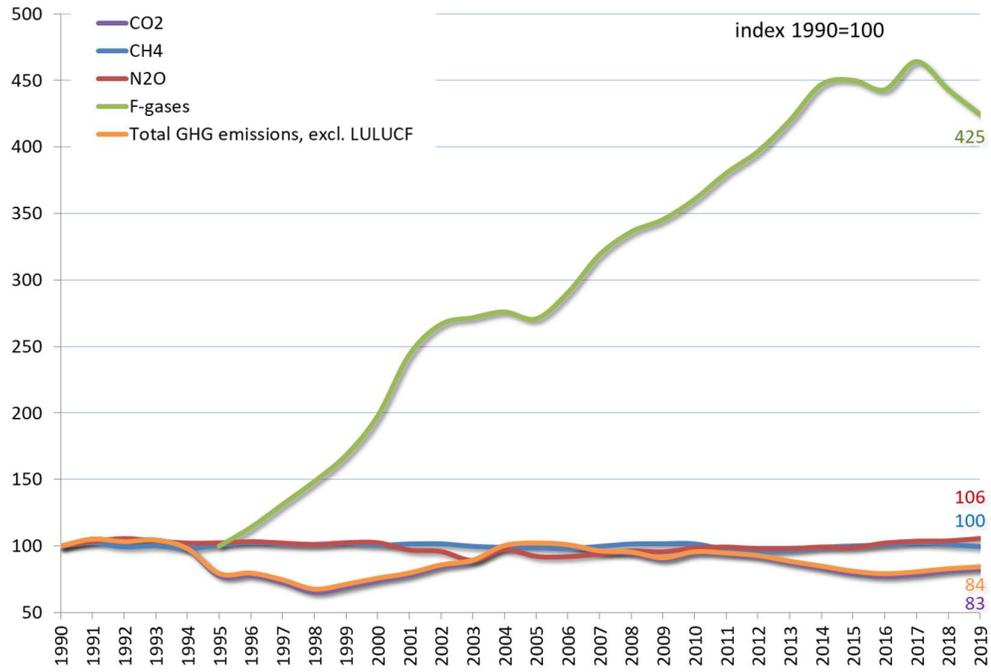
CRF Sectors



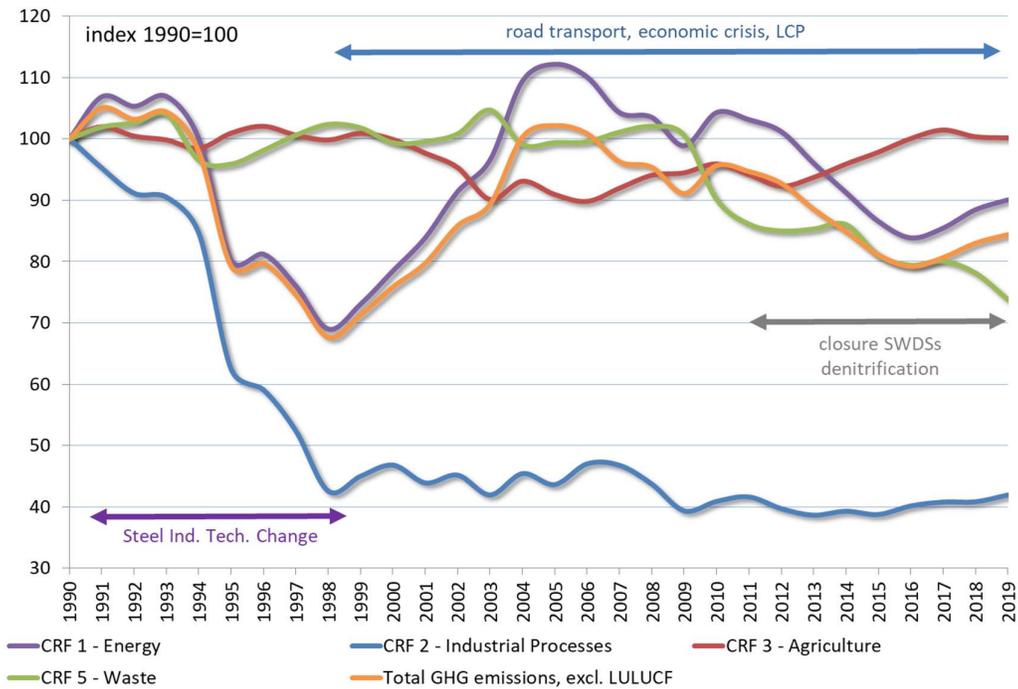
Sources: Environment Agency and MECDD.

Figure 2-30 – Luxembourg’s GHG emissions (excl. LULUCF) – indexes: 1990-2019

GHG



CRF Sectors



Sources: Environment Agency and MECDD.

A good example for a **technological change** in production took place in the iron and steel industry, where the steel production process was moved from blast furnaces to electric arc furnaces between 1994 and 1998 and, therefore, solid fuels (coke) were replaced to a very large extent by electricity and natural gas. Due to that technological change, the total energy consumption in the steel industry was significantly reduced and the “energy-mix” greatly modified. This process change was the main driver for the reduction in GHG emissions observed between 1994 and 1998. Changes also occurred in the industrial and residential/commercial/institutional sectors, where the consumption of liquid fuels (residual oil, gasoil) was reduced in favour of natural gas in conjunction with the extension of the natural gas network in Luxembourg.

The road transportation sector is a clear example about **how activity levels of a source category can influence the overall GHG emission trend**. Indeed, the upward trend for GHG emissions recorded from 1999 to 2004 was merely justified by increasing energy consumption and fuel sales in the transport sector. The stabilization spotted for the inventory years 2004 to 2006 was largely the result of relatively steady sales of road fuels that peaked in 2005. Finally, the decrease in total emissions from 2006 to 2007 and the period of relative stability that followed was driven by a “road fuel sales to non-residents” related emissions reduction, which reached its lower level in 2009 (financial and economic crisis), combined with a reduction of GHG emissions from the power generation sector, the latter being exceptionally important for 2008 when the main power plant of the country underwent a lengthy maintenance. The steady decrease of GHG emission following the year 2010 can mainly be attributed to another lengthy maintenance in 2011 as well as the steady and gradual rampdown of the turbine. Since 2016, the GHG emissions have been rising again, mainly due to increased sales of liquid fuels in the transport sector.

More detailed explanations are provided in Sections 2.3 (dealing with gases) and 2.4 (dealing with CRF Sectors), as well as in the analysis of emission trends for each sector (see the first sections of CRF Sector Chapters 0 to 1).

A fundamental point worth mentioning when analysing Luxembourg’s GHG emission trends and their composition over time, is **the small size of Luxembourg**, and therefore, the special nature of its economy. Indeed, the structure of the economy, the related energy demand and the energy and emission balances may vary significantly, whether a new economic activity starts its operations or an existing one ceases them. This characteristic explains, for instance, the reduction of emissions pertaining to the industrial sector: with 7.9 Mio. t in 1990, CO₂e emissions from industrial processes and fuel combustion in industry accounted for 62% of total GHG emissions. They could eventually be reduced to 2.1 Mio. t in 1998 – i.e. 24% of total GHG emissions – mainly after the reorganization of the steel industry took place in the mid-nineties (move from blast furnaces to electric arc furnaces indicated above). At that time, GHG emissions of Luxembourg were almost one third below the base year level. Another illustrative example is the TWINerg power plant. This plant started its operation in mid-2002 and, by 2010, was responsible for about 0.96 Mio. t CO₂, i.e. around 8% of the total GHG emissions. In the years following 2010, the plant’s activity level progressively decreased until its final shutdown in 2016.

2.3 Description of Emission Trends by Gas

For the different GHG, trends over the period 1990-2019 (and 2018-2019) were as follows:

- CO₂: -17.52% (+1.92%)
- CH₄: -0.35% (-1.47%)
- N₂O: +5.69% (+1.71%)
- F-gases: +324.72% (-4.16%)

For carbon dioxide, the development between 1990 and 2019 hides a V-shape evolution over the period as well as important changes in the sources of CO₂ emissions: declining emissions in industrial combustion, increasing emissions from transport and natural gas fired power plants – as underlined in the previous section.

Total methane emissions have remained fairly stable over the period 1990-2019. In 2019, reduced methane emissions were observed in waste management (-32.70%) as compared to 1990, and increasing emissions in agriculture (+6.47%) and in energy use (+5.55%), the latter being mainly due to an upward trend for fugitive emissions from natural gas distribution and use, and to a lesser extent to a downward trend of combustion related emissions in the energy production industries and the commercial and residential sectors.

Nitrous oxide emissions development between 1990 and 2019 is closely linked to an increase of liquid fuels related emissions from combustion activities (+153.02% in the Energy sector) and to emissions from the waste sector (+99.36%) that could not be balanced by declining emissions from the agriculture (-13.14%) and industrial products and product use sectors (-48.68%). Total N₂O emissions (excl. LULUCF) have increased by 5.69 % since 1990.

With regard to F-gases, HFCs emissions increased by 304.94% in 2019 compared to the base year (1995), whereas SF₆ emissions showed a 495.90% increase between 1995 and 2019. In the case of HFCs emissions, the increase is due to a wider use of mobile and stationary cooling equipment while, in the case of SF₆, the increase is due to an increase in the use of high-voltage electrical equipment as well as noise reduction windows. Table 2-14 shows the detailed evolution of the greenhouse gases and the sector emissions over time while Table 2-15 shows, for each greenhouse gas, the emissions of the main source categories. Figure 2-31 visualizes the data of Table 2-15. These tables and figure offer the opportunity to further analyse emission trends for each one of the gases.

Finally, when including emissions and removals from land use, land use change and forestry (LULUCF), Luxembourg's greenhouse gas emissions amounted to a total of 10430.41 million tonnes CO₂ eq (incl. LULUCF) in 2019. Net removals from the LULUCF sector amounted to 312.39 Gg CO₂ eq. Since 1990, net emissions have decreased by 468.22% per cent (the sector was a source of net emissions in 1990 (84.84 Gg CO₂ eq) and a source of net removals in 1991-2018).

Table 2-14 – Luxembourg’s GHG emissions (excl. LULUCF) –sector-based breakdown: 1990-2019

Gg (1000 t) CO ₂ equivalent	CRF Categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Public Electricity & Heat Production (excl. waste incineration)	1A1a	0.00	0.00	0.00	0.00	0.00	60.48	56.78	59.44	99.57	108.93	56.33	218.57	965.02	971.27	1186.27
Iron & Steel (fuel combustion & processes)	1A2a + 2C1	6396.34	6090.26	5608.11	5844.06	4838.05	2782.00	2518.33	1629.19	451.52	493.31	478.83	548.58	530.79	512.57	558.44
Other Manufacturing Industries & Construction (fuel combustion & processes)	1A2b/c/d/e/f/g + 2A	1447.25	1519.57	1588.20	1471.74	1670.10	1511.01	1566.12	1581.73	1558.65	1744.13	1616.63	1585.20	1503.76	1409.79	1513.88
Road Transportation – national fleet	1A3b	876.25	921.54	963.24	1012.06	1023.18	1079.48	1102.35	1143.15	1198.23	1213.38	1260.91	1335.90	1393.53	1443.18	1467.48
Road Transportation – fuel export	1A3b	1714.29	2262.27	2507.63	2505.94	2553.05	2258.69	2344.64	2564.79	2688.80	2998.22	3586.97	3756.92	3889.93	4396.42	5326.88
Residential Fuel Combustion	1A4b	681.12	816.10	749.67	744.20	708.77	718.70	788.64	764.20	794.63	713.47	1081.46	1174.08	1117.46	1160.31	1240.58
Commercial & Institutional Fuel Combustion	1A4a	641.99	772.21	712.07	704.42	679.00	684.47	763.78	740.46	774.49	693.99	549.21	499.65	501.59	498.06	463.65
Agriculture (fuel combustion, livestock, crops, soils)	1A4c+3	748.20	763.12	750.32	743.83	736.47	752.51	762.06	753.11	748.34	773.48	738.42	719.13	703.93	667.14	689.76
Municipal Waste Incineration (with energy & heat recovery)	1A1a (5C)	35.84	37.50	37.39	35.51	34.80	33.23	25.71	30.46	56.74	64.96	63.11	62.31	63.38	64.97	73.28
Other Transport	1A3a/c/d	26.57	26.81	26.87	27.10	26.41	21.65	23.98	23.65	23.50	23.65	23.23	25.03	22.45	20.01	16.16
Other Energy Sources	1A5 + 1B2	22.72	23.46	48.09	45.75	44.32	36.10	46.27	51.39	62.72	92.81	42.53	57.93	61.80	52.18	54.41
F-gases	2F	0.00	0.00	5.49	12.94	14.19	15.15	17.33	20.10	22.96	26.21	31.08	38.25	41.51	41.75	41.93
Municipal Waste Disposal on Land	5A	92.98	94.91	95.18	93.83	85.00	84.68	84.71	86.76	86.80	86.76	82.63	81.92	82.13	82.24	77.05
Waste Water Handling	5D	12.83	12.98	13.15	13.31	13.47	12.53	12.44	12.52	12.72	12.91	11.64	12.26	11.83	12.01	11.24
Biological Treatment of Solid Waste	5B	0.00	0.00	0.26	2.90	3.64	4.29	6.12	7.19	8.82	8.05	10.82	11.20	12.73	16.56	16.56
Total GHG excluding LULUCF		12727.38	13371.04	13134.73	13286.22	12458.12	10084.08	10148.60	9495.63	8614.78	3079.66	9658.18	10151.68	10928.76	11373.29	12765.15
International Bunkers – Aviation		398.37	416.38	402.62	398.15	505.00	572.33	621.81	743.80	901.53	1017.07	969.38	1048.37	1135.75	1183.17	1287.36
International Bunkers – Marine		0.09	0.09	0.09	0.12	0.10	0.10	0.10	0.09	0.09	0.10	0.12	0.12	0.12	0.12	0.12
CO ₂ Emissions from Biomass		161.59	165.73	166.39	161.85	159.93	156.14	137.39	149.00	144.54	154.39	155.45	170.20	171.48	186.06	206.77

Gg (1000+) CO ₂ equivalent	CRF Categories	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Public Electricity & Heat Production (excl. waste incineration)	1A1a	1178.06 3.06%	1235.93 3.63%	1110.88 3.07%	923.02 2.60%	1121.48 3.67%	1141.69 3.38%	933.95 2.75%	972.19 2.83%	617.25 1.82%	591.44 1.74%	374.14 1.10%	156.16 0.46%	145.30 0.43%	123.21 0.36%	123.09 0.36%
Iron & Steel	1A2a + 2C1	532.47 1.53%	652.24 1.92%	626.33 1.76%	572.31 1.65%	458.02 1.38%	512.66 1.49%	458.21 1.38%	399.35 1.19%	377.89 1.13%	375.83 1.12%	400.62 1.18%	388.30 1.14%	376.97 1.11%	418.59 1.22%	400.56 1.18%
Other Manufacturing Industries & Construction (fuel combustion & processes)	1A2b/c/d/e/f/g + 2A	1507.37 4.09%	1514.46 4.09%	1435.13 4.00%	1371.58 3.96%	1276.99 3.82%	1320.99 3.82%	1358.70 3.98%	1325.08 3.88%	1283.42 3.78%	1298.09 3.82%	1229.72 3.63%	1304.00 3.80%	1311.35 3.80%	1288.14 3.73%	1339.02 3.93%
Road Transportation - national fleet	1A3b	1490.20 4.03%	1546.96 4.34%	1569.13 4.39%	1641.07 4.71%	1626.95 4.70%	1629.28 4.71%	1652.06 4.77%	1650.59 4.76%	1649.01 4.75%	1682.05 4.80%	1687.90 4.79%	1710.76 4.82%	1737.89 4.87%	1733.76 4.86%	1750.84 4.90%
Road Transportation - fuel export	1A3b	5685.70 15.22%	5309.89 14.72%	4992.32 13.92%	5018.98 14.34%	4510.59 13.00%	4870.55 14.00%	5223.91 15.22%	4783.98 14.00%	4439.25 12.82%	3992.35 11.53%	3793.57 10.93%	3799.57 10.93%	3878.91 11.09%	4261.64 12.00%	4383.90 12.46%
Residential Fuel Combustion	1A4b	1214.74 3.34%	1202.79 3.37%	1163.01 3.28%	1195.78 3.49%	1182.48 3.43%	1160.34 3.33%	1063.21 3.09%	1082.32 3.09%	1074.84 3.04%	972.03 2.79%	1085.13 3.04%	1118.23 3.11%	1138.41 3.19%	1042.07 2.93%	950.34 2.73%
Commercial & Institutional Fuel Combustion	1A4a	418.87 1.13%	395.72 1.09%	348.92 0.97%	377.62 1.07%	381.60 1.07%	502.33 1.45%	335.37 0.97%	439.33 1.26%	462.64 1.32%	397.81 1.13%	488.50 1.39%	511.39 1.46%	563.52 1.60%	592.06 1.67%	692.62 1.97%
Agriculture (fuel combustion, livestock, crops, soils)	1A4c+3	673.63 1.82%	666.17 1.81%	680.33 1.89%	697.53 1.99%	700.44 1.99%	711.03 2.00%	697.15 2.00%	683.59 1.98%	689.84 1.99%	705.71 2.00%	719.94 2.03%	735.78 2.07%	745.17 2.08%	737.63 2.07%	736.26 2.06%
Municipal Waste Incineration (with energy & heat recovery)	1A1a (SC)	64.65 0.18%	70.97 0.20%	72.21 0.20%	74.25 0.21%	72.58 0.21%	64.82 0.19%	74.97 0.22%	74.32 0.22%	75.13 0.22%	84.28 0.24%	94.85 0.27%	108.27 0.31%	108.35 0.31%	109.48 0.31%	112.37 0.32%
Other Transport	1A3a/c/d	11.11 0.03%	8.62 0.02%	11.22 0.03%	12.74 0.04%	12.07 0.03%	12.99 0.04%	12.97 0.04%	11.85 0.03%	10.25 0.03%	11.54 0.03%	8.37 0.02%	7.86 0.02%	8.43 0.02%	8.80 0.02%	8.34 0.02%
Other Energy Sources	1A5 + 1B2	53.59 0.15%	56.23 0.16%	52.62 0.15%	50.32 0.14%	50.86 0.14%	54.69 0.16%	47.43 0.14%	48.51 0.14%	41.33 0.12%	39.03 0.11%	35.11 0.10%	32.28 0.09%	31.79 0.09%	31.27 0.09%	31.30 0.09%
F-gases	2F	40.47 0.11%	43.37 0.12%	47.76 0.13%	50.25 0.14%	51.40 0.15%	53.87 0.15%	56.55 0.16%	58.91 0.17%	59.99 0.17%	64.94 0.19%	64.74 0.18%	63.14 0.18%	63.68 0.18%	60.14 0.17%	53.48 0.15%
Municipal Waste Disposal on Land	5A	74.70 0.21%	73.44 0.21%	73.26 0.21%	71.76 0.20%	70.58 0.20%	58.87 0.17%	58.93 0.17%	56.18 0.16%	57.37 0.16%	56.64 0.16%	54.23 0.15%	49.62 0.14%	50.95 0.14%	47.87 0.14%	46.30 0.13%
Waste Water Handling	5D	11.35 0.03%	11.45 0.03%	11.53 0.03%	10.64 0.03%	10.24 0.03%	10.33 0.03%	10.64 0.03%	9.57 0.03%	9.46 0.03%	9.23 0.03%	8.62 0.02%	8.47 0.02%	7.84 0.02%	7.67 0.02%	7.08 0.02%
Biological Treatment of Solid Waste	5B	19.16 0.05%	20.45 0.06%	22.21 0.06%	25.59 0.07%	25.60 0.07%	26.21 0.07%	21.56 0.06%	24.21 0.07%	23.47 0.07%	25.21 0.07%	22.92 0.06%	25.97 0.07%	25.98 0.07%	27.17 0.08%	24.77 0.07%
Total GHG excluding LULUCF		13005.05 100.00%	12836.66 100.00%	12253.91 100.00%	12141.35 100.00%	11596.40 100.00%	12176.42 100.00%	12052.77 100.00%	11807.44 100.00%	11270.40 100.00%	10807.26 100.00%	10324.43 100.00%	10082.90 100.00%	10266.98 100.00%	10565.23 100.00%	10742.80 100.00%
International Bunkers - Aviation		1308.03 NA	1224.15 NA	1315.65 NA	1324.39 NA	1268.85 NA	1302.15 NA	1218.33 NA	1124.17 NA	1129.77 NA	1225.34 NA	1382.31 NA	1533.83 NA	1734.20 NA	1854.35 NA	1814.00 NA
International Bunkers - Marine		0.16 NA	0.17 NA	0.13 NA	0.15 NA	0.12 NA	0.11 NA	0.14 NA	0.13 NA	0.11 NA	0.12 NA	0.12 NA	0.14 NA	0.17 NA	0.15 NA	0.11 NA
CO ₂ Emissions from Biomass		298.59 NA	305.76 NA	450.20 NA	466.67 NA	437.37 NA	453.11 NA	446.42 NA	458.32 NA	495.35 NA	627.78 NA	693.76 NA	739.61 NA	845.23 NA	952.82 NA	1062.35 NA

Sources: Environment Agency and MECDD.

Notes: (1) These percentages are relative to the total GHG emissions, excluding LULUCF.

(2) The methane emissions are converted in CO₂ equivalents by multiplying the emissions by 25, *i.e.* the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon.

(3) The nitrous oxide emissions are converted in CO₂ equivalents by multiplying the emissions by 298, *i.e.* the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

(4) The F-gases are those not covered by the Montreal Protocol, *i.e.* the HFCs, PFCs and SF₆ expressed in CO₂ equivalents using the global warming potential (GWP) values based on the effects of GHG over a 100-year time horizon.

Table 2-15 – Luxembourg’s GHG emissions and removals – details by main gases: 1990-2019

Gg (1000 t) CO ₂ equivalent	1990 (base year)	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
CO₂	11823.34 92.90%	12443.14 93.06%	12209.70 92.96%	12354.74 92.99%	11542.46 92.65%	9151.71 90.75%	9201.61 90.67%	8553.96 90.08%	7675.93 89.10%	8127.85 89.52%	8709.92 90.18%	9207.45 90.70%	9983.58 91.35%	10458.92 91.96%	11828.91 92.67%
of which															
CRF 1 - Energy	10218.66 80.29%	10914.93 81.63%	10752.16 81.86%	10914.93 82.15%	10198.35 81.86%	8165.00 80.97%	8270.72 81.50%	7733.16 81.44%	7014.74 81.43%	7431.26 81.85%	7988.11 82.71%	8540.18 84.13%	9298.88 85.09%	9827.83 86.41%	11141.49 87.28%
CRF 1A1 - Fuel Combustion from Energy Industries	33.48 0.26%	35.03 0.26%	34.93 0.27%	33.23 0.25%	32.51 0.26%	91.47 0.91%	80.75 0.80%	87.83 0.92%	153.76 1.78%	170.97 1.88%	116.64 1.21%	277.95 2.74%	1024.70 9.38%	1032.42 9.08%	1255.23 9.83%
CRF 1A2 - Fuel Combustion from Manuf. Industries & Construction	6250.32 49.11%	6092.59 45.77%	5749.24 43.77%	5885.35 44.30%	5172.77 41.52%	3319.14 32.91%	3166.10 31.20%	2402.85 25.30%	1362.31 15.81%	1551.31 17.09%	1383.48 14.32%	1475.12 14.53%	1360.71 12.45%	1299.11 11.42%	1395.76 10.93%
CRF 1A3 - Fuel Combustion from Transport	2588.98 20.34%	3177.07 23.76%	3461.12 26.35%	3507.79 26.40%	3563.61 26.80%	3322.74 32.95%	3433.69 33.83%	3693.95 38.90%	3874.00 44.97%	4198.83 46.24%	4833.72 50.05%	5081.47 50.06%	5270.90 48.23%	5824.36 51.21%	6774.98 53.07%
of which, "road fuel export" (1)	1698.79 13.35%	2241.72 16.77%	2484.37 18.91%	2482.32 18.68%	2527.88 22.17%	2235.85 22.17%	2321.78 22.88%	2541.27 26.76%	2666.00 30.95%	2974.91 32.76%	3562.29 36.88%	3733.04 36.77%	3867.07 35.38%	4373.05 38.45%	5302.81 41.54%
CRF 1A4 - Fuel Combustion from Other Sectors	1342.75 10.55%	1607.10 12.02%	1480.13 11.27%	1464.95 11.03%	1407.42 11.30%	1420.87 14.09%	1571.66 15.49%	1525.52 16.07%	1590.60 18.46%	1447.17 15.94%	1642.07 17.00%	1681.43 16.56%	1629.01 14.91%	1668.63 14.67%	1715.34 13.44%
CRF 1A5 & 1B2b - Other Energy Sources	3.10 0.02%	3.10 0.02%	2.72 0.20%	23.58 0.18%	22.01 0.18%	10.75 0.11%	18.49 0.18%	22.98 0.24%	34.03 0.40%	62.95 0.69%	12.17 0.13%	24.16 0.24%	3.49 0.12%	3.25 0.03%	0.12 0.00%
CRF 2 - Industrial Processes	1598.38 12.56%	1521.46 11.38%	1450.10 11.04%	1432.60 10.78%	1336.75 10.73%	979.73 9.72%	924.06 9.11%	813.55 8.57%	653.45 7.59%	689.64 7.60%	714.10 7.39%	659.95 6.50%	676.52 6.19%	623.93 5.49%	679.59 5.32%
Other Sources (2)	20.54 0.16%	20.09 0.15%	19.08 0.15%	18.81 0.14%	18.09 0.15%	19.76 0.20%	19.52 0.19%	18.45 0.19%	17.52 0.20%	16.86 0.19%	16.04 0.17%	16.23 0.16%	17.76 0.16%	15.24 0.13%	17.81 0.14%
CH₄ (3)	584.29 4.59%	597.16 4.47%	581.58 4.43%	586.44 4.41%	574.08 4.61%	589.23 5.84%	598.55 5.90%	593.62 6.25%	591.42 6.87%	596.69 6.57%	588.19 6.09%	593.86 5.85%	594.15 5.44%	583.56 5.13%	579.29 4.54%
of which															
CRF 1 - Energy	48.23 0.38%	51.10 0.38%	50.08 0.38%	49.20 0.37%	47.15 0.38%	47.66 0.47%	49.05 0.48%	48.71 0.51%	48.06 0.56%	48.66 0.54%	49.30 0.51%	53.23 0.52%	67.00 0.61%	67.46 0.59%	73.41 0.58%
CRF 3A+3B - Enteric Fermentation and Manure Management	435.51 3.42%	443.50 3.32%	428.35 3.26%	433.82 3.27%	431.84 3.47%	447.32 4.44%	453.76 4.47%	446.81 4.71%	444.26 5.16%	449.39 4.95%	443.61 4.59%	445.67 4.39%	431.03 3.94%	417.28 3.67%	412.84 3.23%
Other Sources (4)	100.55 0.79%	102.55 0.77%	103.15 0.79%	103.41 0.78%	95.09 0.76%	94.24 0.93%	95.74 0.94%	98.09 1.03%	99.10 1.15%	98.64 1.09%	96.28 0.99%	94.96 0.94%	96.12 0.88%	98.82 0.87%	93.04 0.73%
N₂O (5)	318.47 2.50%	329.37 2.46%	336.49 2.56%	330.53 2.49%	325.72 2.61%	326.24 3.24%	329.17 3.24%	325.86 3.43%	322.31 3.74%	326.67 3.60%	326.63 3.38%	309.15 3.05%	305.94 2.80%	284.89 2.43%	310.29 2.43%
of which															
CRF 1 - Energy	34.50 0.27%	39.99 0.30%	43.96 0.33%	46.72 0.35%	49.77 0.40%	47.72 0.47%	48.46 0.48%	49.09 0.52%	48.47 0.56%	49.92 0.55%	51.51 0.53%	51.59 0.51%	51.21 0.47%	51.20 0.45%	52.24 0.41%
CRF 3D - Agricultural Soils	238.80 1.88%	245.46 1.84%	250.54 1.91%	240.85 1.81%	233.41 1.87%	235.34 2.33%	236.64 2.33%	233.37 2.46%	230.37 2.67%	234.56 2.58%	233.00 2.41%	215.36 2.12%	213.21 1.95%	191.25 1.68%	215.93 1.69%
Other Sources (6)	45.17 0.35%	43.92 0.33%	41.99 0.32%	42.96 0.32%	42.53 0.34%	43.17 0.43%	44.07 0.43%	43.39 0.46%	43.47 0.50%	42.19 0.46%	42.12 0.44%	42.19 0.42%	41.52 0.38%	42.44 0.37%	42.13 0.33%
F-gases (7)	1.28 0.01%	1.37 0.01%	6.96 0.05%	14.51 0.11%	15.87 0.13%	16.90 0.17%	19.27 0.19%	22.19 0.23%	25.11 0.29%	28.45 0.31%	33.45 0.35%	41.23 0.41%	45.09 0.41%	45.92 0.40%	46.66 0.37%
Total GHG excluding LULUCF	12727.38 100.00%	13371.04 100.00%	13134.73 100.00%	13286.22 100.00%	12458.12 100.00%	10084.08 100.00%	10148.60 100.00%	9495.63 100.00%	8614.78 100.00%	9079.66 100.00%	9658.18 100.00%	10151.68 100.00%	10928.76 100.00%	11373.29 100.00%	12765.15 100.00%
LULUCF	84.84	-210.46	-560.70	-664.50	-464.70	-584.58	-630.55	-722.39	-605.17	-699.02	-722.13	-704.15	-700.78	-655.60	-675.41

Gg (1000 t) CO ₂ equivalent	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CO₂	12087.02	11919.75	11316.96	11183.69	10638.34	11207.25	11102.38	10866.20	10320.57	9836.04	9347.99	9092.74	9261.34	9568.44	9752.16
	92.94%	92.86%	92.35%	92.11%	91.74%	92.04%	92.11%	92.03%	91.57%	91.01%	90.54%	90.18%	90.21%	90.57%	90.78%
of which															
CRF 1 - Energy	11425.41	11209.46	10615.80	10535.47	10059.76	10606.04	10490.90	10288.06	9762.51	9271.85	8792.30	8514.28	8674.41	8975.65	9139.04
CRF 1A1 - Fuel Combustion from Energy Industries	1238.67	1302.58	1178.80	993.06	1189.72	1202.46	1004.69	1042.28	688.40	670.57	463.36	258.53	246.77	224.11	224.03
CRF 1A2 - Fuel Combustion from Manuf. Industries & Construction	1390.95	1465.38	1369.62	1316.42	1177.18	1254.69	1231.01	1173.52	1133.04	1136.30	1101.71	1144.28	1134.48	1150.98	1165.87
CRF 1A3 - Fuel Combustion from Transport	54.99%	53.21%	53.40%	54.68%	52.74%	53.16%	56.77%	55.37%	56.74%	56.32%	54.68%	54.30%	54.39%	56.41%	56.74%
of which, "road fuel export"(1)	6661.75	5286.71	4967.39	4990.46	4482.60	4837.95	5185.79	4884.63	4745.25	4401.24	3956.65	3764.48	3842.49	4221.17	4341.24
CRF 1A4 - Fuel Combustion from Other Sectors	43.54%	41.18%	40.54%	41.10%	38.66%	39.73%	43.03%	41.37%	42.10%	40.72%	38.32%	37.34%	37.43%	39.95%	40.41%
CRF 1A5 & 1B2b - Other Energy Sources	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
CRF 2 - Industrial Processes	652.11	702.77	693.82	641.12	570.13	593.39	601.98	568.65	547.85	553.51	544.44	567.31	574.01	577.97	598.57
Other Sources (2)	18.97	17.24	17.42	27.28	24.55	27.03	28.09	28.83	30.92	27.82	27.30	28.95	29.92	31.43	33.81
	0.15%	0.13%	0.14%	0.22%	0.21%	0.22%	0.23%	0.24%	0.27%	0.26%	0.26%	0.29%	0.30%	0.31%	0.31%
CH₄ (3)	577.94	574.17	583.35	593.50	594.63	594.28	569.59	561.70	566.09	579.21	585.26	589.46	596.93	590.94	582.25
	4.44%	4.7%	4.76%	4.89%	5.13%	4.88%	4.73%	4.76%	5.02%	5.36%	5.67%	5.85%	5.81%	5.59%	5.42%
of which															
CRF 1 - Energy	72.16	74.19	69.28	67.12	67.49	71.66	62.41	64.74	58.05	56.60	53.76	52.53	51.84	52.58	50.91
CRF 3A+3B - Enteric Fermentation and Manure Management	413.29	407.71	420.73	432.76	434.59	441.40	428.31	418.42	428.90	442.97	455.71	463.61	470.64	466.14	463.67
Other Sources (4)	3.18%	3.18%	3.43%	3.56%	3.75%	3.63%	3.55%	3.54%	3.81%	4.10%	4.41%	4.60%	4.58%	4.41%	4.32%
	92.50	92.26	93.34	93.62	92.55	81.22	78.87	78.54	79.13	79.64	75.79	73.31	74.45	72.22	67.68
	0.71%	0.72%	0.78%	0.77%	0.80%	0.67%	0.65%	0.67%	0.70%	0.74%	0.73%	0.73%	0.73%	0.68%	0.63%
N₂O (5)	294.31	293.64	299.68	307.34	305.04	313.92	316.50	312.49	312.77	316.46	315.09	325.81	330.23	330.94	336.60
	2.26%	2.29%	2.45%	2.53%	2.63%	2.58%	2.63%	2.65%	2.78%	2.93%	3.05%	3.23%	3.22%	3.13%	3.13%
of which															
CRF 1 - Energy	52.28	52.34	54.96	58.23	57.38	62.77	68.52	69.14	70.90	73.16	72.82	74.20	77.69	83.23	87.29
CRF 3D - Agricultural Soils	0.40%	0.41%	0.45%	0.48%	0.49%	0.52%	0.57%	0.59%	0.63%	0.68%	0.71%	0.74%	0.76%	0.79%	0.81%
Other Sources (6)	199.54	198.34	199.83	202.38	202.16	205.81	205.54	202.63	201.22	201.47	201.65	209.13	209.74	204.91	206.75
	1.53%	1.55%	1.63%	1.67%	1.74%	1.69%	1.71%	1.72%	1.79%	1.86%	1.95%	2.07%	2.04%	1.94%	1.92%
	42.49	42.96	44.88	46.72	45.49	45.34	42.44	40.73	40.64	41.83	40.61	42.49	42.81	42.81	42.55
	0.33%	0.33%	0.37%	0.38%	0.39%	0.37%	0.35%	0.34%	0.36%	0.39%	0.39%	0.42%	0.42%	0.41%	0.40%
F-gases (7)	45.78	49.10	53.92	56.83	58.39	60.97	64.30	67.05	70.97	75.55	76.09	74.89	78.48	74.90	71.79
	0.35%	0.38%	0.44%	0.47%	0.50%	0.50%	0.53%	0.57%	0.63%	0.70%	0.74%	0.76%	0.71%	0.67%	
Total GHG excluding LULUCF	13005.05	12836.66	12253.91	12141.35	11596.40	12176.42	12052.77	11807.44	11270.40	10807.26	10324.43	10082.90	10266.98	10565.23	10742.80
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
LULUCF	-620.65	-524.51	-432.36	-448.01	-429.10	-118.08	-289.53	-380.31	-557.83	-470.84	-420.10	-507.87	-374.74	-190.42	-312.93

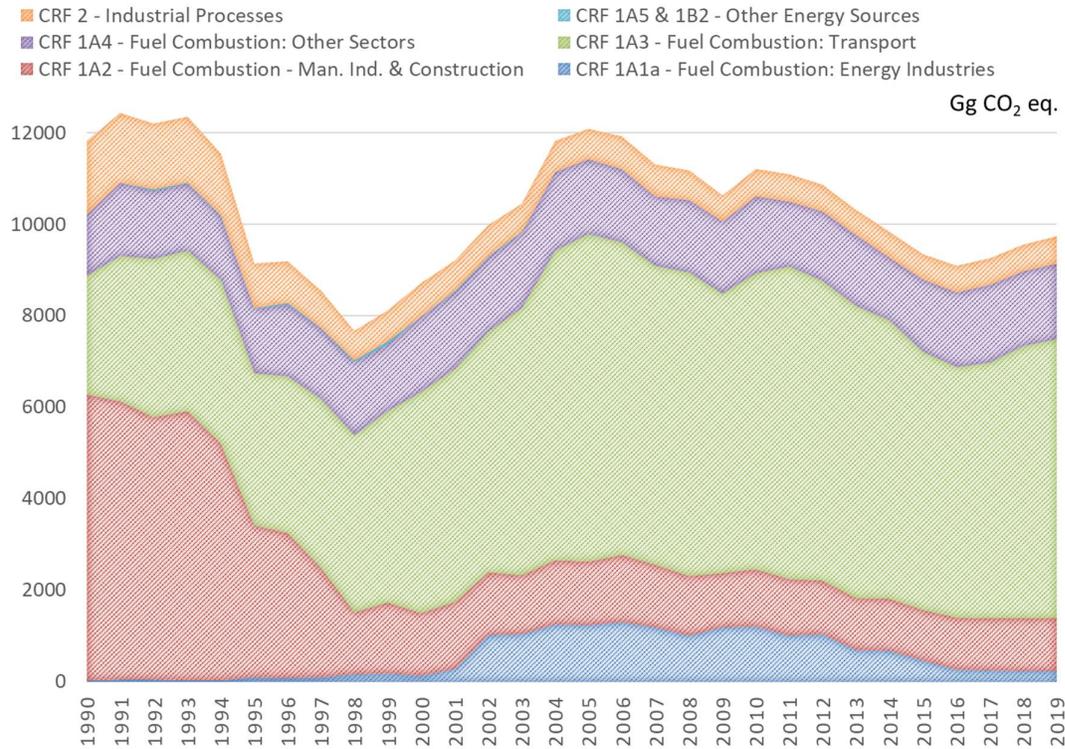
Sources: Environment Agency and MECDD.

- Notes: (1) The methane emissions are converted in CO₂ equivalents by multiplying the emissions by 25, *i.e.* the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon.
- (2) The nitrous oxide emissions are converted in CO₂ equivalents by multiplying the emissions by 298, *i.e.* the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.
- (3) The F-gases are those not covered by the Montreal Protocol, *i.e.* the HFCs, PFCs and SF₆ expressed in CO₂ equivalents using the global warming potential (GWP) values based on the effects of GHG over a 100-year time horizon.
- (4) CRF 1A4a&b: there are breaks in time series between 1999 & 2000: the two CRF 1A4 sub-categories had a very similar level because national energy statistics does not allow for distinguishing these two sub-categories before 2000. Hence, a 50-50 distribution was carried out in the inventories.

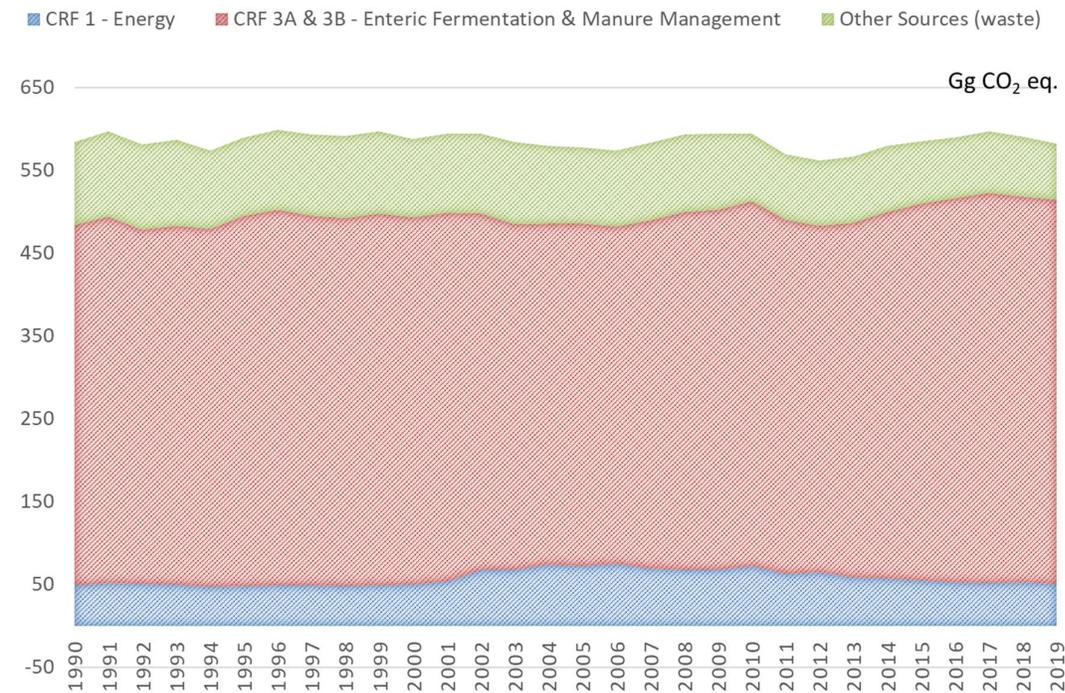
Figure 2-31 – Luxembourg’s GHG emissions (excl. F-gases & LULUCF) – details by main gases:

1990-2019

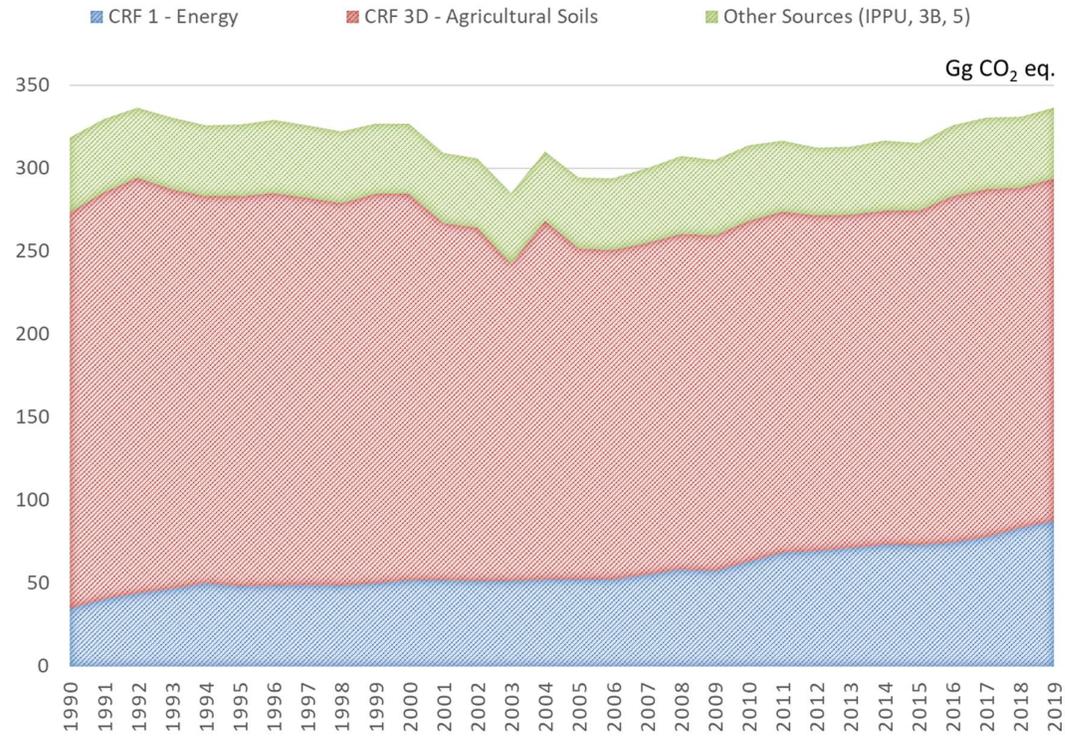
CO₂



CH₄

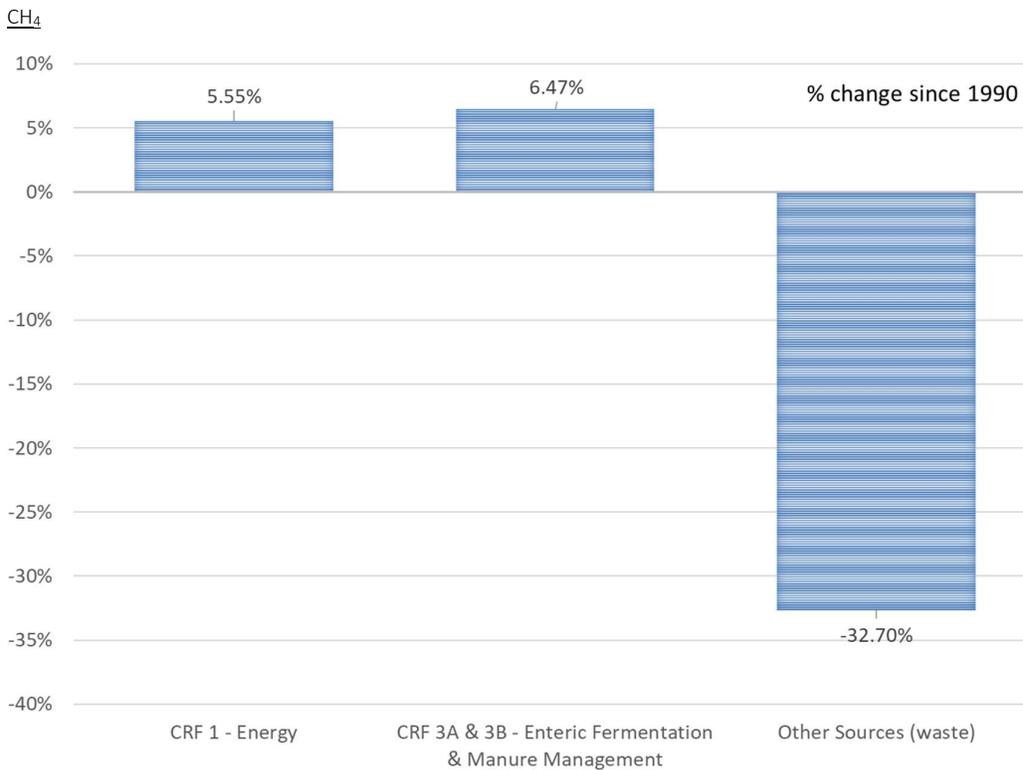
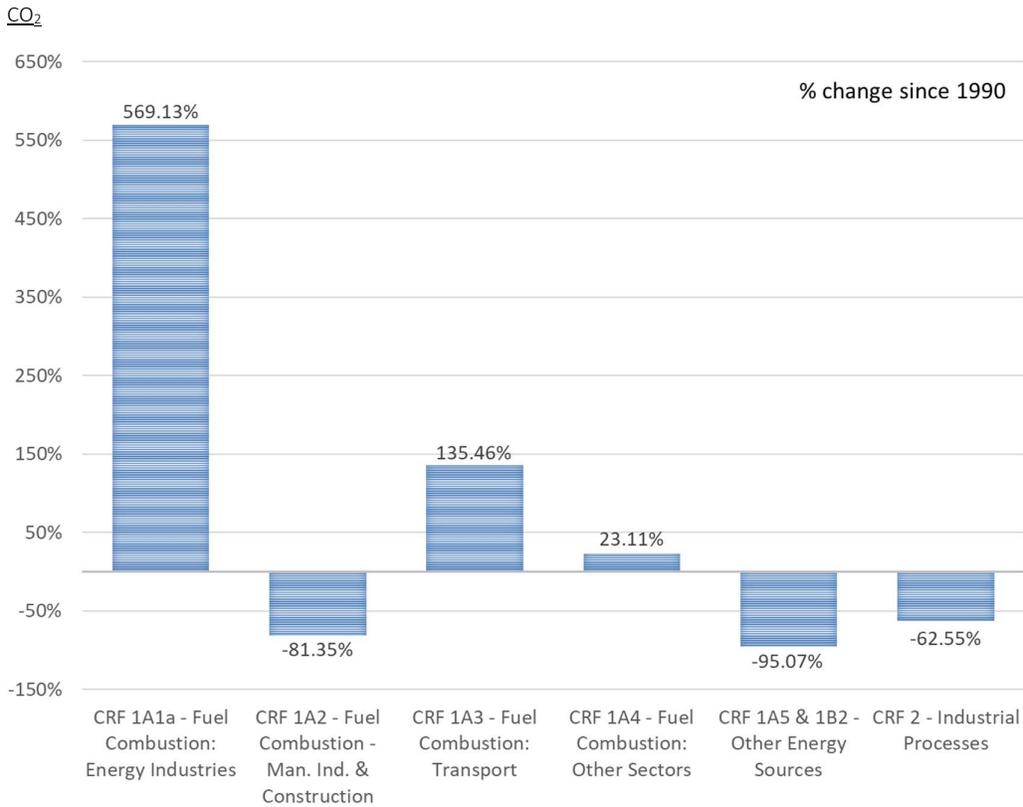


N₂O

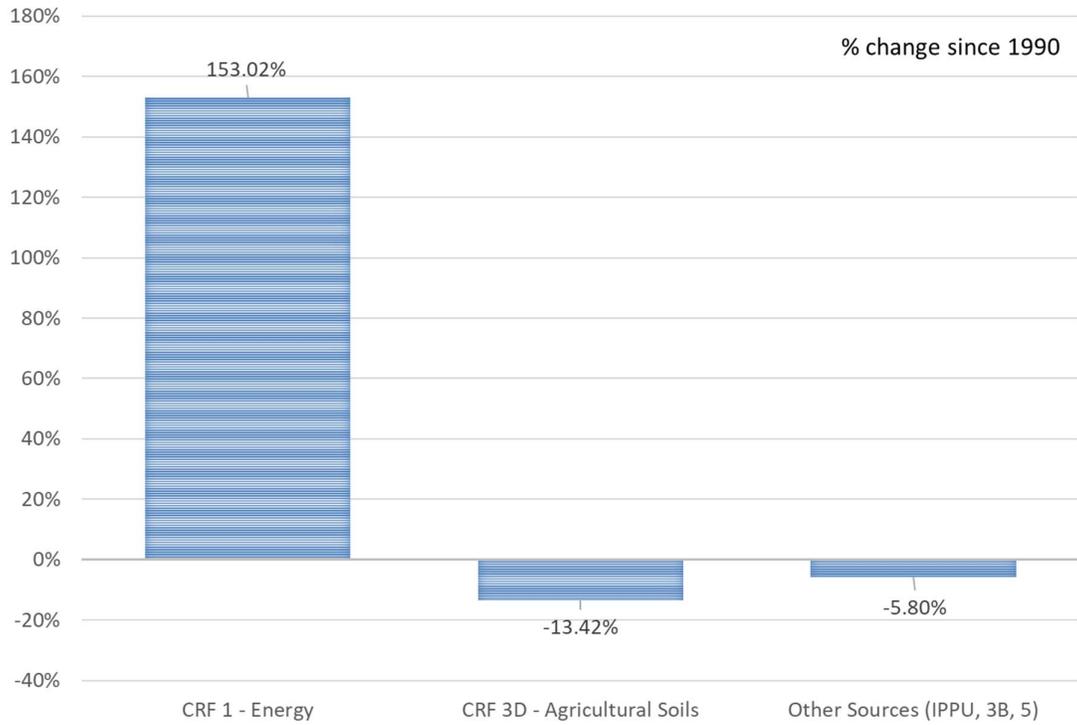


Sources: Environment Agency and MDDI-DEV.

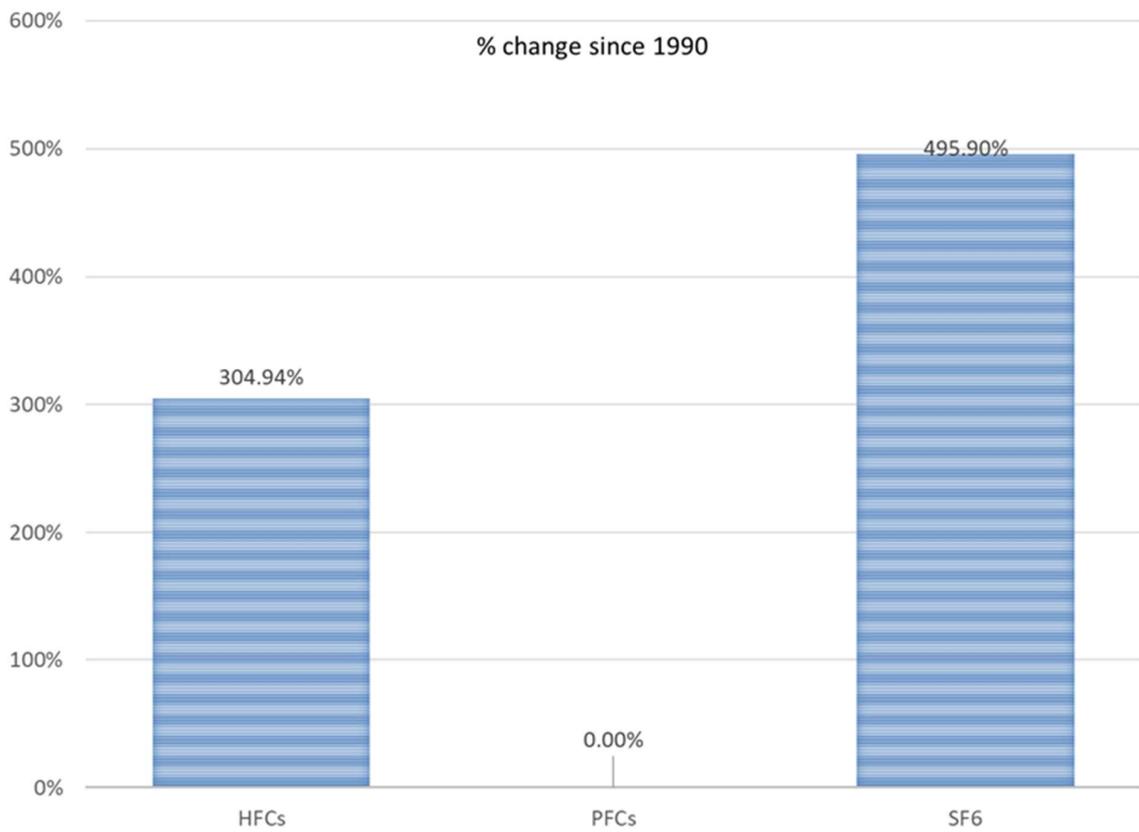
Figure 2-32 – Luxembourg’s GHG emission trends in % (excl. LULUCF) – details by main gases: 1990-2019



N₂O



F-gases



Sources: Environment Agency and MECDD.

Carbon dioxide – CO₂

CRF (sub-) categories covered	1 (1A1, 1A2, 1A3, 1A4, 1A5, 1B2), 2, 3, 4		
Share in total GHG emissions, excl. LULUCF	1990	92.90% =	11 823.34 Gg CO ₂ e
	2019	90.78% =	9 752.16 Gg CO ₂ e

Throughout the period 1990-2019, carbon dioxide has remained the main GHG and accounted for 89% to 93% of the total GHG emissions. However, the structure of CO₂ emissions has evolved with an increase in fuel combustion, which accounted for 80.29% of total GHG emissions for the base year (1990) and climbed up to 85.07% in 2019.

Road transport, and more precisely “road fuel sales to non-residents”, is the main culprit for this development. Indeed, in 1990, fuel combustion from the transport sector accounted for 20.34% of total GHG emissions. Then, with 6.10 Mio. t CO₂, this percentage reached 56.74% in 2019.⁵³ CO₂ emissions due solely to “road fuel sales to non-residents” amounted to about 1.7 Mio. t in 1990 and reached 4.3 Mio. t in 2019,⁵⁴ i.e. a 156% increase (the same comparison shows “only” a 100% increase for road fuel consumed by the national vehicle fleet). In 2019, “road fuel sales to non-residents” represented 71.21% of CO₂ emissions of the transport sector and 44.52% of the total CO₂ emissions. In 1990, these percentages were 65.62% and 14.37%, respectively.

Another important source of CO₂ in Luxembourg are **industrial processes**, mainly carbon oxidizing of pig iron from the steel industry (basic oxygen furnace steel production) and decarbonisation of mineral input in the clinker and glass industry. The steel production process change described above was the main driver behind declining emissions for this sector.

2.3.1 Methane – CH₄

CRF (sub-) categories covered	1, 3A, 3B, 5A, 5B, 5D		
Share in total GHG emissions, excl. LULUCF	1990	4.59% =	584.29 Gg CO ₂ e
	2019	5.42% =	582.25 Gg CO ₂ e

Methane emissions originate above all from the agricultural sector, and more precisely from **enteric fermentation** and from **manure production and management**: around 71-80% of methane emissions over the period 1990-2019. As these emissions have been rather stable, total methane emissions have not varied very much.

For the other methane emitting source categories, there is a decline in **waste and waste water management** related emissions (-32.7%) and growing emissions in **energy use** (+5.55%). The decrease noted for waste is the result of reduced methane emissions from waste landfill sites. The increase observed for energy is mainly due to fugitive emissions from natural gas distribution and use.

53 The highest amount of emissions was recorded for the year 2005: 7.15 Mio. t CO₂ but “only” 55% of total GHG emissions

54 5.7 Mio. t in 2005.

2.3.2 Nitrous oxide – N₂O

CRF (sub-) categories covered	1, 2G, 3B, 3D, 5B and 5D		
Share in total GHG emissions, excl. LULUCF	1990	2.50% =	318.47 Gg CO ₂ e
	2019	3.13% =	336.60 Gg CO ₂ e

The major part of nitrous oxide emissions is caused by **agricultural soils**. Total emissions of N₂O over the period 1990-2019 are rather stable and fluctuate between 285 and 337 Gg CO₂e excl. N₂O from LULUCF, and between 305 and 358 Gg CO₂e incl. N₂O from LULUCF. Another important source that has been generating increasing N₂O emissions since 1990 is **road transportation**, where the incomplete NO_x reduction in catalytic converters of diesel oil motor vehicles leads to N₂O emissions that were multiplied by a factor 4 over the entire period. This increase is due to the increasing share of diesel vehicles on the roads. The increase in N₂O emissions from 1990-2019 (+52.79 Gg CO₂e or +153%) observed for the **Energy sector** is counterbalanced by diminishing nitrous oxide emissions from the **Agriculture sector** (-35.41 Gg or -13%).

2.3.3 Hydrofluorocarbons – HFCs, perfluorocarbons - PFCs and sulphur hexafluoride – SF₆

CRF (sub-) categories covered	2D, 2F, 2G		
Share in total GHG emissions, excl. LULUCF	1990	0.01% =	1.28 Gg CO ₂ e
	2019	0.67% =	71.79 Gg CO ₂ e

The increase in **HFCs** emissions between 1990 and 2019 is explained by a more wide spread use of mobile and stationary cooling equipment as well as of aerosols.

No use of **PFCs** is reported.

SF₆ emissions increased from 1990 onwards following an increasing use of high-voltage electrical devices and a higher amount of gas emitted from noise reduction windows.

2.4 Description of Emission Trends by Category

In 2019, the energy sector accounted for almost 86.36% of the total GHG emissions, excluding LULUCF. Two sectors represent around 6% of the total emissions, excluding LULUCF: industrial processes (6.28%) and agriculture (6.63%). The remaining sector⁵⁵ (waste⁵⁶ (0.73%) was not even reaching 1% of the total GHG emitted in Luxembourg: see Table 2-13 as well as Figure 2-29 and Figure 2-30.

For the different sectors, trends over the period 1990-2019 (and 2018-2019) were as follows:

- Energy: -9.94% (+1.82%)
- Industrial Processes: -58.04% (+2.70%)
- Agriculture: +0.14% (-0.20%)
- LULUCF: -310.65% (-47.00%)
- Waste: -26.14% (-5.53%)

2.4.1 CRF 1 – Energy

GHG covered	CO ₂ , CH ₄ & N ₂ O	
Share in total GHG emissions, excl. LULUCF	1990	80.94% = 10 301.39 Gg CO ₂ e
	2019	86.36% = 9277.24 Gg CO ₂ e

Energy production and consumption related GHG emissions have decreased by 9.94% between 1990 and 2019 - from 10.3 Mio. t CO₂e in 1990 to 9.3 Mio. t CO₂e in 2019. For carbon dioxide, methane and nitrous oxide, the changes over the period 1990-2019 were -10.57%, +5.55% and +153.02%, respectively.

However, the overall trends at sector level hide very different developments at the CRF sub-category level. Within the energy sector, the fastest growing sub-sectors were **energy industries** (1A1) (due to the increasing number of cogeneration (CHP) plants) and **transport** (1A3): +557.01% and +135.62%, respectively between 1990 and 2019. For the other sub-sectors, the observed trends between 1990 and 2019 are -81.21% for **manufacturing industries and construction** (1A2), +22.57% for the **other sectors** (1A4), and +59.11% for **fugitive emissions from fuels** (1B).⁵⁷

In fact, over the period, GHG emissions have been strongly influenced by varying fuel consumption levels in industry, in particular in the energy and the iron and steel industries, as well as in the road transport sector as percentage growths recorded for CRF sub-categories 1A1, 1A2 and 1A3 demonstrate. There are several industrial sites which had relatively high levels of GHG emissions, and which, therefore, have had a strong impact on the national total of GHG emissions. Examples of such sites are the TWINerg power plant (2001-2016), as already described in previous paragraphs, and to a lesser extent several cogeneration (CHP) plants. In the transport sector, road fuel consumption, and even more so road fuel sales, have a very important weight in the national energy balance and, consequently, a significant impact on the total GHG emissions.

55 The sector "Others" is not reported for Luxembourg.

56 The waste sector covers only landfilled waste, wastewater handling and composting activities. Waste incineration, which is the main treatment method for municipal waste in Luxembourg, is carried out in the sole incinerator of the country where energy is recovered. Consequently, waste incineration related emissions are accounted for in CRF sector 1 – Energy (details in Chapters 3 and 8 respectively).

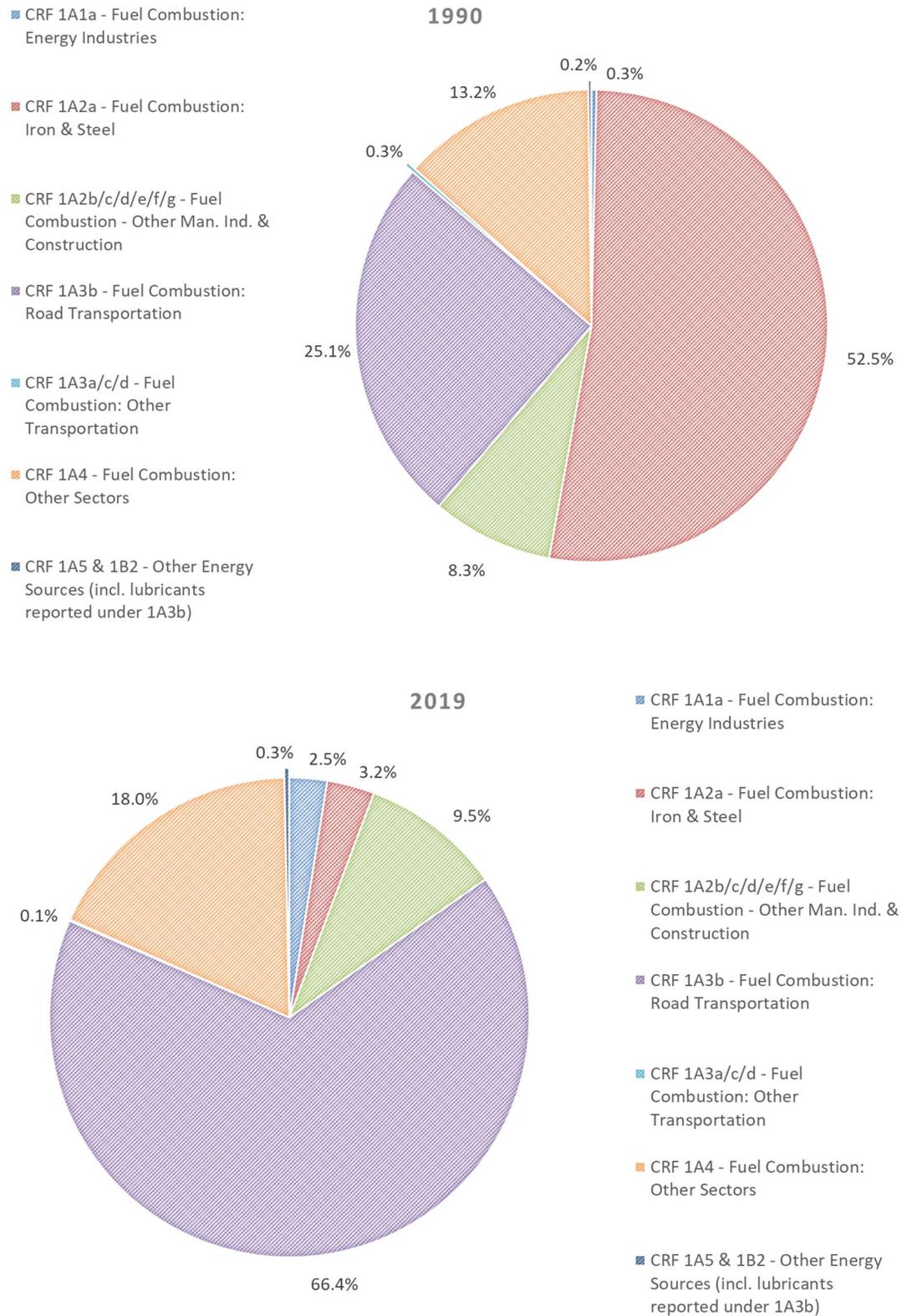
57 Fugitive emission growth is closely linked to natural gas use in Luxembourg.

In the iron and steel industry, the passage from blast furnaces to electric arc furnaces allowed to significantly reduce GHG emissions between 1994 and 1998. Due to the importance of the iron and steel industry in Luxembourg, this evolution hid many other emission trends between 1990 and 1998. After 1998, the increase of road fuel sales and, to a lesser extent, of electric energy production has led to a rather steep increase of GHG emissions in the 1A1 and 1A3 sectors and, by extension, of the national total for GHG emissions.

All these changes briefly presented in the previous paragraphs completely modified the pattern of the energy related GHG emissions with regard to CRF sub-categories share (Figure 2-33) and to the “energy-mix” or fuel usage for energy production and consumption (

Table 2-10 and Table 2-11; Figure 2-19 and Figure 2-20).

Figure 2-33 – CRF sub-categories share in GHG emissions for CRF 1 – Energy: 1990 & 2019



Sources: Environment Agency and MECDD.

2.4.2 CRF 2 – Industrial Processes

GHG covered	CO ₂ , N ₂ O, F-gases	
Share in total GHG emissions, excl. LULUCF	1990	12.64% = 1 608.85 Gg CO ₂ e
	2019	6.28% = 675.07 Gg CO ₂ e

Industrial processes represent the third largest sector in Luxembourg with regard to GHG emissions. The sector includes emissions from industrial installations and from consumption of halocarbons, perfluorocarbons and SF₆ (the fluorinated gases or F-gases). In Luxembourg, when leaving F-gases out, only a few companies and their various production installations are part of CRF sector 2:

- CRF sub-categories 2A1 & 2A3: one cement works unit and one flat glass manufacturing company;
- CRF sub-category 2C1: the iron and steel manufacturing company ArcelorMittal.

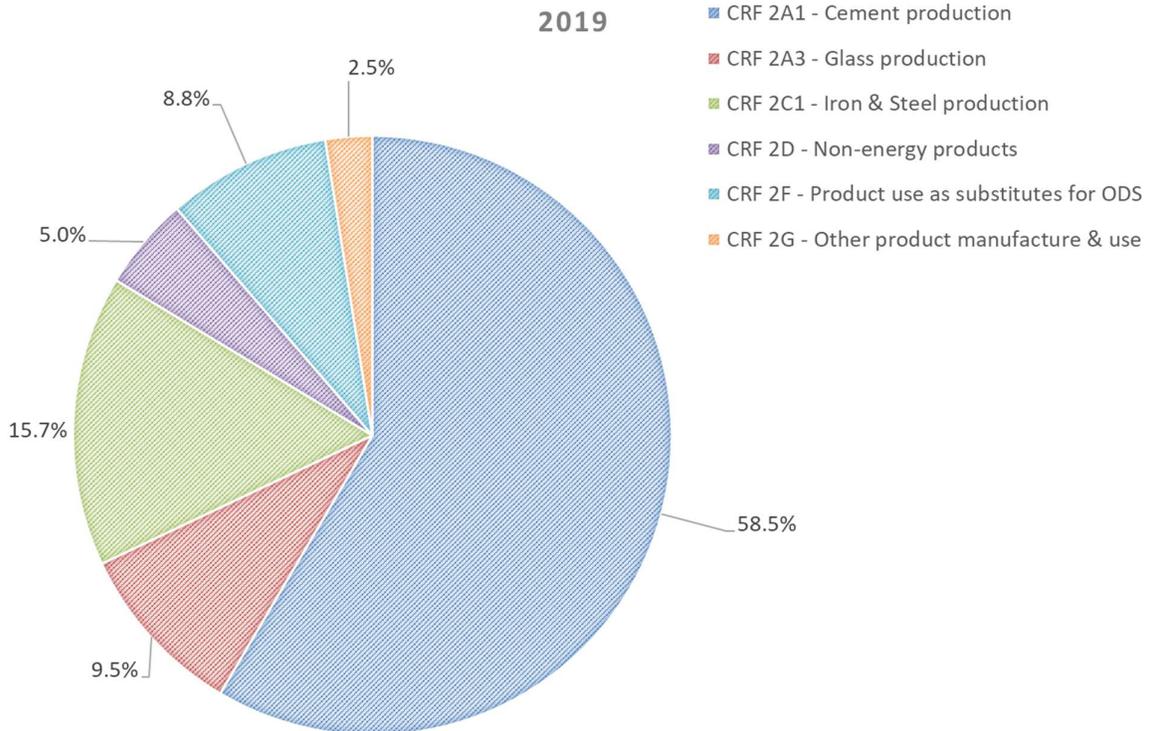
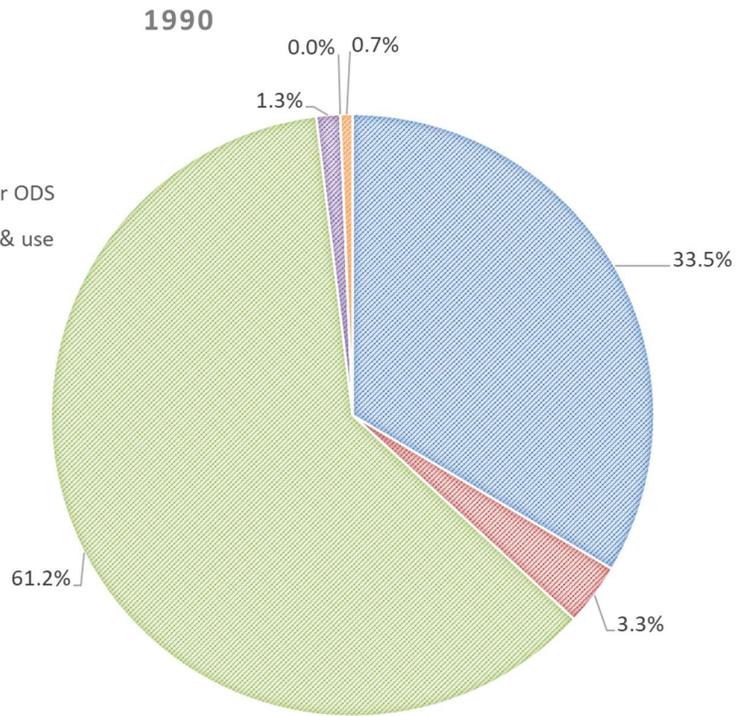
Emissions from industrial processes show a declining trend between 1990 and 1998, following which the emissions became stable. This evolution was mainly driven by **process changes that occurred in the iron & steel industry**. As indicated above, this industry moved from blast to electric arc furnaces between 1994 and 1998. As a consequence, steel industry process emissions in CO₂e decreased by 89.47% over the period 1990-2019. Overall sector emissions in CO₂e fell by about 58.04% between 1990 and 2019, reducing the weight of this sector in total GHG emissions from 12.64% in 1990 to 6.28% in 2019. By gas, however, the picture is different. For carbon dioxide, the decrease over the period 1990-2019 was -62.55% while nitrous oxide saw a decrease of 48.68%. F-gases emissions, on the contrary, increased regularly: +324.72% over the period 1995-2019, but these emissions are minor compared to the total emissions as Figure 2-34 shows.

The striking increase of **F-gases emissions** is the consequence of a growing use in the country, notably due to an increasing use of air conditioning, high-voltage electrical equipment, and noise reduction windows (see Section 4.7). The increasing use of these devices is mainly due to an increase in the number of residents (see Figure 2-15) and of the workforce (see Figure 2-16). The inhabitants and foreign commuters occupy more and more residential, institutional, and commercial buildings, which leads to a greater need for air conditioning (HFC) as well as high-voltage electrical devices (SF₆).

The emission trends briefly described in the previous paragraphs led to a significant change in the composition of industrial processes' GHG emissions: see Figure 2-34.

Figure 2-34 – CRF sub-categories share in GHG emissions for CRF 2 – Industrial Processes: 1990 & 2019

- CRF 2A1 - Cement production
- CRF 2A3 - Glass production
- CRF 2C1 - Iron & Steel production
- CRF 2D - Non-energy products
- CRF 2F - Product use as substitutes for ODS
- CRF 2G - Other product manufacture & use



Sources: Environment Agency and MECDD.

2.4.3 CRF 3 – Agriculture

GHG covered	CO ₂ , CH ₄ , N ₂ O		
Share in total GHG emissions, excl. LULUCF	1990	5.59% =	711.34 Gg CO ₂ e
	2019	6.63% =	712.35 Gg CO ₂ e

Trends in agriculture were quite stable between 1990 and 2019: in general GHG related to agricultural activities have increased by 0.14% (+131.21% for CO₂, +6.47% for methane and -13.14% for nitrous oxide). Enteric Fermentation (3A) saw its emissions increasing by 3.55%, whereas for agricultural soils (3D), the decrease reached 13.42%. For manure management (3B), emissions increased by 14.06% between 1990 and 2019, though opposite variations are observed for the two GHG emitted by this activity: methane increased by 30.17% and nitrous oxide decreased by 10.95%. In 2021, Luxembourg started to report the GHG emissions from other carbon-containing fertilizers (3I). These emissions are small compared to the other agriculture-related emissions (0.59% of all agriculture GHG emissions in 2019).

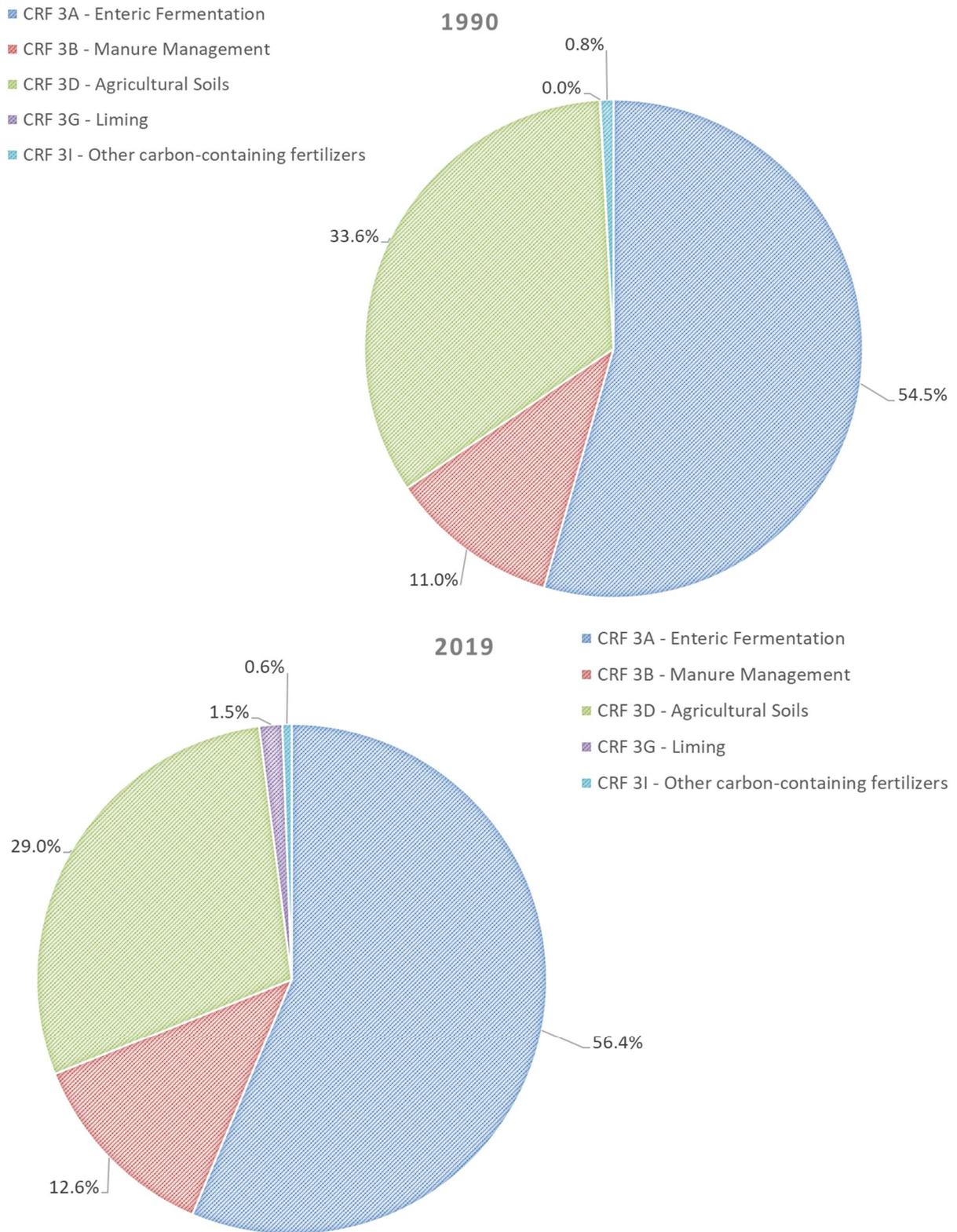
However, the evolution of nitrous oxide emissions stemming from agricultural soils (3D) shapes the overall agriculture emission pattern. Indeed, for both the years 1990 and 2019, CRF category 3D is the biggest contributor to agriculture related emissions, though it is also, as for other Annex I Parties, the agriculture category that shows the highest uncertainty in the inventory. It is also worth noting that the shares of each CRF category under CRF sector 3 for which GHG emissions are reported have barely changed over the period: see **Figure 2-35**.

Looking at **methane** emissions from **manure management**, an increase by 30.17% can be observed for the period 1990-2019. Animals who contributed the most to these emissions were cattle and swine. As far as **nitrous oxide** emissions from **manure management** are concerned, a decrease of 10.95% is observed for the period 1990-2019. These emissions are mainly due to cattle.

Finally, **nitrous oxide** emissions from **agricultural soils** are mainly driven by:

- nitrogen input to soils (such as application of synthetic fertilizers and manure) as well as nitrogen fixed by crops or crop residues;
- nitrogen excretion on pasture, range and paddock;
- by indirect soil emissions due to atmospheric deposition as well as to nitrogen from fertilizers and animals that is lost through leaching and run-off.

Figure 2-35 –CRF sub-categories share in GHG emissions for CRF 3 – Agriculture: 1990 & 2019



Source: Rural Economics Service, Environment Agency, and MECDD.

2.4.4 CRF 5 – Waste

GHG covered	CH ₄ & N ₂ O		
Share in total GHG emissions, excl. LULUCF	1990	0.83% =	105.80 Gg CO ₂ e
	2019	0.73% =	78.14 Gg CO ₂ e

In the waste sector, the main source of GHG was solid waste disposal on land (5A), but its weight decreased over the period 1990-2019 due to the combination of reduced amounts of waste disposed in landfills and of increased emissions arising from composting activities (5B). However, GHG emission reduction for solid waste disposal on land between 1990 and 2019 (-50.21%) still drove a reduction for the overall waste sector despite rising emissions from composting. Wastewater handling emissions (5D) experienced a 44.82% decline in emissions between 1990 and 2019. This decrease was driven by domestic and commercial wastewater treatment – and, more specifically methane related emissions – since industrial wastewater management remained fairly stable throughout the period.

For **solid waste disposal on land**, methane emissions have been reduced due to:

- a decrease in the quantity of waste being stored in authorised landfill sites (two as of today, three in the early 1990s), notably through the development of recycling schemes and the expansion of both the numbers of and the various waste categories collected by recycling centres;
- the aerobic pre-treatment before storage in one of the two landfill sites;
- the recent installation of methane recovery systems at waste dumping sites.

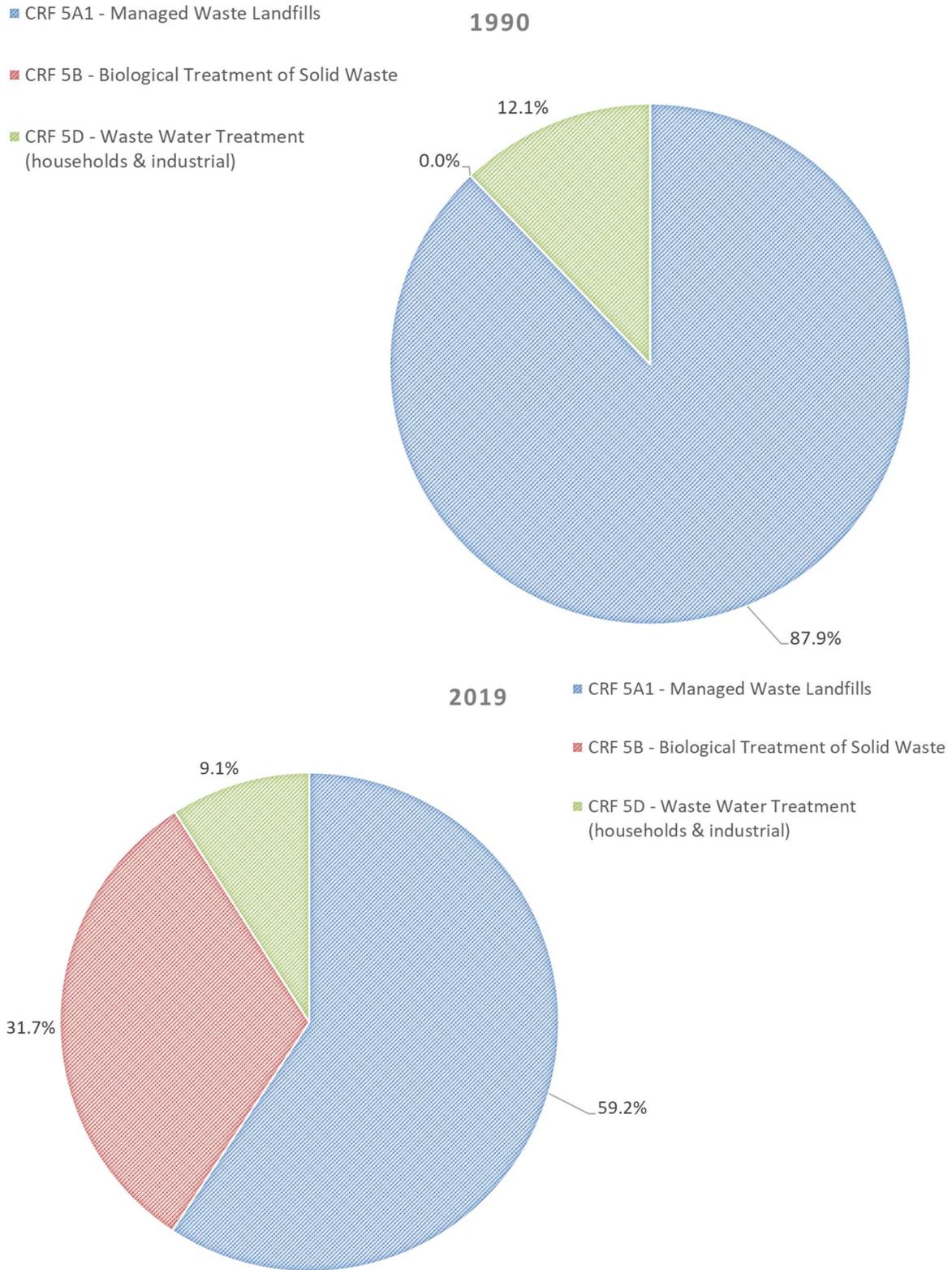
Wastewater treatment plant (WWTP) capacities expressed in population-equivalents have steadily grown since 1990. However, methane and nitrous oxide emissions decreased since 1990. Therefore, technical changes, with regard to wastewater treatment, have had an undeniable role too.

Concerning **compost production**, this activity started on an “industrial scale” only in the early 1990s. It experienced a steady growth from 1993 to 2003 and then more or less stabilizes. Nowadays, 7 composting installations operate in Luxembourg, plus one that co-compost sewage sludge. The latter uses active ventilation and fully operates aerobically – without methane formation. The other plants operate in part under anaerobic conditions, with a residence time in the “composter” of a few weeks.

It is recalled that waste incineration related emissions are part of CRF sub-category 1A1a (public electricity and heat production) since energy is recovered in the sole incinerator of the country and injected in the network.

The emission trends briefly described in the previous paragraphs led to a significant change in the composition of waste related GHG emissions: see Figure 2-36.

Figure 2-36 – CRF sub-categories share in GHG emissions for CRF 5 – Waste: 1990 & 2019



Sources: Environment Agency, Water Agency and MECDD.

2.4.5 CRF sectors – overview

The fact that the iron and steel industry has abandoned blast furnaces between 1994 and 1998, that the TWINerg power plant started fully its operations in 2002, and that fossil fuel consumption as well as road fuel sales have experienced a continuous increase up to 2005, hide many other emission trends and, due to their importance in the national total GHG emissions, they shape the overall pattern of Luxembourg's GHG emissions trend.

2.5 Description of Emission Trends of Indirect GHG and SO₂

Indirect GHG – NO_x, CO, NMVOCs – and SO₂ emissions as recorded in the inventory were extracted from the air pollutants emission inventory Luxembourg is compiling for the UNECE CLRTAP. Please refer to the Informative Inventory Report for more information on the estimation of the air pollutant emissions.⁵⁸

2.6 Description of Emission Trends for the KP-LULUCF Inventory in Aggregate and by Activity, and by Gas

In Luxembourg, LULUCF was a net sink every year, except in 1990.⁵⁹ An important sub-category is forest land, in particular its sub-source forest land remaining forest land (4A1). This sub-category, as well as the sub-category land converted to forest land (4A2), are net sinks for CO₂, whereas other categories and sub-categories reported in the inventory are generally sources of emissions (both CO₂ and N₂O).

The latest inventory shows potential net sinks over the second Kyoto commitment period 2013-2020. Indeed, from the "Accounting" KP-LULUCF table, the expected net carbon sequestration from LULUCF activities (or "Removal Units" – RMUs) reaches 151.87 Gg of CO₂e.⁶⁰ Consequently, forestry and land use changes will not contribute much to Luxembourg's means of meeting its Kyoto commitment. The latter would, therefore, be reached **mainly via national policies and measures and the use of "Kyoto flexible mechanisms"** and not via carbon sinks.

With regard to the KP-LULUCF activities, in 2019, CO₂ removals from **afforestation and reforestation** (AR) in Luxembourg amounted to -161.18 Gg CO₂. Emissions from **deforestation** (D) activities amounted in 2019 to 282.31 Gg CO₂e.

Due to the nature and permanence of ARD areas, there is from 1990 on:

- a steady increase in ARD areas, and related to that,
- a steady increase of removals and emissions, respectively, at these areas.

58 https://www.ceip.at/ms/ceip_home1/ceip_home/status_reporting/2020_submissions/

59 Net emissions in 1990 are the consequence of the important storms that severely hit Luxembourg's forests in early 1989-90.

60 In the "Accounting" KP-LULUCF table, take the sum of A1 & A2, column "Accounting quantity", and divide it by 6: $(-1193.54+282.31)/6 = -151.87$ Gg CO₂e. In the SEF tables, no RMUs are accounted for yet).

3 Energy (CRF Sector 1)

3.1 Sector Overview

Emissions from this sector comprise emissions from fuel combustion activities (source category 1A) and fugitive emissions from fuels (source category 1B). For more details on categories where no emissions occur and categories that are not estimated or that are included elsewhere, please refer to Table 3-4.

Chapter 3 also includes information on and description of methodologies used for estimating GHG emissions as well as references to activity data and emission factors reported under CRF categories 1A – Fuel Combustion Activities and 1B – Fugitive Emissions from Fuels for the period 1990 to 2019.

GHG emissions from fossil fuel combustion are the main source of greenhouse gas emissions in the Grand-Duchy of Luxembourg. In 2019, about 88.65% of national total GHG emissions (excl. LULUCF) were caused by fossil fuel combustion activities in the energy and manufacturing industry, in the transportation sector and in the commercial and residential sector (category 1A). Fugitive emissions only made up about 0.30% of the national total GHG emissions (excl. LULUCF)

GHG emissions related to waste incineration are allocated to IPCC sub-category 1A1a – Fuel Combustion Activities – Energy Industries – Public Electricity and Heat Production (see Section 3.2.6 of this chapter) since energy is recovered and injected into the public electricity and district heating networks.

Process related emissions are considered in CRF Sector 2 – Industrial Processes and Products Use (see Chapter 3.1).

3.1.1 Emission Trends

Figure 3-1 and Table 3-1 show the GHG emission trends from 1990 to 2019 for each of the IPCC categories under CRF Sector 1 - Energy, for which GHG emissions are reported. These are expressed in CO₂ equivalents and include CH₄ and N₂O emissions from biomass, but exclude CO₂ emissions from biomass combustion. CO₂ emissions from biomass combustion are reported under Memory Items and are not accounted for in the national total. GHG emissions from category 5C - Incineration and open burning of waste are accounted for in sub-category 1A1a - Public Electricity and Heat Production, as energy from waste burning is recovered and injected into the public electricity and district heating networks.

Fuel combustion activities (category 1A) related GHG emissions have decreased by 10.07% between 1990 and 2019 from 10.28 million tonnes CO₂ equivalents in 1990 to 9.25 million tonnes CO₂ equivalents in 2019. Carbon dioxide emissions decreased by 10.57% in 2019 compared to the base year. Methane emissions decreased by 31.0%, whereas nitrous oxide emissions increased by 153%, for the same period.

Figure 3-1 – GHG emission trends for CRF Sector 1-Energy: 1990-2019

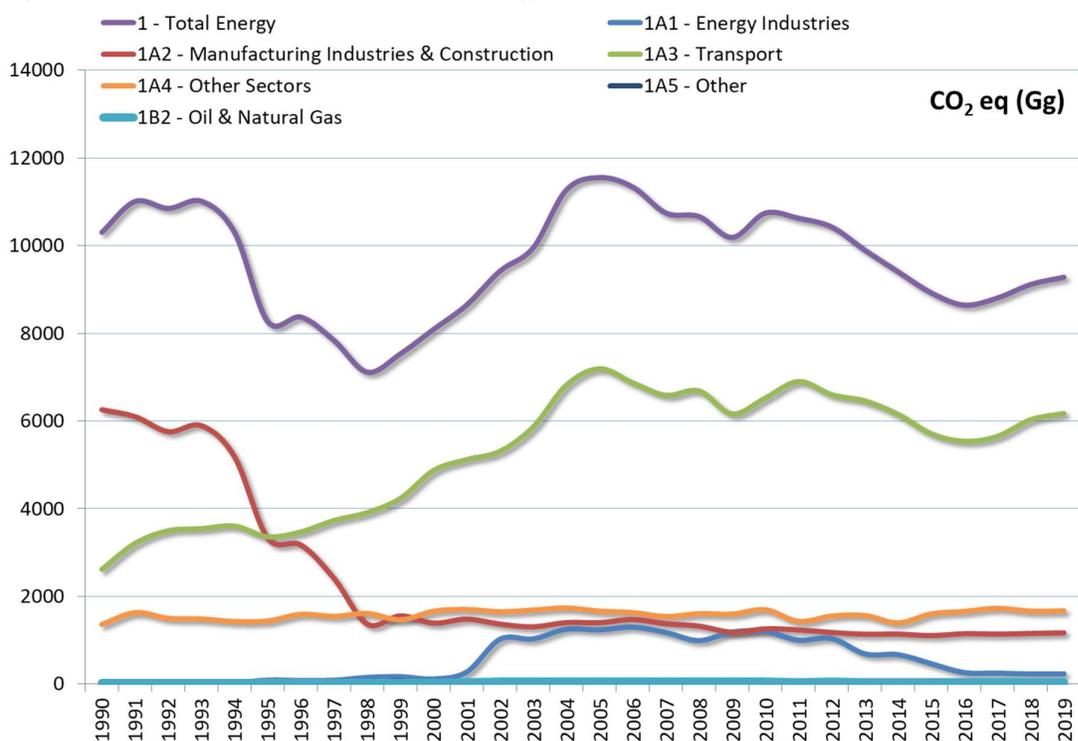


Figure 3-2 illustrates that the overall trend observed at sector level hides very different developments at the sub-category level. Indeed, between 1990 and 2019, GHG emissions have been strongly influenced by varying fuel consumption levels in industry, in particular in the iron and steel industry, as well as in the road transport sector as percentage growths recorded for sub-categories 1A2 – Manufacturing Industries and Construction and 1A3 – Transport demonstrate. There are several industrial sites which had relatively high levels of GHG emissions, and which, therefore, have had a large impact on the national total of GHG emissions. In the transport sector, road fuel consumption, and even more so road fuel sales⁶¹, have a very important weight in the national energy balance, and, consequently, have also a very important impact on the total GHG emissions.

In the iron and steel industry, the technological change from blast furnaces to electric arc furnaces allowed reducing GHG emissions significantly between 1993 and 1998. Due to the importance of the iron and steel industry in Luxembourg, this evolution hid many other emission trends between 1990 and 1998. After 1998, the increase of road fuel sales and, to a lesser extent, the increase of electric energy production has led to a rather steep increase of GHG emissions in these sub-categories and, by extension, of the national total for GHG emissions. In more recent years, the closure of some industrial sites (mainly in the iron and steel industry), the decrease in local electricity production, a reduction in the road fuel sales and the implementation of energy efficiency measures in the building sector, led to a more or less steady decrease in emissions from 2005 onwards.

All the changes briefly presented in the previous paragraphs – as well as in Chapter 2 - completely modified the pattern of the energy related GHG emissions between 1990 and 2019 with regard to the share between sub-categories – see Figure 3-3 – and to the “energy-mix” or fuel use for energy production and consumption – see Table 3-2.

61 See Section 2.2.

Table 3-1 – GHG emission trends in CO₂eq for CRF Sector 1 – Energy: 1990-2019

1 - Energy																
GHG emissions by source & sink category (Gg)																
Year	1A1 - Energy Industries				1A2 - Manufacturing Industries & Construction				1A3 - Transport				1A4 - Other Sectors			
	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)
1990	35.84	33.48	0.036	0.005	6 265.75	6 250.32	0.158	0.039	2 617.11	2 588.98	0.501	0.052	1 359.97	1 342.75	0.451	0.020
1991	37.50	35.03	0.038	0.005	6 108.45	6 092.59	0.154	0.040	3 210.62	3 177.07	0.542	0.067	1 626.00	1 607.10	0.498	0.022
1992	37.39	34.93	0.038	0.005	5 765.30	5 749.24	0.150	0.041	3 497.74	3 461.12	0.501	0.081	1 497.69	1 480.13	0.463	0.020
1993	35.57	33.23	0.036	0.005	5 902.01	5 885.35	0.151	0.043	3 545.09	3 507.79	0.432	0.089	1 482.43	1 464.95	0.465	0.020
1994	34.80	32.51	0.035	0.005	5 189.50	5 172.77	0.146	0.044	3 602.64	3 563.61	0.385	0.099	1 424.01	1 407.42	0.431	0.019
1995	93.72	91.47	0.035	0.005	3 333.05	3 319.14	0.097	0.039	3 359.82	3 322.74	0.323	0.097	1 437.69	1 420.87	0.441	0.020
1996	82.49	80.75	0.027	0.004	3 179.90	3 166.10	0.098	0.038	3 470.97	3 433.69	0.296	0.100	1 588.58	1 571.66	0.434	0.020
1997	89.89	87.83	0.032	0.004	2 415.82	2 402.85	0.077	0.037	3 731.60	3 693.95	0.280	0.103	1 542.27	1 525.52	0.427	0.020
1998	156.31	153.76	0.040	0.005	1 374.24	1 362.31	0.057	0.035	3 910.53	3 874.00	0.259	0.101	1 607.47	1 590.60	0.424	0.021
1999	173.89	170.97	0.045	0.006	1 564.67	1 551.31	0.064	0.039	4 235.25	4 198.83	0.247	0.102	1 463.22	1 447.17	0.403	0.020
2000	119.44	116.64	0.043	0.006	1 397.41	1 383.48	0.064	0.041	4 871.11	4 833.72	0.242	0.105	1 658.44	1 642.07	0.410	0.020
2001	280.88	277.95	0.046	0.006	1 490.06	1 475.12	0.074	0.044	5 117.85	5 081.47	0.230	0.103	1 698.29	1 681.43	0.432	0.020
2002	1 028.40	1 024.70	0.060	0.007	1 375.79	1 360.71	0.067	0.045	5 305.91	5 270.90	0.217	0.099	1 645.20	1 629.01	0.408	0.020
2003	1 036.24	1 032.42	0.062	0.008	1 313.67	1 299.11	0.061	0.044	5 859.62	5 824.36	0.213	0.100	1 684.79	1 668.63	0.408	0.020
2004	1 259.55	1 255.23	0.070	0.009	1 410.55	1 395.76	0.068	0.044	6 810.61	6 774.98	0.207	0.102	1 732.02	1 715.34	0.424	0.020
2005	1 242.72	1 238.67	0.066	0.008	1 406.70	1 390.95	0.095	0.045	7 187.10	7 151.73	0.185	0.103	1 660.74	1 644.87	0.406	0.019
2006	1 306.89	1 302.58	0.070	0.009	1 481.17	1 465.38	0.099	0.045	6 865.57	6 830.68	0.159	0.104	1 626.12	1 610.63	0.398	0.019
2007	1 183.09	1 178.80	0.069	0.009	1 385.05	1 369.62	0.095	0.044	6 580.91	6 543.16	0.144	0.115	1 538.38	1 524.03	0.365	0.017
2008	997.27	993.06	0.068	0.008	1 330.05	1 316.42	0.095	0.038	6 681.16	6 638.84	0.130	0.131	1 602.01	1 586.98	0.387	0.018
2009	1 194.06	1 189.72	0.070	0.009	1 189.42	1 177.18	0.081	0.034	6 157.53	6 115.41	0.115	0.132	1 592.76	1 577.27	0.407	0.018
2010	1 206.51	1 202.46	0.066	0.008	1 267.28	1 254.69	0.092	0.035	6 520.51	6 473.00	0.108	0.150	1 691.48	1 675.70	0.421	0.018
2011	1 008.92	1 004.69	0.068	0.008	1 243.02	1 231.01	0.086	0.033	6 896.47	6 842.10	0.111	0.173	1 425.99	1 412.91	0.342	0.015
2012	1 046.51	1 042.28	0.068	0.009	1 184.61	1 173.52	0.082	0.030	6 593.22	6 537.83	0.106	0.177	1 549.08	1 534.26	0.400	0.016
2013	692.39	688.40	0.063	0.008	1 144.39	1 133.04	0.084	0.031	6 452.51	6 395.34	0.100	0.183	1 560.86	1 545.56	0.428	0.015
2014	675.73	670.57	0.081	0.010	1 148.23	1 136.30	0.087	0.033	6 145.01	6 086.48	0.106	0.188	1 393.61	1 378.33	0.435	0.015
2015	469.00	463.36	0.088	0.012	1 113.19	1 101.71	0.082	0.032	5 703.77	5 645.83	0.110	0.185	1 597.81	1 581.23	0.472	0.016
2016	264.43	258.53	0.092	0.012	1 156.26	1 144.28	0.091	0.033	5 534.15	5 475.21	0.118	0.188	1 653.88	1 636.10	0.516	0.016
2017	253.65	246.77	0.107	0.014	1 146.28	1 134.48	0.090	0.032	5 646.67	5 584.36	0.127	0.198	1 725.54	1 708.65	0.484	0.016
2018	232.68	224.11	0.133	0.018	1 162.44	1 150.98	0.085	0.031	6 027.05	5 959.75	0.138	0.214	1 658.02	1 640.66	0.503	0.016
2019	235.46	224.03	0.177	0.023	1 177.11	1 165.87	0.080	0.031	6 166.49	6 095.98	0.148	0.224	1 666.88	1 653.00	0.385	0.014
Trend 1990-2019	557.01%	569.13%	385.77%	384.07%	-81.21%	-81.35%	-49.08%	-19.64%	135.62%	135.46%	-70.41%	328.16%	22.57%	23.11%	-14.60%	-28.59%
Trend 2018-2019	1.19%	-0.03%	33.06%	33.23%	1.26%	1.29%	-5.17%	-1.20%	2.31%	2.29%	7.31%	4.65%	0.53%	0.75%	-23.45%	-11.20%

1 - Energy												
GHG emissions by source & sink category (Gg)												
Year	1A5 - Other				1B2 - Oil & Natural Gas				1 - Total Energy			
	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)
1990	3.12	3.10	0.000	0.000	19.60	0.03	0.78	NA, NO	10 301.39	10 218.66	1.93	0.12
1991	3.12	3.10	0.000	0.000	20.33	0.03	0.81	NA, NO	11 006.02	10 914.93	2.04	0.13
1992	26.87	26.72	0.003	0.000	21.22	0.03	0.85	NA, NO	10 846.21	10 752.16	2.00	0.15
1993	23.72	23.58	0.003	0.000	22.02	0.03	0.88	NA, NO	11 010.85	10 914.93	1.97	0.16
1994	22.14	22.01	0.003	0.000	22.18	0.03	0.89	NA, NO	10 295.26	10 198.35	1.89	0.17
1995	10.82	10.75	0.001	0.000	25.28	0.03	1.01	NA, NO	8 260.38	8 165.00	1.91	0.16
1996	18.61	18.49	0.002	0.000	27.66	0.04	1.10	NA, NO	8 368.22	8 270.72	1.96	0.16
1997	23.10	22.98	0.003	0.000	28.29	0.04	1.13	NA, NO	7 830.97	7 733.16	1.95	0.16
1998	34.21	34.03	0.004	0.000	28.51	0.04	1.14	NA, NO	7 111.27	7 014.74	1.92	0.16
1999	63.29	62.95	0.008	0.000	29.52	0.04	1.18	NA, NO	7 529.84	7 431.26	1.95	0.17
2000	12.21	12.17	0.001	0.000	30.31	0.04	1.21	NA, NO	8 088.92	7 988.11	1.97	0.17
2001	24.24	24.16	0.002	0.000	33.69	0.04	1.35	NA, NO	8 645.01	8 540.18	2.13	0.17
2002	13.54	13.49	0.001	0.000	48.26	0.06	1.93	NA, NO	9 417.09	9 298.88	2.68	0.17
2003	3.27	3.25	0.000	0.000	48.91	0.06	1.95	NA, NO	9 946.49	9 827.83	2.70	0.17
2004	0.13	0.12	0.000	0.000	54.27	0.07	2.17	NA, NO	11 267.14	11 141.49	2.94	0.18
2005	0.13	0.12	0.000	0.000	53.46	0.07	2.14	NA, NO	11 550.84	11 426.41	2.89	0.18
2006	0.13	0.12	0.000	0.000	56.10	0.07	2.24	NA, NO	11 335.99	11 209.46	2.97	0.18
2007	0.13	0.12	0.000	0.000	52.49	0.07	2.10	NA, NO	10 740.04	10 615.80	2.77	0.18
2008	0.13	0.12	0.000	0.000	50.20	0.07	2.01	NA, NO	10 660.82	10 535.47	2.68	0.20
2009	0.13	0.12	0.000	0.000	50.74	0.07	2.03	NA, NO	10 184.63	10 059.76	2.70	0.19
2010	0.13	0.12	0.000	0.000	54.57	0.07	2.18	NA, NO	10 740.47	10 606.04	2.87	0.21
2011	0.12	0.12	0.000	0.000	47.30	0.06	1.89	NA, NO	10 621.83	10 490.90	2.50	0.23
2012	0.12	0.12	0.000	0.000	48.39	0.06	1.93	NA, NO	10 421.94	10 288.06	2.59	0.23
2013	0.12	0.12	0.000	0.000	41.21	0.05	1.65	NA, NO	9 891.46	9 762.51	2.32	0.24
2014	0.12	0.12	0.000	0.000	38.91	0.05	1.55	NA, NO	9 401.60	9 271.85	2.26	0.25
2015	0.12	0.12	0.000	0.000	34.99	0.05	1.40	NA, NO	8 918.88	8 792.30	2.15	0.24
2016	0.12	0.12	0.000	0.000	32.16	0.04	1.28	NA, NO	8 641.00	8 514.28	2.10	0.25
2017	0.12	0.11	0.000	0.000	31.68	0.04	1.27	NA, NO	8 803.94	8 674.41	2.07	0.26
2018	0.12	0.11	0.000	0.000	31.15	0.04	1.24	NA, NO	9 111.46	8 975.65	2.10	0.28
2019	0.12	0.11	0.000	0.000	31.18	0.04	1.25	NA, NO	9 277.24	9 139.04	2.04	0.29
Trend 1990-2019	-96.23%	-96.34%	-99.61%	-71.33%	59.11%	58.47%	59.11%	NA	-9.94%	-10.57%	5.55%	153.02%
Trend 2018-2019	-0.12%	-0.01%	-6.30%	-2.93%	0.11%	0.11%	0.11%	NA	1.82%	1.82%	-3.19%	4.88%

Source: Environment Agency.

Notes: CH₄ emissions are converted in CO₂eq by multiplying the emissions by 25, *i.e.* the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon. N₂O emissions are converted in CO₂eq by multiplying the emissions by 298, *i.e.* the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

Figure 3-2 – GHG emission trend indexes for CRF Sector 1 – Energy: 1990-2019

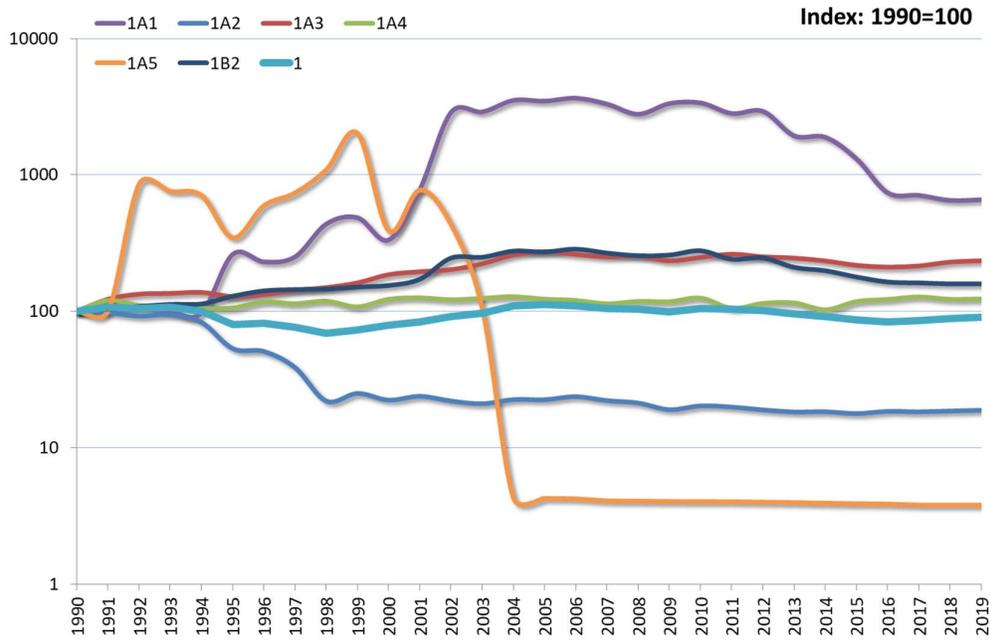


Figure 3-3 – IPCC sub-categories share in GHG emissions for CRF Sector 1 – Energy: 1990 and 2019

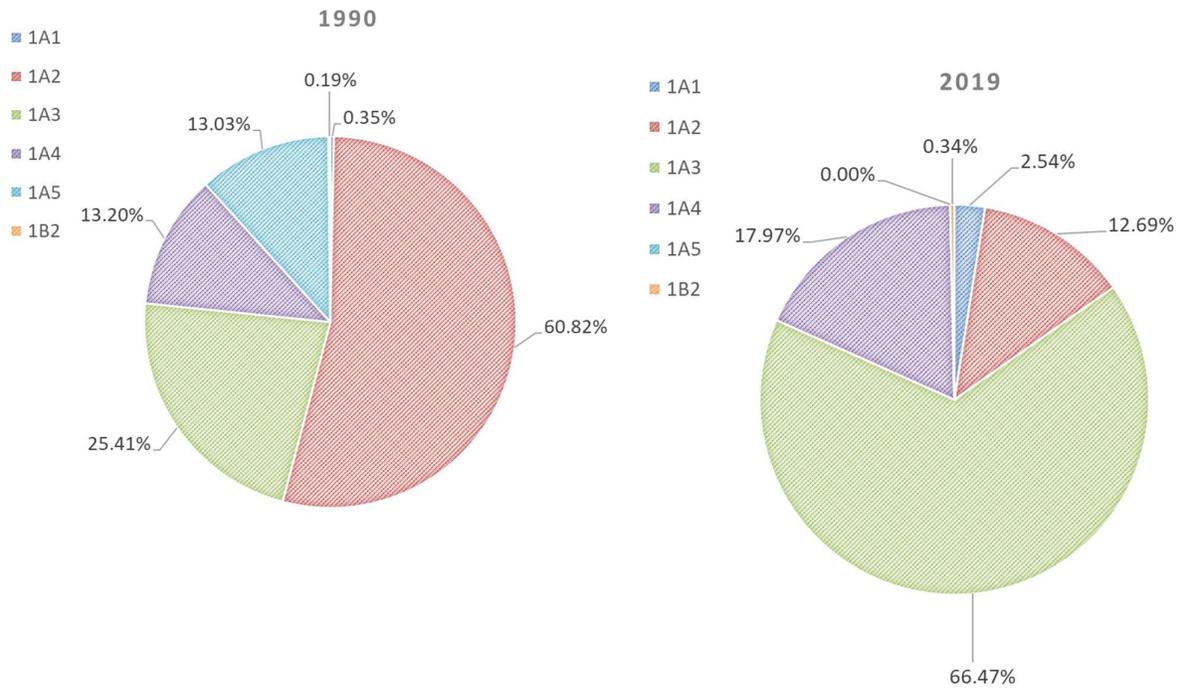


Table 3-2– Final energy consumption trends: 1990-2019

TJ								
Year	Total	Coal	Blast furnace gas	Natural gas (1)	Electricity	Heat (2)	Liquid fuels (3)	Wood & biomass
1990	144 043	34'332	8'457	19'427	14'989	-	66'193	645
1991	151 194	30'815	7'235	20'390	15'198	-	76'912	645
1992	151 495	29'475	6'196	21'227	15'282	-	78'670	645
1993	154 576	30'689	6'514	22'064	15'826	-	78'837	645
1994	151 033	27'268	5'504	21'990	16'747	126	78'754	645
1995	134 632	16'035	2'732	23'907	18'045	586	72'683	645
1996	138 070	15'671	2'512	26'251	17'710	547	74'734	645
1997	136 435	10'422	1'347	27'156	18'254	564	78'047	645
1998	135 560	4'883	-	27'437	19'092	950	82'554	645
1999	142 821	4'836	-	28'436	19'836	986	88'083	645
2000	149 605	4'595	-	28'126	20'790	504	94'661	930
2001	156 682	4'958	-	27'998	21'033	624	100'748	1'321
2002	158 232	3'084	-	28'258	21'261	1'085	103'139	1'406
2003	168 355	2'369	-	28'674	22'252	2'815	110'838	1'407
2004	186 632	3'329	-	29'942	23'007	3'031	125'735	1'587
2005	190 467	3'249	-	29'338	22'149	3'050	130'190	2'490
2006	187 692	3'877	-	30'623	23'806	3'204	123'620	2'562
2007	184 849	3'280	-	29'823	24'098	2'573	120'558	4'519
2008	186 737	3'137	-	30'616	23'750	2'907	121'629	4'697
2009	173 689	2'801	-	28'659	22'005	2'458	113'546	4'219
2010	184 368	2'807	-	31'412	23'735	3'001	118'873	4'541
2011	182 461	2'443	-	27'916	23'343	3'057	121'286	4'415
2012	177 447	2'250	-	28'262	22'450	2'988	116'797	4'700
2013	175 357	2'006	-	27'790	22'316	3'161	114'981	5'103
2014	170 231	2'235	-	26'536	22'256	2'431	110'833	5'938
2015	169 837	2'057	-	27'791	22'407	2'261	108'960	6'360
2016	172 215	2'193	-	29'226	22'922	2'433	108'689	6'752
2017	177 785	1'898	-	28'760	23'016	2'606	113'906	7'599
2018	185 006	1'764	-	28'762	23'252	2'956	120'411	7'861
2019	186 610	1'784	-	28'846	23'027	3'736	121'856	7'361
Trend 1990-2019	29.55%	-94.80%	-100.00%	48.48%	53.63%	NA	84.09%	1041.67%
Share 1990	100.00%	23.83%	5.87%	13.49%	10.41%	NA	45.95%	0.45%
Share 2019	100.00%	0.96%	NA	15.46%	12.34%	2.00%	65.30%	3.94%

Source: STATEC: Statistical Yearbook, Table A4300: <http://www.statistiques.public.lu/>

Notes: (1) based on GCV

(2) heat from cogeneration, including heat recovery from waste incineration

(3) including blended biodiesel

Data extracted on 10th March 2021 (subject to change since that date)

Final energy consumption increased by 29.55% between 1990 and 2019 and passed through a minimum in 1995 and a maximum in 2005. All the energy sources have seen their consumption increase over the period, except coal and blast furnace gas, for which the declining use in the first part of the 1990s was closely related to the discontinuation of the use of blast furnaces in the iron & steel industry. Table 3-2 also shows the dramatic change in the “energy-mix” in Luxembourg between 1990 and 2019, with a dropping share of solid fuels – for which the main part was used in the iron and steel industry – in favour of liquid fuels and natural gas and, to a lesser extent, to new energy sources such as cogeneration and biomass. Biomass is expected to increase more rapidly in the future due to European commitments, also engaged by Luxembourg, to promote the use of biomass, especially solid biomass and biogas.

In 2019, with 65.30% of the final total energy consumption in Luxembourg, liquid fuels are the most important energy source, with diesel being the first liquid fuel in terms of volumes sold. The domestic liquid fuel consumption in Luxembourg is much lower than the level of fuel sales, because large amounts of road fuels are bought by cross-border commuters and transit traffic passing through Luxembourg and thus exported on board of road vehicle tanks. Actually, in 2019, 71.53% of road fuels sold on Luxembourg’s territory are exported inside vehicle tanks and combusted abroad (see

Table 3-64 in Section 3.2.9.3).

The importance of natural gas has increased constantly and significantly since 1990. In 2019, natural gas consumption ranked second after the consumption of liquid fuels. This development followed the continuous extension of the natural gas network in Luxembourg and the substantial increase of Luxembourg's population since 1990, and as such, natural gas becomes more and more the main fuel for heating purposes.

Natural gas has also become the main energy source of Luxembourg’s national electricity production capacity⁶². In 1990, more than 90% of Luxembourg’s electric energy consumption was imported. One medium size power plant of about 70 MW was owned by the iron & steel industry, and partially fed the public network when electricity was produced in excess. That power plant was mainly run on blast furnace gas and was phased out in 1997 after the last blast furnace went out of service.

In the early 1990s, small cogeneration plants appeared. Their installation was encouraged financially by the Government. This development was followed later by some industrial companies which installed gas turbines to produce electricity and heat simultaneously. In mid-2002, the TWINerg power plant – a 350MW gas turbine – started its operation, producing electricity only until 2010. From 2011 onwards, heat is also recovered and fed into a district heating network providing heat for the new development site at Esch-Belval. The TWINerg plant was shut down in 2016. Almost all of these cogeneration plants run on natural gas. Gas oil remains, however, the emergency fuel in case of a natural gas supply disruption.

Table 3-3 summarises electricity production trends in Luxembourg since 1990.

62 This cannot be seen in final energy consumption statistics but only in the primary energy consumption figures.

Table 3-3 – Electricity production trends: 1990-2019

Year	Electricity production (GWh)			
	Total	Thermic (1)	RES (2)	Cogeneration (3)
1990	626	559	68	NO
1991	676	622	54	NO
1992	662	594	68	NO
1993	670	608	62	NO
1994	625	506	86	33
1995	530	347	81	102
1996	474	306	53	114
1997	424	214	92	118
1998	406	105	107	195
1999	389	52	132	205
2000	415	51	144	219
2001	869	457	143	269
2002	2 817	2 333	131	352
2003	2 784	2 285	102	397
2004	3 374	2 787	144	442
2005	3 337	2 737	155	445
2006	3 519	2 866	182	471
2007	3 190	2 599	192	399
2008	2 713	2 089	202	422
2009	3 143	2 571	181	390
2010	3 224	2 607	176	440
2011	2 644	2 049	148	447
2012	2 746	2 104	204	438
2013	1 843	1 157	269	417
2014	1 918	1 241	296	381
2015	1 350	680	320	350
2016	800	113	332	355
2017	936	124	466	346
2018	1 021	124	531	366
2019	1 192	125	644	423
Trend 1990-2019	49.52%	-77.78%	590.88%	NA
Share 1990	100.00%	89.22%	10.78%	NA
Share 2019	100.00%	13.26%	49.82%	36.92%

Sources: STATEC: Statistical yearbook, Table A.4203: <http://www.statistiques.public.lu>

Notes: (1) includes thermal power plants (TWINerg), autoproducer thermal power plants and MSW incineration.

(2) RES=Renewable Energy Sources, includes small hydro-electric power plants, wind power, photo voltaic power.

(3) Cogeneration includes biomethanisation

Data extracted on March 10 2021 (subject to changes since that date)

3.1.2 Completeness

Table 3-4 gives an overview of the IPCC categories included under CRF Sector 1-Energy and provides information on the status of emission estimates of all sub-categories.

Table 3-4 – Overview of CRF Sector 1 – Energy: status of emission estimates for CO₂, CH₄ and N₂O

GHG source & sink category	Description	Status		
		CO ₂	CH ₄	N ₂ O
1A1a	fuel combustion activities – energy industries – public electricity & heat production	X	X	X
1A1b	fuel combustion activities – energy industries – petroleum refining	NO	NO	NO
1A1c	fuel combustion activities – energy industries – manufacture of solid fuels and other energy industries	NO	NO	NO
1A2a	fuel combustion activities – manufacturing industries & construction – iron & steel	X	X	X
1A2b	fuel combustion activities – manufacturing industries & construction – non-ferrous metals	X	X	X
1A2c	fuel combustion activities – manufacturing industries & construction – chemicals	X	X	X
1A2d	fuel combustion activities – manufacturing industries & construction – pulp, paper & print	X (2000-2019)	X (2000-2019)	X (2000-2019)
1A2e	fuel combustion activities – manufacturing industries & construction – food processing, beverages & tobacco	X	X	X
1A2f	fuel combustion activities – manufacturing industries & construction – non-metallic minerals	X	X	X
1A2g	fuel combustion activities – manufacturing industries & construction – other	X	X	X
1A3a	fuel combustion activities – transport – civil aviation	X	X	X
1A3b	fuel combustion activities – transport – road transportation	X	X	X
1A3c	fuel combustion activities – transport – railways	X	X	X
1A3d	fuel combustion activities – transport – navigation	X	X	X
1A3e	fuel combustion activities – transport – other transportation	NO	NO	NO
1A4a	fuel combustion activities – other sectors – commercial/institutional	X	X	X
1A4b	fuel combustion activities – other sectors – residential	X	X	X
1A4c	fuel combustion activities – other sectors – agriculture/forestry/fish farms	X	X	X
1A5a	fuel combustion activities – non-specified – stationary	X (1990-2003)	X (1990-2003)	X (1990-2003)
1A5b	fuel combustion activities – non-specified – mobile	X	X	X
1B1a	fugitive emissions from fuels – solid fuels – coal mining & handling	NO	NO	NO
1B1b	fugitive emissions from fuels – solid fuels – solid fuel transformation	NO	NO	NO
1B1c	fugitive emissions from fuels – solid fuels – other	NO	NO	NO
1B2a	fugitive emissions from fuels – oil & natural gas – oil	NA	NA	NO
1B2b	fugitive emissions from fuels – oil & natural gas – natural gas	X	X	
1B2c	fugitive emissions from fuels – oil & natural gas – venting & flaring	X	X	NO
1B2d	fugitive emissions from fuels – oil & natural gas – other	NA	NA	NA
Memo Items	international bunkers – aviation	X	X	X
Memo Items	international bunkers – marine	X	X	X
Memo Items	multilateral operations	NA	NA	NA
Memo Items	CO ₂ emissions from biomass	X		

Note: X indicates that emissions from this sub-category have been estimated, the grey shaded cells are those also shaded in the CRF tables.

3.2 Fuel Combustion Activities (1.A)

In 2019, GHG emissions of category 1A - Fuel Combustion amounted to a total of 9.25 million tonnes CO₂eq (see Table 3-5). The transport sector (1A3 - Transport) represented the most important source, with a share of 66.69% of the GHG emissions within category 1A (57.40% of national total excl. LULUCF). These emissions include emissions from fuel export, i.e. fuel bought by foreign commuters and transit traffic, but mostly emitted outside of Luxembourg's territory.

Combustion in the commercial and residential sector (1A4 - Other Sectors) was the second largest source of emissions with a share of 18.03% of the GHG emissions within category 1A (15.52% of national total excl. LULUCF), followed by the industrial sector (1A2 - Manufacturing Industries and Construction) and the energy sector (1A1 - Energy) with shares of 12.73% and 2.55%, respectively (10.96% and 2.19% of national total excl. LULUCF, respectively). Emissions from sub-category 1A5 - Other, which includes emissions from other non-specified sources, represented only 0.001% of the GHG emissions within category 1A in 2019.

Table 3-5 - GHG emission trends and shares of 1A-Fuel combustion

1A - Fuel Combustion						
GHG emissions by source category excluding CO ₂ emissions from biomass (Gg CO ₂ eq.)						
Year	1A1 Energy Industries	1A2 Manufacturing Industries & Construction	1A3 Transportation	1A4 Other Sectors	1A5 Other	1A Fuel Combustion
1990	35.8	6 265.7	2 617.1	1 360.0	3.1	10 281.8
1991	37.5	6 108.5	3 210.6	1 626.0	3.1	10 985.7
1992	37.4	5 765.3	3 497.7	1 497.7	26.9	10 825.0
1993	35.6	5 902.0	3 545.1	1 482.4	23.7	10 988.8
1994	34.8	5 189.5	3 602.6	1 424.0	22.1	10 273.1
1995	93.7	3 333.1	3 359.8	1 437.7	10.8	8 235.1
1996	82.5	3 179.9	3 471.0	1 588.6	18.6	8 340.6
1997	89.9	2 415.8	3 731.6	1 542.3	23.1	7 802.7
1998	156.3	1 374.2	3 910.5	1 607.5	34.2	7 082.8
1999	173.9	1 564.7	4 235.2	1 463.2	63.3	7 500.3
2000	119.4	1 397.4	4 871.1	1 658.4	12.2	8 058.6
2001	280.9	1 490.1	5 117.9	1 698.3	24.2	8 611.3
2002	1 028.4	1 375.8	5 305.9	1 645.2	13.5	9 368.8
2003	1 036.2	1 313.7	5 859.6	1 684.8	3.3	9 897.6
2004	1 259.6	1 410.5	6 810.6	1 732.0	0.1	11 212.9
2005	1 242.7	1 406.7	7 187.1	1 660.7	0.1	11 497.4
2006	1 306.9	1 481.2	6 865.6	1 626.1	0.1	11 279.9
2007	1 183.1	1 385.1	6 580.9	1 538.4	0.1	10 687.6
2008	997.3	1 330.1	6 681.2	1 602.0	0.1	10 610.6
2009	1 194.1	1 189.4	6 157.5	1 592.8	0.1	10 133.9
2010	1 206.5	1 267.3	6 520.5	1 691.5	0.1	10 685.9
2011	1 008.9	1 243.0	6 896.5	1 426.0	0.1	10 574.5
2012	1 046.5	1 184.6	6 593.2	1 549.1	0.1	10 373.5
2013	692.4	1 144.4	6 452.5	1 560.9	0.1	9 850.3
2014	675.7	1 148.2	6 145.0	1 393.6	0.1	9 362.7
2015	469.0	1 113.2	5 703.8	1 597.8	0.1	8 883.9
2016	264.4	1 156.3	5 534.2	1 653.9	0.1	8 608.8
2017	253.6	1 146.3	5 646.7	1 725.5	0.1	8 772.3
2018	232.7	1 162.4	6 027.0	1 658.0	0.1	9 080.3
2019	235.5	1 177.1	6 166.5	1 666.9	0.1	9 246.1
Trend 1990-2019	557.01%	-81.21%	135.62%	22.57%	-96.23%	-10.07%
Share 1990	0.35%	60.94%	25.45%	13.23%	0.03%	100.00%
Share 2019	2.55%	12.73%	66.69%	18.03%	0.00%	100.00%

Table 3-6 presents the key source categories of 1A – Fuel Combustion Activities.

Table 3-6 – Key categories of 1A – Fuel Combustion Activities (1990-2019)

1 - Energy Key sources							
IPCC Category	Category Name	Fuel	GHG	LA excl. LULUCF	LA incl. LULUCF	TA excl. LULUCF	TA incl. LULUCF
1A1	Energy Industries	gaseous	CO ₂	95,98-99,01-19	95, 98-99,01-19		
1A1	Energy Industries	other	CO ₂	98, 09, 11-19	98, 04, 06-19	X	X
1A2	Manufacturing Industries and Construction	gaseous	CO ₂	90-19	90-19	X	X
1A2	Manufacturing Industries and Construction	liquid	CO ₂	90-19	90-19		
1A2	Manufacturing Industries and Construction	solid	CO ₂	90-19	90-19	X	X
1A2	Manufacturing Industries and Construction	other	CO ₂	13, 16-19	13, 16-19		
1A3b	Road Transportation	diesel oil	CO ₂	90-19	90-19	X	X
1A3b	Road Transportation	gasoline	CO ₂	90-19	90-19		
1A3b	Road Transportation	diesel oil	N ₂ O		18-19		
1A4	Other Sectors	gaseous	CO ₂	90-19	90-19	X	X
1A4	Other Sectors	liquid	CO ₂	90-19	90-19		
1A5	Other	liquid	CO ₂	99	99		

Source: Environment Agency

Notes: LA= Level Assessment (Tier 1) including respectively excluding LULUCF

TA= Trend Assessment 2019 (Tier 1) including respectively excluding LULUCF

3.2.1 Comparison of the sectoral approach with the reference approach

This section provides a comparative analysis of the reference approach and the sectoral approach, and gives explanations for the differences between the two approaches. Figure 3-4 and Table 3-7 present CO₂ emissions obtained by the sectoral and the reference approaches. The difference for total CO₂ emissions from fuel combustion varies between -0.69% and +2.04% throughout the time-series.

Figure 3-4 - CO₂ emissions obtained with Reference and Sectoral Approach for 1990-2019

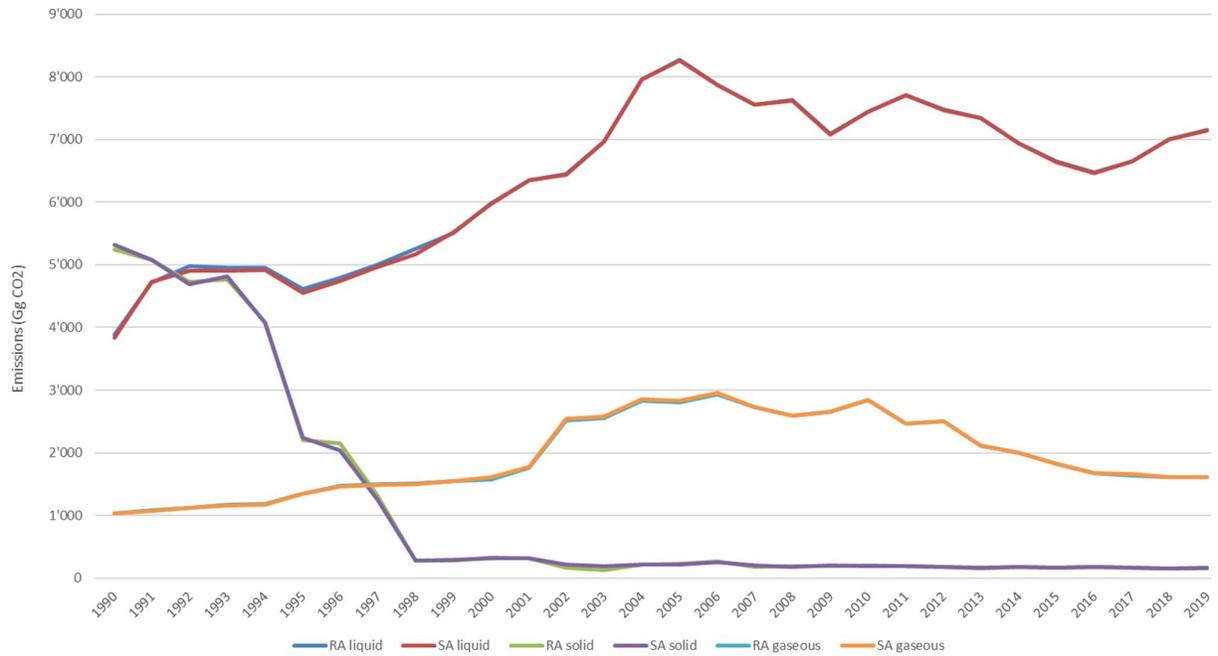


Table 3-7 – CO₂ emissions obtained with Reference and Sectoral Approach (1990-2019)

Year	Reference Approach					Sectoral Approach				
	Solid [Gg CO ₂]	Liquid [Gg CO ₂]	Gaseous [Gg CO ₂]	Other [Gg CO ₂]	Total [Gg CO ₂]	Solid [Gg CO ₂]	Liquid [Gg CO ₂]	Gaseous [Gg CO ₂]	Other [Gg CO ₂]	Total [Gg CO ₂]
1990	5'241	3'881	1'039	33	10'194	5'317	3'832	1'036	33	10'219
1991	5'081	4'719	1'080	35	10'915	5'077	4'728	1'074	35	10'915
1992	4'733	4'980	1'128	35	10'876	4'686	4'909	1'122	35	10'752
1993	4'768	4'951	1'173	33	10'924	4'813	4'909	1'161	33	10'915
1994	4'093	4'961	1'184	33	10'270	4'073	4'919	1'174	33	10'198
1995	2'209	4'612	1'351	31	8'204	2'239	4'552	1'343	31	8'165
1996	2'155	4'788	1'472	24	8'439	2'043	4'742	1'461	24	8'271
1997	1'315	4'999	1'500	28	7'842	1'247	4'966	1'491	28	7'733
1998	280	5'253	1'506	66	7'105	280	5'174	1'495	66	7'015
1999	287	5'514	1'552	73	7'426	296	5'515	1'546	73	7'431
2000	328	5'983	1'580	78	7'969	325	5'976	1'609	78	7'988
2001	320	6'354	1'758	97	8'529	317	6'346	1'781	97	8'540
2002	165	6'446	2'519	105	9'235	215	6'438	2'540	105	9'299
2003	133	6'969	2'556	103	9'761	187	6'962	2'576	103	9'828
2004	218	7'960	2'837	115	11'130	213	7'954	2'859	115	11'141
2005	228	8'270	2'803	109	11'410	224	8'264	2'829	109	11'426
2006	264	7'876	2'937	119	11'195	260	7'873	2'958	119	11'209
2007	178	7'554	2'731	120	10'583	204	7'553	2'731	128	10'616
2008	189	7'625	2'594	128	10'535	186	7'620	2'594	136	10'535
2009	199	7'086	2'657	110	10'052	211	7'074	2'658	117	10'060
2010	202	7'448	2'841	117	10'609	199	7'441	2'842	124	10'606
2011	191	7'712	2'463	123	10'489	191	7'706	2'464	130	10'491
2012	184	7'478	2'499	124	10'284	185	7'473	2'500	130	10'288
2013	160	7'342	2'112	132	9'746	173	7'336	2'113	140	9'762
2014	183	6'939	2'004	136	9'262	186	6'935	2'004	146	9'272
2015	168	6'645	1'827	146	8'786	165	6'640	1'828	159	8'792
2016	181	6'472	1'679	177	8'509	178	6'466	1'680	190	8'514
2017	168	6'652	1'642	179	8'642	173	6'646	1'658	198	8'674
2018	155	7'006	1'609	193	8'964	154	7'000	1'609	212	8'976
2019	156	7'151	1'606	197	9'111	168	7'146	1'608	217	9'139

Table 3-8 presents the relative difference of CO₂ emissions between reference and sectoral approach.

Table 3-8 – Difference of CO₂ emissions by type of fuel

Difference of CO ₂ emissions between sectoral and reference					
[%]					
Year	Solid	Liquid	Gaseous	Other	Total
1990	- 1.44	1.29	0.27	0.00	- 0.24
1991	0.08	- 0.20	0.57	0.00	0.00
1992	1.01	1.44	0.59	0.00	1.16
1993	- 0.93	0.86	1.06	0.00	0.09
1994	0.48	0.84	0.92	0.00	0.70
1995	- 1.33	1.33	0.62	0.00	0.48
1996	5.49	0.96	0.75	0.00	2.04
1997	5.41	0.66	0.56	0.00	1.40
1998	0.02	1.52	0.74	0.00	1.28
1999	- 3.04	- 0.03	0.38	0.00	- 0.07
2000	0.94	0.12	- 1.80	0.00	- 0.24
2001	1.15	0.13	- 1.27	0.00	- 0.13
2002	- 23.52	0.12	- 0.83	0.00	- 0.69
2003	- 28.75	0.09	- 0.76	0.00	- 0.68
2004	2.18	0.07	- 0.76	- 0.08	- 0.10
2005	1.67	0.08	- 0.92	- 0.08	- 0.14
2006	1.72	0.04	- 0.72	- 0.07	- 0.13
2007	- 13.02	0.02	0.00	- 6.01	- 0.31
2008	1.43	0.06	- 0.01	- 5.67	0.00
2009	- 5.63	0.17	- 0.03	- 6.18	- 0.08
2010	1.54	0.09	- 0.02	- 5.53	0.02
2011	- 0.15	0.08	- 0.04	- 5.01	- 0.02
2012	- 0.83	0.07	- 0.02	- 5.29	- 0.04
2013	- 7.27	0.08	- 0.07	- 5.58	- 0.17
2014	- 1.35	0.05	- 0.04	- 7.04	- 0.11
2015	1.56	0.07	- 0.06	- 8.13	- 0.08
2016	1.48	0.09	- 0.03	- 7.06	- 0.06
2017	- 2.67	0.09	- 0.95	- 9.15	- 0.38
2018	0.75	0.09	0.00	- 9.02	- 0.13
2019	- 7.39	0.07	- 0.10	- 8.97	- 0.31

Source: Environment Agency

Note: Positive numbers indicate that CO₂ emissions from the reference approach are higher than emissions from the sectoral approach.

3.2.1.1 Methodology and data sources

The reference approach was compiled based on the 2006 IPCC Guidelines.

The primary data source for production, import, export, stock change, international bunker of fuels was the national energy balance and /or the IEA Energy questionnaires as provided and compiled by the national statistics office (STATEC).

NCVs, CO₂ emission factors and oxidation factors are identical to those used for the sectoral approach, if not otherwise stated in the CRF tables' documentation box.

The amount of carbon which does not lead to fuel combustion emissions was excluded from total carbon. Indeed, carbon excluded from fuel combustion is either emitted in another sector of the inventory (for example as an industrial process emission) or stored in the product manufactured from the fuel.

3.2.1.2 Explanation of differences

The following reasons provide explanations to the differences recorded between the Sectoral Approach and the Reference Approach (CRF table 1.A (b) and 1.A(c)):

- The sectoral approach is based on a combined bottom-up (using plant specific data where available) & top-down (national energy balance) approach. For some IPCC sub-categories, bottom-up activity data is higher than reported by the energy balance. In order to avoid potential underestimation, it is preferred to use the highest data whenever possible. Hence, emissions as calculated in the sectoral approach can be higher than the ones calculated in the reference approach. Please refer to section 3.2.5 for more details on the methodology applied to calculate emissions in the sectoral approach.
- Liquid fuels: difference in CO₂ emissions between the two approaches is +0.07% in 2019 and lies below the 2% significance threshold for the entire timeseries.
- Solid fuels: difference in CO₂ emissions between the two approaches is -7.39% for 2019. For some years there is a significant difference between both approaches (up to 28.75% for 2003). The most likely reason for these differences is that solid fuels are often stored in large quantities, and not immediately combusted after acquisition (sometimes combustion may even occur in a different calendar year). A more detailed investigation on this issue will be carried out together with STATEC and the ETS team, and the methodology will be adapted for Luxembourg's next inventory submission if necessary.
- Gaseous fuels: difference in CO₂ emissions between the two approaches is -0.10% in 2019 and lies below the 2% significance threshold for the entire timeseries.
- Other Fossil Fuels: This category covers three dominating facilities, all covered under the emission trading scheme (ETS). One facility is using secondary fossil fuels such as tires, fluff, waste solvents and sewage sludge as a replacement of standard solid fossil fuels such as coal for its clinker production. The activity data for these secondary fossil fuels, as used in the sectoral approach, are extracted from the ETS reports. However the national energy balance, used for the reference approach, does not report the consumption of such fuels. Hence, the CO₂ emission of these secondary fossil fuels was added to the reference approach, and the difference between the two approaches tends to 0%. However, since submission 2019v1, Luxembourg has added a new type of "other fossil fuel" in its inventory: the fossil part of FAME in biodiesel is considered here since its introduction in 2004 (please refer to page 247 for details). As a consequence, the difference between the sectoral and the reference approach for other fossil fuels is -8.97% in 2019. This results from the fact that the national energy balance considers biodiesel to be 100% biomass.

Category-specific recalculations including changes made in response to the review process Table 3-9 presents the main revisions and recalculations done since submission 2020v1 relevant to the Reference Approach. For the quantitative aspect of these recalculations, please refer to Chapter 10.

Table 3-9 – Recalculations for the Reference Approach

GHG source & sink category	Revisions 2020v1 → 2021v1	Type of revision
All fuels	AD was revised according to the revised energy balance and IEA Questionnaires as provided by STATEC	updated AD

3.2.1.3 Planned improvements

Table 3-10 lists the main improvements planned for the next submission.

Table 3-10 – Planned improvements for the Reference Approach

GHG source & sink category	Planned improvement
Solid fuels – reference approach	Investigate the significant difference for solid fuels between the reference approach and the sectoral approach, and adapt the methodology if necessary

3.2.2 International Bunker Fuels

In 2019, GHG emissions from International Bunkers amounted to 1798.20 Gg CO₂e (see Table 3-11), an increase of approximately 351% compared to 1990, which is mainly due to increased international aviation activities.

Table 3-11 – Activity data and GHG emissions for International Bunkers

International Bunkers - Aviation & Marine												
Activity Data (GJ) and GHG emissions by source & sink category (Gg)												
Year	Aviation (Kerosene & Aviation Gasoline)					Marine (Gas Oil)					Total Activity	Total CO ₂ e _q
	Activity (GJ)	Total CO ₂ e _q	CO ₂	CH ₄	N ₂ O	Activity (GJ)	Total CO ₂ e _q	CO ₂	CH ₄	N ₂ O		
1990	5 516 169	398.37	394.41	0.003	0.013	1 054	0.087	0.078	0.000004	0.000029	5 517 223	398
1991	5 765 550	416.38	412.24	0.003	0.014	1 139	0.094	0.084	0.000005	0.000032	5 766 689	416
1992	5 574 033	402.62	398.54	0.004	0.013	1 065	0.088	0.079	0.000004	0.000030	5 575 098	403
1993	5 512 762	398.15	394.16	0.003	0.013	1 430	0.118	0.106	0.000006	0.000041	5 514 192	398
1994	6 993 817	505.00	500.06	0.004	0.016	1 238	0.103	0.092	0.000005	0.000036	6 995 055	505
1995	7 927 783	572.33	566.83	0.004	0.018	1 246	0.103	0.092	0.000005	0.000037	7 929 029	572
1996	8 614 215	621.81	615.91	0.004	0.019	1 178	0.098	0.087	0.000005	0.000035	8 615 393	622
1997	10 305 632	743.80	736.85	0.004	0.023	1 139	0.095	0.084	0.000005	0.000034	10 306 771	744
1998	12 493 294	901.53	893.27	0.004	0.027	1 140	0.095	0.085	0.000004	0.000034	12 494 434	902
1999	14 095 591	1 017.07	1 007.83	0.005	0.031	1 252	0.104	0.093	0.000005	0.000038	14 096 843	1 017
2000	13 434 073	969.38	960.53	0.005	0.029	1 384	0.116	0.103	0.000005	0.000043	13 435 457	969
2001	14 530 054	1 048.37	1 038.90	0.005	0.031	1 387	0.116	0.103	0.000005	0.000043	14 531 440	1 048
2002	15 742 564	1 135.75	1 125.59	0.005	0.034	1 462	0.122	0.108	0.000005	0.000044	15 744 026	1 136
2003	16 399 902	1 183.17	1 172.59	0.005	0.035	1 490	0.124	0.111	0.000005	0.000044	16 401 392	1 183
2004	17 844 514	1 287.36	1 275.88	0.005	0.038	1 441	0.120	0.107	0.000005	0.000042	17 845 954	1 287
2005	18 131 067	1 308.03	1 296.37	0.005	0.039	1 932	0.159	0.143	0.000006	0.000053	18 132 999	1 308
2006	16 967 777	1 224.15	1 213.19	0.005	0.036	2 041	0.167	0.151	0.000006	0.000053	16 969 817	1 224
2007	18 238 604	1 315.65	1 304.06	0.005	0.038	1 638	0.134	0.121	0.000005	0.000041	18 240 242	1 316
2008	18 359 132	1 324.39	1 312.68	0.005	0.039	1 785	0.145	0.132	0.000005	0.000043	18 360 917	1 325
2009	17 588 864	1 268.85	1 257.60	0.005	0.037	1 430	0.116	0.106	0.000004	0.000033	17 590 294	1 269
2010	18 050 982	1 302.15	1 290.64	0.005	0.038	1 373	0.111	0.102	0.000004	0.000030	18 052 355	1 302
2011	16 887 889	1 218.33	1 207.48	0.005	0.036	1 693	0.136	0.126	0.000005	0.000036	16 889 583	1 218
2012	15 581 431	1 124.17	1 114.07	0.005	0.033	1 631	0.131	0.121	0.000004	0.000034	15 583 063	1 124
2013	15 659 460	1 129.77	1 119.65	0.005	0.034	1 345	0.108	0.100	0.000003	0.000027	15 660 805	1 130
2014	16 985 116	1 218.52	1 214.43	0.005	0.036	1 487	0.119	0.110	0.000004	0.000029	16 986 603	1 219
2015	19 161 778	1 370.06	1 370.07	0.005	0.041	1 516	0.121	0.112	0.000004	0.000029	19 163 294	1 370
2016	21 263 024	1 520.30	1 520.30	0.006	0.045	1 688	0.135	0.125	0.000004	0.000032	21 264 712	1 520
2017	24 041 916	1 719.00	1 719.00	0.006	0.051	2 111	0.169	0.157	0.000005	0.000040	24 044 027	1 719
2018	25 707 727	1 838.10	1 838.10	0.006	0.054	1 831	0.146	0.136	0.000004	0.000033	25 709 558	1 838
2019	25 148 046	1 798.08	1 798.08	0.006	0.053	1 428	0.113	0.106	0.000003	0.000025	25 149 474	1 798
1990-2019	355.90%	351.36%	355.90%	102.72%	305.95%	35.50%	30.21%	35.33%	-29.27%	-14.97%	355.84%	351.29%

Source: Environment Agency

3.2.2.1 Aviation Bunkers

As there is only one airport for commercial aviation in Luxembourg (located next to Luxembourg City), all commercial flights, either coming to Luxembourg or going out of Luxembourg, are international flights. Non-commercial flights are mainly leisure or urgency (medical, police) flights made with small-sized propeller airplanes or helicopters using aviation gasoline. These flights depart and arrive at the same airport in Luxembourg. Based on communication with an expert of the sole aviation fuel reseller (Luxfuel) and with the aviation authorities, about 90% of these non-commercial flights should be considered as domestic flights. The remaining 10% of the light non-commercial aviation flights using aviation gasoline should be considered as international flights, as these flights depart from Luxembourg with an international destination, which could be a small leisure airport in one of the neighbouring countries.⁶³ Consequently, all kerosene sales (commercial flights) and 10% of the aviation gasoline sales (non-commercial flights) and their related emissions are considered as international flights and, thus, are allocated to international bunkers (see also 1A3a – Domestic aviation: section 3.2.9.2.2).

3.2.2.1.1 Activity data

Fuel consumption of jet type kerosene was obtained from the national statistics institute (STATEC) and fuel consumption of aviation gasoline was obtained from the sole vendor of aviation gasoline at the airport (Luxfuel S.A.) (see Table 3-11). Data on the number of landings and take-offs (LTO) has been obtained from national statistics institute (STATEC).

3.2.2.1.2 Methodological issues

The 2006 IPCC Guidelines Tier 2 approach has been applied for flights combusting jet kerosene. This methodology is based on five steps:

- Estimation of the domestic and international fuel consumption totals for aviation. In Luxembourg's case this estimation is straight forward as the entire fuel consumption of jet kerosene is considered as international.
- Estimation of LTO fuel consumption for domestic and international operations. The LTO fuel consumption of international operations (no domestic operations using jet kerosene) are estimated using the Eurostat 2004-2019 data on aircraft types and the EMEP/EEA Guidebook 2019 Master and LTO emission calculator for each aircraft type. The 1990-2003 LTO fuel consumption data are estimated through a linear extrapolation of the 2004-2019 data.
- Estimation of the cruise fuel consumption for domestic and international aviation. The cruise fuel consumption was estimated by calculating the difference between the amount of fuel sold and the LTO fuel consumption.
- Estimation of emissions from LTO and cruise phases for domestic and international aviation. The emissions of LTO and cruise phases are calculated using emission factors from the IPCC 2006 Guidelines (please refer to section 3.2.2.1.3 below for more details).
- Calculation of total emissions = LTO emissions + cruise emissions.

For non-commercial flights, combusting aviation gasoline, the 2006 IPCC Guidelines Tier 1 approach has been used. As explained above, aviation gasoline fuel consumption was split into 90% domestic non-commercial flights and 10% international non-commercial flights. The respective emissions were estimated using the IPCC default emission factors for aviation gasoline (please refer to section 3.2.2.1.3 for more details).

⁶³ This oral communication has been documented internally by the energy expert (ARR 2011, §48).

3.2.2.1.3 Emission factors

The emission factors, used for calculating emissions from International Bunkers – Aviation, are listed in Table 3-12. Emission factors for jet kerosene are taken from the IPCC 2006 Guidelines.

Table 3-12 – Emission factors for International Bunkers - Aviation

International Bunkers - Aviation Emission Factors for 2019								
Fuel	Flight Phase	CO ₂		CH ₄		N ₂ O		Source
		EF	(unit) type	EF	(unit) type	EF	(unit) type	
Jet Kerosene	LTO	71.50	(t/TJ) D	0.00008	(t/LTO) D	0.0001	(t/LTO) D	2006 IPCC GL
	cruise	71.50	(t/TJ) D	0.00	(t/t fuel) D	0.002	(t/t fuel) D	
Aviation gasoline	all	70 000	(kg/TJ) D	0.50	(kg/TJ) D	2.00	(kg/TJ) D	

Source: Environment Agency

3.2.2.2 Marine Bunkers

As motorised navigation only occurs on the Moselle River, about 20% of the total GHG emissions from shipping are considered as international and are, thus, reported under International Bunkers – Marine.

Activity data and emissions are listed in Table 3-11.

For more details on activity data sources, methodological issues, the split between international and domestic navigation and emission factors used, please refer to Section 3.2.9.5.

3.2.2.3 Multilateral Operations

There are no multilateral operations in Luxembourg, hence notation key NO is used.

3.2.2.4 Category-specific recalculations including changes made in response to the review process

Revisions and recalculations relevant to International Bunkers since submission 2020v1 are described in Table 3-13.

Table 3-13 - Recalculations done since submission 2020v1

GHG source & sink category	Revisions 2020v1 → 2021v1	Type of revision
1D1a – International Aviation – jet kerosene	change of methodology for CO ₂ emissions. 1) for LTO: switched from emissions per LTO to emissions per TJ (71.5 t/TJ = default EF IPCC 2006). 2) for cruise: corrected EF from 70 to 71.5 t/TJ (IPCC 2006)	Methodology change & error correction
1D1b – International Navigation – diesel oil, biodiesel, other fossil fuels	The total amounts of gasoline, diesel oil, LPG, bioethanol and biodiesel sold in Luxembourg are obtained from the national energy balance, and the activity data is then allocated to the different road and offroad subcategories with the NEMO and GEORG models developed by TU Graz. No changes were made to the total amounts of the different fuel types, but minor reallocations were done for diesel, biodiesel and other fossil fuels from 1A3d-Domestic Navigation to 1D1b-International navigation for the years 1995-2018 (for details please refer to Table 3-77). These reallocations are due to an update of the specific fuel consumption of offroad vehicles (Schwingshackl, Rexeis, & Weller, 2020).	AD reallocation

3.2.2.5 Category-specific QA/QC and verification

Apart from the standard QA/QC procedures, fuel splits between International Bunker Fuels and national consumptions were checked to avoid omissions or potential double counting. Jet type kerosene consumption as reported by the national statistics institute in the national energy balance and compared to the inventory is considered to be consistent (see Table 3-15 - Discrepancies in International Bunkers – Aviation), except for a small discrepancy for the year 2018 (22 TJ). Also noteworthy is the fact that the national statistical institute does not publish data prior to the year 2000 on its website.

When comparing inventory data with the data as reported by Eurostat, small discrepancies are observed for every year between 1990 and 1999, as well as for 2018.

Furthermore, cross-checking between national statistics and data provided by the fuel provider was also undertaken, and the only discrepancy that could be identified is a difference of 22 TJ for the year 2018. This was brought to the attention of the national statistics institute, which will address this issue for the next version of the national energy balance.

3.2.2.6 Planned Improvements

Planned improvements, as listed in Table 3-14, will be explored, based on available resources.

Table 3-14– Planned improvements for International Bunkers

GHG source & sink category	Planned improvement
International Bunkers	No further improvements planned

Table 3-15 - Discrepancies in International Bunkers – Aviation

Discrepancies in International Bunkers - Aviation between inventory data and international data																															
Product	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Aviation gasoline	kt	1	1	1	:	:	:	:	:	:	:	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Aviation gasoline	TJ	44	44	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Kerosene type jet fuel	kt	128	133	128	125	162	184	201	244	275	323	312	337	365	380	414	421	394	423	426	408	419	392	361	363	394	445	493	558	597	583
Kerosene type jet fuel	TJ	5'517	5'733	5'517	5'388	6'983	7'931	8'664	10'518	11'854	13'923	13'433	14'529	15'742	16'399	17'844	18'130	16'967	18'238	18'358	17'588	18'050	16'887	15'581	15'659	16'984	19'161	21'262	24'041	25'728	25'147
Kerosene type jet fuel	TJ/kt or G/Jt	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105
Source of data	Eurostat																														
Extracted on	08.04.21																														
Product	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Aviation gasoline	TJ											11.484	9.701	10.353	11.136	8.613	6.308	7.134	9.092	8.570	18.053	15.312	12.050	7.844	8.657	7.961	9.570	9.657	9.657	10.223	9.048
Kerosene type jet fuel	TJ											13'433	14'529	15'742	16'399	17'844	18'130	16'967	18'238	18'358	17'588	18'050	16'887	15'581	15'659	16'984	19'161	21'262	24'041	25'728	25'147
Source of data	STATEC																														
Extracted on	08.04.21																														
Product	Unit	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Aviation gasoline	kt	0.078	0.119	0.168	0.217	0.257	0.277	0.283	0.287	0.247	0.253	0.264	0.223	0.238	0.256	0.198	0.145	0.164	0.209	0.197	0.415	0.352	0.277	0.180	0.199	0.183	0.220	0.222	0.212	0.206	0.185
Aviation gasoline	TJ	3.410	5.180	7.310	9.460	11.190	12.050	12.308	12.480	10.742	10.986	11.484	9.701	10.353	11.136	8.613	6.308	7.134	9.092	8.570	18.053	15.312	12.050	7.844	8.657	7.961	9.570	9.659	9.212	8.965	8.042
Aviation gasoline	TJ/kt or G/Jt	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500	43.500
Kerosene type jet fuel	kt	127.963	133.744	129.296	127.870	162.225	183.890	199.814	239.053	289.809	326.980	311.635	337.061	365.192	380.438	413.955	420.603	393.619	423.100	425.897	408.027	418.748	391.764	361.458	363.269	394.022	444.515	493.262	557.731	596.377	583.395
Kerosene type jet fuel	TJ	5'516	5'765	5'573	5'512	6'993	7'927	8'613	10'304	12'492	14'094	13'433	14'529	15'742	16'399	17'844	18'130	16'967	18'238	18'358	17'588	18'050	16'887	15'581	15'659	16'984	19'161	21'262	24'041	25'707	25'147
Kerosene type jet fuel	TJ/kt or G/Jt	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105	43.105
Source of data	GHG inventory submission 2021v1																														
Extracted on	08.04.21																														
Difference	Kerosene type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Inventory/Eurostat	TJ	-2	32	56	124	10	-5	-51	-213	638	172	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-22	0	
Inventory/Statc	TJ	NA	-0	0	0	-0	0	0	-0	-0	0	0	-0	-0	0	0	0	0	-0	-0	-22	0									

3.2.3 Feedstocks and non-energy use

Non-energy use of fuels is considered in the national energy balance. Below explanations for the reported non-energy use is provided together with information on where CO₂ emissions due to manufacture, use and disposal of carbon containing products are considered.

For the fraction of carbon stored, the IPCC default values are applied.

3.2.3.1 Lubricants

Manufacturing: manufacturing of lubricants does not occur in Luxembourg.

Use: Lubricants are either used in road transportation (motor oil and greases) or in the manufacturing and construction industry (mainly greases). Emissions from lubricants use are reported under category 2D1 – Lubricant Use. Please refer to section 4.5.1 for more details on the estimation of emissions from lubricant use.

Disposal: incineration of lubricants (waste oil) does not occur in Luxembourg. Waste oil is either recycled or exported.

3.2.3.2 Bitumen

Manufacturing: manufacturing of bitumen does not occur in Luxembourg.

Use: by default the carbon contained in bitumen is considered to be entirely stored in the product, i.e. asphalt for road paving.

Disposal: CO₂ emissions from the disposal of bitumen are assumed to be negligible. Recycling is not considered.

3.2.3.3 Coke oven coke

Manufacturing: not occurring. All coke used in the iron and steel industry is imported.

Use: CO₂ emissions from coke used in iron and steel industry are reported under 2.C.1 – Iron and Steel Production.

Disposal: not applicable.

3.2.3.4 Other bituminous coal

Manufacturing: Manufacturing of electrodes from anthracite used in the electric arc furnaces does not occur in Luxembourg.

Use: Emissions from the use of electrodes in the iron and steel production are considered in category 2.C.1 – Iron and steel production.

Disposal: not applicable.

3.2.3.5 Other oil products

Manufacturing: not occurring. All products such as white spirits, etc. are imported.

Use: CO₂ emissions from solvent and other products use are considered in category 2.D.3. - Non-energy products from fuels and solvent use – Other – Solvent use.

Disposal: emissions from the disposal of plastics in landfills are considered in 6.A and emissions from incineration, with energy recovery, of waste plastics are considered in 1 A 1 a.

3.2.3.6 Category-specific recalculations including changes made in response to the review process

No revisions and recalculations were done since submission 2020v1.

3.2.3.7 Planned improvements

No further improvements are planned.

3.2.4 CO₂ capture from flue gases and subsequent CO₂ storage

CO₂ capture from flue gases and CO₂ storage is not occurring in Luxembourg.

3.2.5 Country specific issues

3.2.5.1 Activity data

As Luxembourg's industrial sector is relatively small compared to larger countries, one has to keep in mind, that, when analysing trends in activity data, relatively large fluctuations may occur in between years simply due to the fact that a facility was temporally switched off for maintenance reasons, or shut-down for good. This may then be reflected by a sharp decrease in the activity data. On the other hand, the bringing into service of a single installation may lead to a sharp increase of activity data in a source category, and consequently also an increase in emissions.

3.2.5.2 Methodological choices

In general, the IPCC methodologies were applied for IPCC category 1-Energy, except for road transportation and offroad mobile machinery, where detailed calculation models (NEMO and GEORG) were used for non-CO₂ greenhouse gases.

Methodologies used were mostly Tier 1 for solid fuels (except blast furnace gas) and liquid fuels (residual fuel oil, aviation gasoline, kerosene) and Tier 2 for liquid fuels (motor gasoline, diesel oil, gas oil and LPG), gaseous fuel (natural gas), blast furnace gas and waste incineration (Tier 2a, 2006 IPCC Guidelines). For CH₄ and N₂O in road transportation and the off-road sector, the model is considered as a Tier 3 methodology.

Emissions are estimated by multiplying each activity, according to its fuel input, by an emission factor.

Activity data are taken from the energy balance (2000-2019) as compiled by the national statistics institute (STATEC), or obtained directly from plant operators. Energy balance data, covering 1990 to 1999, originates from the Ministry of Economic Affairs (Energy Directorate). Customs and Excise Administration provide data on liquid fuels and biofuels which is used for QA/QC purposes. Activity data obtained through the Emission Trading System (ETS) are used for QA/QC procedures by comparing its data to the data reported by the plant operators.

Net calorific values used for conversion of fuel activity data from physical units into energy units were fixed to national values in agreement with national statistics (STATEC) and the "Office Commercial du Ravitaillement" (OCRA) of the Ministry of Economic Affairs.⁶⁴ These are mostly country-specific values, however, where no such values were available, defaults from the 2006 IPCC Guidelines or the European Directive on Statistics (2006/32/EC) were used (see Table 3-16). For natural gas, please refer to Table 3-17.

Table 3-16 – Fuel Properties for 2019

Fuel Characteristics for 2019						
Country-specific Net Calorific Values and Densities						
Fuel	Net calorific value			Density		
	<i>NCV</i>	<i>Unit</i>	<i>Source</i>	<i>Density</i>	<i>Unit</i>	<i>Source</i>
Anthracite	26.70	GJ/t	2006 IPCC GL			
Bituminous Coal & Coking Coal	24.40	GJ/t	ETS			
Patent Fuel ("boulets")	28.20	GJ/t	2006 IPCC GL			
Brown Coal Briquettes (incl. Lignite dust)	22.20	GJ/t	ETS			
Coke Oven Coke	28.50	GJ/t	EU-2006/32/EC			
Tires	28.20	GJ/t	ETS			
Dry sewage sludge	10.10	GJ/t	ETS			
Humid sewage sludge	2.15	GJ/t	ETS			
Fluff	22.50	GJ/t	ETS			
Waste solvents	29.86	GJ/t	ETS			
Residual Fuel Oil (low / high sulphur)	40.00	GJ/t	EU-2006/32/EC	0.92 / 0.96	kg/l	Fuel Providers
Gas Oil	42.49	GJ/t	Fuel Providers	0.85	kg/l	Fuel Providers
Diesel Oil	42.49	GJ/t	Fuel Providers	0.85	kg/l	Fuel Providers
Gasoline	43.05	GJ/t	Fuel Providers	0.76	kg/l	Fuel Providers
Liquefied Petroleum Gas (LPG)	46.00	GJ/t	EU-2006/32/EC	0.53	kg/l	Fuel Providers
Aviation Gasoline	43.50	GJ/t	Fuel Provider	0.71	kg/l	Fuel Provider
Jet Kerosene	43.11	GJ/t	Fuel Provider			
Other Kerosene	43.80	GJ/t	2006 IPCC GL			
Wood	7.15	GJ/m ³	Statec	0.69	t/m ³	Statec
Pellets	11.00	GJ/m ³	Statec	0.65	t/m ³	Statec
Wood chips	7.81	GJ/m ³	Statec	0.69	t/m ³	Statec
Biogaz	0.02	GJ/m ³	Statec			
Biodiesel (pure)	39.76	GJ/t	Fuel Providers			
Biogasoline (pure)	26.80	GJ/t	Fuel Providers			
Lubricants	40.20	GJ/t	2006 IPCC GL			
Bitumen	40.20	GJ/t	2006 IPCC GL			

Source: Environment Agency

Emission factors are defaults from 2006 IPCC Guidelines for solid (except blast furnace gas) and some liquid fuels and country-specific for natural gas, motor gasoline, gas/diesel oil, and LPG.

3.2.5.3 Country specific emission factors

Blast Furnace Gas

A country-specific CO₂ emission factor for the combustion of blast furnace gas was determined based on emission measurement data and on the CO and CO₂ contents of blast furnace gas produced in Luxembourg's blast furnaces in 1990.⁶⁵ As no further measurements were available until the closure of the blast furnaces in 1997, the same emission factor, *i.e.* 257'181 kg CO₂/TJ, was used for the years 1990 to 1997.

Similarly, a country-specific CO₂ emission factor for blast furnace gas lost in distribution or flared was determined: 245'323 kg CO₂/TJ.

Natural Gas

In Luxembourg, one operator, CREOS S.A. (formerly SOTEG S.A.)⁶⁶, operates the national natural gas network (Figure 3-5). There are four entry points, from where natural gas is imported: two with Belgium (Braz and Pétange) with a capacity of 0.16 and 0.06 mio. Nm³/h, respectively, one with Germany (Remich) with a capacity of 0.19 Mio Nm³/h and one with France (Esch/Alzette) with a capacity of 0.02 mio. Nm³/h.

For the calculation of the country-specific CO₂ emission factor for natural gas, the operator provides the following parameters for each entry point and for each month of a given year:

- chemical composition (methane, ethane, propane, i-butane, n-butane, i-pentane, n-pentane, hexane & higher, CO₂ and N₂) expressed in mol%;
- physical properties: density (kg/Nm³) and gross calorific value (GCV: MJ/Nm³);
- monthly import/consumption (mio. Nm³).⁶⁷

The monthly consumption is converted into energy units (TJ) using the respective NCV, which is calculated by multiplying the GCV with a conversion factor of 0.90⁶⁸.

From the monthly chemical composition, a monthly average "molecular" weight for natural gas (g/mol), "molecular" density (mol/Nm³) and monthly carbon content (mol C/ mol natural gas) are derived for each entry point. The monthly carbon content is then converted into a monthly emission factor (g CO₂/MJ) assuming full oxidation of carbon to carbon dioxide. By multiplying the monthly emission factor with the respective monthly natural gas consumption, a monthly CO₂ emission is obtained. Finally, by dividing the yearly national emissions (sum of the monthly emissions of all 4 entry points) by the yearly national consumption (sum of the monthly consumptions of all 4 entry points), the country-specific emission factor for the respective year is obtained.

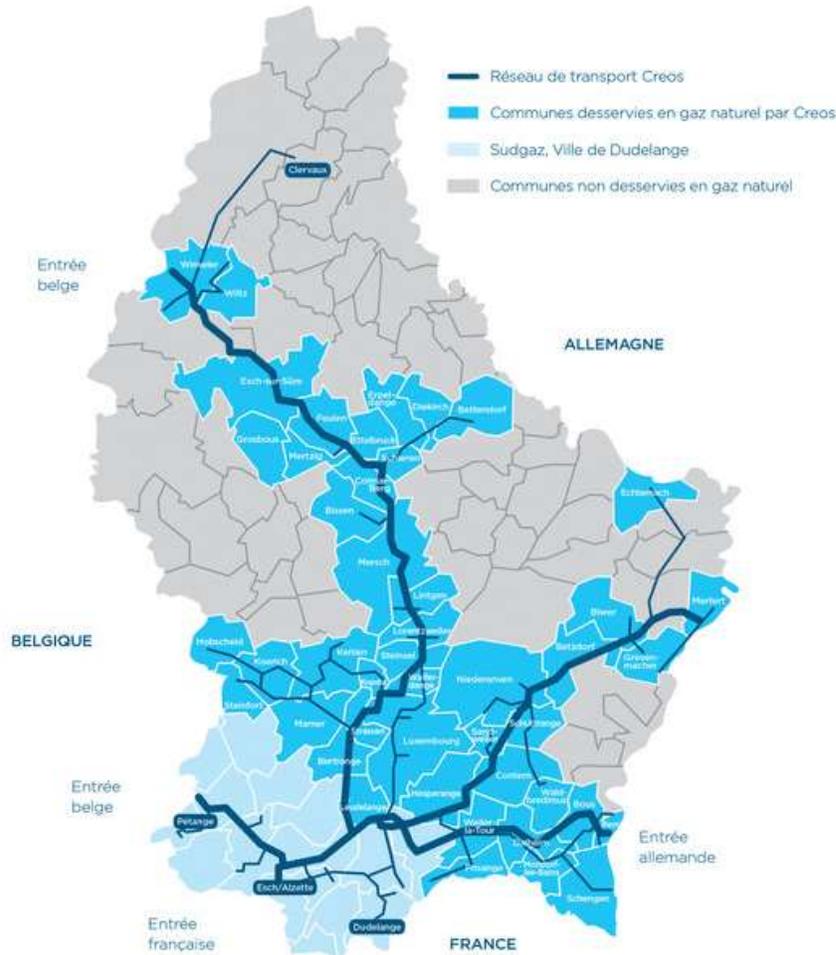
65 TÜV Rheinland, 1990, Bericht: 934/651014.

66 <http://www.creos.lu>

67 Nm³ is defined at a pressure of 1035 mbar and 0 degree Celsius.

68 IEA Energy Statistics Manual, 2005, Table A3.12, p.183

Figure 3-5 - Natural gas network



Source: Creos (<http://www.creos-net.lu/creos-luxembourg/infrastructure/reseau-de-gaz-naturel.html>)

Country-specific NCVs and emission factors have, thus, been obtained for the years 1991, 1995, 2000, 2005-2019 (Table 3-17). For the years in-between, the values have been interpolated.

Table 3-17 - Country-specific NCV and Emission Factors for Natural Gas: 1990-2019

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
EF (t CO ₂ /TJ)	57.76	57.74	57.85	57.89	57.94	57.93	57.55	57.20	56.86	56.52
NCV (MJ/Nm ₃)	36.58	36.67	36.62	36.64	36.66	36.75	36.85	36.92	36.99	37.06
Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
EF (t CO ₂ /TJ)	56.22	56.26	56.40	56.53	56.67	56.91	57.01	56.79	56.66	57.06
NCV (MJ/Nm ₃)	37.10	37.01	36.96	36.91	36.86	36.85	36.72	36.64	36.48	36.72
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
EF (t CO ₂ /TJ)	56.71	56.99	56.79	56.68	56.76	56.76	56.56	56.58	56.21	56.09
NCV (MJ/Nm ₃)	36.73	36.56	36.38	36.19	36.30	36.81	36.93	36.98	36.76	36.78

Source: Environment Agency

Motor Gasoline, Gas/Diesel Oil, Liquefied Petroleum Gas

In Luxembourg, refined oil products such as motor gasoline, gasoil, diesel oil and liquefied petroleum gas (LPG) are exclusively imported from the neighbouring countries Belgium, the Netherlands and Germany, and to a minor extent from France. As the Luxembourgish association of mineral oil companies (Groupement Pétrolier Luxembourgeois a.s.b.l.) was not able to provide country-specific carbon contents of the before-mentioned fuels to the Environment Agency, country-specific emission factors for motor gasoline, gas/diesel oil and LPG were derived from the emission factors of the corresponding import countries in relation with the yearly quantities imported.⁶⁹ Thus, country-specific emission factors have been obtained for the entire time-series (Table 3-18).

Table 3-18 - Country-specific Emission Factors for Gas/Diesel Oil, Motor Gasoline and LPG: 1990-2019 (tCO₂/TJ)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Gas/Diesel Oil	74.17	74.16	74.13	74.17	74.20	74.20	74.19	74.18	74.17	74.17
Motor Gasoline	72.58	72.61	73.25	73.04	72.98	72.93	72.96	72.83	72.88	72.82
LPG	65.07	65.10	65.00	64.93	64.93	64.93	64.93	64.93	64.95	65.26
Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Gas/Diesel Oil	74.21	74.22	74.22	74.19	74.15	74.14	74.14	74.14	74.09	74.07
Motor Gasoline	72.63	72.70	72.68	72.76	72.56	72.63	72.66	72.55	72.51	72.47
LPG	64.94	64.94	64.96	64.98	64.95	64.95	64.96	64.93	64.93	64.96
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Gas/Diesel Oil	74.13	74.11	74.13	74.14	74.07	74.13	74.14	74.15	74.13	74.08
Motor Gasoline	72.44	72.47	72.46	72.60	73.11	73.22	73.20	73.18	73.09	73.16
LPG	64.93	64.93	64.93	64.93	64.93	64.93	65.17	65.23	65.21	65.49

Source: Environment Agency

In submission 2012v1.2, Luxembourg's country specific emission factor was revised in accordance with a technical review recommendation during the 2012 technical review of the greenhouse gas emission inventory of Luxembourg to support the determination of annual emission allocations under the European Decision 406/2009/EC. Indeed, the TERT (Technical Expert Review Team) observed that:

"Luxembourg is using the CO₂ EF value for gasoline used by Belgium that in turn uses the IPCC default value. CO₂ from road transportation is a key category, however the 2000 IPCC Good Practice Guidance (GPG) states in this respect: 'For traded fuels in common circulation, it is good practice to obtain the carbon content of the fuel and net calorific values from fuel suppliers, and use local values wherever possible. If these data are not available, default values can be used.'

69 ARR 2009, § 48

The TERT also notes that the implied EF is at the low end as compared with other Member States (which have country specific data), which could indicate an underestimation of emissions. The TERT also notes that local or country-specific data should be available in Luxembourg and that therefore the use of the default value is not in line with good practice."

In response to this observation and because no data on the carbon content is available in Luxembourg, Luxembourg decided to revise its CO₂ emission factor for motor gasoline, based on the CO₂ emission factor of the two other neighbouring countries from which motor gasoline is imported. Indeed, as the Netherlands and Germany both used a CO₂ EF of 72 tCO₂/TJ at that time, Luxembourg decided to apply the same EF as a country-specific EF for the entire time series, to which the TERT agreed.

Then, during the UNFCCC centralised review in September 2016, the ERT recommended that Luxembourg switches back to the previous approach where a country-specific CO₂ emission factor for gasoline is determined according to the quantities of gasoline imported from the different countries and the respective emission factors used by these countries. This approach is used in this submission for the entire time-series, in all sub-categories to which gasoline is allocated (1A2gvii, 1A3b, 1A3d, 1A4b).

Table 3-19, Table 3-20 and Table 3-21 show the data used for the calculation of the country-specific CO₂ emission factors for gas/diesel oil, motor gasoline and LPG based on imported quantities and emission factors of importing countries. The source for the emission factors of the importing countries is CRF Table1.A(a)s3 from their 2019 submissions to the UNFCCC⁷⁰.

Table 3-19 – Calculation of the country-specific CO₂ emission factor for gas/diesel oil based on imported quantities and emission factors of importing countries

Gas/Diesel Oil imports (kt)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Belgium	668	768	774	825	872	829	892	926	1006	1015
Germany	14	11	17	19	15	14	6	7	17	26
Netherlands	91	135	196	109	65	52	80	81	102	93
Total imports	773	914	987	953	952	895	978	1014	1125	1134
Gas/Diesel Oil EF (tCO₂/TJ)	<i>(IPCC default EF=74.1)</i>									
Belgium	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24
Germany	74.00	74.00	74.00	74.00	74.00	74.00	74.00	74.00	74.00	74.00
Netherlands	73.72	73.72	73.72	73.72	73.72	73.72	73.72	73.55	73.55	73.55
Luxembourg	74.17	74.16	74.13	74.17	74.20	74.20	74.19	74.18	74.17	74.17
Gas/Diesel Oil imports (kt)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Belgium	1260	1329	1389	1391	1624	1715	1689	1542	1586	1574
Germany	42	73	94	228	161	174	158	367	348	201
Netherlands	31	14	8	27	178	245	218	67	133	147
Total imports	1333	1416	1491	1646	1963	2134	2065	1976	2067	1922
Gas/Diesel Oil EF (tCO₂/TJ)	<i>(IPCC default EF=74.1)</i>									
Belgium	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24
Germany	74.00	74.00	74.00	74.00	74.00	74.00	74.00	74.00	74.00	74.00
Netherlands	73.55	73.55	73.55	73.55	73.55	73.55	73.48	72.73	72.52	72.45
Luxembourg	74.21	74.22	74.22	74.19	74.15	74.14	74.14	74.14	74.09	74.07
Gas/Diesel Oil imports (kt)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Belgium	1622	1793	1747	1596	1534	1536	1473	1309	1396	1431
Germany	281	190	215	426	288	276	316	465	432	385
Netherlands	128	138	90	54	146	77	62	26	61	127
Total imports	2031	2121	2052	2076	1968	1889	1851	1800	1890	1943
Gas/Diesel Oil EF (tCO₂/TJ)	<i>(IPCC default EF=74.1)</i>									
Belgium	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24	74.24
Germany	74.00	74.00	74.00	74.00	74.00	74.00	74.00	74.00	74.03	74.03
Netherlands	73.04	72.69	72.49	72.45	72.45	72.45	72.45	72.45	72.45	72.45
Luxembourg	74.13	74.11	74.13	74.14	74.07	74.13	74.14	74.15	74.13	74.08

⁷⁰ <https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/national-inventory-submissions-2019>

Table 3-20 - Calculation of the country-specific CO₂ emission factor for motor gasoline based on imported quantities and emission

factors of importing countries

Motor gasoline imports (kt)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Belgium	396	442	398	405	449	426	440	485	482	492
Germany	5	13	33	41	40	28	17	15	16	15
Netherlands	18	22	101	71	67	57	64	49	55	48
Total imports	419	477	532	517	556	511	521	549	553	555
Motor gasoline EF (tCO₂/TJ)	<i>(IPCC default EF=69.3)</i>									
Belgium	72.41	72.41	72.41	72.41	72.41	72.41	72.41	72.41	72.41	72.41
Germany	73.07	73.06	73.06	73.06	73.07	73.07	73.08	73.07	73.08	73.09
Netherlands	76.34	76.50	76.65	76.64	76.81	76.80	76.78	76.94	76.94	76.94
Luxembourg	72.58	72.61	73.25	73.04	72.98	72.93	72.96	72.83	72.88	72.82
Motor gasoline imports (kt)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Belgium	545	507	494	515	512	451	400	383	346	348
Germany	25	35	31	16	24	22	31	27	60	23
Netherlands	25	32	29	42	15	21	23	18	1	9
Total imports	595	574	554	573	551	494	454	428	407	380
Motor gasoline EF (tCO₂/TJ)	<i>(IPCC default EF=69.3)</i>									
Belgium	72.41	72.41	72.41	72.41	72.41	72.41	72.41	72.41	72.41	72.41
Germany	73.09	73.09	73.09	73.09	73.10	73.10	73.11	73.11	73.12	73.12
Netherlands	76.94	76.94	76.94	76.94	76.94	76.94	76.48	74.72	74.28	73.43
Luxembourg	72.63	72.70	72.68	72.76	72.56	72.63	72.66	72.55	72.51	72.47
Motor gasoline imports (kt)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Belgium	333	338	335	240	221	204	214	202	227	231
Germany	15	8	0	50	70	80	81	91	89	101
Netherlands	0	22	15	27	19	2	0	0	0	0
Total imports	348	368	350	317	310	286	295	293	316	332
Motor gasoline EF (tCO₂/TJ)	<i>(IPCC default EF=69.3)</i>									
Belgium	72.41	72.41	72.41	72.41	72.41	72.41	72.41	72.24	72.23	72.23
Germany	73.12	73.02	73.09	73.09	75.29	75.29	75.29	75.29	75.29	75.29
Netherlands	73.43	73.22	73.56	73.39	73.22	73.02	73.02	73.02	73.02	73.02
Luxembourg	72.44	72.47	72.46	72.60	73.11	73.22	73.20	73.18	73.09	73.16

Table 3-21 - Calculation of the country-specific CO₂ emission factor for LPG based on imported quantities and emission factors of

importing countries

LPG imports (kt)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Belgium	17	16	15	15	14	14	18	24	30	26
Germany	1	2	1	0	0	0	0	0	0	0
Netherlands	1	1	0	0	0	0	0	0	0	6
France	1	1	2	0	0	0	0	0	2	0
Total imports	20	20	18	15	14	14	18	24	32	32
LPG EF (tCO₂/TJ) (IPCC default EF=63.1)										
Belgium	64.93	64.93	64.93	64.93	64.93	64.93	64.93	64.93	64.93	64.93
Germany	65.56	65.56	65.54	65.37	65.33	65.33	65.21	65.21	65.23	64.04
Netherlands	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70
France	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25
Luxembourg	65.07	65.10	65.00	64.93	64.93	64.93	64.93	64.93	64.95	65.26
LPG imports (kt)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Belgium	29	32	24	19	19	16	13	14	14	12
Germany	0	0	0	0	0	0	0	0	0	0
Netherlands	0	0	0	0	0	0	0	0	0	0
France	1	1	2	3	1	1	1	0	0	1
Total imports	30	33	26	22	20	17	14	14	14	13
LPG EF (tCO₂/TJ) (IPCC default EF=63.1)										
Belgium	64.93	64.93	64.93	64.93	64.93	64.93	64.93	64.93	64.93	64.93
Germany	64.40	64.51	64.38	64.95	65.26	65.29	65.36	66.61	65.23	65.25
Netherlands	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70
France	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25
Luxembourg	64.94	64.94	64.96	64.98	64.95	64.95	64.96	64.93	64.93	64.96
LPG imports (kt)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Belgium	14	10	12	11	9	9	10	8	6	6
Germany	0	0	0	0	0	0	2	2	2	2
Netherlands	0	0	0	0	0	0	0	0	0	0
France	0	0	0	0	0	0	0	0	0	0
Total imports	14	10	12	11	9	9	12	10	8	10
LPG EF (tCO₂/TJ) (IPCC default EF=63.1)										
Belgium	64.93	64.93	64.93	64.93	64.93	64.93	64.93	64.93	64.93	64.93
Germany	65.33	65.39	65.40	65.41	65.46	66.35	66.33	66.33	66.33	66.33
Netherlands	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70	66.70
France	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25	65.25
Luxembourg	64.93	64.93	64.93	64.93	64.93	64.93	65.17	65.23	65.21	65.49

3.2.6 Energy Industries (1.A.1): Public Electricity and Heat Production (1.A.1.a)

3.2.6.1 Source category description

This section describes GHG emissions resulting from fuel combustion activities in energy industries, which, in Luxembourg, only originate from public electricity and heat production plants. There is neither manufacturing of solid fuels, nor petroleum refining in Luxembourg. Hence, IPCC category *1A1 – Energy Industries* equals IPCC sub-category *1A1a – Public Electricity and Heat Production*.

In this category CO₂, CH₄ and N₂O emissions from combustion activities for electricity and heat production as well as from municipal waste incineration are reported. In Luxembourg, municipal waste is combusted with energy recovery at the sole waste incineration plant (SIDOR) where recovered heat and electricity are distributed to the urban district network. Therefore, the emissions are reported under fuel combustion emissions.

In 2019, this source category was responsible for 2.55% of GHG emissions from fuel combustion activities (0.35% in 1990) and represented 2.19% of the national total GHG emissions in CO₂e, excluding LULUCF (0.28% in 1990).

Table 3-22 summarizes GHG emissions for category 1.A.1. - Energy Industries. Compared to 2018, GHG emissions have increased by 1.19 %.

Regarding CO₂ emissions, 1A1a - Public electricity and heat production is a key category in 2019 for gaseous fuels and other fuels (MSW): see Table 1-6 in Section 1.5.1.1.

Table 3-22 – GHG emission trends in CO₂eq in category 1A1 – Energy Industries: 1990-2019

1A1 - Energy Industries												
GHG emissions by source & sink category (Gg)												
Year	1A1a - Public Electricity & Heat Production				1A1b - Petroleum Refining				1A1c - Manuf. of Solid Fuels & Other Energy Ind.			
	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)
1990	35.84	33.48	0.036	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1991	37.50	35.03	0.038	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1992	37.39	34.93	0.038	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1993	35.57	33.23	0.036	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1994	34.80	32.51	0.035	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1995	93.72	91.47	0.035	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1996	82.49	80.75	0.027	0.004	NO	NO	NO	NO	NO	NO	NO	NO
1997	89.89	87.83	0.032	0.004	NO	NO	NO	NO	NO	NO	NO	NO
1998	156.31	153.76	0.040	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1999	173.89	170.97	0.045	0.006	NO	NO	NO	NO	NO	NO	NO	NO
2000	119.44	116.64	0.043	0.006	NO	NO	NO	NO	NO	NO	NO	NO
2001	280.88	277.95	0.046	0.006	NO	NO	NO	NO	NO	NO	NO	NO
2002	1 028.40	1 024.70	0.060	0.007	NO	NO	NO	NO	NO	NO	NO	NO
2003	1 036.24	1 032.42	0.062	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2004	1 259.55	1 255.23	0.070	0.009	NO	NO	NO	NO	NO	NO	NO	NO
2005	1 242.72	1 238.67	0.066	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2006	1 306.89	1 302.58	0.070	0.009	NO	NO	NO	NO	NO	NO	NO	NO
2007	1 183.09	1 178.80	0.069	0.009	NO	NO	NO	NO	NO	NO	NO	NO
2008	997.27	993.06	0.068	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2009	1 194.06	1 189.72	0.070	0.009	NO	NO	NO	NO	NO	NO	NO	NO
2010	1 206.51	1 202.46	0.066	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2011	1 008.92	1 004.69	0.068	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2012	1 046.51	1 042.28	0.068	0.009	NO	NO	NO	NO	NO	NO	NO	NO
2013	692.39	688.40	0.063	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2014	675.73	670.57	0.081	0.010	NO	NO	NO	NO	NO	NO	NO	NO
2015	469.00	463.36	0.088	0.012	NO	NO	NO	NO	NO	NO	NO	NO
2016	264.43	258.53	0.092	0.012	NO	NO	NO	NO	NO	NO	NO	NO
2017	253.65	246.77	0.107	0.014	NO	NO	NO	NO	NO	NO	NO	NO
2018	232.68	224.11	0.133	0.018	NO	NO	NO	NO	NO	NO	NO	NO
2019	235.46	224.03	0.177	0.023	NO	NO	NO	NO	NO	NO	NO	NO
Trend 1990-2019	557.01%	569.13%	385.77%	384.07%	NA	NA	NA	NA	NA	NA	NA	NA
Trend 2018-2019	1.19%	-0.03%	33.06%	33.23%	NA	NA	NA	NA	NA	NA	NA	NA

Source: Environment Agency.

Notes: CH₄ emissions are converted in CO₂e by multiplying the emissions by 25, *i.e.* the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon. N₂O emissions are converted in CO₂e by multiplying the emissions by 298, *i.e.* the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

3.2.6.2 Methodological issues

3.2.6.2.1 Activity data

Activity data of the various installations considered in 1A1a:

- combined heat and power (CHP) installations, which have appeared at the beginning of the 1990s. Those installations generally use combustion engines, and they are operated with natural gas and/or gasoil and to a smaller extent with biogas or wood & wood wastes. The activity rates are based on information received from the operators and on the energy balance as compiled by the national statistics institute (STATEC).
- a CHP gas turbine (350MW) running on natural gas and operated since 2002 by Twinerg S.A. Since heat was not recovered from 2002 to 2010, this unit was counted as a thermal power plant and not as a cogeneration plant in official statistics. From 2011 on, however, heat recovery was done and the installation was considered as a cogeneration plant. This classification change has no impact on the GHG emission estimates since it is the fuel(s) used and the technology that matter. The Twinerg plant was shut down during 2016. There are several smaller CHP gas turbines that are operated on industrial sites while producing heat and electricity mainly for the respective industries. Emissions related to these are accounted for in 1A2- Manufacturing Industries and Construction, as these installations are considered as autoproducers.
- one waste incinerator (SIDOR) that is fed with natural gas, gas oil, fluff, and waste (composed of municipal solid waste and bulky waste). The incinerated waste is composed of paper/cardboard, textiles, food waste, wood, garden & park waste, nappies, rubber & leather, plastics, multilayer composite material, metal, glass, other inert waste. The municipal solid waste (MSW) and bulky waste (BW) are provided by the three syndicates SIDEDEC, SIDOR, and SIGRE. Both SIDOR and SIGRE deliver the waste directly to the incinerator while the waste from SIDEDEC first undergoes a pre-treatment at a different facility before arriving at the incinerator (some part is not taken to the incinerator after treatment but deposited on land⁷¹). The waste flow to the incinerator is depicted in Figure 3-6.

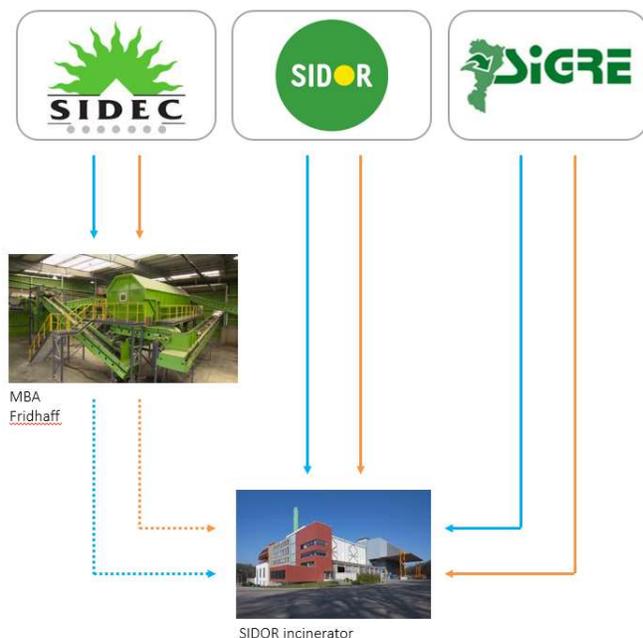


Figure 3-6 Waste flow from the three syndicates SIDEDEC, SIDOR, and SIGRE to the incinerator. The blue lines represent municipal solid waste while the orange lines represent bulky waste. Straight lines represent untreated waste while dotted lines represent treated waste.

71 For the different waste treatment schemes, see Chapter 7 on waste.

No industrial and hazardous wastes are incinerated because they are exported. The MSW, delivered from SIDOR and SIGRE to the incinerator, is split into the twelve MSW fractions mentioned above according to the following studies. The years for which the studies have been done act as pillar years. For the years in-between, a linear interpolation was carried out.

- ECO-Conseil s.à.r.l., "Restabfallanalyse 1992/1994", Luxembourg, 2002;
- ECO-Conseil s.à.r.l., "Restabfallanalyse 2001 im SIDOR", Luxembourg, 2002;
- ECO-Conseil s.à.r.l., "Restabfallanalyse 2004/05 im Großherzogtum Luxemburg, Band 1: Kompendium", Luxembourg, 2005;
- ECO-Conseil s.à.r.l., "Restabfallanalyse 2009/10 im Großherzogtum Luxemburg, Band 1: Kompendium", Luxembourg, 2010;
- ECO-Conseil s.à.r.l., "Restabfallanalyse 2013/14 im Großherzogtum Luxemburg, Band 1: Kompendium", Luxembourg, 2016.
- ECO-Conseil s.à.r.l., "Restabfallanalyse 2018/2019 im Großherzogtum Luxemburg, Endbericht", Luxembourg, 2019.

The BW, delivered from SIDOR and SIGRE to the incinerator, is also split into the twelve MSW fractions according to the following studies. The years for which the studies have been done act as pillar years. For the years in-between, a linear interpolation was carried out.

- ECO-Conseil s.à.r.l., "Sperrmüllanalyse 2009 im Großherzogtum", Luxembourg, 2010.
- ECO-Conseil s.à.r.l., "Sperrmüllanalyse 2015 im Großherzogtum", Luxembourg, 2016.
- ECO-Conseil s.à.r.l., "Sperrmüllanalyse 2020 im Großherzogtum", Luxembourg, 2020.

The part of the waste that originates from the pre-treatment plant (MBA Fridhaff), consisting of both MSW and BW, is split into the twelve fractions according to the study

- ECO-Conseil s.à.r.l., "Abschätzung emittierter Klimagase durch die über die MBA Fridhaff abgeschiedene und verbrannte heizwertreiche Fraktion", Luxembourg, 2009

In the following, both MSW and BW are considered as MSW i.e. the label MSW indicates that the total waste has been split into the 12 categories mentioned above. Table 3-23 gives an overview of the energy consumption by fuel type in 1A1a – Public Electricity and Heat Production.

Table 3-23 - Activity data for IPCC sub-category 1A1a – Public Electricity and Heat Production: 1990-2019

1A1a - Public Electricity & Heat Production					
Activity Data by fuel type (GJ)					
Year	Activity Total (incl. biomass)	Liquid Gas Oil	Gaseous Natural Gas	Biomass Biogas, Wood, Fluff & MSW (bio. fraction)	Other Fluff & MSW (fossil fraction)
1990	NO	NO	NO	882 585	330 708
1991	1 213 293	NO	NO	923 433	346 014
1992	1 269 447	NO	NO	937 765	345 014
1993	1 282 780	NO	NO	892 951	328 222
1994	1 221 173	NO	NO	874 017	321 127
1995	1 195 144	NO	1 043 100	837 466	306 682
1996	2 187 248	900	984 600	652 217	237 269
1997	1 874 986	18 919	1 013 400	765 102	281 066
1998	2 078 487	30 783	1 709 100	708 409	563 404
1999	3 011 697	31 593	1 883 700	807 174	645 035
2000	3 367 501	60 414	920 854	800 882	626 628
2001	2 408 778	55 018	3 808 343	806 156	618 720
2002	5 288 237	48 220	17 031 071	825 573	629 252
2003	18 534 116	46 054	17 102 526	922 212	619 204
2004	18 689 996	46 606	20 850 220	1 015 721	696 697
2005	22 609 244	24 344	20 647 091	990 143	616 125
2006	22 277 703	24 981	21 624 432	1 060 366	678 527
2007	23 388 306	23 409	19 508 383	1 108 546	690 249
2008	21 330 587	49 325	16 205 838	1 173 637	709 240
2009	18 138 040	76 261	19 534 163	1 181 776	702 180
2010	21 494 379	19 416	20 082 942	1 186 276	626 986
2011	21 915 620	18 530	16 344 441	1 291 338	727 724
2012	18 382 034	19 756	17 071 478	1 302 611	724 329
2013	19 118 173	15 040	10 853 489	1 343 216	733 892
2014	12 945 637	13 595	10 369 609	1 944 022	832 438
2015	13 159 665	18 944	6 533 034	2 235 618	905 865
2016	9 693 462	32 034	2 687 859	2 383 900	1 057 872
2017	6 161 664	23 553	2 488 776	2 888 533	1 064 579
2018	6 465 441	17 868	2 090 220	3 805 478	1 073 774
2019	6 987 340	17 469	2 044 285	5 240 798	1 101 586
Trend 1990-2019	NA	NA	NA	493.80%	233.10%
Trend 2018-2019	8.07%	-2.24%	-2.20%	37.72%	2.59%

Source: Environment Agency.

3.2.6.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 1 approach has been applied for biomass burning (biogas & wood and wood wastes), except for the biogenic fraction of MSW. For natural gas, gas oil, and fluff the methodological approach is classified as Tier 2 methodology as country-specific emission factors were used.

For waste incineration, the IPCC methodology Tier 2a (2006 IPCC Guidelines) has been applied. For MSW, it is good practice to calculate CO₂ emissions on the basis of waste fractions (such as paper, wood, plastics) in the waste incinerated, as the following equation shows:

$$CO_2 \text{ emissions} = MSW \cdot \sum_j (WF_j \cdot dm_j \cdot CF_j \cdot FCF_j \cdot OF_j) \cdot \frac{44}{12}$$

with:

- CO₂ emissions = CO₂ emissions in inventory year (Gg/yr)
 MSW = total amount of municipal solid waste as wet weight incinerated or open-burned (Gg/yr)
 WF_j = fraction of waste type/material of component j in the MSW (as wet weight incinerated or open-burned)
 dm_j = dry matter content in the component j of the MSW incinerated or open-burned (fraction)
 CF_j = fraction of carbon in the dry matter (i.e., carbon content) of component j
 FCF_j = fraction of fossil carbon in the total carbon of component j
 OF_j = oxidation factor (fraction)
 44/12 = molecular weight ratio MCO₂(g/mol)/MC(g/mol)

with:

$$\sum_j WF_j = 1$$

j = component of the MSW incinerated such as paper/cardboard, textiles, food waste, wood, garden (yard) and park waste, disposable nappies, rubber and leather, plastics, metal, glass, other inert waste.

IPCC default values for CF_j, FCF_j and OF_j were taken⁷². For the dm_j of the MSW from SIDOR and SIGRE, the IPCC default values were taken. For the treated MSW from SIDEC, the dm_j were taken from the study (ECO-Conseil s.à.r.l., 2009) and are compiled in Table 3-24.

Table 3-24 – Dry matter content in % of wet weight i.e. ratio of dry matter to wet matter.

MSW component	Dry matter content [%]	MSW component	Dry matter content [%]
Paper/cardboard	76.67	Rubber and Leather	95.00
Textiles	76.00	Multilayer composite material	98.46
Food waste	25.00	Plastics	95.78
Wood	94.95	Metal	98.71
Garden and Park waste	25.00	Glass	99.01
Nappies	46.67	Other, Inert waste	87.49

Reported CO₂ emissions of waste incineration are only CO₂ emissions from fossil MSW. However, the activity data includes both biogenic and fossil MSW fractions. This means that biogenic CO₂ emissions are reported under Memo Items.

Calorific values used for conversion of fuel activity data from tonnes into GJ are country-specific and derive from the studies commissioned by the Environment Agency (see Table 3-25) (ECO-Conseil s.à.r.l., Restabfallanalyse 2009/10 im Großherzogtum Luxemburg, Band 1: Kompendium, 2010) (ECO-Conseil s.à.r.l., 2014) (ECO-Conseil s.à.r.l., 2019). The years 2009 and 2014 act as pillar years for the net calorific value of the multilayer composite material. The NCVs for the years in-between were computed through a linear interpolation. The NCVs of the remaining 11 MSW categories remained constant according to the studies.

72 2006 IPCC Guidelines, Vol. 5, Chap. 2, Tab. 2.4, p2.14

Table 3-25 – Net calorific values for MSW components in units of GJ/t.

Year	Paper	Textiles	Food waste	Wood	Garden and park waste	Nappies	Rubber and leather	Multilayer composite material	Plastics	Metal	Glass	Other, inert waste
1990-2009	13.0	13.0	5.0	5.0	5.0	10.0	5.0	15.0	30.0	0.0	0.0	7.0
2010	13.0	13.0	5.0	5.0	5.0	10.0	5.0	15.8	30.0	0.0	0.0	7.0
2011	13.0	13.0	5.0	5.0	5.0	10.0	5.0	16.6	30.0	0.0	0.0	7.0
2012	13.0	13.0	5.0	5.0	5.0	10.0	5.0	17.4	30.0	0.0	0.0	7.0
2013	13.0	13.0	5.0	5.0	5.0	10.0	5.0	18.2	30.0	0.0	0.0	7.0
2014-2019	13.0	13.0	5.0	5.0	5.0	10.0	5.0	19.0	30.0	0.0	0.0	7.0

CH₄ emissions were estimated using the 2006 IPCC Guidelines Tier 1 methodology. CH₄ emissions from incineration of waste are a result of incomplete combustion. Important factors affecting the emissions are temperature, residence time, and air ratio (i.e., air volume in relation to the waste amount). CH₄ emissions are calculated according to the following equation:

$$\text{CH}_4 \text{ Emissions} = \text{Fuel Consumption}_{\text{MSW}} \cdot \text{Emission Factor}_{\text{MSW}}$$

with:

$$\text{CH}_4 \text{ Emissions} = \text{CH}_4 \text{ emissions (kg GHG)}$$

$$\text{Fuel Consumption}_{\text{MSW}} = \text{amount of incinerated MSW (TJ)}$$

$$\text{Emission Factor}_{\text{MSW}} = \text{emission factor (kg gas/TJ)}$$

The CH₄ emissions are relative to the total MSW (biogenic + fossil).

Nitrous oxide is emitted in combustion processes at relatively low combustion temperatures between 500 and 950°C. Other important factors affecting the emissions are the type of air pollution control device, nitrogen type and content of the waste and the fraction of excess air. The N₂O emissions are calculated according to the following equation:

$$N_2O \text{ emission} = \sum_j (IW_j \cdot EF_j) \cdot 10^{-6}$$

with:

$$N_2O \text{ Emissions} = N_2O \text{ emissions in inventory year (Gg/yr)}$$

$$IW_i = \text{amount of incinerated waste of type } i \text{ (Gg/yr)}$$

$$EF_i = N_2O \text{ emission factor (kg } N_2O \text{ /Gg of waste) for waste of type } i$$

$$10^{-6} = \text{conversion from kilogram to gigagram}$$

$$i = \text{category or type of waste incinerated (MSW)}$$

The N₂O emissions are relative to the total MSW (biogenic + fossil).

3.2.6.2.3 Emission factors

Default emission factors are derived from the IPCC 2006 Guidelines (Table 3-26). Country-specific emission factors were determined by the Environment Agency and were calculated from specific data accessible to the Environment Agency (see section 3.2.5.3).

For MSW, CO₂ emissions were not calculated using an emission factor, but instead, the calculation is based on the carbon content of the waste. CO₂ emissions are calculated, as described in section 3.2.6.2.2, by applying the default values listed in Table 2.4 of the 2006 IPCC Guidelines for:

- dry matter content in % of wet weight;
- total carbon content in % of dry weight;
- fossil carbon fraction in % of total carbon.

For CO₂, implied emission factors (IEFs) for the different waste components were calculated by dividing the calculated emissions by the energy content of the MSW waste fraction.

For CH₄, it is good practice to apply the CH₄ emission factors provided in Volume 2, Chapter 2 of the 2006 IPCC Guidelines. The CH₄ default emission factor of 30 kg CH₄/TJ is applied.

For N₂O, the default emission factor of 4.0 kg N₂O/TJ is applied. However, this emission factor might be revised in one of the next submissions, as the 2006 IPCC guidelines recommend to use an EF of 50 g N₂O/t MSW on a wet basis (2006 IPCC Guidelines Vol.5, Chap.5, Table 5.6).

Table 3-26 gives an overview of the different emission factors used for 2019.

Table 3-26 – Emission factors for IPCC sub-category 1A1a – Public Electricity and Heat Production

1A1a - Public Electricity & Heat Production Emission Factors for 2019 (kg/TJ)								
Fuel	Fuel Type	CO ₂		CH ₄		N ₂ O		Source
		EF	type	EF	type	EF	type	
Gas Oil	liquid	74 078	CS	3.00	D	0.60	D	AEV, 2006 IPCC GL
Natural Gas	gaseous	56 091	CS	1.00	D	0.10	D	AEV, 2006 IPCC GL
Biogas	biomass	54 600	D	1.00	D	0.10	D	2006 IPCC GL
Wood & wood wastes	biomass	112 000	D	30.00	D	4.00	D	2006 IPCC GL
Fluff	other/biomass	84 430	CS	30.00	D	4.00	D	ETS, 2006 IPCC GL
MSW	other/biomass	100 605	IEF	30.00	D	4.00	D	AEV, 2006 IPCC GL

Source: Environment Agency.

Notes: IEFs and CS EFs were determined by the Environment Agency.

Table 3-27 gives an overview of the evolution of the implied emission factors per fuel type.

Table 3-27 – Implied emission factors for IPCC sub-category 1A1a – Public Electricity and Heat Production

1A1a - Public Electricity & Heat Production Implied Emission Factors (kg/TJ)												
Year	Liquid Gas Oil			Gaseous Natural Gas			Biomass Biogas, Wood, Fluff & MSW (bio. fraction)			Other Fluff & MSW (fossil fraction)		
	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O
1990	NO	NO	NO	NO	NO	NO	101 241	30.00	4.00	101 241	30.00	4.00
1991	NO	NO	NO	NO	NO	NO	101 241	30.00	4.00	101 241	30.00	4.00
1992	NO	NO	NO	NO	NO	NO	100 396	29.47	3.93	101 241	30.00	4.00
1993	NO	NO	NO	NO	NO	NO	100 353	29.45	3.93	101 241	30.00	4.00
1994	NO	NO	NO	NO	NO	NO	100 334	29.44	3.92	101 241	30.00	4.00
1995	NO	NO	NO	57 929	1.00	0.10	100 183	29.34	3.91	101 241	30.00	4.00
1996	74 192	3.00	0.60	57 546	1.00	0.10	99 882	29.16	3.89	101 241	30.00	4.00
1997	74 179	3.00	0.60	57 205	1.00	0.10	100 327	29.43	3.92	101 241	30.00	4.00
1998	74 170	3.00	0.60	56 863	1.00	0.10	95 802	29.61	3.95	96 362	30.00	4.00
1999	74 174	3.00	0.60	56 522	1.00	0.10	96 213	29.86	3.98	96 362	30.00	4.00
2000	74 212	3.00	0.60	56 221	1.00	0.10	95 476	29.32	3.91	96 362	30.00	4.00
2001	74 216	3.00	0.60	56 258	1.00	0.10	94 700	28.78	3.84	96 362	30.00	4.00
2002	74 217	3.00	0.60	56 396	1.00	0.10	94 622	28.68	3.82	96 373	30.00	4.00
2003	74 192	3.00	0.60	56 533	1.00	0.10	97 507	28.03	3.74	100 348	30.00	4.00
2004	74 154	3.00	0.60	56 671	1.00	0.10	97 161	27.60	3.68	100 716	30.00	4.00
2005	74 137	3.00	0.60	56 910	1.00	0.10	95 713	26.70	3.56	100 373	30.00	4.00
2006	74 138	3.00	0.60	57 008	1.00	0.10	94 921	26.31	3.50	100 147	30.00	4.00
2007	74 141	3.00	0.60	56 793	1.00	0.10	94 591	26.04	3.47	100 150	30.00	4.00
2008	74 085	3.00	0.60	56 665	1.00	0.10	93 961	25.52	3.40	100 246	30.00	4.00
2009	74 074	3.00	0.60	57 056	1.00	0.10	91 778	24.58	3.27	99 022	30.00	4.00
2010	74 128	3.00	0.60	56 712	1.00	0.10	88 615	22.53	3.00	99 008	30.00	4.00
2011	74 114	3.00	0.60	56 988	1.00	0.10	89 206	22.96	3.05	98 770	30.00	4.00
2012	74 134	3.00	0.60	56 793	1.00	0.10	88 272	22.45	2.98	98 405	30.00	4.00
2013	74 141	3.00	0.60	56 680	1.00	0.10	88 959	22.63	3.01	98 249	30.00	4.00
2014	74 069	3.00	0.60	56 756	1.00	0.10	93 015	23.63	3.14	97 334	30.00	4.00
2015	74 128	3.00	0.60	56 760	1.00	0.10	95 670	24.31	3.23	100 611	30.00	4.00
2016	74 136	3.00	0.60	56 561	1.00	0.10	94 463	23.94	3.19	98 432	30.00	4.00
2017	74 149	3.00	0.60	56 577	1.00	0.10	97 507	25.01	3.33	97 892	30.00	4.00
2018	74 130	3.00	0.60	56 209	1.00	0.10	100 403	25.89	3.45	98 059	30.00	4.00
2019	74 078	3.00	0.60	56 091	1.00	0.10	103 483	27.03	3.60	98 108	30.00	4.00

Source: Environment Agency.

The unique trend of the CO₂ implied emission factor for other fuels, which is composed of the fossil fraction of incinerated fluff and MSW and as reported in

Table 3-27, is due to the varying composition of the fossil fraction over time. Indeed, as explained in section 3.2.6.2.1, the composition of the waste fraction is based on several waste analyses. The years for which the studies were done act as pillar years that fix the waste fractions. The waste fractions for the years in-between are calculated through a simple linear interpolation. In addition, since 2002, a high calorific fraction of treated waste, composed of mainly plastics, textiles, rubbers and other waste, also influences the composition of incinerated waste as this high calorific fraction is co-incinerated with the untreated MSW. Hence, the changes in the CO₂ IEF between specific years correspond to the breaks in the composition of incinerated waste.

3.2.6.3 Uncertainties and time-series consistency

The uncertainties for activity data and emission factors used for IPCC category 1A1 – Energy Industries are presented in Table 3-28.

Table 3-28 - Uncertainties for activity data and emission factors used for IPCC category 1A1 – Energy Industries.

IPCC category/Group	Gas	Activity data uncertainty (%)	Emission factor uncertainty (%)
1A1 - Gaseous Fuels	CO ₂	2%	0.5%
1A1 - Gaseous Fuels	CH ₄	2%	50%
1A1 - Gaseous Fuels	N ₂ O	2%	50%
1A1 - Liquid Fuels	CO ₂	2%	0.5%
1A1 - Liquid Fuels	CH ₄	2%	50%
1A1 - Liquid Fuels	N ₂ O	2%	50%
1A1 - Other Fuels	CO ₂	8%	20%
1A1 - Other Fuels	CH ₄	8%	50%
1A1 - Other Fuels	N ₂ O	8%	50%
1A1 - Biomass	CH ₄	7%	50%
1A1 - Biomass	N ₂ O	7%	60%
1A1 – Solid fuels	CO ₂	1%	3%
1A1 – Solid fuels	CH ₄	1%	50%
1A1 – Solid fuels	N ₂ O	1%	50%

The time-series are considered to be consistent with the data reported in the national energy balance.

The annual fluctuations in fuel consumption, especially for natural gas, and the resulting fluctuations of GHG emissions, are explained by the fluctuations of electricity and heat production levels of the plants covering the sector. Indeed, a sharp increase in the natural gas consumption was observed in 2002, with the operational start of a 350 MW gas turbine (Twinerg). Occasional maintenance stops of the 350 MW gas turbine in the years following the operational start (e.g. 2009, 2011) have greatly influenced the energy demand of this category. Since 2013, the electricity production level by the Twinerg gas turbine had been at a relatively low level (due to relatively low electricity prices), and the plant was finally shut down in 2016.

In addition, rotation of the gas oil stocks (used as emergency fuel) can cause fluctuations in the GHG emissions. This was the case in 2008-2009. The dip of fossil MSW incineration in 1996 was due to a fire in the incineration plant, followed by a shut-down for several months. Moreover, since 2015 the incineration plant has added fluff (both fossil and biogenic) to its list of burned materials which adds to the total amount of GHG emissions.

3.2.6.4 Source-specific QA/QC and verification

Activity data for large facilities that are under the European Union Emission Trading Scheme (EU-ETS) are cross-checked from two sources: reports obtained directly from the operator under its operational permit obligations and the EU-ETS registry operator. Both are hosted at the Environment Agency. A list with the large energy consuming facilities along with their respective fuel consumption has been compiled and enables the Single National Entity to quickly cross-check these data with the EU-ETS data. Thus, completeness can be checked on a more systematic basis.

Additionally, cross checks with other relevant sectors, mainly 5 – Waste, are performed to avoid double counting.

Finally, consistency and completeness checks are performed using the tools embedded in CRF Reporter.

3.2.6.5 Category-specific recalculations including changes made in response to the review process

Table 3-29 presents the main revisions and recalculations relevant to category 1A1a - Public Electricity and Heat Production done since the last submission. The quantitative aspect of these recalculations can be found below and in Chapter 10.

Table 3-29 – Recalculations done since submission 2020v1

GHG source & sink category	Revisions 2020v1 → 2021v1	Type of revision
1A1a – gaseous fuels	Revision of the natural gas activity data for 2018 from the national energy balance following an error correction of the net calorific value from 36.98 to 36.76 MJ/Nm ³ .	AD
1A1a - biomass	Revision of the wood and wood products activity data for the years 2017-2018 due to the revised energy balance from the national statistics institute.	AD
1A1a – biomass/other fuels	Error correction of the fossil carbon fraction of the Multilayer Composite Material (from 100% to a weighted function of the fossil carbon fraction of paper and plastics). This change only affects the distribution of biomass and other fuels related GHG emissions over the entire time series.	AD
1A1a – biomass/other fuels	Changes to the internal collection and evaluation procedure of external reports to unify the sources delivering the treated MSW and BW AD to the incineration plant. This changes affects the biomass and fossil fuels AD for 2002-2018.	AD
1A1a – biomass/other fuels	Publication of a new waste management study that sets 2018 up as a pillar year (see section 3.2.6.2.1). The publication affects the MSW AD for the years 2015-2018.	AD
1A1a – biomass/other fuels	Error correction of the Multilayer Composite Material NCV. For 2010-2013, the value was changed from 15 GJ/t to an interpolation between 15 and 19 GJ/t. For 2014-2018, the value was changed from 15 to 19 GJ/t.	AD

Table 3-30 shows the effect of the recalculations listed in Table 3-29 on the total GHG emissions for the entire time series.

Table 3-30 Effects of the recalculations in the 1A1 – Energy industries sector on the GHG emissions between submissions 2020v1 and 2021v1 for the entire time series. Not included are the CO₂ emissions from biomass fuel.

1A1 - Energy Industries GHG emissions (Gg CO₂ eq.)			
Year	2020v1	2021v1	Difference
1990	35.64369	35.83750	0.19381
1991	37.29337	37.49615	0.20278
1992	37.18656	37.38875	0.20219
1993	35.37671	35.56906	0.19235
1994	34.61203	34.80022	0.18819
1995	93.53768	93.71741	0.17973
1996	82.35501	82.49406	0.13905
1997	89.72917	89.89388	0.16472
1998	155.94157	156.31208	0.37051
1999	173.46948	173.89367	0.42419
2000	119.02788	119.43997	0.41209
2001	280.47212	280.87901	0.40689
2002	1027.93480	1028.39929	0.46449
2003	1035.52000	1036.24077	0.72076
2004	1255.94130	1259.55258	3.61128
2005	1241.79836	1242.71519	0.91683
2006	1304.17779	1306.89446	2.71667
2007	1180.55304	1183.08604	2.53301
2008	994.80560	997.27038	2.46477
2009	1190.01317	1194.05582	4.04265
2010	1204.96648	1206.50590	1.53941
2011	1003.03708	1008.92247	5.88539
2012	1042.04187	1046.51307	4.47120
2013	685.47301	692.38547	6.91246
2014	668.58785	675.72758	7.13974
2015	457.36585	468.99587	11.63001
2016	252.08140	264.43067	12.34927
2017	242.77559	253.64788	10.87229
2018	223.60323	232.68458	9.08134

3.2.6.6 Category-specific planned improvements including those in response to the review process

Table 3-31 presents the category-specific planned improvements relevant to category 1A1a - Public Electricity and Heat Production done since the last submission.

Table 3-31 – Planned improvements for category 1.A.1. – Energy Industries

GHG source & sink category	Planned improvement
1A1a - Public Electricity and Heat Production	No planned improvements

3.2.7 Manufacturing Industries and Construction (1.A.2)

3.2.7.1 Source category description

This section describes GHG emissions resulting from fuel combustion activities in manufacturing industries and construction.

This GHG emission inventory includes emissions from categories 1A2a – Iron and Steel, 1A2b – Non-Ferrous Metals, 1A2c – Chemicals, 1A2d – Pulp, Paper and Print, 1A2e – Food Processing, Beverages and Tobacco, 1A2f – Non-metallic minerals and 1A2g – Other.

In 2018, category 1A2 - Manufacturing Industries and Construction was responsible for 12.73% of GHG emissions from fuel combustion activities (60.94% in 1990) and represented 10.96% of the total GHG emissions of Luxembourg, excluding LULUCF (49.23% in 1990). Compared to 2017, emissions of 1A2 increased by 1.26 %.

Table 3-32 summarizes GHG emissions for 1A2 – Manufacturing Industries and Construction and the relevant sub-categories.

Regarding CO₂ emissions, 1A2 – Manufacturing Industries and Construction is a key category, in 2019 for gaseous, liquid, solid and other fuels. It has been a key category for gaseous, liquid and solid fuels from 1990 onwards: see Table 3-6 in Section 3.2.

Table 3-32 – GHG emission trends in Gg for IPCC sub-category 1A2 – Fuel Combustion Activities – Manufacturing Industries and Construction: 1990-2019

1A2 - Manufacturing Industries & Construction GHG emissions by source & sink category (Gg)																
Year	1A2a - Iron & Steel				1A2b - Non-Ferrous Metals				1A2c - Chemicals				1A2d - Pulp, Paper & Print			
	Total CO ₂ eq	CO ₂	CH ₄	N ₂ O	Total CO ₂ eq	CO ₂	CH ₄	N ₂ O	Total CO ₂ eq	CO ₂	CH ₄	N ₂ O	Total CO ₂ eq	CO ₂	CH ₄	N ₂ O
1990	5 411.43	5 404.13	0.109	0.015	28.39	28.37	0.0005	0.0000	170.26	169.83	0.005	0.001	NO	IE	IE	IE
1991	5 152.51	5 145.50	0.104	0.015	29.45	29.42	0.0005	0.0000	186.69	186.15	0.007	0.001	NO	IE	IE	IE
1992	4 754.81	4 748.27	0.097	0.014	29.70	29.67	0.0005	0.0000	173.93	173.51	0.005	0.001	NO	IE	IE	IE
1993	4 920.86	4 913.85	0.104	0.015	29.14	29.12	0.0005	0.0000	181.33	180.87	0.006	0.001	NO	IE	IE	IE
1994	4 067.22	4 061.38	0.087	0.012	35.44	35.41	0.0006	0.0001	200.59	200.13	0.006	0.001	NO	IE	IE	IE
1995	2 316.62	2 313.38	0.049	0.007	36.63	36.60	0.0006	0.0001	196.42	196.07	0.005	0.001	NO	IE	IE	IE
1996	2 101.73	2 098.74	0.045	0.006	58.99	58.93	0.0010	0.0001	199.72	199.37	0.005	0.001	NO	IE	IE	IE
1997	1 335.10	1 333.24	0.028	0.004	41.93	41.89	0.0007	0.0001	188.21	187.93	0.004	0.001	NO	IE	IE	IE
1998	310.83	310.44	0.006	0.001	43.80	43.76	0.0008	0.0001	189.45	189.24	0.004	0.000	NO	IE	IE	IE
1999	345.61	345.17	0.007	0.001	42.66	42.62	0.0007	0.0001	185.77	185.55	0.004	0.000	NO	IE	IE	IE
2000	332.79	332.40	0.007	0.001	41.45	41.41	0.0007	0.0001	207.61	207.37	0.004	0.000	12.91	12.89	0.0003	0.0000
2001	393.82	393.37	0.008	0.001	42.04	42.00	0.0007	0.0001	217.59	217.33	0.004	0.001	15.56	15.53	0.0003	0.0000
2002	375.38	374.96	0.007	0.001	40.36	40.32	0.0007	0.0001	215.29	215.04	0.004	0.000	19.26	19.24	0.0004	0.0000
2003	353.63	353.27	0.006	0.001	46.30	46.26	0.0008	0.0001	224.76	224.51	0.004	0.000	21.74	21.71	0.0004	0.0000
2004	385.99	385.59	0.007	0.001	52.65	52.60	0.0009	0.0001	231.71	231.45	0.004	0.001	19.07	19.05	0.0004	0.0000
2005	379.55	379.17	0.007	0.001	58.39	58.33	0.0010	0.0001	229.69	229.43	0.004	0.000	18.66	18.64	0.0004	0.0000
2006	442.45	442.01	0.008	0.001	61.28	61.22	0.0011	0.0001	217.78	217.56	0.004	0.000	11.51	11.50	0.0002	0.0000
2007	422.84	422.42	0.008	0.001	57.10	57.04	0.0010	0.0001	192.89	192.70	0.004	0.000	7.40	7.39	0.0001	0.0000
2008	403.02	402.62	0.007	0.001	55.54	55.49	0.0010	0.0001	191.10	190.91	0.003	0.000	10.08	10.07	0.0002	0.0000
2009	329.36	329.04	0.006	0.001	48.97	48.92	0.0009	0.0001	144.38	144.24	0.003	0.000	7.96	7.95	0.0001	0.0000
2010	379.04	378.66	0.007	0.001	56.03	55.98	0.0010	0.0001	171.05	170.87	0.003	0.000	5.28	5.27	0.0001	0.0000
2011	334.35	334.02	0.006	0.001	53.81	53.76	0.0009	0.0001	185.23	185.04	0.003	0.000	8.84	8.83	0.0002	0.0000
2012	299.12	298.83	0.005	0.001	54.50	54.45	0.0010	0.0001	180.71	180.51	0.003	0.000	10.77	10.76	0.0002	0.0000
2013	276.30	276.03	0.005	0.000	53.26	53.21	0.0009	0.0001	197.80	197.57	0.004	0.000	13.45	13.43	0.0002	0.0000
2014	273.37	273.10	0.005	0.000	51.52	51.47	0.0009	0.0001	162.54	162.35	0.003	0.000	6.34	6.33	0.0001	0.0000
2015	277.82	277.55	0.005	0.000	49.83	49.78	0.0009	0.0001	144.76	144.60	0.003	0.000	5.50	5.49	0.0001	0.0000
2016	268.96	268.70	0.005	0.000	50.74	50.69	0.0009	0.0001	147.45	147.30	0.003	0.000	5.34	5.33	0.0001	0.0000
2017	269.53	269.27	0.005	0.000	53.87	53.82	0.0010	0.0001	135.17	135.03	0.002	0.000	4.82	4.82	0.0001	0.0000
2018	306.45	306.14	0.006	0.001	51.52	51.47	0.0009	0.0001	123.81	123.68	0.002	0.000	1.62	1.62	0.0000	0.0000
2019	296.86	296.56	0.005	0.001	47.50	47.45	0.0008	0.0001	121.85	121.72	0.002	0.000	1.75	1.74	0.0000	0.0000
Trend 1990-2019	-94.51%	-94.51%	-95.07%	-96.38%	67.30%	67.29%	83.11%	83.11%	-28.43%	-28.33%	-58.14%	-75.46%	NA	NA	NA	NA
Trend 2018-2019	-3.13%	-3.13%	-2.55%	-1.91%	-7.81%	-7.82%	-7.62%	-7.62%	-1.58%	-1.58%	-0.62%	0.63%	7.76%	7.76%	9.74%	12.13%

1A2 - Manufacturing Industries & Construction																
GHG emissions by source & sink category (Gg)																
Year	1A2e - Food Processing, Beverages & Tobacco				1A2f - Non-Metallic Minerals				1A2g - Other				1A2 - Manufacturing Industries & Construction			
	Total CO ₂ eq	CO ₂	CH ₄	N ₂ O	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)
1990	8.19	8.18	0.000	0.000	539.07	536.52	0.0372	0.0054	108.41	103.29	0.005	0.017	6 265.75	6 250.32	0.1576	0.0386
1991	12.85	12.82	0.000	0.000	488.02	486.67	0.0342	0.0050	238.94	233.02	0.008	0.019	6 108.45	6 092.59	0.1536	0.0403
1992	12.52	12.49	0.000	0.000	528.99	526.36	0.0381	0.0056	265.34	258.93	0.008	0.021	5 765.30	5 749.24	0.1498	0.0413
1993	9.17	9.16	0.000	0.000	479.68	477.44	0.0327	0.0048	281.82	274.92	0.008	0.022	5 902.01	5 885.35	0.1514	0.0432
1994	12.15	12.12	0.000	0.000	584.03	581.08	0.0428	0.0063	290.06	282.64	0.010	0.024	5 189.50	5 172.77	0.1461	0.0439
1995	12.36	12.33	0.000	0.000	509.33	506.96	0.0345	0.0051	261.70	253.80	0.008	0.026	3 333.05	3 319.14	0.0970	0.0385
1996	10.90	10.88	0.000	0.000	538.13	535.55	0.0375	0.0055	270.43	262.62	0.009	0.025	3 179.90	3 166.10	0.0976	0.0381
1997	13.79	13.76	0.000	0.000	495.35	493.05	0.0334	0.0049	341.44	332.97	0.010	0.028	2 415.82	2 402.85	0.0769	0.0371
1998	12.91	12.88	0.000	0.000	461.23	458.76	0.0361	0.0052	356.02	347.22	0.010	0.029	1 374.24	1 362.31	0.0569	0.0353
1999	18.15	18.11	0.001	0.000	509.57	506.96	0.0383	0.0055	462.91	452.91	0.014	0.032	1 564.67	1 551.31	0.0639	0.0395
2000	25.11	25.07	0.001	0.000	526.14	523.21	0.0433	0.0062	251.40	241.13	0.009	0.034	1 397.41	1 383.48	0.0640	0.0414
2001	30.83	30.78	0.001	0.000	544.24	540.70	0.0526	0.0074	245.98	235.40	0.008	0.035	1 490.06	1 475.12	0.0744	0.0439
2002	33.13	33.07	0.001	0.000	449.60	446.57	0.0458	0.0064	242.76	231.52	0.007	0.037	1 375.79	1 360.71	0.0666	0.0450
2003	18.75	18.71	0.000	0.000	388.02	385.29	0.0412	0.0057	260.47	249.35	0.008	0.037	1 313.67	1 299.11	0.0613	0.0437
2004	18.66	18.63	0.000	0.000	441.00	437.87	0.0472	0.0066	261.46	250.57	0.007	0.036	1 410.55	1 395.76	0.0678	0.0440
2005	18.95	18.91	0.000	0.000	454.40	451.16	0.0487	0.0068	247.06	235.30	0.033	0.037	1 406.70	1 390.95	0.0946	0.0449
2006	14.66	14.64	0.000	0.000	491.62	487.99	0.0545	0.0076	241.87	230.47	0.031	0.036	1 481.17	1 465.38	0.0994	0.0446
2007	13.95	13.93	0.000	0.000	439.80	436.50	0.0500	0.0069	251.07	239.64	0.033	0.036	1 385.05	1 369.62	0.0954	0.0438
2008	13.96	13.94	0.000	0.000	424.50	421.26	0.0492	0.0068	231.86	222.14	0.034	0.030	1 330.05	1 316.42	0.0952	0.0378
2009	14.71	14.68	0.000	0.000	428.09	425.16	0.0442	0.0061	215.95	207.19	0.027	0.027	1 189.42	1 177.18	0.0809	0.0343
2010	14.60	14.57	0.000	0.000	418.69	415.42	0.0495	0.0068	222.59	213.92	0.031	0.027	1 267.28	1 254.69	0.0918	0.0345
2011	20.45	20.42	0.000	0.000	414.40	411.30	0.0471	0.0065	225.93	217.64	0.028	0.025	1 243.02	1 231.01	0.0858	0.0331
2012	16.92	16.89	0.000	0.000	403.34	400.24	0.0469	0.0064	219.26	211.84	0.025	0.023	1 184.61	1 173.52	0.0820	0.0304
2013	17.84	17.81	0.000	0.000	355.30	352.09	0.0486	0.0067	230.44	222.90	0.025	0.023	1 144.39	1 133.04	0.0845	0.0310
2014	24.66	24.62	0.001	0.000	396.07	392.89	0.0482	0.0066	233.74	225.54	0.030	0.025	1 148.23	1 136.30	0.0875	0.0327
2015	21.46	21.42	0.001	0.000	372.81	369.85	0.0449	0.0062	241.02	233.01	0.028	0.025	1 113.19	1 101.71	0.0821	0.0316
2016	23.52	23.48	0.001	0.000	410.85	407.31	0.0538	0.0074	249.40	241.46	0.028	0.024	1 156.26	1 144.28	0.0908	0.0326
2017	27.38	27.32	0.001	0.000	397.94	394.34	0.0548	0.0075	257.56	249.89	0.026	0.024	1 146.28	1 134.48	0.0901	0.0320
2018	24.03	23.97	0.001	0.000	404.83	401.04	0.0578	0.0079	250.18	243.06	0.017	0.022	1 162.44	1 150.98	0.0846	0.0314
2019	26.24	26.17	0.001	0.000	420.76	416.66	0.0624	0.0085	262.16	255.56	0.008	0.021	1 177.11	1 165.87	0.0802	0.0310
Trend 1990-2019	220.23%	220.14%	251.86%	268.10%	-21.95%	-22.34%	67.75%	56.91%	141.82%	147.42%	63.05%	27.99%	-81.21%	-81.35%	-49.08%	-19.64%
Trend 2018-2019	9.22%	9.20%	14.98%	18.31%	3.94%	3.90%	7.90%	8.15%	4.79%	5.14%	-51.04%	-4.56%	1.26%	1.29%	-5.17%	-1.20%

Source: Environment Agency.

Notes: CH₄ emissions are converted in CO₂e by multiplying the emissions by 25, i.e. the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon. N₂O emissions are converted in CO₂e by multiplying the emissions by 298, i.e. the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horiz

Iron and Steel (1A2a)

3.2.7.1.1 Source category description

In 2019, fuel combustion in iron and steel was responsible for 3.21% of GHG emissions from fuel combustion activities (this share was 52.63% in 1990) and represented 2.76% of the total GHG emissions in CO₂eq, excluding LULUCF (42.52% in 1990). Compared to 2018, emissions have decreased by 3.13% and compared to 1990, decreased by 94.51%.

3.2.7.1.2 Methodological issues

3.2.7.1.2.1 Activity Data

The iron and steel industry has been among the most important industrial activities in Luxembourg, both in terms of energy consumption and in terms of added value. As already stressed earlier in this report, important technological changes took place between 1993 and 1997 with the move from blast furnaces to electric arc furnaces. This led to large changes in air emissions. Today, the iron and steel industry has a specific energy consumption which is much lower than it was in 1990 but which is still relatively high at Luxembourg's scale.

Emissions from fuel combustion activities in the iron and steel industry are accounted for under category 1A2a – Iron & Steel. CO₂ process related emissions are included under category 2C1 - Iron & Steel Production (see Section 4.4.1).

Blast furnace gas is a side product of the iron produced in blast furnaces and can be used as fuel for combustion purposes. This was the case in Luxembourg until 1997, when the last blast furnace was blown out. Blast furnace gas was used by the iron and steel industry for heating purposes and for electricity production. Thus, blast furnace gas is to be considered as a secondary fuel. This has to be taken into account when comparing official energy balances (as published by the national statistics institute) with the energy balance used to prepare the emission inventories. Indeed, solid fuels, coke in particular, do not appear as fuel for combustion activities in blast furnaces in emission inventories, as these are mainly used for reduction purposes, and as such are considered in category 2C1 - Iron & Steel Production. Instead of solid fuels, blast furnace gas (although considered as a solid fuel by the IPCC) is considered in category 1A2a (see also Section 4.4.1).

Table 3-33 gives a summary of which combustion activities are included for estimating GHG emissions pertaining to category 1A2a – Iron & Steel.

Table 3-33 – Iron and steel combustion activities included in the GHG inventory

Combustion activity	SNAP ⁷³ code
Combustion plants 50-300 MW	030102
Combustion plants <50 MW	030103
Blast Furnace Cowper's	030203
Sinter and pelletizing plants	030301
Reheating furnaces steel and iron	030302
Grey iron foundries	030303
Electric furnace steel plants	040207
Mobile Sources and Machinery in Industry	080800
Blast furnace gas distribution losses and flaring	NA

Combustion plants 50-300 MW

One power plant, operated until 1997 by the iron and steel industry, located on a site called Terres Rouges, and fed with blast furnace gas, residual fuel oil and/or natural gas. The activity rates are based on information received from the plant operator⁷⁴ and from a study (TÜV 1990). The electricity produced was used in the installations of the iron and steel industry (autoproducer). Overproduction was fed into the public electricity network.

Combustion plants <50 MW

Various combustion plants were operated mainly for heating purposes until 1997, when the last blast furnace was shut down. They were fed with blast furnace gas, residual fuel oil and/or natural gas. After 1997, these combustion plants were replaced by installations running on natural gas or gasoil. The related fuel consumption data were and still are received directly from the operator.

Blast furnace cowpers

Blast furnace cowpers have been used until 1997. They were fed with blast furnace gas and with natural gas. The related fuel consumption data were received directly from the operator.

Sinter and pelletizing plants

The sole sinter plant has been used until 1997. Its activity data, i.e. fuel consumption (coke oven coke, coal, blast furnace gas and natural gas) and production have been established in detail for the year 1990 based on information received from the operator. The fuel consumptions of the following years have been extrapolated based on the consumption data of 1990 and on the sintered ore production from 1990 - 1997.

73 Technology oriented Standardized Nomenclature for Air Pollutants (SNAP)

74 Later Arcelor-Arbed, and now Arcelor-Mittal.

Reheating furnaces steel and iron

The reheating furnaces have been used during the whole period 1990 - 2014. Their operation is directly related to steel rolling. Their activity data (natural gas consumption) were received from the operator. In 2012, as a consequence of the economic crisis, the steel rolling facilities as well as the electric arc furnace on the site in Schiffflange were temporarily switched off. In 2015, it was decided to finally close these facilities.

Grey iron foundries

The activity data (coking coke consumption) of those foundries have been estimated in the early 1990s (TÜV 1990), and no new data have been received since. Therefore, the values in the inventories have been kept rather constant. In 1997, grey iron production was stopped simultaneously with the last blast furnace.

Electric furnace steel plants

The first electric furnace steel plant appeared in 1994. Beside electric energy, natural gas is used for the fusion of scrap. The related fuel consumption data were received directly from the operator.

Blast Furnace Gas Distribution Losses and Flaring

A certain amount of blast furnace gas (BFG) is either lost during distribution or vented to avoid over-pressurization of the pipes or flared. The amount of BFG lost, vented or flared was obtained from the national statistics institute (STATEC).

Mobile Sources and Machinery in Industry

Activity data on the consumption of diesel oil, used in mobile sources and machinery were derived from energy balance as produced by the national statistics institute (STATEC). Since submission 2015, emissions of mobile machinery are reported under category 1.A.2.g.vii – Off-road vehicles and other machinery (see section 3.2.7.7).

The fuel consumption data obtained by the operators (bottom-up) were matched with the top-down data obtained from the national statistics institute (STATEC) to avoid double counting or underestimation.

Table 3-34 gives a summary of the amount of energy used in category 1A2a – Iron and Steel.

Table 3-34 – Activity data for category 1A2a – Iron and Steel: 1990-2019

1A2a - Iron & Steel						
Activity Data by fuel type (GJ)						
Year	Activity Total	Solid	Liquid	Gaseous	Biomass	Other
		Blast Furnace Gas, Coke Oven Coke, Coking Coke, Other Bituminous Coal	Residual Fuel Oil, Gas Oil	Natural Gas		
1990	31 802 460	24 297 184	632 309	6 872 966	NO	NO
1991	29 861 528	23 212 906	1 082 023	5 566 599	NO	NO
1992	28 074 837	21 153 539	1 543 162	5 378 135	NO	NO
1993	28 969 294	22 278 448	1 368 941	5 321 905	NO	NO
1994	24 669 272	18 169 300	1 249 467	5 250 505	NO	NO
1995	16 128 469	9 509 657	650 277	5 968 535	NO	NO
1996	15 348 355	8 471 037	559 065	6 318 253	NO	NO
1997	11 405 449	4 700 381	505 079	6 199 989	NO	NO
1998	5 294 530	NO	498 093	4 796 437	NO	NO
1999	5 898 927	NO	634 967	5 263 960	NO	NO
2000	5 797 134	NO	360 167	5 436 967	NO	NO
2001	6 869 204	NO	385 452	6 483 752	NO	NO
2002	6 541 567	NO	339 077	6 202 490	NO	NO
2003	6 220 436	NO	91 251	6 129 185	NO	NO
2004	6 756 649	NO	153 569	6 603 080	NO	NO
2005	6 631 230	NO	103 627	6 527 604	NO	NO
2006	7 729 439	NO	79 708	7 649 731	NO	NO
2007	7 418 081	NO	64 889	7 353 192	NO	NO
2008	7 091 888	NO	43 438	7 048 451	NO	NO
2009	5 757 748	NO	31 033	5 726 715	NO	NO
2010	6 653 746	NO	75 689	6 578 058	NO	NO
2011	5 848 948	NO	40 643	5 808 306	NO	NO
2012	5 257 870	NO	12 569	5 245 302	NO	NO
2013	4 864 371	NO	17 984	4 846 388	NO	NO
2014	4 808 149	NO	12 163	4 795 986	NO	NO
2015	4 884 289	NO	18 432	4 865 857	NO	NO
2016	4 744 566	NO	19 592	4 724 974	NO	NO
2017	4 746 012	NO	42 844	4 703 168	NO	NO
2018	5 432 516	NO	43 760	5 388 755	NO	NO
2019	5 269 448	NO	54 832	5 214 617	NO	NO
Trend 1990-2019	-83.43%	NA	-91.33%	-24.13%	NA	NA
Trend 2018-2019	-3.00%	NA	25.30%	-3.23%	NA	NA

Source: Environment Agency.

3.2.7.1.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 1 approach has been applied for residual fuel oil and solid fuels except for blast furnace gas (recorded under solid fuels according to the 2006 IPCC Guidelines). For natural gas, gas oil, diesel oil and blast furnace gas, the methodological approach is classified as a Tier 2 methodology as country-specific emissions factor were used.

Special care was taken with solid fuels to avoid double counting with IPCC sub-category 2C1 - Iron and Steel Production. As already stated (section 3.2.7.1.2.1), the use of natural gas and BFG is considered as a combustion activity under 1A2a, whereas the use of coal (other bituminous coal), coke oven coke, and some residual fuel oil was used in the blast furnaces to produce BFG and for reduction purposes. These emissions are accounted for in category 2C1.

3.2.7.1.2.3 Emission factors

Default emission factors are derived from the 2006 IPCC Guidelines. Country-specific or plant specific emission factors were determined by the Environment Agency and are either derived from a study (TÜV 1990) or were calculated from specific data accessible to the Environment Agency from the operator (Table 3-35).

For blast furnace gas combusted in blast furnaces or combustion plants, a plant specific CO₂ emission factor, which is at the same time country-specific as there was only one plant in Luxembourg, was applied. This EF was derived from a study in the year 1990 and is based on measurements of the BFG composition (see also section 3.2.5.3). The CH₄ and N₂O emission factors are default values from the 2006 IPCC Guidelines. The CO₂ EF for BFG lost in distribution and flaring is also plant specific and was based on measurements and BFG composition.⁶⁵ Generally, BFG consists of about 60 percent nitrogen, 18-20% carbon dioxide and some oxygen. The rest is mostly carbon monoxide, which has a fairly low heating value. When calculating the emissions from distribution losses, it is assumed that BFG is completely oxidised to CO₂ in the atmosphere. Therefore, the same emission factor as for flaring was used. Since no default values for CH₄ and N₂O from BFG lost in distribution and flaring are given in neither the 1996 Revised IPCC Guidelines nor in the 2006 IPCC Guidelines, the default values for coal were applied.

Table 3-35 gives an overview of the different emission factors used in this submission.

Table 3-35 – Emission factors for category 1A2a – Iron and Steel

1A2a Iron & Steel								
Emission Factors for 2019 (kg/TJ)								
Fuel	Fuel Type	CO ₂		CH ₄		N ₂ O		Source
		EF	type	EF	type	EF	type	
Blast furnace gas	solid	257 181	PS, CS	1.00	D	0.10	D	TüV 1990 2006 IPCC GL
BFG (DistLoss&Flar)	solid	245 323	PS, CS	1.00	D	0.10	D	TüV 1990 2006 IPCC GL
Coke Oven Coke	solid	107 000	D	10.00	D	1.50	D	2006 IPCC GL
Other Bituminous Coal	solid	94 600	D	10.00	D	1.50	D	2006 IPCC GL
Coking Coke	solid	94 600	D	10.00	D	1.50	D	2006 IPCC GL
Residual Fuel Oil	liquid	77 400	D	3.00	D	0.60	D	2006 IPCC GL
Gas Oil	liquid	74 078	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 091	CS	1.00	D	0.10	D	AEV 2006 IPCC GL

Source: Environment Agency.

Table 3-36 gives an overview of the evolution of the implied emission factors per fuel type.

Time-series are considered to be consistent, also in comparison with energy data as reported by the national statistics institute. For solid fuels, the relatively high CO₂ IEF, compared to usual solid fuels, stems from the fact that blast furnace gas is the predominant fuel in this category. Other solid fuels, such as coke oven coke, other bituminous coal or coking coal only played a minor role, and were mainly used in the sole sinter and pelletizing plant and in grey iron foundries. For liquid fuels, the CO₂ IEF was higher in the early 1990s due to the increased use of residual fuel oil, which was replaced by gas/diesel oil with the switch to electric arc steel production.

Table 3-36 – Implied emission factors for IPCC sub-category 1A2a – Iron and Steel

1A2a Iron & Steel									
Implied Emission Factors (kg/TJ)									
Year	Solid			Liquid			Gaseous		
	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O
1990	204 087	4.13	0.59	76 614	3.00	0.60	57 755	1.00	0.10
1991	204 235	4.11	0.58	76 874	3.00	0.60	57 743	1.00	0.10
1992	204 137	4.11	0.58	77 075	3.00	0.60	57 848	1.00	0.10
1993	202 008	4.24	0.60	76 935	3.00	0.60	57 894	1.00	0.10
1994	201 498	4.27	0.61	76 894	3.00	0.60	57 940	1.00	0.10
1995	201 690	4.27	0.61	76 322	3.00	0.60	57 929	1.00	0.10
1996	199 816	4.37	0.62	76 020	3.00	0.60	57 546	1.00	0.10
1997	200 038	4.37	0.62	75 863	3.00	0.60	57 205	1.00	0.10
1998	NO	NO	NO	75 695	3.00	0.60	56 863	1.00	0.10
1999	NO	NO	NO	75 024	3.00	0.60	56 522	1.00	0.10
2000	NO	NO	NO	74 212	3.00	0.60	56 221	1.00	0.10
2001	NO	NO	NO	74 216	3.00	0.60	56 258	1.00	0.10
2002	NO	NO	NO	74 217	3.00	0.60	56 396	1.00	0.10
2003	NO	NO	NO	74 192	3.00	0.60	56 533	1.00	0.10
2004	NO	NO	NO	74 154	3.00	0.60	56 671	1.00	0.10
2005	NO	NO	NO	74 137	3.00	0.60	56 910	1.00	0.10
2006	NO	NO	NO	74 138	3.00	0.60	57 008	1.00	0.10
2007	NO	NO	NO	74 141	3.00	0.60	56 793	1.00	0.10
2008	NO	NO	NO	74 085	3.00	0.60	56 665	1.00	0.10
2009	NO	NO	NO	74 074	3.00	0.60	57 056	1.00	0.10
2010	NO	NO	NO	74 128	3.00	0.60	56 712	1.00	0.10
2011	NO	NO	NO	74 114	3.00	0.60	56 988	1.00	0.10
2012	NO	NO	NO	74 134	3.00	0.60	56 793	1.00	0.10
2013	NO	NO	NO	74 141	3.00	0.60	56 680	1.00	0.10
2014	NO	NO	NO	74 069	3.00	0.60	56 756	1.00	0.10
2015	NO	NO	NO	74 128	3.00	0.60	56 760	1.00	0.10
2016	NO	NO	NO	74 136	3.00	0.60	56 561	1.00	0.10
2017	NO	NO	NO	74 149	3.00	0.60	56 577	1.00	0.10
2018	NO	NO	NO	74 130	3.00	0.60	56 209	1.00	0.10
2019	NO	NO	NO	74 078	3.00	0.60	56 091	1.00	0.10

Source: Environment Agency.

3.2.7.2 Non-Ferrous Metals (1A2b)

3.2.7.2.1 Source category description

In Luxembourg, non-ferrous metals activities cover mainly secondary aluminium production from aluminium scrap.

In 2019, fuel combustion due to non-ferrous metal production was responsible for 0.51% of GHG emissions from fuel combustion activities (0.28% in 1990) and represented 0.44% of the national total GHG emissions in CO₂e, excluding LULUCF (0.22% in 1990). Compared to 2018, emissions declined by 7.81% and compared to 1990, they increased by 67.30%.

3.2.7.2.2 Methodological issues & time series consistency

3.2.7.2.2.1 Activity data

Liquefied petroleum gas (LPG) was an important fuel used in the secondary aluminium production. It was slowly substituted by natural gas. Generally, the fuel consumption data were obtained from the operators. The activity data for secondary aluminium production are listed in Table 3-37.

The activity data reported here are the data reported by the operators to the Environment Agency through their annual reporting obligations. This bottom-up data could not be matched with top-down data from the national statistics institute as no such data are reported for this category. Due to confidentiality reasons, this data are reported under the iron & steel industry by national statistics.

However, to avoid double counting, the bottom-up data were subtracted from the top-down data from official statistics reported for category 1A2a - Iron and Steel.

Table 3-37 - Activity data for category 1A2b - Non-Ferrous Metals: 1990-2019

1A2b - Non-Ferrous Metals						
Activity Data by fuel type (GJ)						
Year	Activity Total	Solid	Liquid LPG	Gaseous Natural Gas	Biomass	Other
1990	462 005	NO	230 000	232 005	NO	NO
1991	480 174	NO	230 000	250 174	NO	NO
1992	484 471	NO	230 000	254 471	NO	NO
1993	474 992	NO	230 000	244 992	NO	NO
1994	574 091	NO	307 372	266 719	NO	NO
1995	593 787	NO	314 594	279 193	NO	NO
1996	983 700	NO	314 594	669 106	NO	NO
1997	724 596	NO	56 951	667 645	NO	NO
1998	757 076	NO	87 447	669 629	NO	NO
1999	740 541	NO	86 796	653 745	NO	NO
2000	722 935	NO	88 251	634 683	NO	NO
2001	733 199	NO	86 796	646 403	NO	NO
2002	715 027	NO	NO	715 027	NO	NO
2003	818 250	NO	NO	818 250	NO	NO
2004	928 110	NO	NO	928 110	NO	NO
2005	1 025 041	NO	NO	1 025 041	NO	NO
2006	1 073 850	NO	NO	1 073 850	NO	NO
2007	1 004 376	NO	NO	1 004 376	NO	NO
2008	979 207	NO	NO	979 207	NO	NO
2009	857 430	NO	NO	857 430	NO	NO
2010	987 086	NO	NO	987 086	NO	NO
2011	943 399	NO	NO	943 399	NO	NO
2012	958 750	NO	NO	958 750	NO	NO
2013	938 733	NO	NO	938 733	NO	NO
2014	906 812	NO	NO	906 812	NO	NO
2015	877 014	NO	NO	877 014	NO	NO
2016	896 259	NO	NO	896 259	NO	NO
2017	951 239	NO	NO	951 239	NO	NO
2018	915 753	NO	NO	915 753	NO	NO
2019	845 966	NO	NO	845 966	NO	NO
Trend 1990-2019	83.11%	NA	NA	264.63%	NA	NA
Trend 2018-2019	-7.62%	NA	NA	-7.62%	NA	NA

Source: Environment Agency.

3.2.7.2.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 2 approach has been applied for liquid (LPG) and gaseous fuels (natural gas).

3.2.7.2.2.3 Emission factors

Country-specific EFs for CO₂ from LPG and natural gas were used. Default EFs from the 2006 IPCC Guidelines have been applied for CH₄ and N₂O (Table 3-38).

Table 3-38 – Emission factors for category 1A2b – Non-Ferrous Metals

1A2b - Non-Ferrous Metals								
Emission Factors for 2019 (kg/TJ)								
Fuel	Fuel Type	CO ₂		CH ₄		N ₂ O		Source
		EF	type	EF	type	EF	type	
LPG	liquid	65 489	CS	1.00	D	0.10	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 091	CS	1.00	D	0.10	D	AEV 2006 IPCC GL

Source: Environment Agency.

3.2.7.3 Chemicals (1A2c)

3.2.7.3.1 Source category description

In Luxembourg, chemical activities cover mainly the production of tires, various plastic films and synthetic non-woven textiles. Also included in this category are the emissions of two gas turbines operated by the chemical industry for heat and electricity production (autoproducers).

In 2019, fuel combustion from the chemical industry was responsible for 1.32% of GHG emissions from fuel combustion activities (1.66% in 1990) and represented 1.13% of the national total GHG emissions, excluding LULUCF (1.34% in 1990). Compared to 2018, emissions decreased by 1.58% and compared to 1990, decreased by 28.43%.

3.2.7.3.2 Methodological issues & time-series consistency

3.2.7.3.2.1 Activity data

Annual fuel consumption data of residual fuel oil, gas oil, diesel oil and natural gas were obtained from the operators. Diesel oil is mainly used by mobile sources and machinery, whereas the remaining fuels are mainly combusted in stationary units for heating purposes.

The activity data reported here are the data reported by the operators to the Environment Agency through their annual reporting obligations. The bottom-up data on natural gas, between 1990 and 1999, could not be matched to the top-down data from the national statistics institute as no such data are reported for this category. To avoid double counting, the bottom-up data for this period were subtracted from the top-down data from official statistics reported for category 1A2g - Other. For natural gas (2000-2019) and liquid fuels (residual fuel oil, gas oil, diesel oil) the matching exercise was done within the category 1A2c as top-down data are reported for this category by the national statistics institute. Activity data for the chemical industry are listed in Table 3-39.

Fluctuations in activity data may occur due to temporal shut-down of installations (e.g. for maintenance). This may then be reflected in the activity data by a sharp decrease as in 2007 when maintenance on one of the gas turbines operated by the chemical industry led to a 9% decrease compared to the previous year.⁷⁵ The dip in 2009 is explained by the global economic downturn due to the financial and economic crisis. 2010 showed a slight recovery, with a stabilisation until 2013. The decrease observed in 2014 is mainly due to the phase out of one of the gas turbines, being replaced by energy efficient boilers.

75 ARR 2009, § 61.

Table 3-39- Activity data for category 1A2c - Chemicals: 1990-2019

1A2c - Chemicals						
Activity Data by fuel type (GJ)						
Year	Activity Total	Solid	Liquid Residual Fuel Oil, Gas Oil	Gaseous Natural Gas	Biomass	Other
1990	2 455 706	NO	1 460 983	994 723	NO	NO
1991	2 563 192	NO	1 975 924	587 269	NO	NO
1992	2 520 181	NO	1 453 902	1 066 279	NO	NO
1993	2 597 533	NO	1 595 269	1 002 264	NO	NO
1994	2 964 983	NO	1 490 527	1 474 456	NO	NO
1995	3 096 655	NO	895 987	2 200 668	NO	NO
1996	3 166 826	NO	905 480	2 261 347	NO	NO
1997	3 105 924	NO	541 574	2 564 350	NO	NO
1998	3 282 717	NO	145 022	3 137 695	NO	NO
1999	3 223 167	NO	211 883	3 011 284	NO	NO
2000	3 618 830	NO	218 707	3 400 122	NO	NO
2001	3 782 763	NO	253 681	3 529 081	NO	NO
2002	3 744 542	NO	220 952	3 523 590	NO	NO
2003	3 918 509	NO	170 242	3 748 267	NO	NO
2004	4 023 985	NO	197 211	3 826 775	NO	NO
2005	3 979 273	NO	174 153	3 805 119	NO	NO
2006	3 791 898	NO	82 726	3 709 171	NO	NO
2007	3 373 071	NO	66 911	3 306 160	NO	NO
2008	3 356 005	NO	43 290	3 312 715	NO	NO
2009	2 516 779	NO	37 732	2 479 048	NO	NO
2010	2 990 086	NO	75 118	2 914 968	NO	NO
2011	3 226 530	NO	68 167	3 158 363	NO	NO
2012	3 127 706	NO	165 874	2 961 833	NO	NO
2013	3 415 054	NO	229 291	3 185 763	NO	NO
2014	2 806 391	NO	177 507	2 628 884	NO	NO
2015	2 520 520	NO	88 559	2 431 961	NO	NO
2016	2 603 415	NO	2 972	2 600 443	NO	NO
2017	2 375 064	NO	37 567	2 337 497	NO	NO
2018	2 188 135	NO	38 371	2 149 764	NO	NO
2019	2 154 691	NO	48 078	2 106 613	NO	NO
Trend 1990-2019	-12.26%	NA	-96.71%	111.78%	NA	NA
Trend 2018-2019	-1.53%	NA	25.30%	-2.01%	NA	NA

Source: Environment Agency.

3.2.7.3.2.2 Methodological issues

The 2006 IPCC Guidelines Tier 1 approach has been applied for residual fuel oil, whereas the 2006 IPCC Guidelines Tier 2 approach was applied for gas oil and natural gas.

3.2.7.3.2.3 Emission factors

The 2006 IPCC Guidelines default EFs have been applied for CO₂ for residual fuel oil, whereas for gas oil and natural gas country-specific EFs were used. Default EFs have been applied for CH₄ and N₂O (Table 3-40).

Table 3-40 – Emission factors for category 1A2c – Chemicals

1A2c - Chemicals								
Emission Factors for 2019 (kg/TJ)								
Fuel	Fuel Type	CO ₂		CH ₄		N ₂ O		Source
		EF	type	EF	type	EF	type	
Residual Fuel Oil	liquid	77 400	D	3.00	D	0.60	D	2006 IPCC GL
Gas Oil	liquid	74 078	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 091	CS	1.00	D	0.10	D	AEV 2006 IPCC GL

Source: Environment Agency.

Table 3-41 gives an overview of the evolution of the implied emission factors per fuel type.

For liquid fuels, the CO₂ IEF was higher in the early 1990s due to the increased use of residual fuel oil, which was gradually replaced by gas/diesel oil in the mid 1990s.

Table 3-41 – Implied emission factors for category 1A2c – Chemicals

1A2c - Chemicals						
Implied Emission Factors (kg/TJ)						
Year	Liquid			Gaseous		
	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O
1990	76 923	3.00	0.60	57 755	1.00	0.10
1991	77 049	3.00	0.60	57 743	1.00	0.10
1992	76 914	3.00	0.60	57 848	1.00	0.10
1993	77 005	3.00	0.60	57 894	1.00	0.10
1994	76 955	3.00	0.60	57 940	1.00	0.10
1995	76 550	3.00	0.60	57 929	1.00	0.10
1996	76 465	3.00	0.60	57 546	1.00	0.10
1997	76 141	3.00	0.60	57 205	1.00	0.10
1998	74 630	2.98	0.60	56 863	1.00	0.10
1999	72 438	2.90	0.58	56 522	1.00	0.10
2000	74 117	3.00	0.60	56 221	1.00	0.10
2001	74 077	2.99	0.60	56 258	1.00	0.10
2002	73 880	2.99	0.60	56 396	1.00	0.10
2003	74 047	2.99	0.60	56 533	1.00	0.10
2004	73 962	2.99	0.60	56 671	1.00	0.10
2005	73 979	2.99	0.60	56 910	1.00	0.10
2006	73 794	2.99	0.60	57 008	1.00	0.10
2007	73 680	2.98	0.60	56 793	1.00	0.10
2008	73 861	2.99	0.60	56 665	1.00	0.10
2009	73 956	3.00	0.60	57 056	1.00	0.10
2010	73 933	2.99	0.60	56 712	1.00	0.10
2011	74 064	3.00	0.60	56 988	1.00	0.10
2012	74 134	3.00	0.60	56 793	1.00	0.10
2013	74 141	3.00	0.60	56 680	1.00	0.10
2014	74 069	3.00	0.60	56 756	1.00	0.10
2015	74 128	3.00	0.60	56 760	1.00	0.10
2016	74 136	3.00	0.60	56 561	1.00	0.10
2017	74 149	3.00	0.60	56 577	1.00	0.10
2018	74 130	3.00	0.60	56 209	1.00	0.10
2019	74 078	3.00	0.60	56 091	1.00	0.10

Source: Environment Agency.

3.2.7.4 Pulp, Paper and Print (1A2d)

3.2.7.4.1 Source category description

In Luxembourg, this source category only covers the printing industry. No pulp or paper production occurs in Luxembourg. Included in this sub-category are the emissions from stationary combustion plants (<50 MW). Emissions from mobile sources and machinery used in this category are reported under category 1.A.2.g.vii – Off-road vehicles and other machinery.

In 2019, fuel combustion from the paper and print industry was responsible for 0.02% of GHG emissions from fuel combustion activities and represented 0.02% of the national total GHG emissions in CO₂e, excluding LULUCF. Compared to 2018, emissions increased by 7.76%.

3.2.7.4.2 Methodological issues

3.2.7.4.2.1 Activity data

Annual fuel consumption data for gas oil, diesel oil and natural gas were derived from national statistics for the period 2000-2019. Diesel oil is mainly used by mobile sources and machinery (reported under category 1.A.2.g.vii – Off-road vehicles and other machinery), whereas the remaining fuels are mainly combusted in stationary units for heating purposes. For 1990-1999, no activity data are available from national statistics, hence the notation key IE was used in the CRF tables. For these years, the data are included in 1A2g - Other.

Activity data for the pulp, paper and print industry are listed in Table 3-42.

Table 3-42- Activity data for category 1A2d - Pulp, Paper and Print: 1990-2019

1A2d - Pulp, Paper & Print Activity Data by fuel type (GJ)						
Year	Activity Total	Solid	Liquid Gas Oil, Diesel Oil	Gaseous Natural Gas	Biomass	Other
1990	IE	NO	IE	IE	NO	NO
1991	IE	NO	IE	IE	NO	NO
1992	IE	NO	IE	IE	NO	NO
1993	IE	NO	IE	IE	NO	NO
1994	IE	NO	IE	IE	NO	NO
1995	IE	NO	IE	IE	NO	NO
1996	IE	NO	IE	IE	NO	NO
1997	IE	NO	IE	IE	NO	NO
1998	IE	NO	IE	IE	NO	NO
1999	IE	NO	IE	IE	NO	NO
2000	222 948	NO	19 980	202 968	NO	NO
2001	266 625	NO	29 781	236 843	NO	NO
2002	331 511	NO	30 456	301 055	NO	NO
2003	378 444	NO	17 956	360 488	NO	NO
2004	329 795	NO	20 482	309 314	NO	NO
2005	323 026	NO	14 804	308 222	NO	NO
2006	199 751	NO	6 580	193 171	NO	NO
2007	128 782	NO	4 379	124 403	NO	NO
2008	176 705	NO	3 210	173 495	NO	NO
2009	138 620	NO	2 335	136 285	NO	NO
2010	91 754	NO	3 941	87 812	NO	NO
2011	154 293	NO	2 195	152 098	NO	NO
2012	189 025	NO	1 217	187 807	NO	NO
2013	236 517	NO	1 603	234 914	NO	NO
2014	111 331	NO	663	110 668	NO	NO
2015	96 366	NO	1 393	94 973	NO	NO
2016	93 858	NO	1 213	92 645	NO	NO
2017	84 539	NO	1 898	82 641	NO	NO
2018	28 156	NO	1 939	26 217	NO	NO
2019	30 293	NO	2 430	27 864	NO	NO
Trend 1990-2019	NA	NA	NA	NA	NA	NA
Trend 2018-2019	7.59%	NA	25.30%	6.28%	NA	NA

Source: Environment Agency

3.2.7.4.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 2 approach was applied for gas oil and natural gas.

3.2.7.4.2.3 Emission factors

Country-specific CO₂ EFs were used for gasoil and natural gas, whereas 2006 IPCC default EFs have been applied for CH₄ and N₂O (Table 3-43).

Table 3-43 – Emission factors for category 1A2d - Pulp, Paper and Print

1A2d - Pulp, Paper & Print Emission Factors for 2019 (kg/TJ)								
Fuel	Fuel Type	CO ₂		CH ₄		N ₂ O		Source
		EF	type	EF	type	EF	type	
Gas Oil	liquid	74 078	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 091	CS	1.00	D	0.10	D	AEV 2006 IPCC GL

Source: Environment Agency

Table 3-44 gives an overview of the evolution of the implied emission factors per fuel type.

Table 3-44 – Implied emission factors for category 1A2d - Pulp, Paper and Print

1A2d - Pulp, Paper & Print Implied Emission Factors (kg/TJ)						
Year	Liquid			Gaseous		
	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O
1990	NO	NO	NO	NO	NO	NO
1991	NO	NO	NO	NO	NO	NO
1992	NO	NO	NO	NO	NO	NO
1993	NO	NO	NO	NO	NO	NO
1994	NO	NO	NO	NO	NO	NO
1995	NO	NO	NO	NO	NO	NO
1996	NO	NO	NO	NO	NO	NO
1997	NO	NO	NO	NO	NO	NO
1998	NO	NO	NO	NO	NO	NO
1999	NO	NO	NO	NO	NO	NO
2000	74 212	3.00	0.60	56 221	1.00	0.10
2001	74 216	3.00	0.60	56 258	1.00	0.10
2002	74 217	3.00	0.60	56 396	1.00	0.10
2003	74 192	3.00	0.60	56 533	1.00	0.10
2004	74 154	3.00	0.60	56 671	1.00	0.10
2005	74 137	3.00	0.60	56 910	1.00	0.10
2006	74 138	3.00	0.60	57 008	1.00	0.10
2007	74 141	3.00	0.60	56 793	1.00	0.10
2008	74 085	3.00	0.60	56 665	1.00	0.10
2009	74 074	3.00	0.60	57 056	1.00	0.10
2010	74 128	3.00	0.60	56 712	1.00	0.10
2011	74 114	3.00	0.60	56 988	1.00	0.10
2012	74 134	3.00	0.60	56 793	1.00	0.10
2013	74 141	3.00	0.60	56 680	1.00	0.10
2014	74 069	3.00	0.60	56 756	1.00	0.10
2015	74 128	3.00	0.60	56 760	1.00	0.10
2016	74 136	3.00	0.60	56 561	1.00	0.10
2017	74 149	3.00	0.60	56 577	1.00	0.10
2018	74 130	3.00	0.60	56 209	1.00	0.10
2019	74 078	3.00	0.60	56 091	1.00	0.10

Source: Environment Agency

3.2.7.5 Food Processing, Beverages and Tobacco (1A2e)

3.2.7.5.1 Source category description

In Luxembourg, this category covers mainly the production of beer, milk, milk products, and tobacco products. Included in this category are the emissions from combustion plants (<50 MW) operated by the food processing, beverages and tobacco industry. Emissions from mobile sources and machinery used in this category are reported under category 1.A.2.g.vii – Off-road vehicles and other machinery.

In 2019, fuel combustion from the food processing, beverages and tobacco industry was responsible for 0.28% of GHG emissions from fuel combustion activities (0.08% in 1990) and represented 0.24% of the national total GHG emissions excluding LULUCF (0.06% in 1990). Compared to 2018, emissions increased by 9.22% and compared to 1990, increased by 220.23%.

For liquid fuels, some exceptional inter-annual changes have been observed for the years 1993/1994 (+83%), 1998/1999 (+94%), 2008/2009 (+62%), and 2016/2017 (+93%). The main drivers of these inter-annual changes are an increase in gas oil consumption as reported by the national energy balance (1993/1994 and 2016/2017), a switch from residual fuel oil to gas oil (1998/1999), and the emptying of gas oil stocks at one facility prior to shutting down (2008/2009).

3.2.7.5.2 Methodological issues & time-series consistency

3.2.7.5.2.1 Activity data

Annual fuel consumption data of residual fuel oil, gas oil, diesel oil and natural gas were obtained from the operators through their annual reporting obligations. Diesel oil is mainly used by mobile sources and machinery (reported under category 1.A.2.g.vii – Off-road vehicles and other machinery), whereas the remaining fuels are mainly combusted in stationary units for heating purposes. The bottom-up data on natural gas, for 1990-1999, could not be matched to the top-down data from national statistics as no such data are reported for this category. To avoid double counting, the bottom-up data on natural gas were subtracted from the top-down data from national statistics reported for category 1A2g - Other. For natural gas (2000-2019) and liquid fuels (residual fuel oil, gas oil, diesel oil), the matching exercise was done within the category 1A2e as top-down data are available for this sub-category from national statistics. Activity data for the food processing, beverages and tobacco industry are listed in Table 3-45.

Table 3-45- Activity data for category 1A2e - Food Processing, Beverages and Tobacco: 1990-2019

1A2e - Food Processing, Beverages & Tobacco						
Activity Data by fuel type (GJ)						
Year	Activity Total	Solid	Liquid Residual fuel oil, Gas Oil, Diesel Oil	Gaseous Natural Gas	Biomass	Other
1990	123 939	NO	58 127	65 812	NO	NO
1991	193 080	NO	97 625	95 455	NO	NO
1992	190 024	NO	89 556	100 468	NO	NO
1993	144 772	NO	46 041	98 731	NO	NO
1994	185 088	NO	84 354	100 734	NO	NO
1995	188 732	NO	84 363	104 369	NO	NO
1996	169 396	NO	66 232	103 164	NO	NO
1997	209 521	NO	103 053	106 468	NO	NO
1998	199 012	NO	88 135	110 877	NO	NO
1999	266 940	NO	170 840	96 100	NO	NO
2000	414 541	NO	97 766	316 776	NO	NO
2001	499 227	NO	145 965	353 262	NO	NO
2002	540 419	NO	141 656	398 763	NO	NO
2003	303 252	NO	85 093	218 159	NO	NO
2004	299 949	NO	89 488	210 460	NO	NO
2005	305 846	NO	83 200	222 646	NO	NO
2006	238 614	NO	55 292	183 321	NO	NO
2007	227 830	NO	51 653	176 177	NO	NO
2008	228 536	NO	50 825	177 712	NO	NO
2009	230 932	NO	82 440	148 492	NO	NO
2010	232 193	NO	72 615	159 577	NO	NO
2011	337 278	NO	61 839	275 438	NO	NO
2012	275 554	NO	63 516	212 037	NO	NO
2013	290 831	NO	68 843	221 988	NO	NO
2014	406 318	NO	82 381	323 937	NO	NO
2015	346 636	NO	92 931	253 705	NO	NO
2016	384 262	NO	92 421	291 842	NO	NO
2017	425 396	NO	178 615	246 781	NO	NO
2018	365 154	NO	184 944	180 210	NO	NO
2019	391 213	NO	226 966	164 248	NO	NO
Trend 1990-2019	215.65%	NA	290.46%	149.57%	NA	NA
Trend 2018-2019	7.14%	NA	22.72%	-8.86%	NA	NA

Source: Environment Agency.

3.2.7.5.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 1 approach has been applied for residual fuel oil, whereas the 2006 IPCC Guidelines Tier 2 approach was applied for gas oil, diesel oil and natural gas.

3.2.7.5.2.3 Emission factors

The 2006 IPCC Guidelines default EFs have been applied for CO₂ from residual fuel oil, whereas for gas oil and natural gas country specific EFs were used. Default EFs have been applied for CH₄ and N₂O (Table 3-46).

Table 3-46 – Emission factors for category 1A2e – Food Processing, Beverages and Tobacco

1A2e - Food Processing, Beverages & Tobacco								
Emission Factors for 2019 (kg/TJ)								
Fuel	Fuel Type	CO ₂		CH ₄		N ₂ O		Source
		EF	type	EF	type	EF	type	
Residual Fuel Oil	liquid	77 400	D	3.00	D	0.60	D	2006 IPCC GL
Gas Oil	liquid	74 078	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 091	CS	1.00	D	0.10	D	AEV 2006 IPCC GL

Source: Environment Agency

Table 3-47 gives an overview of the evolution of the implied emission factors per fuel type.

Table 3-47 – Implied emission factors for category 1A2e – Food Processing, Beverages and Tobacco

1A2e - Food Processing, Beverages & Tobacco						
Implied Emission Factors (kg/TJ)						
Year	Liquid			Gaseous		
	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O
1990	75 265	3.00	0.60	57 755	1.00	0.10
1991	74 850	3.00	0.60	57 743	1.00	0.10
1992	74 602	3.00	0.60	57 848	1.00	0.10
1993	74 713	3.00	0.60	57 894	1.00	0.10
1994	74 490	3.00	0.60	57 940	1.00	0.10
1995	74 494	3.00	0.60	57 929	1.00	0.10
1996	74 623	3.00	0.60	57 546	1.00	0.10
1997	74 405	3.00	0.60	57 205	1.00	0.10
1998	74 591	3.00	0.60	56 863	1.00	0.10
1999	74 189	3.00	0.60	56 522	1.00	0.10
2000	74 238	3.00	0.60	56 221	1.00	0.10
2001	74 708	3.00	0.60	56 258	1.00	0.10
2002	74 704	3.00	0.60	56 396	1.00	0.10
2003	74 982	3.00	0.60	56 533	1.00	0.10
2004	74 888	3.00	0.60	56 671	1.00	0.10
2005	75 048	3.00	0.60	56 910	1.00	0.10
2006	75 684	3.00	0.60	57 008	1.00	0.10
2007	75 920	3.00	0.60	56 793	1.00	0.10
2008	76 055	3.00	0.60	56 665	1.00	0.10
2009	75 252	3.00	0.60	57 056	1.00	0.10
2010	76 004	3.00	0.60	56 712	1.00	0.10
2011	76 405	3.00	0.60	56 988	1.00	0.10
2012	76 296	3.00	0.60	56 793	1.00	0.10
2013	75 978	3.00	0.60	56 680	1.00	0.10
2014	75 699	3.00	0.60	56 756	1.00	0.10
2015	75 587	3.00	0.60	56 760	1.00	0.10
2016	75 472	3.00	0.60	56 561	1.00	0.10
2017	74 806	3.00	0.60	56 577	1.00	0.10
2018	74 826	3.00	0.60	56 209	1.00	0.10
2019	74 731	3.00	0.60	56 091	1.00	0.10

Source: Environment Agency

3.2.7.6 Non-Metallic Minerals (1A2f)

3.2.7.6.1 Source category description

Source category 1A2f – Non-metallic minerals covers industrial activities such as glass, clinker / cement and ceramics production.

In 2019, fuel combustion emissions reported under 1A2f – Non-metallic minerals were responsible for 4.55% of GHG emissions from fuel combustion activities (this share was 5.24% in 1990) and represented 3.92% of the national total GHG emissions excluding LULUCF (4.24% in 1990). Compared to 2018, emissions increased by 3.94% and compared to 1990, decreased by 21.95%.

3.2.7.6.2 Methodological issues

3.2.7.6.2.1 Activity data

Under 1A2f – Non-metallic minerals, the following activities have been considered (Table 3-48):

Table 3-48 – Combustion activities included in 1A2f – Non-metallic minerals

Description	SNAP code
Cement (Clinker)	030311
Flat glass	030314
Fine ceramic materials	030320

Cement (Clinker)

One industrial site produces clinker in Luxembourg. Its major fuel is other bituminous coal, but use is also made of residual oil, natural gas and special types of waste: shredded tires, fluff and sewage sludge. These waste types contain a certain biogenic fraction, which is annually reported by the operator and is taken into consideration when estimating the emissions. The consumption data of these fuels are transmitted annually to the Environment Agency by the operator.

Flat glass

There are two flat glass plants in Luxembourg. Their main fuel is natural gas. LPG is also used but in very little quantities.

Fine ceramic materials

One major production site of ceramic materials existed in Luxembourg (Villeroy & Boch) using natural gas as fuel. However, the production site was closed down in 2010.

Activity data for the non-metallic minerals industry are listed in Table 3-49.

Table 3-49 – Activity data by fuel type of category 1A2f – Non-metallic minerals: 1990-2019

1A2f - Non-Metallic Minerals Activity Data by fuel type (GJ)						
Year	Activity Total	Solid	Liquid Residual Fuel Oil, Gas Oil, LPG	Gaseous Natural Gas	Biomass Sewage Sludge, Tires, Fluff	Other Tires, Fluff
1990	7 102 444	3 302 589	317 025	3 482 830	NO	NO
1991	6 397 674	3 028 845	278 951	3 089 878	NO	NO
1992	6 835 989	3 404 630	332 101	3 099 259	NO	NO
1993	6 338 557	2 850 457	340 640	3 147 461	NO	NO
1994	7 488 467	3 840 609	371 987	3 275 872	NO	NO
1995	6 741 314	3 000 573	378 163	3 362 578	NO	NO
1996	7 069 180	3 303 931	366 957	3 398 292	NO	NO
1997	6 597 961	2 886 032	450 532	3 261 397	NO	NO
1998	6 156 959	2 674 118	353 846	2 949 422	48 484	131 088
1999	6 899 166	2 819 127	458 326	3 446 649	47 267	127 797
2000	7 085 633	3 127 895	133 449	3 555 847	72 479	195 963
2001	7 361 385	3 119 891	114 647	3 543 132	157 603	426 112
2002	6 378 646	2 093 325	100 703	3 482 189	197 108	505 321
2003	5 515 258	1 793 790	97 186	2 956 142	202 949	465 191
2004	6 265 189	2 070 876	122 662	3 310 857	252 132	508 662
2005	6 387 203	2 190 698	89 426	3 333 205	236 807	537 068
2006	6 782 853	2 577 804	77 093	3 286 321	263 980	577 654
2007	6 317 411	1 989 234	70 777	3 372 178	296 661	588 562
2008	6 123 579	1 805 356	58 034	3 340 782	259 929	659 478
2009	6 072 757	2 043 207	37 557	3 314 606	198 932	478 455
2010	6 024 774	1 855 755	23 877	3 222 306	283 272	639 565
2011	5 956 208	1 819 386	29 527	3 255 395	260 635	591 265
2012	5 830 526	1 742 721	32 119	3 181 655	270 977	603 054
2013	5 017 178	1 657 980	27 785	2 343 360	278 590	709 462
2014	5 648 747	1 792 071	57 737	2 892 559	265 698	640 681
2015	5 406 420	1 527 342	51 459	2 943 615	245 290	638 714
2016	5 870 753	1 699 332	67 561	2 982 705	227 998	893 158
2017	5 706 038	1 607 521	124 409	2 789 923	234 627	949 558
2018	5 894 889	1 431 036	126 900	2 998 642	232 073	1 106 238
2019	6 141 661	1 579 485	158 240	2 964 834	286 561	1 152 540
Trend 1990-2019	-13.53%	-52.17%	-50.09%	-14.87%	NA	NA
Trend 2018-2019	4.19%	10.37%	24.70%	-1.13%	23.48%	4.19%

Source: Environment Agency

3.2.7.6.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 1 approach has been applied for solid fuels and residual fuel oil, whereas the 2006 IPCC Guidelines Tier 2 approach was applied for natural gas, gas oil and LPG. CO₂ emissions from the biogenic fractions of tires, fluff and sewage sludge are reported under memory items. The biogenic fraction of tires, which are used since 1998 in the clinker production, was set to 27% for the entire time-series in accordance with the EU-ETS declarations from the plant operator. This value is validated by two independent reports from "Verein Deutscher Zementwerke e. V."⁷⁶ and "Aliapur"⁷⁷ on the use of tires as secondary fuels.

The biogenic fraction of fluff, which is used since 2006 as secondary fuel in the clinker production, is determined annually by the plant operator, in accordance with the EU Emissions Trading System Monitoring and Reporting Guidelines⁷⁸.

3.2.7.6.2.3 Emission factors

The 2006 IPCC Guidelines default CO₂ EFs have been applied for residual fuel oil and for other bituminous coal. For tires, sewage sludge, solvents, and fluff, plant-specific CO₂ emission factors were used. For natural gas, gas oil and LPG country-specific CO₂ EFs were used. IPCC default EFs have been applied for CH₄ and N₂O (Table 3-50).

Table 3-50 – Emission factors for category 1A2f – Non-metallic minerals

1A2f - Non-Metallic Minerals Emission Factors for 2019 (kg/TJ)								
Fuel	Fuel Type	CO ₂		CH ₄		N ₂ O		Source
		EF	type	EF	type	EF	type	
Other Bituminous Coal	solid	94 600	D	10.00	D	1.50	D	2006 IPCC GL
Residual Fuel Oil	liquid	77 400	D	3.00	D	0.60	D	2006 IPCC GL
Gas Oil	liquid	74 078	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
LPG	liquid	65 489	CS	1.00	D	0.10	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 091	CS	1.00	D	0.10	D	AEV 2006 IPCC GL
Sewage Sludge	other/biomass	90 718	PS	30.00	D	4.00	D	ETS 2006 IPCC GL
Solvents	other	69 940	PS	30.00	D	4.00	D	ETS 2006 IPCC GL
Tires	other/biomass	88 000	PS	30.00	D	4.00	D	ETS 2006 IPCC GL
Fluff	other/biomass	84 430	PS	30.00	D	4.00	D	ETS 2006 IPCC GL

Source: Environment Agency

76 http://www.vdz-online.de/fileadmin/gruppen/vdz/3LiteraturRecherche/Taetigkeitsbericht07/V/DZ_Kap_II.pdf

77 http://www.aliapur.fr/media/files/RetD_new/Conferences_Publications/Pneus_usages_comme_combustible_alternatif_extrait.pdf

78 http://ec.europa.eu/clima/policies/ets/monitoring/index_en.htm

Table 3-51 gives an overview of the evolution of the implied emission factors per fuel type.

The increase of the CO₂ IEF of biomass from 2002 onwards is due to the use of different types of biomass over time. Indeed, tires (CO₂ EF: 88.00 t CO₂/TJ) are used since 1998 as secondary fuel in the clinker production. Since 2002, sewage sludge (CO₂ EF: 90.72 t CO₂/TJ) and since 2006, fluff, (CO₂ EF: 84.43 t CO₂/TJ) are co-incinerated in the clinker production.

Table 3-51 – Implied emission factors for category 1A2f – Non-metallic minerals

1A2f - Non-Metallic Minerals Implied Emission Factors (kg/TJ)															
Year	Solid			Liquid			Gaseous			Biomass			Other		
	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O
1990	94 600	10.00	1.50	72 369	2.18	0.40	57 755	1.00	0.10	NO	NO	NO	NO	NO	NO
1991	94 600	10.00	1.50	74 295	2.79	0.55	57 743	1.00	0.10	NO	NO	NO	NO	NO	NO
1992	94 600	10.00	1.50	75 285	2.95	0.59	57 848	1.00	0.10	NO	NO	NO	NO	NO	NO
1993	94 600	10.00	1.50	75 059	2.94	0.59	57 894	1.00	0.10	NO	NO	NO	NO	NO	NO
1994	94 600	10.00	1.50	75 158	3.00	0.60	57 940	1.00	0.10	NO	NO	NO	NO	NO	NO
1995	94 600	10.00	1.50	74 869	2.95	0.59	57 929	1.00	0.10	NO	NO	NO	NO	NO	NO
1996	94 600	10.00	1.50	74 786	2.94	0.59	57 546	1.00	0.10	NO	NO	NO	NO	NO	NO
1997	94 600	10.00	1.50	74 287	2.80	0.55	57 205	1.00	0.10	NO	NO	NO	NO	NO	NO
1998	94 600	10.00	1.50	75 006	3.00	0.60	56 863	1.00	0.10	88 000	30.00	4.00	88 000	30.00	4.00
1999	94 600	10.00	1.50	74 641	2.99	0.60	56 522	1.00	0.10	88 000	30.00	4.00	88 000	30.00	4.00
2000	94 600	10.00	1.50	76 097	2.93	0.58	56 221	1.00	0.10	88 000	30.00	4.00	88 000	30.00	4.00
2001	94 600	10.00	1.50	76 205	3.00	0.60	56 258	1.00	0.10	88 000	30.00	4.00	88 000	30.00	4.00
2002	94 600	10.00	1.50	76 033	2.98	0.60	56 396	1.00	0.10	88 680	30.00	4.00	88 062	30.00	4.00
2003	94 600	10.00	1.50	76 599	3.00	0.60	56 533	1.00	0.10	89 999	30.00	4.00	88 204	30.00	4.00
2004	94 600	10.00	1.50	76 418	2.98	0.59	56 671	1.00	0.10	91 334	30.00	4.00	88 386	30.00	4.00
2005	94 600	10.00	1.50	76 615	3.00	0.60	56 910	1.00	0.10	90 117	30.00	4.00	88 218	30.00	4.00
2006	94 600	10.00	1.50	76 981	3.00	0.60	57 008	1.00	0.10	90 119	30.00	4.00	88 016	30.00	4.00
2007	94 600	10.00	1.50	77 038	3.00	0.60	56 793	1.00	0.10	89 578	30.00	4.00	87 239	30.00	4.00
2008	94 600	10.00	1.50	76 507	3.00	0.60	56 665	1.00	0.10	88 828	30.00	4.00	86 018	30.00	4.00
2009	94 600	10.00	1.50	74 074	3.00	0.60	57 056	1.00	0.10	92 348	30.00	4.00	83 544	30.00	4.00
2010	94 600	10.00	1.50	74 128	3.00	0.60	56 712	1.00	0.10	90 986	30.00	4.00	86 547	30.00	4.00
2011	94 600	10.00	1.50	74 114	3.00	0.60	56 988	1.00	0.10	90 284	30.00	4.00	87 058	30.00	4.00
2012	94 600	10.00	1.50	74 134	3.00	0.60	56 793	1.00	0.10	89 501	30.00	4.00	86 737	30.00	4.00
2013	94 600	10.00	1.50	74 141	3.00	0.60	56 680	1.00	0.10	86 561	30.00	4.00	85 079	30.00	4.00
2014	94 600	10.00	1.50	74 069	3.00	0.60	56 756	1.00	0.10	85 751	30.00	4.00	85 705	30.00	4.00
2015	94 600	10.00	1.50	73 454	2.85	0.56	56 760	1.00	0.10	88 021	30.00	4.00	85 334	30.00	4.00
2016	94 600	10.00	1.50	74 002	2.97	0.59	56 561	1.00	0.10	85 445	30.00	4.00	81 563	30.00	4.00
2017	94 600	10.00	1.50	74 039	2.98	0.59	56 577	1.00	0.10	85 480	30.00	4.00	79 209	30.00	4.00
2018	94 600	10.00	1.50	74 032	2.98	0.59	56 209	1.00	0.10	85 085	30.00	4.00	79 289	30.00	4.00
2019	94 600	10.00	1.50	74 024	2.99	0.60	56 091	1.00	0.10	86 235	30.00	4.00	77 417	30.00	4.00

Source: Environment Agency

3.2.7.7 Other (1A2g)

3.2.7.7.1 Source category description

Source category *1A2g – Other* covers all the remaining industrial activities not previously mentioned and is divided into two sub-categories:

- *1.A.2.g.vii – Off-road vehicles and other machinery*, which includes all types of mobile machinery used in *1A2 - Manufacturing industry and Construction*, such as power generators, fork lifts, excavators, etc.
- *1.A.2.g.viii – Other Manufacturing Industries*, which includes stationary combustion in manufacturing of transport equipment, machinery, mining and quarrying, wood and wood products, construction, textile and leather and non-specified industry.

In 2019, fuel combustion emissions reported under *1A2g - Other* manufacturing industries and construction were responsible for 2.84% of GHG emissions from fuel combustion activities (this share was 1.05% in 1990) and represented 2.44% of the national total GHG emissions excluding LULUCF (0.85% in 1990). Compared to 2018, emissions increased by 4.79% and compared to 1990, increased by 141.82%.

3.2.7.7.2 Methodological issues

3.2.7.7.2.1 Activity data

The following combustion activities have been considered in category *1A2g - Other* (Table 3-52):

Table 3-52 – Combustion activities included in 1A2g - Other

Description	SNAP code
Combustion plants < 50 MW	030103
Gas Turbines	030104
Asphalt concrete plants	030313
Other mobile sources and machinery in Industry	080800
Other mobile equipment	081000

Combustion plants <50 MW

This source includes all kind of smaller combustion installations for heat or steam production. As the number of this kind of boilers is quite important, they have not always been treated individually. Various types of fuel were and still are used: anthracite, residual fuel oil, gas oil, LPG, natural gas. Where information about the fuel combustion in these boilers was available, it was received directly from the operator.

Gas Turbines

This source includes one gas turbine used in the wood processing industry for heat and electricity production running on natural gas. The information about the fuel combustion is received directly from the operator.

Asphalt concrete plants

There are three asphalt concrete plants in Luxembourg. Their main fuel is lignite (brown coal briquettes) followed by natural gas and gas oil. Fuel consumption data were obtained by the operators.

Mobile Sources and Machinery in Industry and Other Mobile Equipment

Activity data are based on the stock data of mobile machinery used in industry and construction equipment, as well as on economic indicators such as the gross value added for the industrial sector.

Activity data for *1A2g – Other* are listed in Table 3-53.

Table 3-53 – Activity data by fuel type of category 1A2g – Other: 1990-2019

1A2g - Other									
Year	Activity Total (excl. biomass)	1.A.2.g.vii - Off-road vehicles and other machinery			1.A.2.g.viii - Other Manufacturing Industries				
		Liquid	Biomass	Other fossil fuels	Solid	Liquid	Gaseous	Biomass	Other
		Diesel Oil, Gasoline	Biodiesel, Biogasoline	Fossil part of biodiesel	Other Bituminous Coal, Brown Coal Briquettes	Residual Fuel Oil, Gas Oil, LPG	Natural Gas	Wood and Wood Waste	
1990	1 419 507	618 365	NO	NO	206 140	182 270	412 733	NO	NO
1991	3 608 633	700 883	NO	NO	199 769	293 602	2 414 378	NO	NO
1992	4 041 884	760 284	NO	NO	217 880	251 723	2 811 997	NO	NO
1993	4 341 606	824 978	NO	NO	161 445	225 392	3 129 790	NO	NO
1994	4 341 612	866 765	NO	NO	320 437	251 136	2 903 274	NO	NO
1995	3 932 115	922 207	NO	NO	160 119	264 601	2 585 188	NO	NO
1996	4 062 316	892 581	NO	NO	254 976	219 399	2 695 360	NO	NO
1997	5 310 457	950 701	NO	NO	225 135	254 493	3 880 127	NO	NO
1998	5 566 675	971 738	NO	NO	183 946	502 140	3 908 852	NO	NO
1999	7 081 938	1 056 669	NO	NO	218 107	1 685 840	4 121 322	NO	NO
2000	3 565 796	1 111 339	NO	NO	232 377	849 550	1 372 530	NO	NO
2001	3 488 099	1 140 315	NO	NO	168 958	863 745	1 315 081	NO	NO
2002	3 406 268	1 268 813	NO	NO	138 204	836 117	1 163 134	NO	NO
2003	3 644 125	1 320 679	NO	NO	145 892	1 051 361	1 126 193	NO	NO
2004	3 677 731	1 393 239	410	23	147 911	881 834	1 254 724	NO	NO
2005	3 452 487	1 395 734	386	22	144 819	703 149	1 208 763	880 933	NO
2006	3 395 924	1 505 417	404	23	136 831	465 284	1 288 369	856 579	NO
2007	3 473 543	1 786 711	45 242	2 581	142 414	485 132	1 056 706	918 261	NO
2008	3 216 270	1 665 303	40 910	2 334	139 665	501 626	907 342	979 662	NO
2009	2 972 326	1 685 511	42 059	2 400	156 912	235 671	891 832	754 820	NO
2010	2 996 071	1 752 769	40 286	2 188	211 674	268 931	760 510	863 371	NO
2011	3 078 321	1 877 816	39 631	2 084	171 154	173 690	853 577	785 914	NO
2012	2 997 338	1 770 743	45 874	2 192	191 369	172 989	860 045	682 906	NO
2013	3 192 475	1 858 567	56 072	2 630	135 996	220 157	975 125	715 237	NO
2014	3 184 664	2 126 335	83 202	4 145	147 760	108 588	797 836	872 512	NO
2015	3 251 909	2 214 344	104 661	5 813	188 807	126 160	716 784	807 701	NO
2016	3 395 358	2 259 615	116 506	6 371	153 878	185 152	790 341	813 359	NO
2017	3 474 045	2 223 163	149 775	8 341	196 635	336 271	709 636	727 688	NO
2018	3 336 837	2 295 881	154 221	8 591	183 866	357 227	491 273	442 124	NO
2019	3 527 175	2 368 730	158 470	8 829	184 430	401 151	564 035	141 769	NO
Trend 1990-2019	148.48%	283.06%	NA	NA	-10.53%	120.09%	36.66%	NA	NA
Trend 2018-2019	5.70%	3.17%	2.76%	2.77%	0.31%	12.30%	14.81%	-67.93%	NA

Source: Environment Agency

3.2.7.7.2.2 Methodological choices

For CO₂, the 2006 IPCC Guidelines Tier 1 approach has been applied for solid fuels, residual fuel oil and biomass fuels (wood and wood waste), whereas the 2006 IPCC Guidelines Tier 2 approach was applied for natural gas, gas oil, diesel oil, gasoline and LPG. For CH₄ and N₂O from stationary combustion, the 2006 IPCC Guidelines Tier 1 approach has been applied for all fuels.

For CH₄ and N₂O from off-road vehicles and other machinery, the GEORG (Grazer Emissionsmodell für Off-Road Geräte) model developed by the TU Graz was used. This methodology conforms to the requirements of the IPCC 2006 GL Tier 3 methodology. Input data to the model are:

- Machinery stock data (obtained through inquiries and statistical extrapolation);
- Assumptions on drop-out rates of machinery (broken down machinery will be replaced);
- Operating time (obtained through inquiries), related to age of machinery.

From machinery stock data and drop-out rates an age structure of the off-road machinery was obtained by GEORG. Four categories of engine types were considered. Depending on the fuel consumption of the engine the ratio power of the engine was calculated. Emissions were calculated by multiplying an engine specific emission factor (expressed in g/kWh) by the average engine power, the operating time and the number of vehicles.

3.2.7.7.2.3 Emission factors

The 2006 IPCC Guidelines default CO₂ EFs have been applied for biomass fuels, residual fuel oil and for solid fuels. For natural gas, gas oil, diesel oil, gasoline and LPG country-specific EFs were used. For stationary combustion, IPCC default EFs have been applied for CH₄ and N₂O.

For mobile combustion (diesel oil, motor gasoline, biofuels), country-specific values, derived from the GEORG model, have been applied for CH₄ and N₂O (Table 3-54).

The country specific CO₂ EFs for diesel oil and gasoline, as described in section 3.2.5.3, were used (Tier 2). CH₄ and N₂O emissions were determined with the GEORG model (

Table 3-72). The CH₄ emission factors are based on the EMEP/EEA 2016 Guidebook (Tier 3) while N₂O emission factors are based on (Hausberger, 2006). For biogasoline, biodiesel and other fossil fuels (fossil part of biodiesel, please refer to page 247 for details), the European CO₂ implied emission factors⁷⁹ for gasoline (71270 g/GJ) and diesel oil (73450 g/GJ) were applied.

Table 3-54 – Emission factors for category 1A2g – Other

1A2g - Other								
Emission Factors for 2019 (kg/TJ)								
Fuel	Fuel Type	CO ₂		CH ₄		N ₂ O		Source
		EF	type	EF	type	EF	type	
Other Bituminous Coal	solid	94 600	D	10.00	D	1.50	D	2006 IPCC GL
Brown Coal Briquettes	solid	97 500	D	10.00	D	1.50	D	2006 IPCC GL
Residual Fuel Oil	liquid	77 400	D	3.00	D	0.60	D	2006 IPCC GL
Gas Oil	liquid	74 078	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
Diesel Oil	liquid	74 078	CS	0.15	CS	8.23	CS	AEV
Gasoline	liquid	73 162	CS	19.55	CS	1.60	CS	AEV
LPG	liquid	65 489	CS	1.00	D	0.10	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 091	CS	1.00	D	0.10	D	AEV 2006 IPCC GL
Wood / wood wastes	biomass	112 000	D	30.00	D	4.00	D	2006 IPCC GL

Source: Environment Agency

79 UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

Table 3-55 gives an overview of the evolution of the implied emission factors for liquid fuels used by off-road vehicles and other machinery.

Table 3-55 – Implied emission factors for category 1.A.2.g.vii – Off-road vehicles and other machinery

1.A.2.g.vii - Off-road vehicles and other machinery Implied Emission Factors (kg/TJ)			
Year	Liquid		
	CO ₂	CH ₄	N ₂ O
1990	74 160	3.52	26.34
1991	74 146	3.51	26.37
1992	74 123	3.50	26.39
1993	74 164	3.49	26.41
1994	74 188	3.44	26.71
1995	74 193	3.35	27.30
1996	74 184	3.29	27.65
1997	74 170	3.22	28.10
1998	74 161	3.13	28.68
1999	74 165	3.04	29.27
2000	74 201	2.98	29.69
2001	74 206	2.94	29.95
2002	74 207	2.62	28.77
2003	74 182	2.25	27.23
2004	74 144	1.96	25.30
2005	74 128	1.72	23.36
2006	74 129	1.45	21.06
2007	74 131	1.08	17.14
2008	74 075	0.89	14.89
2009	74 065	0.80	13.72
2010	74 117	0.71	12.54
2011	74 104	0.62	11.41
2012	74 124	0.57	10.77
2013	74 131	0.52	10.37
2014	74 063	0.43	9.55
2015	74 123	0.36	8.97
2016	74 130	0.32	8.65
2017	74 143	0.30	8.43
2018	74 124	0.27	8.19
2019	74 072	0.24	8.00

Source: Environment Agency

Table 3-56 gives an overview of the evolution of the implied emission factors for fuels used in stationary combustion by other manufacturing industries.

Table 3-56 – Implied emission factors for category 1.A.2.g.viii – Other manufacturing industries

1.A.2.g.viii - Other Manufacturing Industries Implied Emission Factors (kg/TJ)												
Year	Solid			Liquid			Gaseous			Biomass		
	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O
1990	97 393	10.00	1.50	74 171	3.00	0.60	57 755	1.00	0.10	NO	NO	NO
1991	97 411	10.00	1.50	75 549	3.00	0.60	57 743	1.00	0.10	NO	NO	NO
1992	97 419	10.00	1.50	74 200	3.00	0.60	57 848	1.00	0.10	NO	NO	NO
1993	97 376	10.00	1.50	74 601	3.00	0.60	57 894	1.00	0.10	NO	NO	NO
1994	97 438	10.00	1.50	75 232	3.00	0.60	57 940	1.00	0.10	NO	NO	NO
1995	97 374	10.00	1.50	75 697	3.00	0.60	57 929	1.00	0.10	NO	NO	NO
1996	97 430	10.00	1.50	74 987	3.00	0.60	57 546	1.00	0.10	NO	NO	NO
1997	97 447	10.00	1.50	72 933	2.73	0.53	57 205	1.00	0.10	NO	NO	NO
1998	97 401	10.00	1.50	69 643	2.02	0.35	56 863	1.00	0.10	NO	NO	NO
1999	97 445	10.00	1.50	71 388	2.37	0.44	56 522	1.00	0.10	NO	NO	NO
2000	97 500	10.00	1.50	69 269	1.80	0.30	56 221	1.00	0.10	NO	NO	NO
2001	97 500	10.00	1.50	69 845	1.92	0.33	56 258	1.00	0.10	NO	NO	NO
2002	97 500	10.00	1.50	69 719	1.89	0.32	56 396	1.00	0.10	NO	NO	NO
2003	97 500	10.00	1.50	69 899	1.99	0.35	56 533	1.00	0.10	NO	NO	NO
2004	97 500	10.00	1.50	70 014	2.07	0.37	56 671	1.00	0.10	NO	NO	NO
2005	97 500	10.00	1.50	69 579	2.01	0.35	56 910	1.00	0.10	112 000	30.00	4.00
2006	97 500	10.00	1.50	68 955	1.87	0.32	57 008	1.00	0.10	112 000	30.00	4.00
2007	97 500	10.00	1.50	68 240	1.72	0.28	56 793	1.00	0.10	112 000	30.00	4.00
2008	97 500	10.00	1.50	66 932	1.44	0.21	56 665	1.00	0.10	112 000	30.00	4.00
2009	97 500	10.00	1.50	67 880	1.64	0.26	57 056	1.00	0.10	112 000	30.00	4.00
2010	97 500	10.00	1.50	74 672	2.99	0.60	56 712	1.00	0.10	112 000	30.00	4.00
2011	97 500	10.00	1.50	74 853	3.00	0.60	56 988	1.00	0.10	112 000	30.00	4.00
2012	97 500	10.00	1.50	74 719	3.00	0.60	56 793	1.00	0.10	112 000	30.00	4.00
2013	97 500	10.00	1.50	74 478	3.00	0.60	56 680	1.00	0.10	112 000	30.00	4.00
2014	97 500	10.00	1.50	74 279	2.98	0.60	56 756	1.00	0.10	112 000	30.00	4.00
2015	97 500	10.00	1.50	74 128	3.00	0.60	56 760	1.00	0.10	112 000	30.00	4.00
2016	97 500	10.00	1.50	74 427	3.00	0.60	56 561	1.00	0.10	112 000	30.00	4.00
2017	97 500	10.00	1.50	74 702	3.00	0.60	56 577	1.00	0.10	112 000	30.00	4.00
2018	97 500	10.00	1.50	74 764	3.00	0.60	56 209	1.00	0.10	112 000	30.00	4.00
2019	97 500	10.00	1.50	74 379	3.00	0.60	56 091	1.00	0.10	112 000	30.00	4.00

Source: Environment Agency

3.2.7.8 Uncertainties and time-series consistency

The uncertainties for activity data and emission factors used for IPCC category 1A2 – *Manufacturing Industries and Construction* are presented in Table 3-57.

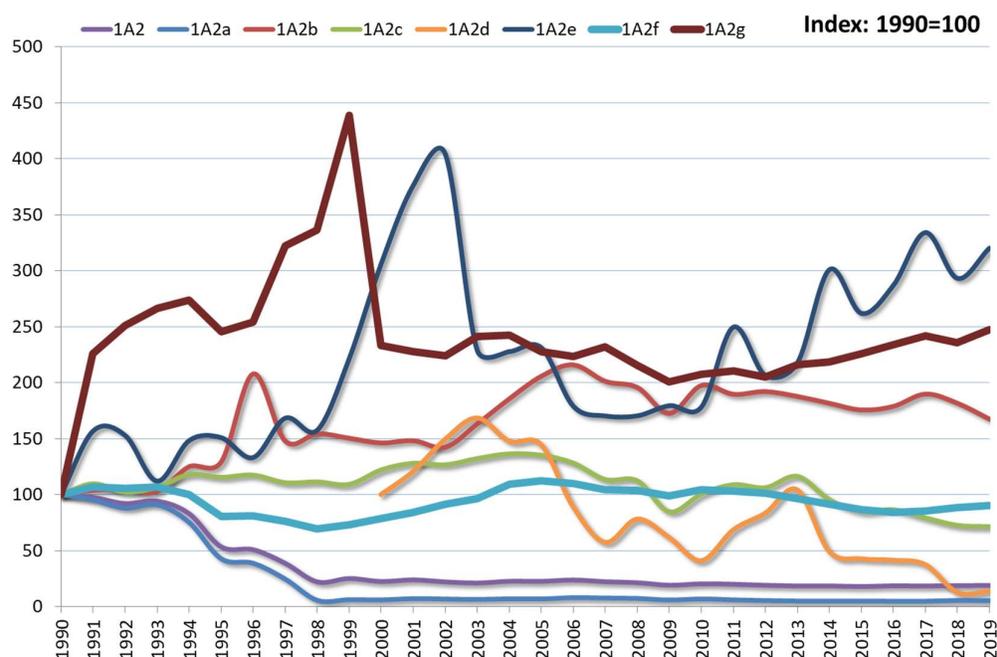
Table 3-57 - Uncertainties for activity data and emission factors used for IPCC category 1A2 – Manufacturing Industries and Construction.

IPCC category/Group	Gas	Activity data uncertainty (%)	Emission factor uncertainty (%)
1A2 - Gaseous Fuels	CO ₂	2%	0.5%
1A2 - Gaseous Fuels	CH ₄	2%	50%
1A2 - Gaseous Fuels	N ₂ O	2%	50%
1A2 - Liquid Fuels	CO ₂	2%	0.5%
1A2 - Liquid Fuels	CH ₄	2%	50%
1A2 - Liquid Fuels	N ₂ O	2%	50%
1A2 - Other Fuels	CO ₂	8%	20%
1A2 - Other Fuels	CH ₄	8%	50%
1A2 - Other Fuels	N ₂ O	8%	50%
1A2 - Biomass	CH ₄	7%	50%
1A2 - Biomass	N ₂ O	7%	60%
1A2 - Solid Fuels	CO ₂	1%	3%
1A2 - Solid Fuels	CH ₄	1%	50%
1A2 - Solid Fuels	N ₂ O	1%	50%

Generally, the time-series, as reported in category 1A2 - *Manufacturing Industries and Construction* are considered to be consistent (

Figure 3-7).

Figure 3-7 – GHG emission trend indices for category 1A2 – Manufacturing Industries and Construction: 1990-2019



The general trend of GHG emissions in 1A2 is greatly influenced by sub-categories 1A2a - Iron and Steel and 1A2f – Non-Metallic Minerals. Fluctuations in emissions of the other sub-categories only influence the general trend on a decreased scale.

However, at a deeper level, and especially for categories 1A2d, 1A2e and 1A2g, time series seem to be less consistent. This is either due to the lack of specific activity data (for example for 1A2d where no category-specific AD is available for the years 1990-1999 so that the notation key IE is used and the corresponding emissions are reported under 1A2g), or due to short-term switches in the energy mix (rotation of gas oil stocks), maintenance stops, closure or start-up of new facilities, etc.

For more specific information on time-series consistency, please refer to the methodological issues as described in the respective categories above.

3.2.7.9 Source-specific QA/QC and verification

Activity data for large facilities that have reporting obligations under the European Union Emission Trading System (EU-ETS) are cross-checked between two sources: reports obtained directly from (1) the operator under its operational permit obligations and (2) the EU-ETS registry operator. Both are hosted at the Environment Agency. A list with the large energy consuming facilities along with their respective fuel consumption has been compiled and enables the Single National Entity to quickly cross-check this data with the EU-ETS data. Thus, completeness can be checked on a more systematic basis.

Additionally, cross checks with other relevant sectors, mainly sector 2 – Industrial Processes and Product Use, are performed to avoid double counting.

Finally, consistency and completeness checks are performed using the tools embedded in CRF Reporter.

3.2.7.10 Category-specific recalculations including changes made in response to the review process

Table 3-58 presents the main revisions and recalculations done since the last submission to the UNFCCC and relevant to category 1A2 - Manufacturing Industries and Construction. The quantitative aspect of these recalculations can be found below and in Chapter 10.

Table 3-58 – Recalculations done since submission 2020v1

GHG source & sink category	Revisions 2020v1 → 2021v1	Type of revision
1A2	Fuel consumption data for natural gas and heating gas oil for the years 2017-2018 was revised due to the revised energy balance from the national statistics institute.	AD
1A2	Revision of natural gas activity data for 2018 from the national energy balance following an error correction of the net calorific value from 36.98 to 36.76 MJ/Nm ³ .	AD
1A2a 1A2gviii	Revision of natural gas activity data for 1990-1994 and 1996-1999 due to the revised energy balance from the national statistics institute.	AD
1A2b	Revision of natural gas activity data for 2018 following an error correction from 412 TJ to 452 TJ.	AD
1A2e 1A2gviii	Revision of residual fuel oil activity data for 2002, 2003, and 2005 in 1A2e from 0 TJ to 21.7 TJ (2002), 21.0 TJ (2003), and 23.2 TJ (2005), respectively. These changes redistribute the residual fuel oil AD from sub-category 1A2gviii to 1A2e such that no effect on the total GHG emissions is observed.	AD
1A2e	Revision of gas oil activity data for one installation for 2008, leading to an increase by 44 GJ.	AD
1A2gviii	Revision of gas oil activity data for 2018 following an error correction from 6.7 TJ to 18.6 TJ.	AD
1A2	The country-specific CO ₂ EFs for LPG were revised for the years 2017-2018 due to changes of the emission factors of the importing countries: 2017: from 65213 to 65232 kg/TJ 2018: from 65212.1277 to 65212.1283 kg/TJ.	CO ₂ EF
1A2gvii	The country-specific CO ₂ EFs for motor gasoline were revised for the years 2017-2018 due to changes of the emission factors of the importing countries: 2017: from 73300 to 73181 kg/TJ 2018: from 73216 to 73093 kg/TJ.	CO ₂ EF
1A2f	The country-specific CO ₂ EFs for fluff, sewage sludge, and solvents were revised for 2018 following an error correction: Fluff: from 82829 to 82199 kg/TJ Sewage sludge: from 91640 to 90794 kg/TJ Solvents: from 72780 to 73730 kg/TJ.	CO ₂ EF

Table 3-59 shows the effect of the recalculations listed in Table 3-58 on the total GHG emissions for the entire time series.

Table 3-59 – Effect of the recalculations in the 1A2 – Manufacturing industries and construction on the GHG emissions between submissions 2020v1 and 2021v1 for the entire time series.

1A2 - Manufacturing industries and construction GHG emissions (Gg CO ₂ eq.)			
Year	2020v1	2021v1	Difference
1990	6265.74792	6265.74799	0.00007
1991	6108.45256	6108.45250	-0.00007
1992	5765.29893	5765.29900	0.00007
1993	5902.01398	5902.01405	0.00007
1994	5189.49617	5189.49610	-0.00007
1995	3333.05089	3333.05089	0.00000
1996	3179.90438	3179.90450	0.00012
1997	2415.81577	2415.81574	-0.00003
1998	1374.23740	1374.23756	0.00015
1999	1564.66859	1564.66865	0.00006
2000	1397.40881	1397.40881	0.00000
2001	1490.05833	1490.05833	0.00000
2002	1375.79207	1375.79207	0.00000
2003	1313.66827	1313.66827	0.00000
2004	1410.54909	1410.54909	0.00000
2005	1406.69837	1406.69837	0.00000
2006	1481.16888	1481.16888	0.00000
2007	1385.05097	1385.05097	0.00000
2008	1330.05138	1330.05467	0.00329
2009	1189.41899	1189.41899	0.00000
2010	1267.27917	1267.27917	0.00000
2011	1243.01608	1243.01608	0.00000
2012	1184.61205	1184.61205	0.00000
2013	1144.38578	1144.38578	0.00000
2014	1148.22928	1148.22928	0.00000
2015	1113.19443	1113.19443	0.00000
2016	1156.25875	1156.25875	0.00000
2017	1144.58186	1146.28083	1.69897
2018	1164.29766	1162.43891	-1.85875

Source: Environment Agency

3.2.7.11 Category-specific planned improvements including those in response to the review process

Taking into account the potential contribution of identified improvements in the total GHG emissions and the corresponding resources needed to make these improvements effective, developments presented in Table 3-60 will be explored.

Table 3-60 – Planned improvements for category 1A2– Manufacturing Industries and Construction.

GHG source & sink category	Planned improvement
1A2	No further improvements planned

3.2.9 Transport (1.A.3)

3.2.9.1 Source category description

This section describes GHG emissions resulting from fuel combustion activities in the transport sector.

The 2021 GHG inventory submission includes emissions from IPCC sub-categories *1A3a – Domestic aviation*, *1A3b – Road Transportation*, *1A3c – Railways* and *1A3d – Domestic Navigation*. This submission does not record any GHG emissions for the IPCC sub-category *1A3e – Other Transportation*.

In 2019, this source category was responsible for 66.69% of GHG emissions from fuel combustion activities (this share was only 25.45% in 1990) and represented 57.40% of the national total GHG emissions excluding LULUCF (coming from 20.56% in 1990). Compared to 2018, emissions increased by 2.31% and compared to 1990 they increased by 135.62%.

ory 1A3.

Table 3-61 summarizes GHG emissions for IPCC Sub-category 1A3.

Table 3-61 – GHG emission trends in CO₂eq for IPCC sub-category 1A3 – Transport: 1990-2019

1A3 - Transport GHG emissions by source & sink category (Gg)												
Year	1A3a - Civil Aviation				1A3b - Road Transportation				1A3c - Railways			
	Total CO ₂ eq	CO ₂	CH ₄	N ₂ O	Total CO ₂ eq	CO ₂	CH ₄	N ₂ O	Total CO ₂ eq	CO ₂	CH ₄	N ₂ O
1990	0.22	0.21	0.000002	0.00001	2 590.54	2 562.64	0.50	0.05	24.91	24.823	0.0020	0.00012
1991	0.33	0.33	0.000002	0.00001	3 183.81	3 150.51	0.54	0.07	24.90	24.819	0.0020	0.00012
1992	0.46	0.46	0.000003	0.00001	3 470.88	3 434.49	0.50	0.08	24.89	24.809	0.0019	0.00012
1993	0.60	0.60	0.000004	0.00002	3 518.00	3 480.94	0.43	0.09	24.91	24.824	0.0019	0.00012
1994	0.71	0.70	0.000005	0.00002	3 576.23	3 537.45	0.38	0.10	24.19	24.105	0.0019	0.00012
1995	0.77	0.76	0.000005	0.00002	3 338.17	3 301.30	0.32	0.10	19.59	19.519	0.0015	0.00010
1996	0.78	0.78	0.000006	0.00002	3 446.99	3 409.93	0.29	0.10	21.89	21.810	0.0017	0.00011
1997	0.79	0.79	0.000006	0.00002	3 707.95	3 670.52	0.28	0.10	21.51	21.437	0.0016	0.00011
1998	0.68	0.68	0.000005	0.00002	3 887.03	3 850.73	0.26	0.10	21.51	21.434	0.0016	0.00011
1999	0.70	0.69	0.000005	0.00002	4 211.60	4 175.41	0.24	0.10	21.51	21.435	0.0016	0.00011
2000	0.67	0.66	0.000005	0.00002	4 847.88	4 810.70	0.24	0.10	21.30	21.222	0.0016	0.00011
2001	0.66	0.65	0.000005	0.00002	5 092.82	5 056.68	0.23	0.10	22.95	22.870	0.0017	0.00012
2002	0.61	0.61	0.000004	0.00002	5 283.46	5 248.70	0.21	0.10	20.28	20.211	0.0015	0.00011
2003	0.71	0.71	0.000005	0.00002	5 839.61	5 804.59	0.21	0.10	17.67	17.614	0.0012	0.00009
2004	0.62	0.62	0.000004	0.00002	6 794.45	6 759.03	0.20	0.10	14.04	13.991	0.0010	0.00007
2005	0.62	0.61	0.000004	0.00002	7 175.99	7 140.81	0.18	0.10	8.91	8.882	0.0006	0.00005
2006	0.53	0.52	0.000004	0.00001	6 856.95	6 822.22	0.16	0.10	6.64	6.623	0.0004	0.00003
2007	0.56	0.55	0.000004	0.00002	6 569.69	6 532.11	0.14	0.11	9.21	9.177	0.0006	0.00005
2008	0.53	0.53	0.000004	0.00002	6 668.42	6 626.29	0.13	0.13	10.57	10.541	0.0006	0.00005
2009	0.55	0.54	0.000004	0.00002	6 145.46	6 103.49	0.11	0.13	10.17	10.145	0.0005	0.00005
2010	0.54	0.54	0.000004	0.00002	6 507.51	6 460.17	0.11	0.15	10.98	10.951	0.0005	0.00005
2011	0.57	0.57	0.000004	0.00002	6 883.50	6 829.28	0.11	0.17	11.01	10.985	0.0005	0.00005
2012	0.50	0.49	0.000004	0.00001	6 581.38	6 526.12	0.11	0.18	9.97	9.949	0.0004	0.00005
2013	0.48	0.47	0.000003	0.00001	6 442.25	6 385.20	0.10	0.18	8.58	8.565	0.0003	0.00004
2014	0.51	0.50	0.000004	0.00001	6 133.47	6 075.06	0.11	0.19	9.77	9.747	0.0003	0.00004
2015	0.61	0.60	0.000004	0.00002	5 695.40	5 637.56	0.11	0.18	6.66	6.642	0.0002	0.00003
2016	0.61	0.61	0.000004	0.00002	5 526.29	5 467.45	0.12	0.19	6.09	6.078	0.0002	0.00002
2017	0.59	0.58	0.000004	0.00002	5 638.24	5 576.04	0.13	0.20	6.61	6.594	0.0002	0.00003
2018	0.57	0.56	0.000004	0.00002	6 018.25	5 951.06	0.14	0.21	7.02	7.008	0.0002	0.00003
2019	0.51	0.51	0.000004	0.00001	6 158.16	6 087.73	0.15	0.22	6.78	6.767	0.0002	0.00003
Trend 1990-2019	135.84%	135.84%	135.84%	135.84%	137.72%	137.56%	-70.32%	331.78%	-72.78%	-72.74%	-89.73%	-79.33%

1A3 - Transport GHG emissions by source & sink category (Gg)								
Year	1A3d - Navigation				1A3 - Transport			
	Total CO ₂ eq	CO ₂	CH ₄	N ₂ O	Total CO ₂ eq	CO ₂	CH ₄	N ₂ O
1990	1.45	1.30	0.0013	0.00037	2 617.11	2 588.98	0.50	0.05
1991	1.58	1.42	0.0016	0.00039	3 210.62	3 177.07	0.54	0.07
1992	1.51	1.36	0.0018	0.00036	3 497.74	3 461.12	0.50	0.08
1993	1.59	1.42	0.0018	0.00040	3 545.09	3 507.79	0.43	0.09
1994	1.51	1.35	0.0017	0.00038	3 602.64	3 563.61	0.38	0.10
1995	1.30	1.16	0.0014	0.00034	3 359.82	3 322.74	0.32	0.10
1996	1.31	1.17	0.0014	0.00035	3 470.97	3 433.69	0.30	0.10
1997	1.35	1.20	0.0013	0.00037	3 731.60	3 693.95	0.28	0.10
1998	1.30	1.17	0.0013	0.00036	3 910.53	3 874.00	0.26	0.10
1999	1.44	1.29	0.0013	0.00041	4 235.25	4 198.83	0.25	0.10
2000	1.27	1.13	0.0010	0.00038	4 871.11	4 833.72	0.24	0.11
2001	1.42	1.27	0.0011	0.00043	5 117.85	5 081.47	0.23	0.10
2002	1.55	1.39	0.0012	0.00046	5 305.91	5 270.90	0.22	0.10
2003	1.62	1.45	0.0012	0.00048	5 859.62	5 824.36	0.21	0.10
2004	1.50	1.34	0.0011	0.00044	6 810.61	6 774.98	0.21	0.10
2005	1.58	1.42	0.0010	0.00045	7 187.10	7 151.73	0.18	0.10
2006	1.45	1.31	0.0008	0.00040	6 865.57	6 830.68	0.16	0.10
2007	1.46	1.32	0.0008	0.00040	6 580.91	6 543.16	0.14	0.11
2008	1.63	1.48	0.0009	0.00043	6 681.16	6 638.84	0.13	0.13
2009	1.35	1.23	0.0007	0.00034	6 157.53	6 115.41	0.12	0.13
2010	1.47	1.35	0.0007	0.00036	6 520.51	6 473.00	0.11	0.15
2011	1.39	1.27	0.0006	0.00034	6 896.47	6 842.10	0.11	0.17
2012	1.37	1.26	0.0005	0.00033	6 593.22	6 537.83	0.11	0.18
2013	1.19	1.10	0.0005	0.00027	6 452.51	6 395.34	0.10	0.18
2014	1.27	1.17	0.0005	0.00028	6 145.01	6 086.48	0.11	0.19
2015	1.11	1.03	0.0004	0.00024	5 703.77	5 645.83	0.11	0.19
2016	1.16	1.07	0.0004	0.00025	5 534.15	5 475.21	0.12	0.19
2017	1.24	1.15	0.0004	0.00028	5 646.67	5 584.36	0.13	0.20
2018	1.21	1.12	0.0004	0.00026	6 027.05	5 969.75	0.14	0.21
2019	1.05	0.98	0.0003	0.00022	6 166.49	6 095.98	0.15	0.22
Trend 1990-2019	-27.60%	-25.27%	-74.95%	-41.72%	135.62%	135.46%	-70.41%	328.16%

Source: Environment Agency

3.2.9.2 Domestic aviation (1A3a)

3.2.9.2.1 Source category description

In Luxembourg, domestic aviation, excluding international flights, is a very small activity. There is only one airport for commercial aviation in Luxembourg operated by lux-Airport (Findel). Therefore, all commercial flights, either inbound or outbound, are international flights. For this reason, emissions of kerosene consumption are not included in the national total of Luxembourg, but under international bunkers – aviation, as a memo item. However, private flights with Luxembourg as a start and return point are considered as domestic flights. These are mainly leisure or emergency (medical, police) flights made with small-sized propeller planes or helicopters using aviation gasoline.

In 2019, domestic aviation fuel consumption was responsible for 0.006% of GHG emissions from fuel combustion activities (0.002% in 1990) and represented 0.005% of the national total GHG emissions in CO₂e, excluding LULUCF (0.002% in 1990). Compared to 2018, emissions decreased by 10.29%, and compared to 1990 they increased by 135.84%. In absolute terms, 1A3a emitted 0.51 Gg CO₂e in 2019.

Fuel consumption emissions from domestic aviation are not a key source.

3.2.9.2.2 Methodological issues & time-series consistency

3.2.9.2.2.1 Activity data

There is only one company selling aviation fuels in Luxembourg: Luxfuel S.A.. Activity data for aviation gasoline is obtained directly from this company.

For aviation gasoline, a country-specific NCV (obtained directly from the sole vendor, Luxfuel S.A.) of 43.5 GJ/t aviation gasoline has been applied for converting activity data.

Expert judgement has been made for determining the share of aviation gasoline that is being exported – international flights - and the share that is allocated to domestic flights. Based on information obtained from the airport authorities, and from the aviation sport clubs registered in Luxembourg, it can be assumed that 90% of aviation gasoline sales are directed towards domestic flights.

3.2.9.2.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 1 approach has been applied for domestic flights. As it is assumed that 90% of aviation gasoline sales are directed towards domestic flights, the emissions of the remaining 10% (international flights) have been accounted for under emissions from international bunker fuels – aviation. Please also refer to section 0 where more details on the split between domestic aviation and international aviation are described.

3.2.9.2.2.3 Emission factors

Default CO₂, CH₄ and N₂O emission factors for aviation gasoline, from the 2006 IPCC Guidelines, were used to calculate the corresponding emissions.

Activity data and emission factors for IPCC sub-category 1A3a – Domestic aviation are listed in

Table 3-62.

The time-series are considered to be consistent, although the split between domestic and international flights - combusting aviation gasoline - is kept constant over the entire time-series due to a lack of specific annual information.

Table 3-62– Activity data and emission factors for IPCC sub-category 1A3a – Domestic aviation: 1990-2019

1A3a - Civil Aviation Aviation Gasoline								
Year	Activity (GJ)	Emission Factors (kg/TJ)						
		CO ₂	type	CH ₄	type	N ₂ O	type	source
1990	3 069	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1991	4 662	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1992	6 579	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1993	8 514	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1994	10 071	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1995	10 845	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1996	11 078	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1997	11 232	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1998	9 667	70 000	D	0.50	D	2.00	D	2006 IPCC GL
1999	9 887	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2000	9 418	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2001	9 354	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2002	8 670	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2003	10 095	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2004	8 850	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2005	8 768	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2006	7 466	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2007	7 904	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2008	7 576	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2009	7 739	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2010	7 646	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2011	8 120	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2012	7 059	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2013	6 749	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2014	7 176	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2015	8 630	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2016	8 693	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2017	8 291	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2018	8 068	70 000	D	0.50	D	2.00	D	2006 IPCC GL
2019	7 238	70 000	D	0.50	D	2.00	D	2006 IPCC GL
Trend 1990-2019	135.84%	0.00%		0.00%		0.00%		

Source: Environment Agency

3.2.9.3 Road Transportation (1A3b)

3.2.9.3.1 Source category description

In 2019, road transportation was responsible for 66.60% of GHG emissions from fuel combustion activities (this share was only 25.20% in 1990) and represented 57.32% of the national total GHG emissions excluding LULUCF (20.35% in 1990). In absolute terms, GHG emissions from road transportation reached 6158 Gg CO₂e in 2019. Compared to 2018, GHG emissions increased by 2.40%.

With 46.77% of the total GHG emissions from Luxembourg, road transportation - diesel oil is the largest key category in 2019 (please refer to Table 1-6). Regarding CO₂, sub-category 1A3b has been a key category for both diesel oil and gasoline without interruption since 1990 (with and without LULUCF, Table 1-7 and Table 1-9). For N₂O, sub-category 1A3b is a key category for diesel in 2018 and 2019, but only for the assessment including LULUCF (Table 1-9).

Luxembourg reports emissions from lubricants exclusively under category 2.D.1 (please refer to section 4.5.1.1). The activity data obtained from the national statistics institute (Statec) does not allow for a disaggregation of the lubricants consumption between 2-stroke engines and other applications. Furthermore, the number of 2-stroke engines in Luxembourg is very low; the gasoline consumption by this vehicle category in 2019 was 10 tonnes. Assuming a mixture of 1:50 as suggested by the IPCC 2006 Guidelines, the lubricant consumption of 2-stroke engines is about 0.2 tonnes, and the associated CO₂ emissions are 0.0006 kt CO₂ emissions, which is below the threshold of significance.

Emissions from road transportation, as reported in the CRF tables, are shown in **Table 3-63**.

As already explained in previous sections of the NIR (please refer to Chapter 2 on emission trends), Luxembourg's situation regarding emissions from *1A3b - Road Transportation* is quite unique, due to the high share of fuel export in vehicle tanks.

Figure 3-8 shows the evolution of fuel sold (*i.e.* blended fuel) in Luxembourg. Diesel oil is by far the most sold fuel, for both the domestic and the transiting fleets.

Figure 3-9 and

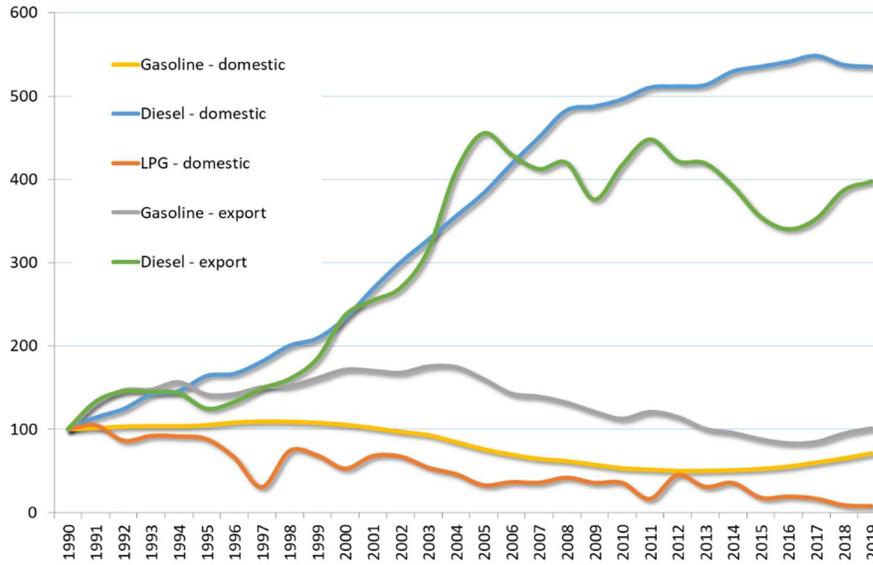
Table 3-64 detail the quantities of blended fuel sold to the domestic fleet and the amount of fuel exported. In 2019, GHG emissions from road fuel export were 2.5 times higher than those from the domestic fleet.

Table 3-63 – Activity data, emissions, and implied emission factor trends of IPCC sub-category 1A3b – Road Transportation: 1990-2019

1A3b - Road Transportation												
Activity Data, Emissions and Implied Emission Factors												
Year	Activity (GJ)					Emissions (Gg)				Implied Emission Factors (kg/TJ)		
	Total (excl. biomass)	Gasoline (blended)	Diesel (blended)	LPG	Biomass	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)
1990	34 950 217	17 663 486	17 112 390	174 340	NO	2 590.54	2 562.64	0.50	0.05	73 323	14.24	1.48
1991	42 938 305	20 717 627	22 038 150	182 528	NO	3 183.81	3 150.51	0.54	0.07	73 373	12.54	1.55
1992	46 614 793	22 417 111	24 047 446	150 236	NO	3 470.88	3 434.49	0.50	0.08	73 678	10.67	1.72
1993	47 294 933	22 532 289	24 602 288	160 356	NO	3 518.00	3 480.94	0.43	0.09	73 601	9.06	1.87
1994	48 078 551	23 372 993	24 546 213	159 344	NO	3 576.23	3 537.45	0.38	0.10	73 576	7.92	2.04
1995	44 887 292	22 046 032	22 687 712	153 548	NO	3 338.17	3 301.30	0.32	0.10	73 546	7.13	2.16
1996	46 345 206	22 354 776	23 875 200	115 230	NO	3 446.99	3 409.93	0.29	0.10	73 577	6.32	2.15
1997	49 911 918	23 253 271	26 605 379	53 268	NO	3 707.95	3 670.52	0.28	0.10	73 540	5.55	2.05
1998	52 341 502	23 376 245	28 836 365	128 892	NO	3 887.03	3 850.73	0.26	0.10	73 569	4.89	1.92
1999	56 749 106	24 173 920	32 455 863	119 324	NO	4 211.60	4 175.41	0.24	0.10	73 577	4.30	1.78
2000	65 369 123	24 964 107	40 313 107	91 908	NO	4 847.88	4 810.70	0.24	0.10	73 593	3.66	1.60
2001	68 650 285	24 538 589	43 993 476	118 220	NO	5 092.82	5 056.68	0.23	0.10	73 659	3.30	1.49
2002	71 230 571	23 918 281	47 195 036	117 254	NO	5 283.46	5 248.70	0.21	0.10	73 686	3.00	1.39
2003	78 720 260	24 344 139	54 282 282	93 840	NO	5 839.61	5 804.59	0.21	0.10	73 737	2.68	1.27
2004	91 666 206	23 603 163	67 981 578	80 316	5 567	6 794.45	6 759.03	0.20	0.10	73 735	2.24	1.11
2005	96 762 834	21 492 936	75 211 434	57 270	5 432	7 175.99	7 140.81	0.18	0.10	73 797	1.89	1.06
2006	92 413 302	19 309 525	73 038 942	63 710	5 414	6 856.95	6 822.22	0.16	0.10	73 823	1.71	1.12
2007	88 510 096	18 474 580	69 871 488	62 468	582 322	6 569.69	6 532.11	0.14	0.11	73 801	1.61	1.29
2008	89 824 114	17 583 070	72 066 407	73 002	585 428	6 668.42	6 626.29	0.13	0.13	73 770	1.43	1.45
2009	82 755 228	16 196 143	66 401 891	62 069	596 943	6 145.46	6 103.49	0.11	0.13	73 754	1.38	1.59
2010	87 501 227	15 049 483	72 298 754	62 187	559 571	6 507.51	6 460.17	0.11	0.15	73 829	1.22	1.71
2011	92 490 822	15 339 333	77 036 790	28 717	792 508	6 883.50	6 829.28	0.11	0.17	73 837	1.19	1.87
2012	88 380 849	14 963 394	73 247 782	78 450	709 234	6 581.38	6 526.12	0.11	0.18	73 841	1.19	2.00
2013	86 413 922	13 619 715	72 637 022	53 780	758 556	6 442.25	6 385.20	0.10	0.18	73 891	1.15	2.12
2014	82 197 803	13 064 248	68 936 347	62 029	1 067 196	6 133.47	6 075.06	0.11	0.19	73 908	1.28	2.28
2015	76 206 566	12 175 085	63 831 804	31 113	1 388 708	5 695.40	5 637.56	0.11	0.18	73 977	1.44	2.43
2016	73 904 933	11 828 986	61 866 864	33 627	1 518 545	5 526.29	5 467.45	0.12	0.19	73 980	1.58	2.54
2017	75 369 541	12 504 114	62 600 092	29 070	1 735 541	5 638.24	5 576.04	0.13	0.20	73 983	1.68	2.63
2018	80 474 156	13 661 431	66 546 810	15 439	1 872 601	6 018.25	5 951.06	0.14	0.21	73 950	1.71	2.66
2019	82 360 507	14 273 517	67 819 253	13 514	2 196 984	6 158.16	6 087.73	0.15	0.22	73 916	1.79	2.72
Trend 1990-2019	135.65%	-19.19%	296.32%	-92.25%	NA	137.72%	137.56%	-70.32%	331.78%	0.81%	-87.41%	83.23%
Trend 2018-2019	2.34%	4.48%	1.91%	-12.47%	17.32%	2.32%	2.30%	7.38%	4.67%	-0.05%	4.93%	2.28%

Source: Environment Agency

Figure 3-8– Fuel sold trends - indexes - for 1A3b – Road Transportation by fuel type: 1990-2019
index: year 1990



Source: Environment Agency

Figure 3-9 – Domestic and exported fuel sold trends - indexes - for 1A3b – Road Transportation by fuel type: 1990-2019

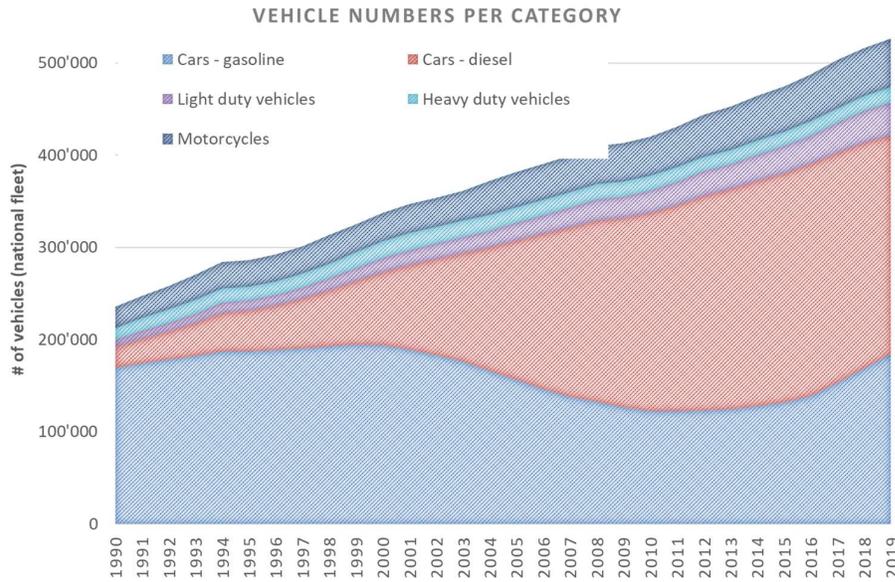


Table 3-64 – Domestic and road fuel export emissions for 1A3b - Road Transportation: 1990-2019

1A3b - Road Transportation										
CO ₂ eq emissions (Gg)										
Year	National Total (excl. CO ₂ from biomass)	CO ₂ from biomass	CH ₄ and N ₂ O from biomass	GHG from other fossil fuels	domestic road fuel emissions (excl. CO ₂ from biomass)			road fuel export emissions (excl. CO ₂ from biomass)		
					Gasoline	Diesel	LPG	Gasoline	Diesel	LPG
1990	2590.54	NO	NO	NO	593.84	270.85	11.57	712.69	1001.60	NO
1991	3183.81	NO	NO	NO	601.52	307.91	12.12	931.54	1330.73	NO
1992	3470.88	NO	NO	NO	617.92	335.36	9.96	1055.35	1452.28	NO
1993	3518.00	NO	NO	NO	618.98	382.46	10.62	1058.25	1447.69	NO
1994	3576.23	NO	NO	NO	618.41	394.21	10.56	1120.30	1432.76	NO
1995	3338.17	NO	NO	NO	625.79	443.51	10.18	1013.18	1245.51	NO
1996	3446.99	NO	NO	NO	643.91	450.80	7.64	1018.09	1326.55	NO
1997	3707.95	NO	NO	NO	649.27	490.35	3.53	1074.62	1490.17	NO
1998	3887.03	NO	NO	NO	647.53	542.18	8.52	1084.28	1604.52	NO
1999	4211.60	NO	NO	NO	638.84	566.63	7.91	1148.17	1850.04	NO
2000	4847.88	NO	NO	NO	622.60	632.25	6.06	1215.91	2371.06	NO
2001	5092.82	NO	NO	NO	599.99	728.13	7.78	1206.95	2549.97	NO
2002	5283.46	NO	NO	NO	571.21	814.61	7.71	1187.45	2702.48	NO
2003	5839.61	NO	NO	NO	548.38	888.63	6.16	1241.28	3155.14	NO
2004	6794.45	1.48	0.01	0.08	497.02	965.20	5.27	1231.68	4095.20	NO
2005	7175.99	1.54	0.01	0.09	446.48	1039.97	3.75	1127.66	4558.04	NO
2006	6856.95	1.45	0.01	0.08	407.96	1134.83	4.17	1005.63	4304.26	NO
2007	6569.65	134.52	0.74	7.46	375.75	1189.29	4.08	973.57	4018.75	NO
2008	6668.38	133.52	0.85	7.47	360.21	1276.10	4.77	922.40	4096.58	NO
2009	6145.41	124.58	0.89	6.99	334.61	1288.29	4.05	845.41	3665.18	NO
2010	6507.46	124.86	0.97	6.67	309.78	1315.44	4.06	785.65	4084.90	NO
2011	6883.45	138.48	1.16	6.32	293.54	1356.64	1.87	823.04	4400.87	NO
2012	6581.32	143.90	1.32	6.70	290.72	1354.75	5.11	797.79	4124.92	NO
2013	6442.18	163.77	1.58	7.60	291.55	1353.96	3.50	700.83	4083.15	NO
2014	6133.37	208.19	2.14	9.93	294.76	1383.24	4.04	663.68	3775.57	NO
2015	5695.26	243.44	2.63	12.38	297.51	1388.37	2.03	596.89	3395.46	NO
2016	5526.14	261.05	2.93	12.89	310.11	1398.46	2.20	558.48	3241.09	NO
2017	5638.03	330.91	3.88	17.35	341.44	1394.54	1.90	576.30	3302.60	NO
2018	6018.02	359.04	4.22	18.40	365.03	1367.72	1.01	636.26	3625.38	NO
2019	6157.92	384.46	4.51	18.67	387.31	1362.64	0.89	659.73	3724.17	NO
<i>Trend 1990-2019</i>	137.71%	NA	NA	NA	-34.78%	403.11%	-92.33%	-7.43%	271.82%	NA
<i>Trend 2018-2019</i>	2.32%	7.08%	6.74%	1.50%	6.10%	-0.37%	-12.10%	3.69%	2.73%	NA
<i>Share 1990</i>	NA	NA	NA	NA	22.92%	10.46%	0.45%	27.51%	38.66%	NA
<i>Share 2019</i>	NA	NA	NA	NA	6.29%	22.13%	0.01%	10.71%	60.48%	NA

Source: Environment Agency

3.2.9.3.2 Methodological issues & time series consistency

3.2.9.3.2.1 Activity data

Table 3-65 and Table 3-66 show the activity data by vehicle category for fuel sold in Luxembourg and fuel used within the country's borders, respectively. The total amounts of fuel sold were taken from the national energy balance provided by STATEC, and the share of fuel used in Luxembourg was determined with the method described on page 246.

Table 3-65 – Activity data of 1A3b Road transport – Fuel sold

1 A Mobile Fuel Combustion					
Activity Data by vehicle category (GJ)					
1 A 3 b Road transport - FUEL SOLD					
Year	Activity Total (incl. biomass)	1 A 3 b i Passenger cars	1 A 3 b ii LDV	1 A 3 b iii HDV and buses	1 A 3 b iv Mopeds & motorcycles
1990	34 950 217	21'476'366	584'532	12'847'468	41'850
1991	42 938 305	25'638'484	644'148	16'610'429	45'244
1992	46 614 793	28'001'084	680'454	17'883'526	49'729
1993	47 294 933	28'391'003	750'472	18'096'158	57'301
1994	48 078 551	30'627'552	804'122	16'583'731	63'145
1995	44 887 292	29'144'830	853'650	14'825'701	63'112
1996	46 345 206	29'967'626	897'236	15'414'765	65'579
1997	49 911 918	31'806'252	950'744	17'089'978	64'944
1998	52 341 502	32'828'460	1'007'660	18'439'005	66'376
1999	56 749 106	34'851'031	1'126'516	20'703'345	68'215
2000	65 369 123	37'225'963	1'230'587	26'844'550	68'024
2001	68 650 285	38'225'564	1'292'502	29'063'591	68'629
2002	71 230 571	38'988'881	1'369'541	30'801'329	70'820
2003	78 720 260	41'386'940	1'423'324	35'836'192	73'804
2004	91 686 325	42'349'859	1'488'124	47'769'889	78'453
2005	96 783 759	40'939'660	1'562'159	54'204'962	76'977
2006	92 433 016	39'302'968	1'635'859	51'416'380	77'809
2007	90 343 095	39'789'514	1'747'432	48'729'155	76'994
2008	91 643 033	40'295'485	1'828'285	49'442'360	76'903
2009	84 452 304	39'334'342	1'832'129	43'205'005	80'828
2010	89 202 036	38'506'662	1'888'988	48'726'898	79'489
2011	94 384 103	41'100'084	1'973'537	51'229'091	81'391
2012	90 341 523	40'867'761	2'010'554	47'381'869	81'339
2013	88 644 440	38'473'106	2'027'840	48'059'122	84'372
2014	85 036 043	38'019'181	2'096'251	44'833'357	87'253
2015	79 529 707	36'616'134	2'105'580	40'717'272	90'721
2016	77 469 928	35'662'193	2'223'200	39'489'851	94'685
2017	79 883 123	35'791'130	2'294'049	41'700'333	97'610
2018	85 374 709	37'171'259	2'393'695	45'711'263	98'492
2019	87 615 980	38'702'144	2'469'883	46'343'997	99'956
Trend					
1990-2019	150.69%	80.21%	322.54%	260.72%	138.84%

Source: Environment Agency

Table 3-66 – Activity data of 1A3b Road transport – Fuel used

1 A Mobile Fuel Combustion					
Activity Data by vehicle category (GJ)					
1 A 3 b Road transport - FUEL USED					
Year	Activity Total (incl. biomass)	1 A 3 b i Passenger cars	1 A 3 b ii LDV	1 A 3 b iii HDV and buses	1 A 3 b iv Mopeds & motorcycles
1990	11 840 027	9'003'021	584'532	2'210'624	41'850
1991	12 446 551	9'341'774	644'148	2'415'386	45'244
1992	12 933 479	9'697'859	680'454	2'505'437	49'729
1993	13 610 621	9'986'687	750'472	2'816'162	57'301
1994	13 762 400	10'282'060	804'122	2'613'074	63'145
1995	14 522 079	10'626'875	853'650	2'978'442	63'112
1996	14 824 379	11'076'409	897'236	2'785'155	65'579
1997	15 389 364	11'500'054	950'744	2'873'622	64'944
1998	16 141 572	12'013'206	1'007'660	3'054'329	66'376
1999	16 357 425	12'383'149	1'126'516	2'779'545	68'215
2000	17 014 433	12'755'853	1'230'587	2'959'968	68'024
2001	18 016 096	13'251'212	1'292'502	3'403'753	68'629
2002	18 791 372	13'597'593	1'369'541	3'753'418	70'820
2003	19 451 127	14'046'936	1'423'324	3'907'064	73'804
2004	19 796 564	14'232'532	1'488'124	3'997'456	78'453
2005	20 084 174	14'389'801	1'562'159	4'055'237	76'977
2006	20 833 634	14'839'867	1'635'859	4'280'099	77'809
2007	21 565 866	15'269'731	1'747'432	4'471'709	76'994
2008	22 550 249	15'962'159	1'828'285	4'682'901	76'903
2009	22 360 494	15'966'940	1'832'129	4'480'597	80'828
2010	22 335 740	15'661'634	1'888'988	4'705'630	79'489
2011	22 655 965	15'687'752	1'973'537	4'913'284	81'391
2012	22 659 610	15'862'207	2'010'554	4'705'511	81'339
2013	22 688 314	15'981'261	2'027'840	4'594'840	84'372
2014	23 324 887	16'175'531	2'096'251	4'965'852	87'253
2015	23 586 233	16'447'345	2'105'580	4'942'588	90'721
2016	23 999 989	16'736'368	2'223'200	4'945'737	94'685
2017	24 636 741	16'978'562	2'294'049	5'266'521	97'610
2018	24 603 394	17'066'937	2'393'695	5'044'270	98'492
2019	24 934 832	17'355'005	2'469'883	5'009'988	99'956
Trend 1990-2019	110.60%	92.77%	322.54%	126.63%	138.84%

Source: Environment Agency

Figure 3-10 shows the evolution of the vehicle numbers per category since 1990 (national fleet). The number of diesel-fuelled passenger cars has strongly increased whereas the vehicle numbers in the other categories show a less pronounced rise or even a slight decrease in the case of passenger cars with otto engines. The same trends are observed for the total mileage driven in Luxembourg (Figure 3-11).

Figure 3-10 – Vehicle numbers per category (national fleet).

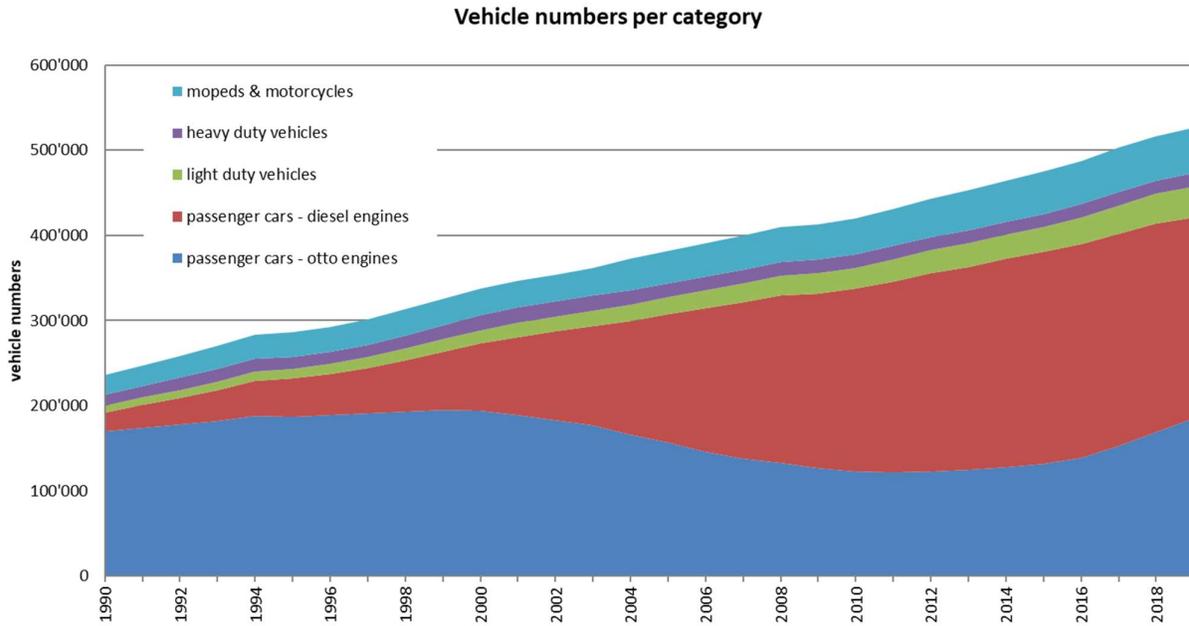


Figure 3-11 – Total mileage driven in Luxembourg.

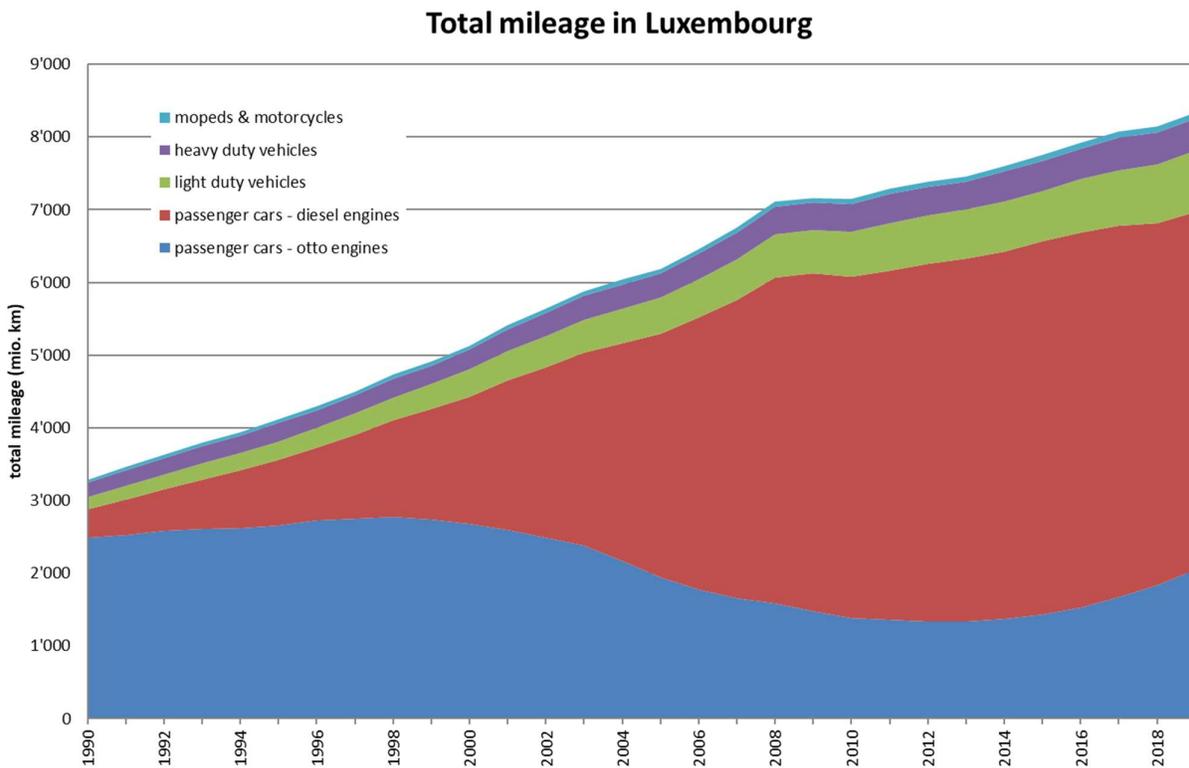
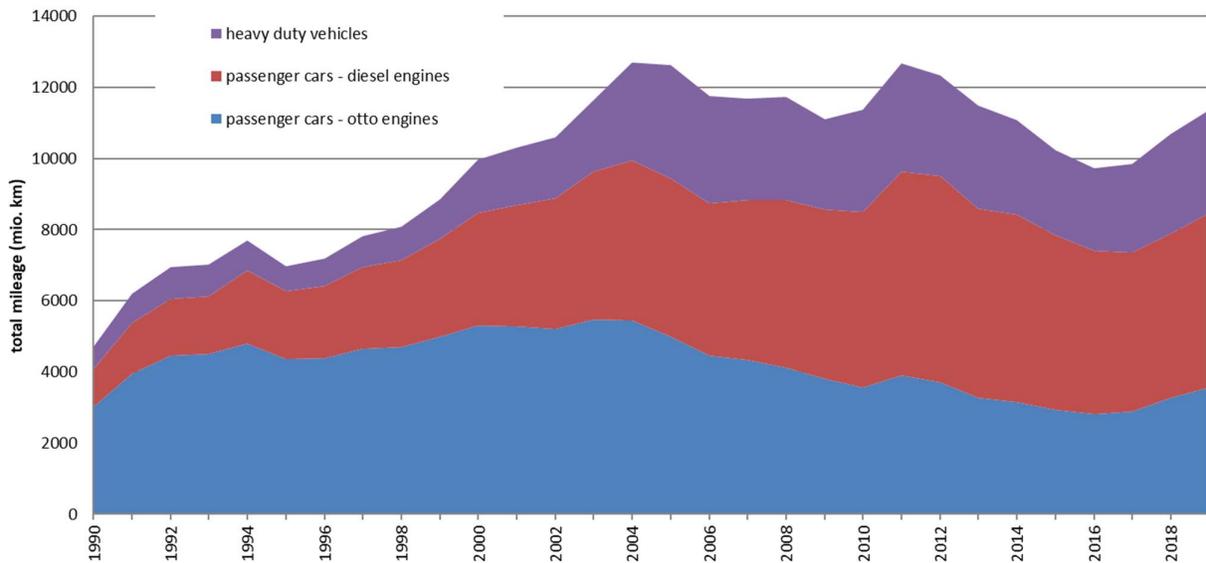


Figure 3-12 shows that the total mileage driven outside Luxembourg with fuel purchased in Luxembourg has approximately doubled since 1990. While the mileage driven with gasoline exported in passenger car tanks has remained relatively stable, the mileage driven with diesel exported from Luxembourg in the tanks of passenger cars and heavy-duty vehicles has significantly increased.

Figure 3-12 – Total mileage outside Luxembourg with fuel sold in Luxembourg.

Total mileage outside Luxembourg with fuel sold in Luxembourg



3.2.9.3.2.2 Methodology - The model NEMO and its application to Luxembourg’s road transport situation

The model NEMO (Network Emission Model) was developed at the Institute for Internal Combustion Engines and Thermodynamics (IVT) at the Graz University of Technology (TUG) as tool for the simulation of traffic related emissions in road networks. Typical applications reach from emission inventories for cities, regions and countries to complex measures like environmental zones or promotion of alternative propulsion systems. An interface to macro scale traffic models, such as VISUM and to air quality modelling is available.

NEMO combines both detailed calculation of the vehicle fleet composition and simulation of emission factors on a vehicle level. NEMO calculates the percentages of different vehicle layers on the overall traffic volume as a function of year and considered road type based on data on vehicle stock, composition of new registrations and vehicle usage. The simulation of the emissions of the different vehicle layers is based on the correlation of the specific engine emission behaviour (emissions in grams per kilowatt-hour engine work) with the cycle average engine power in a normalised format. The calculation of the required engine power is based on average speed and additional kinematic parameters for the description of the cycle dynamics for a given road section. Compared to more detailed instantaneous emission models - which are usually based on simulation in 1Hz time resolution – this simplified approach gives no disadvantage for the modelling of emissions on large street networks as in most of the cases 1Hz data for vehicle operation are not available. An additional benefit of the NEMO simulation approach is the short computing time.

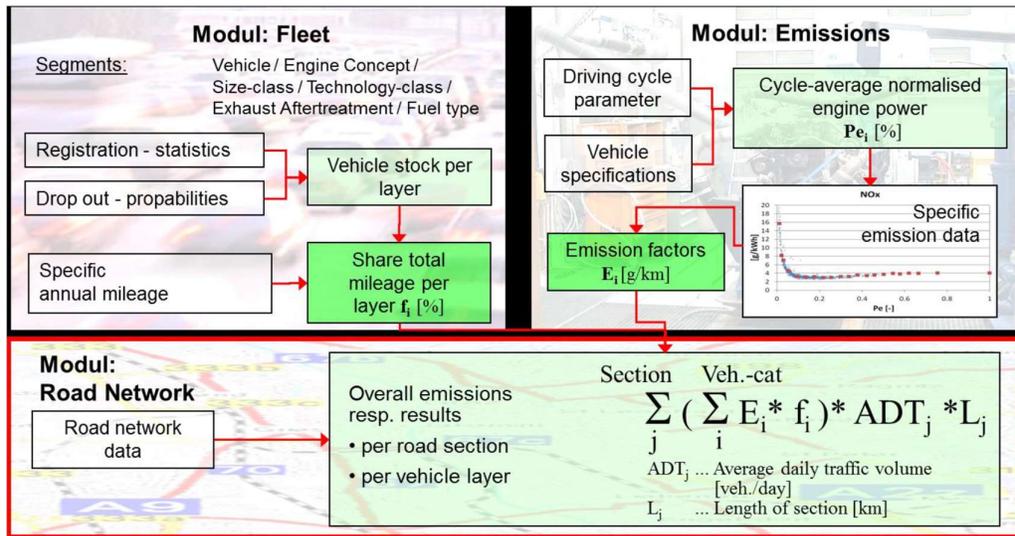
The parameterisation of NEMO is based on data from European in-use measurements which are also used for the Handbook Emission Factors of Road Transport (HBEFA)⁸⁰. NEMO is updated regularly according to recent data on emission behaviour and vehicle technologies. For the present submission, HBEFA 4.1 (released in November 2019, the latest reference database including all available in-use emission tests and recent forecasts for up-coming vehicle technology) was used. All on-road vehicle categories are covered; a

⁸⁰ <http://www.hbefa.net/>

tool for the transport sectors rail and inland waterway shipping is also available. NEMO is equipped with a Graphical User Interface which allows for efficient data editing, scenario handling and display of model results.

A crucial point in emission modelling is the characterisation of driving behaviour on the single road sections. For NEMO a method was developed, which allows for automatized derivation of driving behaviour based on a link with common traffic models. These models use the peak hour driving time between knots of the street work as resistance parameter for allocation of traffic volumes to the single road sections. NEMO imports this data together with the parameters of the capacity-restraint functions and calculates the daily average velocity for each road section. Based on functions derived from the driving cycles used in the HBEFA then the kinematic parameters needed for emission simulation (vehicle stop time and average brake deceleration) are assessed.

Figure 3-13– Schematic picture of the model NEMO



NEMO calculates the emissions for all regulated pollutants (NO_x, THC, CO, PM exhaust) for hot vehicle operation. Fuel consumption is simulated based on a slightly extended method which also considers the energy content of the applied fuel type. The emissions of CO₂ and SO₂ are simulated based on fuel consumption and fuel specifications. The non-regulated pollutants N₂O, NH₃, CH₄, NMVOC and C₆H₆ are calculated with an approach similar to the HBEFA 4.1 based on fixed emission factors for certain vehicle categories and driving situations.

Additional influencing mechanisms on the emission output of road traffic implemented in NEMO are:

- Cold start effects for each vehicle class (data and approach compatible to the HBEFA 4.1), cold start of HDV vehicles according to (Rexeis, Schwingshackl, Dippold, & Hausberger, 2013)
- Influence of mileage and maintenance on the emissions of gasoline vehicles (method and data compatible to the HBEFA4.1)
- Calibration of fuel consumption based on statistics of g/km CO₂ of new registered vehicles in the NEDC type approval and literature on the discrepancies between NEDC and real world CO₂ reduction rates (HBEFA4.1)
- Evaporation from gasoline emissions (data and approach compatible to the HBEFA 4.1)

- Ambient temperature influence on NOx emission of Diesel passenger cars and LCV (method and data compatible to the HBEFA4.1)
- Consideration of electrified propulsion systems like hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV) (data and approach compatible to the HBEFA4.1).

Particle emissions due to vehicle induced abrasion processes (“PM non-exhaust”) are taken into account by NEMO in addition to the PM-exhaust emissions. The calculation of the PM non-exhaust emissions is based on the values published in (Schmidt, Düring, & Lohmeyer, 2011) and (B. Notter, M. Keller, & B. Cox, 28. August 2019; Including update in 11.2019).

The main innovations of HBEFA4.1 which are implemented in NEMO for submission 2021v1 are:

- Update of emission factors for “hot” operation conditions
 - New and more measurements
 - New version of emission model PHEM
- New traffic situations and driving cycles
 - New Heavy Stop&go traffic situation
 - Higher dynamic parameter for the driving cycles (in PHEM)
- Real energy consumption
 - Real energy consumption factors are in NEMO compatible with HBEFA4.1
 - The CO₂ calibration method of HBEFA4.1, is based on the already existed method in NEMO
- Alternative propulsion concepts
 - PHEV, BEV for passenger cars and LCV as well as CNG busses are implemented in NEMO and are compatible with HBEFA4.1
- Actualisation of emission factors
 - Updated cold start emission factors
 - Updated evaporation emission factors
 - Updated emission factors of non-regulated pollutants like e.g. HC, NO₂, N₂O, NH₃, non-exhaust particular matter
- Better fleet segmentation
 - Implementation of 3 size classes for LCV
 - Implementation of 2 size classes for motorcycles
- Software Updates
 - Includes the effects of the software updates according to “diesel gate”
- Ambient temperature effects
 - Update of the correction factors of NOx emissions for different ambient temperatures for passenger cars
 - Implementing correction factors of NOx emissions for different ambient temperatures for LCV
- Actualisation of vehicle data
 - Update of: Vehicle weights, Loads, power, driving resistances.

As already mentioned above, the major part of the fuel sold in Luxembourg is exported inside vehicle tanks. The split of the total fuel into domestic fuel use and exported fuel is thus a key element of the calculation of Luxembourg's total GHG emissions. This split is performed in several steps:

- (i) estimation of the domestic fuel consumption with the NEMO model
- (ii) calculation of the amount of exported fuel by subtracting the amount obtained in step (i) from the total national fuel consumption obtained from Statec
- (iii) the entire amount of exported gasoline is attributed to passenger cars
- (iv) the amount of diesel exported by passenger cars is determined by taking into account the result of step (iii) and the shares of gasoline- and diesel-fuelled cars in the trans-border fleet
- (v) the amount of diesel exported by heavy duty vehicles is obtained by subtracting the amount of diesel exported by passenger cars from the total amount of exported diesel
- (vi) now the mileages of the passenger cars and heavy duty vehicles responsible for the fuel export can be determined based on their fuel consumption
- (vii) finally the emissions caused by domestic fuel use and exported fuel are calculated separately by NEMO.

The share of diesel- and gasoline-fueled cars in the commuter fleets is based on the shares of the fleets of the neighboring regions (Belgium, Grand-Est for France, Rhineland-Palatinate and Saarland for Germany). However, the detailed composition of each of these fleets (age, technology) is supposed to be identical to the structures of Luxembourg's domestic fleet (i.e. the CH₄ IEF of the domestic gasoline-fueled passenger car fleet is applied to the gasoline-fueled commuting passenger car fleet, etc), due to a lack of region-specific fleet data from the neighboring countries.

In the case of passenger cars, the justification for assuming a similar age/technology composition of the commuter fleets is that the owners of these vehicles work in Luxembourg, have significantly higher salaries than if they were working in their home country, and thus have higher living standards than their non-commuting fellow citizens. As a consequence, the commuter fleets are supposed to be more similar to Luxembourg's domestic fleet than to the average fleet of the commuters' country of residence.

For heavy-duty vehicles, the fleet composition is also considered to be identical to the one of the Luxembourgish fleet, which is rather modern. This is justified through an expert judgement (personal communication) by Luxembourg's customs office (Administration des Douanes et Accises). Indeed, the national and transiting heavy-duty vehicles fleet are very similar and consist roughly of 80% new models (aged 1-5 years), 15% older models (aged 5-10 years), and 5% even older models (aged more than 10 years).

The GHG emissions from road transportation were calculated with the NEMO model (version 5.0.1 with HBEFA 4.1) for the timeseries 1990-2019 (Schwingshackl & Rexeis, 2020).

The values of the country-specific CO₂ emission factors for gasoline, diesel oil and LPG are given in section 3.2.5.3. For an overview of the implied emission factors for motor gasoline, diesel oil, LPG and liquid biomass please refer to Table 3-18. For biogasoline and biodiesel, European CO₂ implied emission factors⁸¹ for gasoline (71270 g/GJ) and diesel oil (73450 g/GJ), respectively, were used as emission factors.

81 UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

Biodiesel sold in Luxembourg since 2004 is mainly composed of FAME (fatty acid methyl ester). In more recent years, also HVO (hydrated vegetable oil) is used for blending with diesel. While HVO is of 100% biogenic origin, FAME biodiesel from methanol contains a small proportion of fossil carbon if the methanol is produced from a fossil fuel (which is generally the case). During the production process of FAME, the vegetable oil is trans-esterified with methanol to produce the FAME and the by-product glycerol. The latter is removed during the purification process. Hence, each FAME molecule contains one carbon atom originating from methanol, which is very likely of fossil origin. The percentage of fossil carbon in FAME, thus, depends on the chain length of the different components of the oil (fatty acid derivatives), as well as the proportion of different components (origin of the oil, i.e. rapeseed oil, sunflower oil, palm oil, etc.). Based on the detailed composition of the FAME mixture sold in Luxembourg in 2019 (no detailed information is currently available for other years), it has been calculated that 5.3% of the carbon atoms are of fossil origin. The fraction of 5.3% correlates very well with the value presented in ⁸². 5.3% of the FAME activity data and the associated GHG emissions are thus not allocated to “biomass” but to “other fossil fuels – biodiesel (fossil component)” in each CRF subcategory with biodiesel consumption, i.e. 1A3bi-iv, 1A3c, 1A3d and 1D1b, 1A2gvii, 1A4cii, and 1A5b. For the fossil part of biodiesel the same emission factors are applied than for biodiesel. This recalculation was done in response to a Potential Problem formulated in the course of the UNFCCC in-country review of Luxembourg’s 2018 submission, which took place in October 2018.

⁸² Environ. Sci. Technol. 2008, 42, 2476–2482 (table 2, p. 2480)

Table 3-67 – Activity data, emissions and emission factors for other fossil fuels (fossil part of biodiesel) used in sector 1A3b – Road transportation.

1A3b - Road Transportation - Other fossil fuels								
Activity Data, Emissions and Implied Emission Factors								
Year	Activity (GJ)	Emissions (Gg)				Implied Emission Factors (kg/TJ)		
		Total CO ₂ eq	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O
1990	NO	NO	NO	NO	NO	NO	NO	NO
1991	NO	NO	NO	NO	NO	NO	NO	NO
1992	NO	NO	NO	NO	NO	NO	NO	NO
1993	NO	NO	NO	NO	NO	NO	NO	NO
1994	NO	NO	NO	NO	NO	NO	NO	NO
1995	NO	NO	NO	NO	NO	NO	NO	NO
1996	NO	NO	NO	NO	NO	NO	NO	NO
1997	NO	NO	NO	NO	NO	NO	NO	NO
1998	NO	NO	NO	NO	NO	NO	NO	NO
1999	NO	NO	NO	NO	NO	NO	NO	NO
2000	NO	NO	NO	NO	NO	NO	NO	NO
2001	NO	NO	NO	NO	NO	NO	NO	NO
2002	NO	NO	NO	NO	NO	NO	NO	NO
2003	NO	NO	NO	NO	NO	NO	NO	NO
2004	1 148	0.08	0.08	0.000001	0.00000	73 450	0.66	0.90
2005	1 194	0.09	0.09	0.000001	0.00000	73 450	0.59	0.93
2006	1 125	0.08	0.08	0.000001	0.00000	73 450	0.54	1.06
2007	101 560	7.50	7.46	0.000049	0.00013	73 450	0.49	1.29
2008	101 635	7.51	7.47	0.000044	0.00016	73 450	0.44	1.53
2009	95 125	7.04	6.99	0.000041	0.00016	73 450	0.43	1.72
2010	90 803	6.72	6.67	0.000038	0.00017	73 450	0.42	1.87
2011	85 983	6.37	6.32	0.000038	0.00018	73 450	0.45	2.05
2012	91 223	6.76	6.70	0.000046	0.00020	73 450	0.50	2.23
2013	103 405	7.67	7.60	0.000056	0.00024	73 450	0.54	2.35
2014	135 178	10.03	9.93	0.000092	0.00034	73 450	0.68	2.51
2015	168 564	12.52	12.38	0.000146	0.00045	73 450	0.87	2.66
2016	175 456	13.04	12.89	0.000187	0.00049	73 450	1.07	2.79
2017	236 265	17.56	17.35	0.000286	0.00068	73 450	1.21	2.87
2018	250 476	18.62	18.40	0.000324	0.00073	73 450	1.30	2.92
2019	254 223	18.91	18.67	0.000359	0.00076	73 450	1.41	2.99
Trend 2018-2019	1.50%	1.53%	1.50%	10.64%	4.21%	0.00%	9.01%	2.67%

Source: Environment Agency

Table 3-68, Table 3-69, Table 3-70 and Table 3-71 present the implied emission factors for each vehicle category.

Table 3-68 – Implied emission factors for passenger cars.

1 A Mobile Fuel Combustion Implied Emission Factor (IEF) of GHG by source category (g/GJ)			
Year	1 A 3 b i Road transport: Passenger cars		
	CO ₂ (fossil)	CH ₄	N ₂ O
1990	73405	21.848	2.079
1991	73382	19.729	2.244
1992	73782	16.519	2.522
1993	73646	13.856	2.766
1994	73616	11.342	2.907
1995	73590	9.859	3.034
1996	73534	8.691	3.028
1997	73309	7.673	2.899
1998	73510	6.820	2.730
1999	73462	6.095	2.552
2000	73315	5.525	2.405
2001	73449	5.059	2.267
2002	73475	4.632	2.129
2003	73499	4.248	2.003
2004	73392	3.864	1.906
2005	73441	3.486	1.837
2006	73521	3.127	1.790
2007	73497	2.862	1.750
2008	73513	2.562	1.724
2009	73513	2.335	1.729
2010	73567	2.208	1.800
2011	73538	2.164	1.909
2012	73639	2.111	2.007
2013	73680	2.103	2.119
2014	73840	2.290	2.290
2015	73873	2.504	2.448
2016	73877	2.779	2.579
2017	73852	3.011	2.639
2018	73760	3.177	2.671
2019	73746	3.294	2.749

Table 3-69 – Implied emission factors for light duty vehicles.

1 A Mobile Fuel Combustion			
Implied Emission Factor (IEF) of GHG by source category (g/GJ)			
Year	1 A 3 b ii Road transport: Light duty vehicles		
	CO ₂ (fossil)	CH ₄	N ₂ O
1990	73605	6.919	0.674
1991	73661	6.242	0.616
1992	73880	5.536	0.556
1993	73893	4.835	0.494
1994	73929	4.352	0.535
1995	73943	4.024	0.642
1996	73924	3.962	0.866
1997	73932	3.241	0.974
1998	73970	2.835	1.056
1999	73994	2.526	1.166
2000	74039	2.120	1.288
2001	74076	1.805	1.404
2002	74100	1.515	1.487
2003	74100	1.285	1.546
2004	74076	1.059	1.591
2005	74077	0.924	1.637
2006	74086	0.841	1.678
2007	74091	0.771	1.715
2008	74039	0.703	1.737
2009	74032	0.641	1.753
2010	74085	0.612	1.784
2011	74076	0.606	1.835
2012	74098	0.671	1.942
2013	74111	0.779	2.091
2014	74048	0.968	2.247
2015	74112	1.186	2.451
2016	74120	1.463	2.652
2017	74133	1.816	2.918
2018	74111	2.182	3.168
2019	74062	2.568	3.389

Table 3-70 – Implied emission factors for heavy-duty vehicles.

1 A Mobile Fuel Combustion Implied Emission Factor (IEF) of GHG by source category (g/GJ)			
Year	1 A 3 b iii Road transport: Heavy duty vehicles		
	<i>CO₂ (fossil)</i>	<i>CH₄</i>	<i>N₂O</i>
1990	74171	1.392	0.555
1991	74157	1.308	0.542
1992	74129	1.264	0.540
1993	74172	1.241	0.544
1994	74197	1.213	0.550
1995	74202	1.269	0.559
1996	74192	1.181	0.553
1997	74179	1.075	0.544
1998	74170	0.986	0.538
1999	74174	0.866	0.528
2000	74212	0.755	0.510
2001	74216	0.700	0.480
2002	74217	0.662	0.449
2003	74192	0.616	0.413
2004	74154	0.567	0.390
2005	74137	0.494	0.460
2006	74138	0.419	0.587
2007	74141	0.343	0.845
2008	74085	0.270	1.166
2009	74074	0.229	1.382
2010	74128	0.188	1.578
2011	74114	0.156	1.762
2012	74134	0.134	1.903
2013	74141	0.116	2.011
2014	74069	0.101	2.109
2015	74128	0.086	2.190
2016	74136	0.075	2.248
2017	74149	0.065	2.286
2018	74130	0.057	2.306
2019	74078	0.052	2.327

Table 3-71 – Implied emission factors for mopeds and motorcycles.

1 A Mobile Fuel Combustion Implied Emission Factor (IEF) of GHG by source category (g/GJ)			
Year	1 A 3 b iv Road transport: Mopeds & motorcycles		
	CO ₂ (fossil)	CH ₄	N ₂ O
1990	72583	246.067	1.223
1991	72612	232.376	1.224
1992	73253	221.379	1.225
1993	73039	199.752	1.226
1994	72984	186.727	1.217
1995	72932	187.024	1.221
1996	72964	181.893	1.203
1997	72829	183.812	1.199
1998	72876	182.119	1.195
1999	72816	169.023	1.188
2000	72625	168.199	1.187
2001	72700	165.399	1.184
2002	72682	161.109	1.182
2003	72757	155.661	1.180
2004	72559	165.332	1.187
2005	72629	163.034	1.193
2006	72660	160.028	1.191
2007	72547	159.016	1.194
2008	72515	157.456	1.196
2009	72473	150.157	1.194
2010	72436	151.477	1.200
2011	72468	148.394	1.200
2012	72455	149.425	1.204
2013	72597	144.170	1.212
2014	73106	139.337	1.217
2015	73216	132.764	1.222
2016	73197	126.576	1.226
2017	73181	120.920	1.233
2018	73093	113.964	1.240
2019	73162	111.611	1.245

3.2.9.4 Railways (1A3c)

3.2.9.4.1 Source category description

Railways related GHG emissions are quite low in Luxembourg. The reason is that Luxembourg's national railway company, *CFL (Chemins de Fer Luxembourgeois)*, uses almost exclusively locomotives powered by electricity.

In 2019, railways fuel consumption (diesel oil and biodiesel) was responsible for 0.07% of GHG emissions from fuel combustion activities (0.24% in 1990) and represented 0.06% of the total GHG emissions in CO₂e, excluding LULUCF (0.20% in 1990). Compared to 2018, emissions decreased by 3.44% to reach 6.78 Gg CO₂e in 2019. Compared to 1990, emissions decreased by 72.78%.

Activity data, GHG emissions and emission factors used to estimate emissions from 1A3c are shown in

Table 3-72. The V-shaped emission trend is mainly due to restructuring activities in the mid 2000s, where less diesel driven locomotive were used. Since 2007, the number of diesel driven locomotives has stabilised again between 70 and 80 units being operated per year.

GHG emissions from railways are not a key source.

Table 3-72 – Activity data, emissions and emission factors for IPCC sub-category 1A3c – Railways: 1990-2019

1A3c - Railways												
Diesel Oil, biodiesel												
Year	Activity (GJ)	Emissions (Gg) excl. CO ₂ from biomass				Emission Factors (kg/TJ)						
		Total CO ₂ eq	CO ₂	CH ₄	N ₂ O	CO ₂	type	CH ₄	type	N ₂ O	type	source
1990	334 678	24.91	24.82	0.0020	0.0001	74 171	CS	5.84	D	0.37	D	AEV, 2006 IPCC GL
1991	334 678	24.90	24.82	0.0020	0.0001	74 157	CS	5.83	D	0.37	D	AEV, 2006 IPCC GL
1992	334 678	24.89	24.81	0.0019	0.0001	74 129	CS	5.81	D	0.37	D	AEV, 2006 IPCC GL
1993	334 678	24.91	24.82	0.0019	0.0001	74 172	CS	5.79	D	0.37	D	AEV, 2006 IPCC GL
1994	324 884	24.19	24.11	0.0019	0.0001	74 197	CS	5.76	D	0.37	D	AEV, 2006 IPCC GL
1995	263 059	19.59	19.52	0.0015	0.0001	74 202	CS	5.72	D	0.38	D	AEV, 2006 IPCC GL
1996	293 972	21.89	21.81	0.0017	0.0001	74 192	CS	5.69	D	0.38	D	AEV, 2006 IPCC GL
1997	288 989	21.51	21.44	0.0016	0.0001	74 179	CS	5.66	D	0.38	D	AEV, 2006 IPCC GL
1998	288 989	21.51	21.43	0.0016	0.0001	74 170	CS	5.62	D	0.39	D	AEV, 2006 IPCC GL
1999	288 989	21.51	21.44	0.0016	0.0001	74 174	CS	5.58	D	0.39	D	AEV, 2006 IPCC GL
2000	285 971	21.30	21.22	0.0016	0.0001	74 212	CS	5.54	D	0.39	D	AEV, 2006 IPCC GL
2001	308 159	22.95	22.87	0.0017	0.0001	74 216	CS	5.49	D	0.40	D	AEV, 2006 IPCC GL
2002	272 319	20.28	20.21	0.0015	0.0001	74 217	CS	5.34	D	0.40	D	AEV, 2006 IPCC GL
2003	237 417	17.67	17.61	0.0012	0.0001	74 192	CS	5.25	D	0.40	D	AEV, 2006 IPCC GL
2004	188 676	14.04	13.99	0.0010	0.0001	74 154	CS	5.16	D	0.40	D	AEV, 2006 IPCC GL
2005	119 802	8.91	8.88	0.0006	0.0000	74 137	CS	4.97	D	0.39	D	AEV, 2006 IPCC GL
2006	89 333	6.64	6.62	0.0004	0.0000	74 138	CS	4.77	D	0.39	D	AEV, 2006 IPCC GL
2007	123 786	9.21	9.18	0.0006	0.0000	74 141	CS	4.48	D	0.38	D	AEV, 2006 IPCC GL
2008	142 279	10.57	10.54	0.0006	0.0001	74 085	CS	4.17	D	0.37	D	AEV, 2006 IPCC GL
2009	136 957	10.17	10.14	0.0005	0.0001	74 074	CS	3.84	D	0.36	D	AEV, 2006 IPCC GL
2010	147 731	10.98	10.95	0.0005	0.0001	74 128	CS	3.53	D	0.35	D	AEV, 2006 IPCC GL
2011	148 215	11.01	10.98	0.0005	0.0001	74 114	CS	3.21	D	0.34	D	AEV, 2006 IPCC GL
2012	134 201	9.97	9.95	0.0004	0.0000	74 134	CS	3.05	D	0.33	D	AEV, 2006 IPCC GL
2013	115 526	8.58	8.57	0.0003	0.0000	74 141	CS	2.76	D	0.31	D	AEV, 2006 IPCC GL
2014	131 600	9.77	9.75	0.0003	0.0000	74 069	CS	2.47	D	0.30	D	AEV, 2006 IPCC GL
2015	89 610	6.66	6.64	0.0002	0.0000	74 128	CS	2.33	D	0.29	D	AEV, 2006 IPCC GL
2016	81 985	6.09	6.08	0.0002	0.0000	74 136	CS	2.30	D	0.28	D	AEV, 2006 IPCC GL
2017	88 926	6.61	6.59	0.0002	0.0000	74 149	CS	2.17	D	0.27	D	AEV, 2006 IPCC GL
2018	94 545	7.02	7.01	0.0002	0.0000	74 130	CS	2.11	D	0.26	D	AEV, 2006 IPCC GL
2019	91 355	6.78	6.77	0.0002	0.0000	74 078	CS	2.06	D	0.26	D	AEV, 2006 IPCC GL
Trend 1990-2019	-72.70%	-72.78%	-72.74%	-89.73%	-79.33%	-0.13%		-64.73%		-29.01%		

Source: Environment Agency

3.2.9.4.2 Methodological issues & time-series consistency

3.2.9.4.2.1 Activity data

Diesel oil consumption is obtained directly from the sole railway company (CFL). Activity data is consistent with the data reported by the national statistics institute in their energy balance (2000-2019). For the years 1990-1999, the energy balance (based on the IEA Questionnaire) does not report any consumption data for railways. Hence, the inventory fully relies on data as reported by the national railway company, which were available for the years 1993-1995 and 2001. The consumption for the years from 1996-2000 was interpolated based on the numbers of diesel driven locomotives running in the respective year. Similarly, for 1990-1992, the data was extrapolated based on the number of diesel driven locomotives.

3.2.9.4.2.2 Methodology

The 2006 IPCC Guidelines Tier 2 approach has been applied for CO₂ (use of country specific CO₂ emission factor). CH₄ and N₂O emissions were determined with the GEORG model (for details, please refer to section 3.2.7.7.2.2.).

3.2.9.4.2.3 Emission factors

The country specific CO₂ EF for diesel oil as described in section 3.2.5.3 was used (Tier 2). CH₄ and N₂O emissions were determined with the GEORG model based on HBEFA 4.1 (

Table 3-72). The CH₄ emission factors are based on the EMEP/EEA 2019 Guidebook (Tier 3 approach, chapter 1.A.3.c Railways, p. 13, table 3-6) while N₂O emission factors are based on (Hausberger, 2006). For biodiesel and other fossil fuels (fossil part of biodiesel, please refer to page 247 for details), the European CO₂ implied emission factor⁸³ for diesel oil (73450 g/GJ) was applied.

3.2.9.5 Domestic Navigation (1A3d)

3.2.9.5.1 Source category description

As Luxembourg has no direct access to the sea, there are no maritime activities taking place. Similarly, Luxembourg has only one river where shipping activities are allowed, the Moselle, a border river with Germany. Shipping activities are mainly passenger (leisure and tourism) and freight activities.

In 2019, fuel consumption in navigation was responsible for 0.01% of GHG emissions from fuel combustion activities (0.01% in 1990) and represented 0.01% of the total GHG emissions in CO₂e, excluding LULUCF (0.01% in 1990). Compared to 2018, emissions have decreased by 13.52%. Compared to 1990, emissions have decreased by 27.60%.

Activity data and GHG emissions from *1A3d* are shown in Table 3-73.

Navigation related GHG emissions are not a key source.

83 UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

Table 3-73 – Activity data and emissions for IPCC Sub-category 1A3d – Domestic Navigation: 1990-2019

1A3d - Navigation					
Gas Oil, Diesel Oil, Biodiesel, Motor Gasoline, Bioethanol					
Year	Activity (GJ)	Emissions (Gg)			
		Total CO ₂ eq	CO ₂	CH ₄	N ₂ O
1990	17 686	1.45	1.30	0.0013	0.00037
1991	19 273	1.58	1.42	0.0016	0.00039
1992	18 355	1.51	1.36	0.0018	0.00036
1993	19 241	1.59	1.42	0.0018	0.00040
1994	18 300	1.51	1.35	0.0017	0.00038
1995	15 754	1.30	1.16	0.0014	0.00034
1996	15 901	1.31	1.17	0.0014	0.00035
1997	16 295	1.35	1.20	0.0013	0.00037
1998	15 778	1.30	1.17	0.0013	0.00036
1999	17 416	1.44	1.29	0.0013	0.00041
2000	15 287	1.27	1.13	0.0010	0.00038
2001	17 135	1.42	1.27	0.0011	0.00043
2002	18 741	1.55	1.39	0.0012	0.00046
2003	19 600	1.62	1.45	0.0012	0.00048
2004	18 122	1.50	1.34	0.0011	0.00044
2005	19 200	1.58	1.42	0.0010	0.00045
2006	17 780	1.45	1.31	0.0008	0.00040
2007	17 875	1.46	1.32	0.0008	0.00040
2008	20 016	1.63	1.48	0.0009	0.00043
2009	16 680	1.35	1.23	0.0007	0.00034
2010	18 236	1.47	1.35	0.0007	0.00036
2011	17 179	1.39	1.27	0.0006	0.00034
2012	17 079	1.37	1.26	0.0005	0.00033
2013	14 896	1.19	1.10	0.0005	0.00027
2014	15 817	1.27	1.17	0.0005	0.00028
2015	13 869	1.11	1.03	0.0004	0.00024
2016	14 475	1.16	1.07	0.0004	0.00025
2017	15 481	1.24	1.15	0.0004	0.00028
2018	15 161	1.21	1.12	0.0004	0.00026
2019	13 182	1.05	0.98	0.0003	0.00022
Trend 1990-2019	-25.46%	-27.60%	-25.27%	-74.95%	-41.72%

Source: Environment Agency

3.2.9.5.2 Methodological issues & time-series consistency

3.2.9.5.2.1 Activity data

For tourist boats, fuel consumption data (diesel and biodiesel) is obtained directly from the two national operators as no data is available from the official statistics. Indeed, no consumption is reported in the IEA Joint Questionnaire on oil products, probably due to the fact that the consumption is below 0.5 kt and that no digits are allowed in the questionnaire. The activity data are listed in Table 3-73.

Concerning the fuel consumption of leisure boats (yachts, jet-skis, etc), no data is available at this stage. However, only one (very) small marina exists on Luxembourg's side of the Moselle River: Schwesbange. This marina is equipped with a gasoline and diesel oil filling station. The amount of fuel sold at this station was obtained from the operator for the entire time-series.⁸⁴ It is assumed that the quantities sold at this station are being combusted entirely on Luxembourg's side of the river. These fuel quantities are included in the total fuel consumption in the national energy balance, hence there is no risk of double-counting emissions from leisure boats (Luxembourg's ARR 2018, para. E.14).

84 ARR 2009, §55

3.2.9.5.2.2 Methodology

The Tier 2 approach has been applied for CO₂ (use of country specific CO₂ emission factors as described in section 3.2.5.3), while CH₄ and N₂O emissions were determined with the GEORG model (Tier 3, for details, please refer to section 3.2.7.7.2.2).

Due to the particular geographical situation of the Moselle River, freight shipping activities, which are executed on barges, which do not refuel in Luxembourg's sole commercial port (Merttert), are not accounted for in Luxembourg's GHG inventory. These activities are exclusively international, *i.e.* destination is always abroad. For passenger shipping activities, the situation is different. There are two companies executing passenger shipping on the Moselle River. As communicated by these companies, about 80% of their journeys are to be considered domestic (from Luxembourg to Luxembourg), and the remaining 20% to be considered international (from Luxembourg to an international destination, or *vice versa*). Thus, the emissions from gasoil, reported under IPCC sub-category 1A3d - *Domestic Navigation*, cover the 80% of domestic journeys. The emissions relating to the remaining 20% international journeys are reported under international bunkers – marine.

3.2.9.5.2.3 Emission factors

Table 3-74 shows the implied emission factors for 2018. The country-specific CO₂ EFs as described in section 3.2.5.3 were used. The CH₄ emission factors are based on the EMEP/EEA 2016 Guidebook (Tier 3 approach) while N₂O emission factors are based on (Hausberger, 2006). For biofuels and other fossil fuels (fossil part of biodiesel, please refer to page 247 for details), European CO₂ implied emission factors⁸⁵ for gasoline (71270 g/GJ) and diesel oil (73450 g/GJ) were applied.

Table 3-74 – Emission factors for IPCC sub-category 1A3d – Domestic Navigation

1A3d - Navigation								
Emission Factors for 2019 (kg/TJ)								
Fuel	Fuel Type	CO ₂		CH ₄		N ₂ O		Source
		EF	type	EF	type	EF	type	
Diesel Oil	liquid	74 078	CS	2.16	CS	17.41	CS	AEV
Motor Gasoline	liquid	73 162	CS	168.27	CS	0.78	CS	AEV

Source: Environment Agency

85 UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

3.2.9.6 Other Transportation (1A3e)

No activities have been identified for Luxembourg, hence notation key NA.

Whereas the IPCC 2006 Guidelines recommend to report emissions from vehicles and mobile machinery used within the agriculture, forestry, industry (including construction and maintenance), residential, and sectors, such as airport ground support equipment, agricultural tractors, chain saws, forklifts, snowmobiles in IPCC sub-category *1A3e – Other Transportation*, Luxembourg reports these emissions in the relevant IPCC sub-categories as follows:

- 1A2 Manufacturing Industries and Construction: sub-category 1A2g vii
- 1A4b ii Residential: Household and gardening
- 1A4c ii Agriculture: Tractors, Harvesters, etc.
- 1A5b Mobile: military equipment

Pipeline compressors, reported under *1A3e – Other Transportation*, do not exist in Luxembourg.

3.2.9.7 Uncertainties and time-series consistency

The uncertainties for activity data and emission factors used for IPCC category *1A3 – Transport* are presented in Table 3-75.

Table 3-75: uncertainties for activity data and emission factors used for IPCC category 1A3 – Transport.

IPCC category/Group	Gas	Activity data uncertainty	Emission factor / estimation parameter uncertainty
1A3a - Transport - Civil Aviation	CO ₂	10%	5%
1A3a - Transport - Civil Aviation	CH ₄	10%	100%
1A3a - Transport - Civil Aviation	N ₂ O	10%	150%
1A3b - Road Transportation - Diesel Oil	CO ₂	2%	2%
1A3b - Road Transportation - Diesel Oil	CH ₄	2%	20%
1A3b - Road Transportation - Diesel Oil	N ₂ O	2%	20%
1A3b - Road Transportation - Gasoline	CO ₂	2%	2%
1A3b - Road Transportation - Gasoline	CH ₄	2%	20%
1A3b - Road Transportation - Gasoline	N ₂ O	2%	20%
1A3b - Road Transportation - LPG	CO ₂	2%	2%
1A3b - Road Transportation - LPG	CH ₄	2%	40%
1A3b - Road Transportation - LPG	N ₂ O	2%	100%
1A3b - Road Transportation - biomass	CH ₄	2%	20%
1A3b - Road Transportation - biomass	N ₂ O	2%	20%
1A3b - Road Transportation - other fossil fuels	CO ₂	20%	2%
1A3b - Road Transportation - other fossil fuels	CH ₄	20%	20%
1A3b - Road Transportation - other fossil fuels	N ₂ O	20%	20%
1A3c - Railways - liquid fuels	CO ₂	2%	2%
1A3c - Railways - liquid fuels	CH ₄	2%	20%
1A3c - Railways - liquid fuels	N ₂ O	2%	20%
1A3c - Railways - biomass	CH ₄	2%	20%
1A3c - Railways - biomass	N ₂ O	2%	20%
1A3c - Railways - other fossil fuels	CO ₂	20%	2%
1A3c - Railways - other fossil fuels	CH ₄	20%	20%
1A3c - Railways - other fossil fuels	N ₂ O	20%	20%
1A3d - Navigation - liquid fuels	CO ₂	2%	2%
1A3d - Navigation - liquid fuels	CH ₄	2%	20%
1A3d - Navigation - liquid fuels	N ₂ O	2%	20%
1A3d - Navigation - biomass	CH ₄	2%	20%
1A3d - Navigation - biomass	N ₂ O	2%	20%
1A3d - Navigation - other fossil fuels	CO ₂	20%	2%
1A3d - Navigation - other fossil fuels	CH ₄	20%	20%
1A3d - Navigation - other fossil fuels	N ₂ O	20%	20%

The time-series reported under *1A3 - Transportation*, are considered as being consistent. For more specific information on time-series consistency, please refer to the methodological issues as described in the respective sub-categories above.

3.2.9.8 Source-specific QA/QC and verification

Activity data obtained directly from the operators was crosschecked with official statistics, if available, for plausibility.

Consistency and completeness checks have been performed using the tools embedded in CRF Reporter.

3.2.9.9 Category-specific recalculations including changes made in response to the review process

Table 3-76 presents the main revisions and recalculations done since submission 2020v1 relevant to IPCC sub-category 1A3 - *Transport*. For the impact of these recalculations on national total emissions, please refer to Chapter 10.

Table 3-76 – Recalculations done since submission 2020v1

GHG source & sink category	Revisions 2020v1 → 2021v1	Type of revision
1A3b/c/d	The country-specific CO ₂ EFs for motor gasoline were revised for the years 2017-2018 due to changes of the emission factors of the importing countries: 2017: from 73300 to 73181 kg/TJ 2018: from 73216 to 73093 kg/TJ.	updated EF
1A3d	Error correction for CO ₂ emissions from biomass / other fossil fuels for the years 2004-2018	AD correction
1A3d	The total amounts of gasoline, diesel oil, LPG, bioethanol and biodiesel sold in Luxembourg are obtained from the national energy balance, and the activity data is then allocated to the different road and offroad subcategories with the NEMO and GEORG models developed by TU Graz. No changes were made to the total amounts of the different fuel types, but minor reallocations were done for diesel, biodiesel and other fossil fuels from 1.A.3.d-Domestic Navigation to 1.D.1.b-International navigation for the years 1995-2018 (Table 3-77). These reallocations are due to an update of the specific fuel consumption of offroad vehicles (Schwingshackl, Rexeis, & Weller, 2020).	AD reallocation

Table 3-77 - Activity data reallocated from 1.A.3.d – Domestic navigation to 1.D.1.b – International navigation.

activity data reallocated from 1A3d to 1D1b (GJ)			
year	diesel	biodiesel	other fossil fuels
1990			
1991			
1992			
1993			
1994			
1995	1.20		
1996	2.89		
1997	5.05		
1998	6.81		
1999	9.41		
2000	12.31		
2001	14.26		
2002	16.89		
2003	19.36		
2004	20.50	0.01	0.00
2005	31.20	0.01	0.00
2006	34.46	0.01	0.00
2007	29.27	0.75	0.04
2008	33.01	0.82	0.05
2009	26.37	0.66	0.04
2010	26.81	0.62	0.03
2011	33.19	0.70	0.04
2012	32.44	0.84	0.04
2013	27.12	0.82	0.04
2014	27.83	1.09	0.05
2015	25.88	1.23	0.07
2016	26.67	1.38	0.08
2017	30.56	2.07	0.12
2018	25.23	1.70	0.09

3.2.9.10 Category-specific planned improvements including those in response to the review process

Taking into account the potential contribution of identified improvements in the total GHG emissions and the corresponding resources needed to make these improvements effective, developments presented in Table 3-78 will be explored.

Table 3-78 – Planned improvements for IPCC Sub-category 1A3 – Transport

GHG source & sink category	Planned improvement
1A3 - Transportation	No planned improvements

3.2.10 Other Sectors (1.A.4)

3.2.10.1 Source category description

This section describes GHG emissions resulting from fuel combustion activities in the category *1A4 - Other sectors* and covers combustion activities from stationary combustion and mobile combustion in sub-categories:

- *1A4a – Commercial/Institutional*
- *1A4b – Residential*
- *1A4c - Agriculture/Forestry/Fishing*

In 2019, category *1A4 - Other sectors* was responsible for 18.03% of GHG emissions from fuel combustion activities (this share was 13.23% in 1990) and represented around 15.52% of the total GHG emissions excluding LULUCF (10.69% in 1990).

Compared to 2018, emissions increased by 0.53%, to attain the level of 1666.88 Gg CO₂e. Compared to 1990 emissions increased by 22.57%, mainly due to the steady increase in population and economic activity over the last two decades.

1A4 – Other Sectors is a key category regarding CO₂ emissions from gaseous and liquid fuels. It has been a key category for gaseous and liquid fuels without interruption since 1990, see Table 3-6 in Section 3.2.

Table 3-79 – GHG emission trends for category 1A4 – Other Sectors: 1990-2019

1A4 - Other Sectors												
GHG emissions by source & sink category excluding CO ₂ emissions from biomass (Gg)												
Year	1A4a - Commercial/Institutional				1A4b - Residential				1A4c - Agriculture/Forestry/Fisheries			
	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)	Total CO ₂ eq	CO ₂ (excl. biomass)	CH ₄ (incl. biomass)	N ₂ O (incl. biomass)
1990	641.99	638.88	0.08	0.004	681.12	669.82	0.37	0.007	36.86	34.06	0.006	0.009
1991	772.21	768.41	0.09	0.005	816.10	803.75	0.40	0.008	37.69	34.94	0.006	0.009
1992	712.07	708.63	0.09	0.004	749.67	738.15	0.37	0.007	35.94	33.35	0.006	0.008
1993	704.42	701.05	0.08	0.004	744.20	732.61	0.38	0.007	33.82	31.29	0.006	0.008
1994	679.00	675.77	0.08	0.004	708.77	698.06	0.35	0.007	36.23	33.59	0.006	0.008
1995	684.47	681.26	0.08	0.004	718.70	707.75	0.35	0.007	34.52	31.86	0.005	0.008
1996	763.78	760.23	0.09	0.004	788.64	778.00	0.34	0.007	36.16	33.43	0.006	0.009
1997	740.46	736.96	0.09	0.004	764.20	753.71	0.33	0.007	37.61	34.85	0.006	0.009
1998	774.49	770.85	0.09	0.005	794.63	784.28	0.33	0.007	38.35	35.48	0.006	0.009
1999	693.99	690.79	0.08	0.004	713.47	703.62	0.31	0.007	55.75	52.75	0.008	0.009
2000	549.21	547.10	0.06	0.002	1 081.46	1 070.12	0.35	0.009	27.77	24.85	0.004	0.009
2001	499.65	497.48	0.06	0.002	1 174.08	1 161.98	0.37	0.010	24.56	21.96	0.004	0.008
2002	501.59	499.36	0.06	0.002	1 117.46	1 106.22	0.34	0.009	26.15	23.43	0.004	0.009
2003	498.06	496.01	0.06	0.002	1 160.31	1 148.88	0.35	0.009	26.42	23.74	0.004	0.009
2004	463.65	461.76	0.05	0.002	1 240.58	1 228.49	0.37	0.010	27.79	25.09	0.004	0.009
2005	418.87	417.16	0.05	0.002	1 214.74	1 203.07	0.36	0.009	27.13	24.64	0.004	0.008
2006	395.72	394.31	0.04	0.001	1 202.79	1 191.13	0.35	0.009	27.62	25.20	0.004	0.008
2007	348.92	347.65	0.04	0.001	1 163.01	1 152.22	0.33	0.009	26.45	24.16	0.004	0.007
2008	377.62	376.31	0.04	0.001	1 195.78	1 184.44	0.34	0.009	28.61	26.23	0.004	0.008
2009	381.60	380.27	0.04	0.001	1 182.48	1 170.61	0.36	0.009	28.68	26.39	0.004	0.007
2010	502.33	500.45	0.05	0.002	1 160.34	1 148.60	0.36	0.009	28.81	26.65	0.004	0.007
2011	335.37	334.09	0.04	0.001	1 063.21	1 053.37	0.30	0.008	27.41	25.45	0.004	0.006
2012	439.33	437.68	0.05	0.002	1 082.32	1 071.02	0.35	0.009	27.43	25.56	0.004	0.006
2013	462.64	460.75	0.05	0.002	1 074.84	1 062.97	0.37	0.009	23.38	21.84	0.004	0.005
2014	397.81	396.09	0.05	0.002	972.03	959.98	0.38	0.008	23.77	22.26	0.003	0.005
2015	488.50	486.42	0.06	0.002	1 085.13	1 072.06	0.41	0.009	24.19	22.74	0.003	0.005
2016	511.39	509.17	0.06	0.002	1 118.23	1 104.05	0.45	0.010	24.27	22.89	0.003	0.004
2017	563.52	560.99	0.06	0.003	1 138.41	1 125.35	0.42	0.009	23.62	22.31	0.003	0.004
2018	592.06	589.43	0.07	0.003	1 042.07	1 028.62	0.43	0.009	23.89	22.61	0.004	0.004
2019	692.62	689.47	0.08	0.004	950.34	940.83	0.30	0.007	23.91	22.70	0.003	0.004
Trend 1990-2019	7.89%	7.92%	4.61%	-3.41%	39.53%	40.46%	-18.14%	-6.13%	-35.13%	-33.35%	-45.00%	-57.42%
Trend 2018-2019	16.99%	16.97%	18.58%	22.44%	-8.80%	-8.53%	-30.16%	-26.04%	0.10%	0.38%	-10.55%	-4.49%

Source: Environment Agency

Notes:

CO₂ emissions do not include CO₂ emissions from biomass which are reported under Memo Items.

CH₄ emissions are converted in CO₂e by multiplying the emissions by 25, *i.e.* the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon.

N₂O emissions are converted in CO₂e by multiplying the emissions by 298, *i.e.* the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

3.2.10.2 Commercial/Institutional (1.A.4.a)

3.2.10.2.1 Source category description

In 2019, fuel combustion activities from the commercial and institutional sector were responsible for 7.49% of GHG emissions from fuel combustion activities (this share was 6.24% in 1990). With regard to total GHG emissions excluding LULUCF, *1A4a – Commercial/Institutional* covered 6.45% in 2019 and 5.04% in 1990. Compared to 2018, GHG emissions have increased by 16.99% to reach the level of 692.62 Gg CO₂e in 2019. Compared to 1990, emissions in this sub-category increased by 7.89%.

3.2.10.2.2 Methodological issues & time-series consistency

3.2.10.2.2.1 Activity data

Under *1A4a – Commercial/Institutional*, emissions from non-industrial commercial and institutional combustion plants (<50 MW) are accounted, thus covering numerous small combustion units, mainly for the heating purpose of buildings. No specific bottom-up data are available, so that emission estimates solely rely on top-down data from the national energy balance.

However, for the period 1990-1999, fuel consumption data are only reported under the so-called “*domestic sector*” by the national energy balance, covering consumption data for commercial and institutional as well as for residential combustion units. Consequently, data were distributed arbitrarily, *i.e.* 50% are reported under *1A4a – Commercial/Institutional* and 50% under *1A4b – Residential*. From 2000 onwards, the consumption data reported by the national energy balance are properly split between the two categories *1A4a* and *1A4b*.

The total activity rate of category *1A4a* has been relatively constant in recent years (Table 3-80), with sharp decreases in 2007, 2011 and 2014, probably due to relatively mild winters.

Table 3-80 – Activity data for category 1A4a – Commercial/Institutional

1A4a - Commercial/Institutional						
Activity Data by fuel type (GJ)						
Year	Activity Total (excl. biomass)	Solid	Liquid Gas Oil, LPG	Gaseous Natural Gas	Biomass Biogas, Wood & Wood Wastes	Other
1990	9 296 234	NO	6 359 553	2 936 681	NO	NO
1991	11 122 560	NO	7 822 330	3 300 231	NO	NO
1992	10 323 786	NO	6 985 232	3 338 554	NO	NO
1993	10 259 447	NO	6 708 868	3 550 579	NO	NO
1994	9 898 224	NO	6 406 937	3 491 287	NO	NO
1995	10 042 374	NO	6 223 973	3 818 401	NO	NO
1996	11 278 090	NO	6 794 806	4 483 284	NO	NO
1997	10 906 999	NO	6 718 170	4 188 829	NO	NO
1998	11 461 250	NO	6 954 434	4 506 816	2 000	NO
1999	10 384 398	NO	5 942 758	4 441 640	3 000	NO
2000	8 894 708	NO	2 673 823	6 220 885	20 662	NO
2001	7 804 461	NO	3 312 877	4 491 584	33 361	NO
2002	7 912 102	NO	3 009 270	4 902 833	45 078	NO
2003	7 936 416	NO	2 693 297	5 243 119	37 993	NO
2004	7 327 999	NO	2 685 214	4 642 785	29 753	NO
2005	6 586 701	NO	2 495 701	4 091 000	28 389	NO
2006	6 476 826	NO	1 498 922	4 977 905	28 240	NO
2007	5 703 014	NO	1 383 477	4 319 537	27 609	NO
2008	6 310 986	NO	1 090 665	5 220 321	33 579	NO
2009	6 355 581	NO	1 079 899	5 275 683	42 033	NO
2010	8 138 769	NO	2 428 020	5 710 750	36 856	NO
2011	5 344 212	NO	1 927 682	3 416 530	39 684	NO
2012	7 126 052	NO	2 107 114	5 018 938	43 946	NO
2013	7 415 628	NO	2 527 936	4 887 692	59 255	NO
2014	6 337 408	NO	2 292 116	4 045 292	68 671	NO
2015	7 618 626	NO	3 316 512	4 302 114	54 843	NO
2016	8 069 140	NO	3 218 903	4 850 237	87 382	NO
2017	8 504 458	NO	4 732 067	3 772 390	51 792	NO
2018	9 013 301	NO	4 785 164	4 228 136	46 254	NO
2019	10 436 740	NO	5 972 961	4 463 779	49 640	NO
Trend 1990-2019	12.27%	NA	-6.08%	52.00%	NA	NA
Trend 2018-2019	15.79%	NA	24.82%	5.57%	7.32%	NA

Source: Environment Agency

3.2.10.2.2 Methodology

The 2006 IPCC Guidelines Tier 2 approach has been applied for CO₂ for all fuels except for biomass (only biogas is used) for which a Tier 1 approach was used. For CH₄ and N₂O, the 2006 IPCC Guidelines Tier 1 approach was used.

3.2.10.2.3 Emission factors

Default CH₄ and N₂O emission factors have been applied for all fuels. For biomass (biogas, wood & wood wastes) the IPCC default EFs were applied. For gas oil, LPG, and natural gas, country-specific CO₂ emission factors were used (Table 3-81).

Table 3-81 – Emission factors for category 1A4a – Commercial/Institutional

1A4a - Commercial/Institutional Emission Factors for 2019 (kg/TJ)								
Fuel	Fuel Type	CO ₂		CH ₄		N ₂ O		Source
		EF	type	EF	type	EF	type	
LPG	liquid	65 489	CS	5.00	D	0.10	D	AEV 2006 IPCC GL
Gas Oil	liquid	74 078	CS	10.00	D	0.60	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 091	CS	5.00	D	0.10	D	AEV 2006 IPCC GL
Biogas	biomass	54 600	D	5.00	D	0.10	D	2006 IPCC GL
Wood & Wood Wastes	biomass	112 000	D	300.00	D	4.00	D	2006 IPCC GL

Source: Environment Agency

Table 3-82 gives an overview of the evolution of the implied emission factors per fuel type. The slight fluctuations for the CH₄ and NO₂ IEFs for liquid fuels are due to fluctuations in the fuel mix (gas oil and LPG).

Table 3-82 – Implied emission factors for IPCC sub-category 1A4a – Commercial/Institutional

1A4a - Commercial/Institutional Implied Emission Factors (kg/TJ)									
Year	Biomass			Liquid			Gaseous		
	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O
1990	NO	NO	NO	73 790	9.79	0.58	57 755	5.00	0.10
1991	NO	NO	NO	73 871	9.84	0.58	57 743	5.00	0.10
1992	NO	NO	NO	73 799	9.82	0.58	57 848	5.00	0.10
1993	NO	NO	NO	73 857	9.83	0.58	57 894	5.00	0.10
1994	NO	NO	NO	73 902	9.84	0.58	57 940	5.00	0.10
1995	NO	NO	NO	73 919	9.85	0.58	57 929	5.00	0.10
1996	NO	NO	NO	73 914	9.85	0.59	57 546	5.00	0.10
1997	NO	NO	NO	74 029	9.92	0.59	57 205	5.00	0.10
1998	54 600	5.00	0.10	73 992	9.90	0.59	56 863	5.00	0.10
1999	54 600	5.00	0.10	73 996	9.90	0.59	56 522	5.00	0.10
2000	64 673	56.77	0.78	73 810	9.78	0.58	56 221	5.00	0.10
2001	70 298	85.68	1.17	73 893	9.83	0.58	56 258	5.00	0.10
2002	82 520	148.49	2.00	74 058	9.91	0.59	56 396	5.00	0.10
2003	69 387	81.00	1.10	74 109	9.96	0.60	56 533	5.00	0.10
2004	61 886	42.45	0.60	73 977	9.90	0.59	56 671	5.00	0.10
2005	60 977	37.78	0.53	73 863	9.85	0.59	56 910	5.00	0.10
2006	57 239	18.56	0.28	73 736	9.78	0.58	57 008	5.00	0.10
2007	57 558	20.20	0.30	73 968	9.91	0.59	56 793	5.00	0.10
2008	61 151	38.67	0.55	73 811	9.85	0.59	56 665	5.00	0.10
2009	65 362	60.31	0.83	73 397	9.63	0.56	57 056	5.00	0.10
2010	63 650	51.51	0.71	72 729	9.24	0.52	56 712	5.00	0.10
2011	58 593	25.52	0.37	72 310	9.02	0.50	56 988	5.00	0.10
2012	65 585	61.46	0.85	72 440	9.08	0.51	56 793	5.00	0.10
2013	71 433	91.51	1.24	72 674	9.20	0.52	56 680	5.00	0.10
2014	74 982	109.75	1.48	72 636	9.22	0.52	56 756	5.00	0.10
2015	65 039	58.65	0.81	73 038	9.41	0.54	56 760	5.00	0.10
2016	69 606	82.12	1.12	72 954	9.34	0.53	56 561	5.00	0.10
2017	55 472	9.48	0.16	73 448	9.61	0.56	56 577	5.00	0.10
2018	55 949	11.93	0.19	73 512	9.65	0.57	56 209	5.00	0.10
2019	55 239	8.28	0.14	73 513	9.67	0.57	56 091	5.00	0.10

Source: Environment Agency

3.2.10.3 Residential (1A4b)

3.2.10.3.1 Source category description

In 2019, fuel combustion activities in the residential sector were responsible for 10.28% of GHG emissions from fuel combustion activities (6.62% in 1990). With regard to total GHG emissions excluding LULUCF emissions from *1A4b – Residential* reached 8.85% in 2019 and 5.35% in 1990. Compared to 2019, GHG emissions decreased by 8.80% and compared to 1990, they increased by 39.53%.

3.2.10.3.2 Methodological issues & time-series consistency

3.2.10.3.2.1 Activity data

Under *1A4b – Residential*, the following activities have been classified:

- *Non-industrial residential combustion plants < 50 MW*: This source category covers numerous smaller combustion units, mainly for heating purposes. No specific bottom-up data are available, so that emission estimates solely rely on top-down data provided by the national statistics institute. The consumption of coke, hard coal (other bituminous coal), lignite briquettes (brown coal briquettes), patent fuels, wood, gas oil, LPG and natural gas was obtained from the national statistics institute.
However, for 1990-1999, the consumptions of gas oil and natural gas are reported under the so-called “*domestic sector*” by the national statistics institute, covering consumptions both from commercial and institutional as well as from residential combustion. Consequently, data were distributed arbitrarily, *i.e.* 50% was allocated to *1A4a - Commercial/Institutional* and 50% to *1A4b - Residential*. From 2000 onwards, the consumptions reported by the national statistics institute are properly split between the two sub-categories *1A4a* and *1A4b*.
- *Household and gardening*: Gasoline consumption was allocated to this sub-category. An average of 0.57 motorised gardening tools per household was assumed (*Komobile, FVT, 2017*).

In order to verify the potential off-road fuel use by commuters (e.g. export in jerrycans for household and gardening use) to estimate the quantity of fuel sold to trans-border commuters and likely used for non-transport purposes such as motorized gardening equipment and off-road vehicles, publicly available statistics and literature on socio-economic behaviors of commuters have been reviewed (e.g. publications from Luxembourg’s Institute of Socio-Economic Research). However, no information has been found on the potential off-road fuel export by commuters working in Luxembourg. Hence, estimating the amount of fuel exported for household/gardening applications would be a challenging task, and the uncertainty of the resulting emissions would be extremely high. In this context, Luxembourg calculated a “worst-case scenario” in which commuters use as much fuel for gardening tools and leisure boats per capita as residents and fuel them exclusively with fuel purchased in Luxembourg. This allows determining the maximum amount of fuel that could possibly be reallocated from passenger cars to off-road applications, and the resulting change in CH₄ and N₂O emissions due to different emission factors. Based on activity data and implied emission factors from Luxembourg’s submission from April 2018, the resulting change in total emissions for the different inventory years would range between +0.0028 and +0.0168 Gg CO₂eq, and between 0.00002% and 0.00015% of Luxembourg’s national total emissions of the respective years. Even an extremely conservative assumption would thus lead to an emission difference that is several orders of magnitude below the threshold of significance.

Activity data for both stationary and mobile sources, as described above, are listed in Table 3-83.

Table 3-83 – Activity data for category 1A4b – Residential

1A4b - Residential						
Fuel consumption by fuel type (GJ)						
Year	Activity Total (excl. biomass)	Solid	Liquid	Gaseous	Biomass	Other
		Coke Oven Coke, Brown Coal Briquettes, Other Bituminous Coal	Gas Oil, LPG, Gasoline	Natural Gas	Wood & Wood Wastes	
1990	9 630 362	268 741	6 424 941	2 936 681	645 000	NO
1991	11 501 417	313 244	7 887 942	3 300 231	645 000	NO
1992	10 642 936	253 192	7 051 190	3 338 554	645 000	NO
1993	10 597 074	271 499	6 774 996	3 550 579	645 000	NO
1994	10 143 361	179 141	6 472 934	3 491 287	645 000	NO
1995	10 322 208	214 226	6 289 581	3 818 401	645 000	NO
1996	11 476 950	133 647	6 860 019	4 483 284	645 000	NO
1997	11 095 381	123 577	6 782 975	4 188 829	645 000	NO
1998	11 615 387	89 753	7 018 819	4 506 816	645 000	NO
1999	10 532 514	83 642	6 007 233	4 441 640	645 000	NO
2000	16 006 101	63 651	9 381 808	6 560 642	632 256	NO
2001	17 408 515	51 351	10 115 994	7 241 170	682 708	NO
2002	16 658 067	40 632	9 297 132	7 320 304	630 859	NO
2003	17 350 226	29 511	9 464 317	7 856 398	644 245	NO
2004	18 573 664	27 390	10 030 033	8 516 240	686 572	NO
2005	18 212 379	30 074	9 645 313	8 536 993	656 953	NO
2006	17 892 751	25 786	9 967 333	7 899 632	658 908	NO
2007	17 378 037	21 523	9 495 483	7 861 031	588 324	NO
2008	17 963 411	19 861	9 536 065	8 407 485	645 803	NO
2009	17 697 467	21 702	9 448 809	8 226 956	716 440	NO
2010	17 756 022	25 322	8 127 993	9 602 707	742 230	NO
2011	16 296 865	22 774	7 246 272	9 027 820	579 968	NO
2012	16 389 264	18 751	8 054 899	8 315 615	725 014	NO
2013	16 403 697	26 584	7 580 067	8 797 046	798 616	NO
2014	14 930 998	20 855	6 466 468	8 443 674	885 662	NO
2015	16 611 721	25 796	7 390 590	9 195 335	940 318	NO
2016	17 206 462	24 557	7 399 980	9 781 925	1 059 203	NO
2017	17 832 492	15 951	6 600 491	11 216 050	951 554	NO
2018	16 330 245	9 964	6 167 406	10 152 875	1 043 019	NO
2019	15 195 209	10 421	4 913 464	10 271 325	649 303	NO
Trend 1990-2019	57.78%	-96.12%	-23.53%	249.76%	0.67%	NA
Trend 2018-2019	-6.95%	4.59%	-20.33%	1.17%	-37.75%	NA

Source: Environment Agency

3.2.10.3.2.2 Methodology

For stationary sources, the 2006 IPCC Guidelines Tier 2 approach has been applied for CO₂, while the Tier 1 approach was used for CH₄ and N₂O.

For mobile sources, the 2006 IPCC Guidelines Tier 2 approach has been applied for CO₂, while the method used for CH₄ and N₂O is based on the GEORG model which conforms to the requirements of the IPCC 2006 GL Tier 3 methodology. The methodology is described in section 3.2.7.7.2.2.

3.2.10.3.2.3 Emission factors

For stationary combustion sources, country-specific CO₂ emission factors and default CH₄ and N₂O emission factors from the 2006 IPCC Guidelines were used for the main fuels: see Table 3-84. For mobile machinery, the country-specific CO₂ EF for gasoline as described in section 3.2.5.3 was used (Tier 2). CH₄ and N₂O emissions were determined with the GEORG model (

Table 3-72). The CH₄ emission factors are based on the EMEP/EEA 2016 Guidebook (Tier 3) while N₂O emission factors are based on (Hausberger, 2006). For biogasoline, the European CO₂ implied emission factor⁸⁶ for gasoline (71270 g/GJ) was applied.

Table 3-84 – Emission factors for IPCC sub-category 1A4b – Residential

1A4b - Residential Emission Factors for 2019 (kg/TJ)								
Fuel	Fuel Type	CO ₂		CH ₄		N ₂ O		Source
		EF	type	EF	type	EF	type	
Coke Oven Coke	solid	107 000	D	300.00	D	1.50	D	2006 IPCC GL
Brown Coal Briquettes	solid	97 500	D	300.00	D	1.50	D	2006 IPCC GL
Other Bituminous Coal	solid	94 600	D	300.00	D	1.50	D	2006 IPCC GL
Patent Fuels	solid	97 500	D	300.00	D	1.50	D	2006 IPCC GL
LPG	liquid	65 489	CS	5.00	D	0.10	D	AEV 2006 IPCC GL
Gas Oil	liquid	74 078	CS	10.00	D	0.60	D	AEV 2006 IPCC GL
Gasoline	liquid	73 162	CS	82.76	CS	1.13	CS	AEV
Natural Gas	gaseous	56 091	CS	5.00	D	0.10	D	AEV 2006 IPCC GL
Wood & Wood Wastes	biomass	112 000	D	300.00	D	4.00	D	2006 IPCC GL

Source: Environment Agency

Table 3-85 gives an overview of the evolution of the implied emission factors per fuel type.

86 UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

Table 3-85 – Implied emission factors for IPCC sub-category 1A4b – Residential

1A4b - Residential									
Implied Emission Factors (kg/TJ)									
Year	Solid			Liquid			Gaseous		
	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O
1990	97 464	300	1.50	73 777	12.40	0.58	57 755	5.00	0.10
1991	97 593	300	1.50	73 861	11.97	0.59	57 743	5.00	0.10
1992	97 515	300	1.50	73 794	12.21	0.59	57 848	5.00	0.10
1993	98 441	300	1.50	73 849	12.33	0.59	57 894	5.00	0.10
1994	97 530	300	1.50	73 893	12.41	0.59	57 940	5.00	0.10
1995	101 287	300	1.50	73 909	12.39	0.59	57 929	5.00	0.10
1996	97 350	300	1.50	73 905	12.09	0.59	57 546	5.00	0.10
1997	97 367	300	1.50	74 017	12.09	0.60	57 205	5.00	0.10
1998	97 365	300	1.50	73 982	11.91	0.60	56 863	5.00	0.10
1999	97 303	300	1.50	73 983	12.16	0.60	56 522	5.00	0.10
2000	97 500	300	1.50	74 087	11.34	0.60	56 221	5.00	0.10
2001	97 500	300	1.50	74 101	11.21	0.60	56 258	5.00	0.10
2002	97 500	300	1.50	74 155	11.32	0.60	56 396	5.00	0.10
2003	97 500	300	1.50	74 158	11.30	0.60	56 533	5.00	0.10
2004	97 500	300	1.50	74 097	11.15	0.60	56 671	5.00	0.10
2005	97 500	300	1.50	74 057	11.07	0.60	56 910	5.00	0.10
2006	97 500	300	1.50	74 069	10.93	0.60	57 008	5.00	0.10
2007	97 500	300	1.50	74 106	10.88	0.60	56 793	5.00	0.10
2008	97 500	300	1.50	74 044	10.75	0.60	56 665	5.00	0.10
2009	97 500	300	1.50	73 987	10.62	0.60	57 056	5.00	0.10
2010	97 500	300	1.50	74 009	10.60	0.60	56 712	5.00	0.10
2011	97 500	300	1.50	74 061	10.61	0.60	56 988	5.00	0.10
2012	97 500	300	1.50	74 107	10.51	0.60	56 793	5.00	0.10
2013	97 500	300	1.50	74 110	10.52	0.60	56 680	5.00	0.10
2014	97 500	300	1.50	74 031	10.60	0.60	56 756	5.00	0.10
2015	97 500	300	1.50	74 097	10.52	0.60	56 760	5.00	0.10
2016	97 500	300	1.50	74 105	10.52	0.60	56 561	5.00	0.10
2017	97 500	300	1.50	74 121	10.59	0.60	56 577	5.00	0.10
2018	97 500	300	1.50	74 093	10.63	0.60	56 209	5.00	0.10
2019	97 500	300	1.50	74 018	10.77	0.60	56 091	5.00	0.10

Source: Environment Agency

3.2.10.4 Agriculture/Forestry/Fishing (1A4c)

3.2.10.4.1 Source category description

Luxembourg reports emissions for the following sub-categories:

- *Stationary (1A4c.i)*
- *Off-road vehicles and other machinery (1A4c.ii)*

Sub-category *1A4c.iii Fishing* (mobile combustion) does not exist in Luxembourg.

In 2019, fuel combustion activities in agriculture and forestry were responsible for 0.26% of GHG emissions from fuel combustion activities (0.36% in 1990). With regard to total GHG emissions excluding LULUCF, emissions from *1A4c – Agriculture/Forestry/ Fishing* reached 0.22% in 2019 and 0.29% in 1990. Compared to 2018, GHG emissions increased by 0.10% and compared to 1990, they decreased by 35.13%.

Emissions of *1A4c - Agriculture/Forestry/Fishing* are shown in

Table 3-79 at the beginning of this section.

3.2.10.4.2 Methodological issues & time-series consistency

3.2.10.4.2.1 Activity data

Under 1A4c – Agriculture/Forestry/Fishing, the following activities have been classified:

- *Non-industrial combustion plants in agriculture, forestry and aquaculture:* the fuel consumption data of this activity are derived from the national energy balance. However, only the consumption of gas oil is reported for the entire time-series. Natural gas is only reported from 2000-2010 and from 2014-2019, but its consumption is very small (around 36 GJ for 2019). Other fuels might be included elsewhere by the national energy balance.
- *Mobile machinery used in forestry and agriculture:* Diesel oil and gasoline consumption was attributed to mobile machinery used in forestry and agriculture (i.e. tractors, harvesters, chainsaws, etc.) based on stock data and economic indicators (*Komobile, FVT, 2017*).

Activity data from both stationary and mobile sources, as described above, are listed in Table 3-86.

Table 3-86 – Activity data and implied emission factors for category 1A4c – Agriculture/Forestry/Fishing

1A4c - Agriculture/Forestry/Fishing										
Activity Data and Implied Emission Factors (kg/TJ)										
Year	Activity (GJ)	Liquid			Gaseous			Biomass		
		CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O	CO ₂	CH ₄	N ₂ O
1990	459 277	74 152	12.42	19.48	NO	NO	NO	NO	NO	NO
1991	471 334	74 139	12.46	18.54	NO	NO	NO	NO	NO	NO
1992	449 947	74 119	12.85	18.24	NO	NO	NO	NO	NO	NO
1993	421 890	74 158	13.12	19.03	NO	NO	NO	NO	NO	NO
1994	452 782	74 182	12.69	18.54	NO	NO	NO	NO	NO	NO
1995	429 408	74 186	12.71	19.78	NO	NO	NO	NO	NO	NO
1996	450 720	74 178	12.43	19.25	NO	NO	NO	NO	NO	NO
1997	469 877	74 164	12.23	18.68	NO	NO	NO	NO	NO	NO
1998	479 436	74 156	11.91	19.13	NO	NO	NO	54 600	5.00	0.10
1999	714 319	74 164	11.16	13.20	NO	NO	NO	54 600	5.00	0.10
2000	343 614	74 188	12.10	28.20	56 221	5.00	0.10	54 600	5.00	0.10
2001	317 699	74 191	12.94	28.34	56 258	5.00	0.10	54 600	5.00	0.10
2002	343 529	74 192	11.92	27.96	56 396	5.00	0.10	54 600	5.00	0.10
2003	376 688	74 169	11.31	27.17	56 533	5.00	0.10	54 600	5.00	0.10
2004	426 651	74 131	10.37	25.77	56 671	5.00	0.10	54 621	5.00	0.13
2005	459 715	74 115	10.08	24.15	56 910	5.00	0.10	54 613	5.00	0.12
2006	495 673	74 117	9.57	22.93	57 008	5.00	0.10	54 611	5.00	0.11
2007	512 832	74 117	9.60	21.93	56 793	5.00	0.10	55 424	4.91	1.07
2008	578 355	74 064	8.78	21.04	56 665	5.00	0.10	55 324	4.90	0.91
2009	629 453	74 053	8.54	20.03	57 056	5.00	0.10	55 208	4.91	0.75
2010	575 942	74 105	8.28	18.81	56 712	5.00	0.10	55 313	4.89	0.82
2011	538 413	74 092	8.29	17.73	NO	NO	NO	55 299	5.08	0.76
2012	542 801	74 111	8.21	16.75	NO	NO	NO	55 444	4.88	0.85
2013	470 786	74 116	9.30	16.03	NO	NO	NO	55 541	4.84	0.91
2014	432 227	74 054	8.97	15.26	56 756	5.00	0.10	56 268	4.83	1.46
2015	439 496	74 115	8.57	14.19	56 760	5.00	0.10	56 645	4.99	1.64
2016	472 297	74 122	8.36	13.30	56 561	5.00	0.10	56 423	5.04	1.38
2017	480 688	74 134	8.56	12.75	56 577	5.00	0.10	56 703	4.82	1.53
2018	503 779	74 114	8.32	12.19	56 209	5.00	0.10	56 526	4.92	1.35
2019	435 847	74 065	8.07	11.62	56 091	5.00	0.10	57 566	5.19	1.92

Source: Environment Agency

3.2.10.4.2.2 Methodological issues

For stationary sources, the 2006 IPCC Guidelines Tier 2 approach has been applied for CO₂, while the Tier 1 approach was used for CH₄ and N₂O.

For mobile sources, the 2006 IPCC Guidelines Tier 2 approach has been applied for CO₂, while the method used for CH₄ and N₂O is based on the GEORG model which conforms to the requirements of the IPCC 2006 GL Tier 3 methodology. The methodology is described in section 3.2.7.7.2.2.

3.2.10.4.2.3 Emission factors

Country-specific CO₂ emission factors have been applied for natural gas, gas oil and diesel oil. For stationary sources, default 2006 IPCC emission factors were used for CH₄, N₂O and CO₂ from biomass. For mobile sources, the country-specific CO₂ EFs for diesel oil and gasoline as described in section 3.2.5.3 were used (Tier 2). CH₄ and N₂O emissions were determined with the GEORG model (

Table 3-72). The CH₄ emission factors are based on the EMEP/EEA 2016 Guidebook (Tier 3) while N₂O emission factors are based on (Hausberger, 2006). For biogasoline, biodiesel and other fossil fuels (fossil part of biodiesel, please refer to page 247 for details), the European CO₂ implied emission factors⁸⁷ for gasoline (71270 g/GJ) and diesel oil (73450 g/GJ) were applied (Table 3-87).

Table 3-87 – Emission factors for category 1A4c – Agriculture/Forestry/Fishing

1A4c - Agriculture/Forestry/Fishing Emission Factors for 2019 (kg/TJ)								
Fuel	Fuel Type	CO ₂		CH ₄		N ₂ O		Source
		EF	type	EF	type	EF	type	
Gas Oil	liquid	74 078	CS	10.00	D	0.60	D	AEV 2006 IPCC GL
Diesel Oil	liquid	74 078	CS	0.73	CS	12.37	CS	AEV
Gasoline	liquid	73 162	CS	513.76	CS	0.59	CS	AEV
Biogas	biomass	54 600	D	5.00	D	0.10	D	2006 IPCC GL
Natural Gas	gaseous	56 091	CS	5.00	D	0.10	D	AEV 2006 IPCC GL

Source: Environment Agency

An overview of the evolution of the implied emission factors per fuel type is given in Table 3-86.

87 UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

3.2.10.5 Uncertainties and time-series consistency

The uncertainties for activity data and emission factors used for IPCC category *1A4 – Other Sectors* are presented in Table 3-88.

Table 3-88: uncertainties for activity data and emission factors used for IPCC category *1A4 – Other Sectors*.

IPCC category/Group	Gas	Activity data uncertainty (%)	Emission factor uncertainty (%)
1A4 - Gaseous Fuels	CO ₂	2%	0.5%
1A4 - Gaseous Fuels	CH ₄	2%	50%
1A4 - Gaseous Fuels	N ₂ O	2%	50%
1A4 - Liquid Fuels	CO ₂	2%	0.5%
1A4 - Liquid Fuels	CH ₄	2%	50%
1A4 - Liquid Fuels	N ₂ O	2%	50%
1A4 - Biomass	CH ₄	7%	50%
1A4 - Biomass	N ₂ O	7%	60%
1A4 - Solid Fuels	CO ₂	1%	3%
1A4 - Solid Fuels	CH ₄	1%	50%
1A4 - Solid Fuels	N ₂ O	1%	50%

The time series reported under *1A4 - Other Sectors*, are considered to be consistent, to the best of data availability. Further investigations will be needed, in collaboration with the national statistics institute, to see whether, for the years 1990-1999, the arbitrary 50/50 split between 1A4a and 1A4b could be replaced by a more accurate split.

3.2.10.6 Source-specific QA/QC and verification

Standard QA/QC procedures (including consistency and completeness checks) were executed according to the QA/QC policy.

3.2.10.7 Category-specific recalculations including changes made in response to the review process

Table 3-89 presents the main revisions and recalculations relevant to category 1A4 – *Other Sectors* since the last submission to the UNFCCC. The quantitative aspect of these recalculations can be found below and in Chapter 10.

Table 3-89 – Recalculations done since submission 2020v1

GHG source & sink category	Revisions 2020v1 → 2021v1	Type of revision
1A4a	Due to a revision of the energy balance by the national statistics institute, the following fuel consumption data were revised: <ul style="list-style-type: none"> • Natural gas for 1990-1994, 1996-1999, 2017-2018; • Biogas for 2017-2018; • Gas oil for 2017-2018. 	AD
1A4b	Due to a revision of the energy balance by the national statistics institute, the following fuel consumption data were revised: <ul style="list-style-type: none"> • Natural gas for 2017-2018; • Wood & Wood Wastes for 2018. 	AD
1A4c	Due to a revision of the energy balance by the national statistics institute, the following fuel consumption data were revised: <ul style="list-style-type: none"> • Natural gas for 2017-2018; • Biogas for 2017-2018. 	AD
1A4	Revision of natural gas activity data for 2018 from the national energy balance following an error correction of the net calorific value from 36.98 to 36.76 MJ/Nm ³ .	AD
1A4a, 1A4b	The country-specific CO ₂ EFs for LPG were revised for the years 2017-2018 due to changes of the emission factors of the importing countries: 2017: from 65213 to 65232 kg/TJ 2018: from 65212.1277 to 65212.1283 kg/TJ	CO ₂ EF
1A4b	The country-specific CO ₂ EFs for motor gasoline were revised for the years 2017-2018 due to changes of the emission factors of the importing countries: 2017: from 73300 to 73181 kg/TJ 2018: from 73216 to 73093 kg/TJ.	CO ₂ EF

3.2.10.8 Category-specific planned improvements including those in response to the review process

Considering the potential contribution of identified improvements in the total GHG emissions and the corresponding resources needed to make these improvements effective, developments presented in Table 3-90 will be explored.

Table 3-90 – Planned improvements for category 1A4 – *Other Sectors*

GHG source & sink category	Planned improvement
1A4a – Commercial/Institutional, 1A4b – Residential	collecting information helping to refine the fuel consumption split between the commercial/institutional sectors, on the one hand, and the residential sector, on the other hand.

3.2.12 Other (1.A.5.)

3.2.12.1 Source category description

This section describes GHG emissions resulting from fuel combustion activities in category *1A5 – Other*. It covers combustion activities from stationary combustion and mobile combustion in sub-categories:

- *1A5a – Stationary*: Building and Plant Site Fuel Powered Machinery
- *1A5b – Mobile*: Military Vehicles

In 2019, category 1A5 - Other was responsible for 0.001% of GHG emissions from fuel combustion activities (this share was 0.03% in 1990) and represented around 0.001% of the total GHG emissions excluding LULUCF (0.03% in 1990).

Compared to 2018, emissions decreased by 0.12%, to attain the level of 0.12 Gg CO₂e. Compared to 1990 emissions decreased by 96.23%.

1A5 - Other related CO₂ emissions from liquid fuels have been identified as a key category only for the year 1999.

Table 3-91 summarizes GHG emissions for category 1A5 – Other.

Table 3-91 – GHG emission trends in CO₂e for category 1A5 – Other: 1990-2019

1A5 - Other												
GHG emissions by source & sink category (Gg)												
Year	1A5a - Stationary				1A5b - Mobile				1A5 - Other			
	Total CO ₂ eq	CO ₂	CH ₄	N ₂ O	Total CO ₂ eq	CO ₂	CH ₄	N ₂ O	Total CO ₂ eq	CO ₂	CH ₄	N ₂ O
1990	2.98	2.98	0.0002	0.0000	0.14	0.13	0.000006	0.000	3.12	3.10	0.000	0.000
1991	2.98	2.98	0.0002	0.0000	0.14	0.13	0.000006	0.000	3.12	3.10	0.000	0.000
1992	26.73	26.59	0.0034	0.0002	0.14	0.13	0.000006	0.000	26.87	26.72	0.003	0.000
1993	23.58	23.46	0.0030	0.0002	0.14	0.13	0.000006	0.000	23.72	23.58	0.003	0.000
1994	22.00	21.88	0.0028	0.0002	0.14	0.13	0.000005	0.000	22.14	22.01	0.003	0.000
1995	10.68	10.62	0.0013	0.0001	0.14	0.13	0.000005	0.000	10.82	10.75	0.001	0.000
1996	18.47	18.37	0.0023	0.0001	0.14	0.12	0.000005	0.000	18.61	18.49	0.002	0.000
1997	22.96	22.85	0.0027	0.0001	0.14	0.12	0.000005	0.000	23.10	22.98	0.003	0.000
1998	34.07	33.91	0.0041	0.0002	0.14	0.12	0.000005	0.000	34.21	34.03	0.004	0.000
1999	63.15	62.83	0.0078	0.0004	0.14	0.12	0.000005	0.000	63.29	62.95	0.008	0.000
2000	12.08	12.05	0.0009	0.0000	0.14	0.12	0.000004	0.0000	12.21	12.17	0.001	0.000
2001	24.10	24.04	0.0019	0.0000	0.14	0.12	0.000004	0.0000	24.24	24.16	0.002	0.000
2002	13.40	13.37	0.0010	0.0000	0.14	0.12	0.000004	0.0000	13.54	13.49	0.001	0.000
2003	3.14	3.13	0.0002	0.0000	0.13	0.12	0.000004	0.0000	3.27	3.25	0.000	0.000
2004	NO	NO	NO	NO	0.13	0.12	0.000003	0.0000	0.13	0.12	0.0000	0.0000
2005	NO	NO	NO	NO	0.13	0.12	0.000003	0.0000	0.13	0.12	0.0000	0.0000
2006	NO	NO	NO	NO	0.13	0.12	0.000003	0.0000	0.13	0.12	0.0000	0.0000
2007	NO	NO	NO	NO	0.13	0.12	0.000003	0.0000	0.13	0.12	0.0000	0.0000
2008	NO	NO	NO	NO	0.13	0.12	0.000002	0.0000	0.13	0.12	0.0000	0.0000
2009	NO	NO	NO	NO	0.13	0.12	0.000002	0.0000	0.13	0.12	0.0000	0.0000
2010	NO	NO	NO	NO	0.13	0.12	0.000002	0.0000	0.13	0.12	0.0000	0.0000
2011	NO	NO	NO	NO	0.12	0.12	0.000002	0.0000	0.12	0.12	0.0000	0.0000
2012	NO	NO	NO	NO	0.12	0.12	0.000002	0.0000	0.12	0.12	0.0000	0.0000
2013	NO	NO	NO	NO	0.12	0.12	0.000002	0.0000	0.12	0.12	0.0000	0.0000
2014	NO	NO	NO	NO	0.12	0.12	0.000002	0.0000	0.12	0.12	0.0000	0.0000
2015	NO	NO	NO	NO	0.12	0.12	0.000001	0.0000	0.12	0.12	0.0000	0.0000
2016	NO	NO	NO	NO	0.12	0.12	0.000001	0.0000	0.12	0.12	0.0000	0.0000
2017	NO	NO	NO	NO	0.12	0.11	0.000001	0.0000	0.12	0.11	0.0000	0.0000
2018	NO	NO	NO	NO	0.12	0.11	0.000001	0.0000	0.12	0.11	0.0000	0.0000
2019	NO	NO	NO	NO	0.12	0.11	0.000001	0.0000	0.12	0.11	0.0000	0.0000
Trend 1990-2019	NA	NA	NA	NA	-16.46%	-10.85%	-83.86%	-68.45%	-96.23%	-96.34%	-99.61%	-71.33%
Trend 2018-2019	NA	NA	NA	NA	-0.12%	-0.01%	-6.30%	-2.93%	-0.12%	-0.01%	-6.30%	-2.93%

Source: Environment Agency

Notes:

CO₂ emissions do not include CO₂ emissions from biomass which are reported under Memo Items.

CH₄ emissions are converted in CO₂e by multiplying the emissions by 25, i.e. the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon.

N₂O emissions are converted in CO₂e by multiplying the emissions by 298, i.e. the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

3.2.12.2 Stationary (1A5a)

3.2.12.2.1 Source category description

In 2019, no emissions from fuel combustion activities from *1A5a - Stationary* were reported (notation key NO). In 1990, this category was responsible for 0.03% of GHG emissions from fuel combustion activities. With regard to total GHG emissions excluding LULUCF, the share was 0.02% in 1990.

3.2.12.2.2 Methodological issues & time-series consistency:

3.2.12.2.2.1 Activity data

Fuel consumption data (gas oil, LPG) are obtained from the national statistics institute and were attributed to this sub-category based on expert judgement. Activity data are listed in Table 3-92.

3.2.12.2.2.2 Methodology

The 2006 IPCC Guidelines Tier 2 approach has been applied to CO₂, whereas the Tier 1 approach was applied to CH₄ and N₂O.

Table 3-92 – Activity data and implied emission factors for category *1A5 – Other*

1A5 - Other								
Activity Data and Implied Emission Factors (kg/TJ)								
Year	1A5a - Stationary - Liquid (LPG, Gas Oil)				1A5b - Mobile - Liquid (Diesel Oil)			
	Activity (GJ)	CO ₂	CH ₄	N ₂ O	Activity (GJ)	CO ₂	CH ₄	N ₂ O
1990	45 728	65 068	5.00	0.10	1 715	74 171	3.33	26.53
1991	45 728	65 099	5.00	0.10	1 712	74 157	3.31	26.57
1992	364 308	72 984	9.37	0.54	1 710	74 129	3.29	26.62
1993	321 934	72 859	9.29	0.53	1 707	74 172	3.27	26.66
1994	300 654	72 788	9.24	0.52	1 699	74 197	3.21	27.00
1995	148 456	71 565	8.58	0.46	1 686	74 202	3.12	27.57
1996	252 683	72 699	9.19	0.52	1 675	74 192	3.04	28.10
1997	321 685	71 041	8.30	0.43	1 664	74 179	2.96	28.63
1998	473 779	71 566	8.59	0.46	1 653	74 170	2.87	29.17
1999	869 847	72 231	8.91	0.49	1 643	74 174	2.79	29.68
2000	185 497	64 943	5.00	0.10	1 636	74 212	2.74	30.02
2001	370 223	64 942	5.00	0.10	1 631	74 216	2.70	30.25
2002	205 847	64 957	5.00	0.10	1 626	74 217	2.57	29.78
2003	48 158	64 976	5.00	0.10	1 620	74 192	2.34	28.67
2004	NO	NO	NO	NO	1 619	74 154	2.14	26.84
2005	NO	NO	NO	NO	1 621	74 137	1.94	24.40
2006	NO	NO	NO	NO	1 623	74 138	1.74	21.92
2007	NO	NO	NO	NO	1 583	74 141	1.57	19.37
2008	NO	NO	NO	NO	1 589	74 085	1.46	16.99
2009	NO	NO	NO	NO	1 592	74 074	1.39	15.02
2010	NO	NO	NO	NO	1 597	74 128	1.33	13.55
2011	NO	NO	NO	NO	1 602	74 114	1.29	12.45
2012	NO	NO	NO	NO	1 595	74 134	1.21	11.58
2013	NO	NO	NO	NO	1 588	74 141	1.09	10.95
2014	NO	NO	NO	NO	1 574	74 069	0.97	10.47
2015	NO	NO	NO	NO	1 561	74 128	0.86	10.04
2016	NO	NO	NO	NO	1 554	74 136	0.75	9.67
2017	NO	NO	NO	NO	1 530	74 149	0.66	9.35
2018	NO	NO	NO	NO	1 530	74 130	0.60	9.06
2019	NO	NO	NO	NO	1 531	74 078	0.56	8.79

Source: Environment Agency

3.2.12.2.3 Emission factors

Country-specific CO₂ emission factors were applied to gas oil and LPG, whereas for CH₄ and N₂O, default 2006 IPCC emission factors were used (Table 3-93).

Table 3-93 – Emission factors for category 1A5 – Other

1A5 - Other								
Emission Factors for 2019 (kg/TJ)								
Fuel	Fuel Type	CO ₂		CH ₄		N ₂ O		Source
		EF	type	EF	type	EF	type	
LPG	liquid	65 489	CS	5.00	D	0.10	D	AEV 2006 IPCC GL
Gas Oil	liquid	74 078	CS	10.00	D	0.60	D	AEV 2006 IPCC GL
Diesel Oil	liquid	74 078	CS	0.60	CS	9.06	CS	AEV

Source: Environment Agency

An overview of the evolution of the implied emission factors per fuel type is given in Table 3-92.

3.2.12.3 Mobile (1A5b)

3.2.12.3.1 Source category description

In 2019, fuel combustion activities in 1A5b – Mobile were responsible for 0.001% of GHG emissions from fuel combustion activities (0.001% in 1990). With regard to total GHG emissions excluding LULUCF emissions from 1A5b – Mobile reached 0.001% in 2019 and 0.001% in 1990. Compared to 2018, GHG emissions decreased by 0.12% and compared to 1990, they decreased by 16.47%.

3.2.12.3.2 Methodological issues & time-series consistency

3.2.12.3.2.1 Activity data

Fuel consumption data (diesel oil, biodiesel) from military vehicles was attributed to this sub-category based on expert judgement (Komobile, FVT, 2017). Activity data is listed in Table 3-92.

3.2.12.3.2.2 Methodology

The 2006 IPCC Guidelines Tier 2 approach has been applied for CO₂, while the method used for CH₄ and N₂O is based on the GEORG model which conforms to the requirements of the IPCC 2006 GL Tier 3 methodology. The methodology is described in section 3.2.7.7.2.2.

3.2.12.3.2.3 Emission factors

The country specific CO₂ EF for diesel oil as described in section 3.2.5.3 was used (Tier 2). CH₄ and N₂O emissions were determined with the GEORG model (

Table 3-72). The CH₄ emission factors are based on the EMEP/EEA 2016 Guidebook (Tier 3) while N₂O emission factors are based on (Hausberger, 2006).

For biodiesel and other fossil fuels (fossil part of biodiesel, please refer to 247 for details), the European CO₂ implied emission factor for diesel oil (73450 g/GJ) was applied.

3.2.12.4 Uncertainties and time-series consistency

The uncertainties for activity data and emission factors used for IPCC category *1A5 – Other* are presented in Table 3-94.

Table 3-94: uncertainties for activity data and emission factors used for IPCC category 1A5 – Other.

IPCC category/Group	Gas	Activity data uncertainty (%)	Emission factor uncertainty (%)
1A5 - Gaseous Fuels	CO2	2%	0.5%
1A5 - Gaseous Fuels	CH4	2%	50%
1A5 - Gaseous Fuels	N2O	2%	50%

The time series reported under *1A5 - Other* are considered to be consistent.

3.2.12.5 Source-specific QA/QC and verification

Standard QA/QC procedures (including consistency and completeness checks) were executed according to the QA/QC policy.

Category-specific recalculations including changes made in response to the review process.

Table 3-95 presents the main revisions and recalculations relevant to category *1A5 – Other* since the last submission to the UNFCCC.

Table 3-95 – Recalculations done since submission 2020v1

GHG source & sink category	Revisions 2020v1 → 2021v1	Type of revision
1A5	No changes	

3.2.12.6 Category-specific planned improvements including those in response to the review process

No further improvements are planned.

3.3 Fugitive Emissions from Fuels (1.B)

3.3.1 Solid Fuels (1.B.1)

This category does not exist in Luxembourg.

3.3.2 Oil and natural gas and other emissions from energy production (1.B.2)

3.3.2.1 Source category description

In Luxembourg, fugitive emissions only occur from natural gas transmission and storage and distribution (sub-categories *1B2b3 – Transmission and Storage* and *1B2b4 – Distribution*) as well as from natural gas venting of transmission and distribution networks (sub-category *1B2c – Venting*). Other fugitive emissions – because they are closely linked to production, processing or exploration – are not occurring in Luxembourg.

Fugitive emissions from the distribution of refined oil products (category 1B2a5) are reported with notation key *NA* in the CRF tables, as only NMVOC emissions occur.

In 2019, fugitive emissions from category *1B2 – Oil and natural gas and other emissions from energy production* were responsible for 0.34% of GHG emissions from the energy sector (0.19% in 1990) and represented 0.29% of the total GHG emissions excluding LULUCF (0.15% in 1990). Compared to 2018, fugitive GHG emissions increased by 0.11% and compared to 1990, they increased by 59.11% due to a higher natural gas consumption.

Table 3-96 – GHG emission trends in CO₂e for category 1B2 – Oil and natural gas and other emissions from energy production: 1990-2019

1B2 - Oil and Natural Gas																
CO ₂ e emissions (Gg)																
Year	1B2a - Oil				1B2b - Natural Gas				1B2c - Venting & Flaring				1B2d - Other			
	Total	CO ₂	CH ₄	N ₂ O	Total	CO ₂	CH ₄	N ₂ O	Total	CO ₂	CH ₄	N ₂ O	Total	CO ₂	CH ₄	N ₂ O
1990	NA	NA	NA	NO	19.39	0.03	19.36	NO,NA	0.21	0.00	0.21	NO	NA	NA	NA	NO
1991	NA	NA	NA	NO	20.11	0.03	20.09	NO,NA	0.22	0.00	0.22	NO	NA	NA	NA	NO
1992	NA	NA	NA	NO	20.99	0.03	20.96	NO,NA	0.23	0.00	0.23	NO	NA	NA	NA	NO
1993	NA	NA	NA	NO	21.79	0.03	21.76	NO,NA	0.24	0.00	0.24	NO	NA	NA	NA	NO
1994	NA	NA	NA	NO	21.94	0.03	21.91	NO,NA	0.24	0.00	0.24	NO	NA	NA	NA	NO
1995	NA	NA	NA	NO	25.01	0.03	24.98	NO,NA	0.27	0.00	0.27	NO	NA	NA	NA	NO
1996	NA	NA	NA	NO	27.36	0.04	27.33	NO,NA	0.30	0.00	0.30	NO	NA	NA	NA	NO
1997	NA	NA	NA	NO	27.98	0.04	27.95	NO,NA	0.31	0.00	0.31	NO	NA	NA	NA	NO
1998	NA	NA	NA	NO	28.20	0.04	28.17	NO,NA	0.31	0.00	0.31	NO	NA	NA	NA	NO
1999	NA	NA	NA	NO	29.20	0.04	29.16	NO,NA	0.32	0.00	0.32	NO	NA	NA	NA	NO
2000	NA	NA	NA	NO	29.98	0.04	29.94	NO,NA	0.33	0.00	0.33	NO	NA	NA	NA	NO
2001	NA	NA	NA	NO	33.32	0.04	33.27	NO,NA	0.37	0.00	0.37	NO	NA	NA	NA	NO
2002	NA	NA	NA	NO	47.72	0.06	47.66	NO,NA	0.53	0.00	0.53	NO	NA	NA	NA	NO
2003	NA	NA	NA	NO	48.36	0.06	48.30	NO,NA	0.54	0.00	0.54	NO	NA	NA	NA	NO
2004	NA	NA	NA	NO	53.67	0.07	53.60	NO,NA	0.60	0.00	0.60	NO	NA	NA	NA	NO
2005	NA	NA	NA	NO	52.87	0.07	52.80	NO,NA	0.59	0.00	0.59	NO	NA	NA	NA	NO
2006	NA	NA	NA	NO	55.48	0.07	55.41	NO,NA	0.62	0.00	0.62	NO	NA	NA	NA	NO
2007	NA	NA	NA	NO	51.91	0.07	51.84	NO,NA	0.58	0.00	0.58	NO	NA	NA	NA	NO
2008	NA	NA	NA	NO	49.64	0.07	49.57	NO,NA	0.56	0.00	0.56	NO	NA	NA	NA	NO
2009	NA	NA	NA	NO	50.18	0.07	50.11	NO,NA	0.56	0.00	0.56	NO	NA	NA	NA	NO
2010	NA	NA	NA	NO	53.96	0.07	53.89	NO,NA	0.61	0.00	0.60	NO	NA	NA	NA	NO
2011	NA	NA	NA	NO	46.78	0.06	46.72	NO,NA	0.52	0.00	0.52	NO	NA	NA	NA	NO
2012	NA	NA	NA	NO	47.85	0.06	47.79	NO,NA	0.54	0.00	0.54	NO	NA	NA	NA	NO
2013	NA	NA	NA	NO	40.74	0.05	40.69	NO,NA	0.46	0.00	0.46	NO	NA	NA	NA	NO
2014	NA	NA	NA	NO	38.47	0.05	38.42	NO,NA	0.44	0.00	0.43	NO	NA	NA	NA	NO
2015	NA	NA	NA	NO	34.60	0.05	34.55	NO,NA	0.39	0.00	0.39	NO	NA	NA	NA	NO
2016	NA	NA	NA	NO	31.80	0.04	31.75	NO,NA	0.36	0.00	0.36	NO	NA	NA	NA	NO
2017	NA	NA	NA	NO	31.32	0.04	31.28	NO,NA	0.36	0.00	0.36	NO	NA	NA	NA	NO
2018	NA	NA	NA	NO	30.79	0.04	30.75	NO,NA	0.36	0.00	0.36	NO	NA	NA	NA	NO
2019	NA	NA	NA	NO	30.83	0.04	30.78	NO,NA	0.36	0.00	0.36	NO	NA	NA	NA	NO
Trend 1990-2019	NA	NA	NA	NA	58.99%	58.99%	58.99%	NA	69.44%	23.08%	69.52%	NA	NA	NA	NA	NA
Trend 2018-2019	NA	NA	NA	NA	0.11%	0.11%	0.11%	NA	0.11%	0.11%	0.11%	NA	NA	NA	NA	NA

Source: Environment Agency

Notes: CH₄ emissions are converted in CO₂e by multiplying the emissions by 25, i.e. the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon.

3.3.2.2 Methodological issues

3.3.2.2.1 Activity data

Activity data on national natural gas consumption are obtained from the national statistics institute and are listed in Table 3-97.

Table 3-97 – Activity data for category 1B2 – Oil and natural gas and other emissions from energy production: 1990-2019

Natural Gas Consumption (GJ)									
1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
17'933'319	18'646'146	19'434'015	20'184'363	20'334'429	23'237'685	25'491'951	26'121'114	26'375'112	27'358'065
2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
28'119'435	31'177'039	44'596'356	45'132'516	50'018'454	49'248'164	51'513'517	48'083'276	45'774'534	46'592'327
2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
50'108'059	43'235'365	44'010'941	37'284'498	35'310'029	32'201'184	29'685'081	29'283'800	28'621'878	28'667'601

Source: STATEC: national energy balance.

3.3.2.2.2 Methodology

For sub-categories 1B2b3 – *Transmission and Storage* and 1B2b4 – *Distribution* the 2006 IPCC Guidelines Tier 1 approach has been applied.

For sub-category 1B2c – *Venting*, a Tier 3 approach was applied. According to Luxembourg’s natural gas network operator, 2016 was a typical year with regard to venting (no major works in the gas network) with a vented volume of approximately 2’000 Nm³. In 2017, 40’000 Nm³ were vented due to major works (in that specific year). Unfortunately, the operator was not able to provide annual activity data on venting activities for the other years of the time series, and, hence, extrapolation of vented volumes was challenging due to the high variability that is apparent for 2016 and 2017. In order to circumvent this problem, the ratio of the average vented quantity between 2016 and 2017 (approx. 22000 Nm³) and the corresponding annual consumption was taken and extrapolated (as a constant) over the entire time series. Hence, by multiplying this ratio with the annual natural gas consumption an annual quantity of vented natural gas for the entire time series was obtained. Using the annual natural gas composition, and in particular the methane and carbon dioxide content as obtained by the operator, the vented quantities of methane and CO₂ could thus be calculated. The method used is comparable to the Tier 3 approach according to 2006 IPCC Guidelines (Vol. 2, Chap. 4, p. 4.66).

3.3.2.2.3 Emission factors

For sub-categories *1B2b3 – Transmission and Storage* and *1B2b4 – Distribution*, the 2006 IPCC Guidelines default emission factors have been applied:

- Natural Gas Transmission - CO₂: 8.8*10⁻⁷ Gg/10⁶ m³
- Natural Gas Distribution - CO₂: 5.1*10⁻⁵ Gg/10⁶ m³
- Natural Gas Transmission - CH₄: 4.8*10⁻⁴ Gg/10⁶ m³
- Natural Gas Distribution - CH₄: 1.1*10⁻³ Gg/10⁶ m³

Emission factors from the 2006 IPCC Guidelines were selected as these best reflect the modern and regularly serviced transmission and distribution natural gas networks in Luxembourg. The distribution network is continuously expanded as the population grows (approx. 2.5% per year), whereas the length of the transmission network has remained constant over the last years.

Emission factors venting

3.3.2.3 Uncertainties and time-series consistency

The uncertainties for activity data and emission factors used for IPCC category *1B2 - Oil and natural gas and other emissions from energy production* are presented in Table 3-98.

Table 3-98: uncertainties for activity data and emission factors used for IPCC category 1B2 - Oil and natural gas and other emissions from energy production.

IPCC category/Group	Gas	Activity data uncertainty (%)	Emission factor uncertainty (%)
1B2 – Natural Gas	CO ₂	2%	100%
1B2 – Natural Gas	CH ₄	2%	100%

The time series reported under *1B2 - Oil and natural gas and other emissions from energy production* are considered to be consistent. Fluctuations in the time series occur due to maintenance stops of large industrial plants such as the 350 MWe CHP gas turbine (Twinerg, closed in 2016), the closure of iron and steel facilities (2012 - ArcelorMittal Schifflange) or more heat demand due to colder winters. Although the population grows rapidly in Luxembourg, this does not necessarily induce a growth in natural gas demand as buildings get more and more energy efficient through better insulation.

3.3.2.4 Source-specific QA/QC and verification

Standard QA/QC procedures were followed.

Consistency and completeness checks have been performed using the tools embedded in CRF Reporter.

3.3.2.5 Category-specific recalculations including changes made in response to the review process

Table 3-99 presents the main revisions and recalculations relevant to category 1B2 – Oil and natural gas and other emissions from energy production since the last submission to the UNFCCC. Table 3-100 illustrates the annual changes in GHG emissions following the described recalculations.

Table 3-99 – Recalculations done since submission 2020v1

GHG source & sink category	Revisions 2020v1 → 2021v1	Type of revision
1B2biii4 & 1B2biii5- natural gas transmission and distribution	Activity data was revised for 2018 due to revisions of the national natural gas consumption in the energy balance. Emissions decreased by 0.06 Gg CO ₂ eq. and 0.13 Gg CO ₂ eq. respectively. Further, very small revisions occurred in the years 1990-1994 and 1996-1999, impacting total CO ₂ eq. emissions by less than 0.000003 Gg.	AD revision
1B2c – natural gas venting	CO ₂ and CH ₄ emissions from natural gas venting of transmission and distribution networks (sub-category 1B2c – Venting) are first estimated in submission 2021v1. This category was added to the inventory following a review recommendation in the UNFCCC Review 2018 (ARR 2018, E.26), in the EU-ESD review 2020 (LU-1B2c-2020-0001) and recently in the UNFCCC Review 2020 (preliminary finding: 2020LUXQA38).	New emission source added

Table 3-100 – Recalculations in sector 1B2 – Oil & Natural gas.

1B2 - Oil & Natural Gas Recalculations (Gg CO ₂ eq)			
Year	1B2biii4 - Transmission	1B2biii5 - Distribution	1B2c - Venting
1990	0.00	0.00	0.21
1991	0.00	0.00	0.22
1992	0.00	0.00	0.23
1993	0.00	0.00	0.24
1994	0.00	0.00	0.24
1995			0.27
1996	0.00	0.00	0.30
1997	0.00	0.00	0.31
1998	0.00	0.00	0.31
1999	0.00	0.00	0.32
2000			0.33
2001			0.37
2002			0.53
2003			0.54
2004			0.60
2005			0.59
2006			0.62
2007			0.58
2008			0.56
2009			0.56
2010			0.61
2011			0.52
2012			0.54
2013			0.46
2014			0.44
2015			0.39
2016			0.36
2017			0.36
2018	- 0.06	- 0.13	0.36

3.3.2.6 Category-specific planned improvements including those in response to the review process

Taking into account the potential contribution of identified improvements in the total GHG emissions and the corresponding resources needed to make these improvements effective, developments presented in Table 3-101 will be explored.

Table 3-101 – Planned improvements for category 1B2 – Oil and natural gas and other emissions from energy production

GHG source & sink category	Planned improvement
1B2a5 - Distribution of refined oil products	Assess whether these emissions occur and, if appropriate, estimate and report fugitive emissions from the infrastructure supporting the transport, distribution, storage and sale of refined fuel oils.

4 Industrial Processes (CRF sector 2)

4.1 Sector Overview

Chapter 4.1 includes information on and description of methodologies used for estimating GHG emissions as well as references to activity data and emission factors reported under CRF Sector 2 – *Industrial Processes* for the period 1990 to 2019.

Emissions from this sector comprise emissions from the following categories: mineral products (2A), metal production (2C) and consumption of halocarbons (2F), SF₆ and N₂O (2G). For more details on categories where emissions are not occurring and categories that are not estimated or included elsewhere, see Table 4-3 and Table 4-4.

Only process related emissions are considered in this sector. Emissions due to fuel combustion in manufacturing industries are allocated to IPCC Sub-category 1A2 – *Fuel Combustion Activities – Manufacturing Industries and Construction* (see section 0).

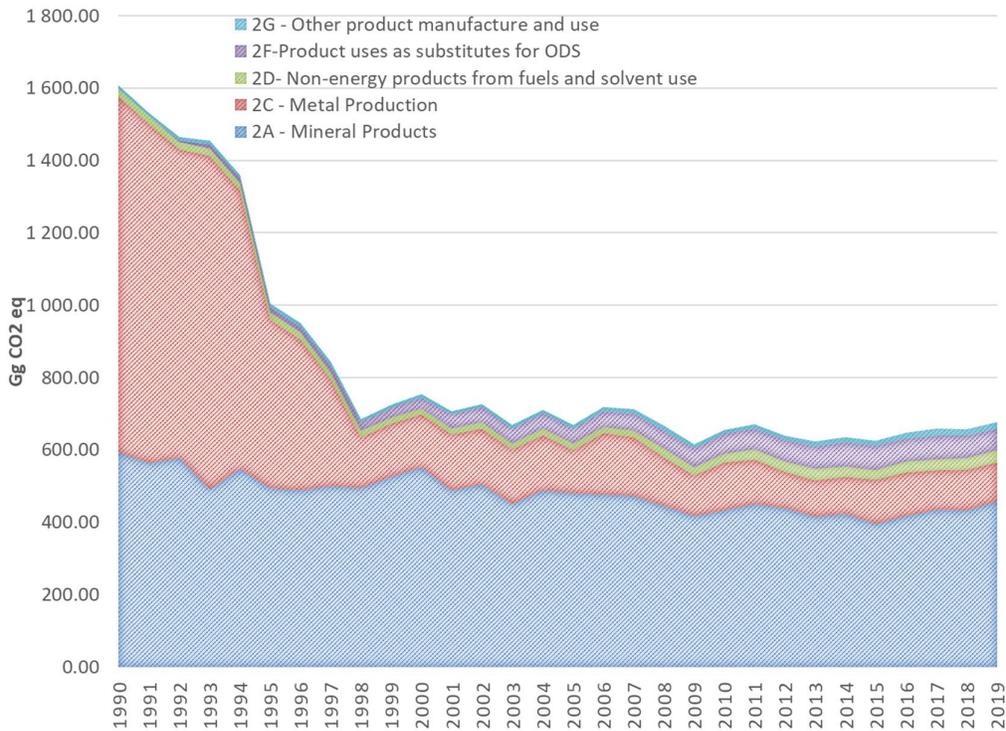
4.1.1 Emission Trends

This section briefly describes the emission trends from 1990 to 2019 for each of the IPCC categories under CRF Sector 2 for which GHG emissions are reported – *i.e.* categories 2A – *Mineral Products*, 2C – *Metal Production*, 2D-*Non-energy products from fuels and solvent use*, 2F-*Product uses as substitutes for ODS*, and 2G- *Other product manufacture and use*.

Industrial process emissions include emissions from industrial installations and from consumption of halocarbons and SF₆ (the fluorinated gases (HFCs and SF₆) or F-gases), while PFCs are not in use in Luxembourg. The most important emitting activities are clinker, flat glass and iron and steel productions. With regard to F-gases, increasing emissions are mainly due to a growing use of air conditioning, high-voltage electrical equipment, and noise reduction windows (see Section 4.7).

As shown in Figure 4-1 and Table 4-1, emissions of GHG due to industrial processes have decreased by about 57.97% between 1990 and 2019, (-62.55%-for carbon dioxide). The observed rise in F-gas emissions is associated with the low usage rate of F-gas during the early and mid-90s. Indeed, the switch from CFC to F-gases took several years to complete. In addition, a rise in the number of F-gas applications, such as air conditioning systems in cars, is also linked to the growing emissions of F-gases. It is for the IPCC Category 2C – *Metal Production* that CO₂ emissions have decreased the most over the same period: 89.24%. For IPCC Category 2A – *Mineral Products* the decline is limited to 22.63%- for CO₂ emissions.

Figure 4-1 – GHG emission trends for CRF Sector 2 – Industrial Processes: 1990-2019



The trend observed for the iron and steel production units is, of course, linked to the dramatic change that occurred in the 1990s with regard to the production process: move from blast furnaces to electrical arc furnaces. This technological change has already been developed in previous chapters (see, e.g., Chapter 2.4) and will not be detailed once again here.

The striking increase of F-gas emissions is the consequence of supposedly growing use in the country of air conditioning, high-voltage electrical equipment, and noise reduction windows - but also of the hypothesis made for their estimation: see Section 4.7. The increasing use of these devices is mainly due to an increase in the number of residents (see Figure 2-15) and of the workforce (see Figure 2-16). The inhabitants and foreign commuters occupy more and more residential, institutional, and commercial buildings, which leads to a greater need for air conditioning (HFC) as well as high-voltage electrical devices (SF₆).

Figure 4-2 and

Figure 4-3 provide a quick overview on industrial processes related emission trends between 1990 and 2019. More explanations are presented in the subsequent sections detailing each of the sector source sub-categories.

Table 4-1 – GHG emission trends in CO₂e for CRF Sector 2 – Industrial Processes: 1990-2019

2 - Industrial Processes													
GHG emissions by source & sink category (Gg CO ₂ eq)													
Year	2A - Mineral Products				2C - Metal Production				2D- Non-energy products from fuels and solvent use				
	Total	CO ₂	CH ₄	N ₂ O	Total	CO ₂	CH ₄	N ₂ O	Total	CO ₂	CH ₄	N ₂ O	
1990	592.93	592.93		NO	984.91	984.91		NO	20.54	20.54		NO	NO
1991	563.63	563.63		NO	937.74	937.74		NO	20.09	20.09		NO	NO
1992	577.72	577.72		NO	853.29	853.29		NO	19.08	19.08		NO	NO
1993	490.59	490.59		NO	923.19	923.19		NO	18.81	18.81		NO	NO
1994	547.82	547.82		NO	770.83	770.83		NO	18.09	18.09		NO	NO
1995	494.58	494.58		NO	465.38	465.38		NO	19.76	19.76		NO	NO
1996	487.94	487.94		NO	416.60	416.60		NO	19.52	19.52		NO	NO
1997	501.01	501.01		NO	294.10	294.10		NO	18.45	18.45		NO	NO
1998	495.24	495.24		NO	140.69	140.69		NO	17.52	17.52		NO	NO
1999	525.08	525.08		NO	147.70	147.70		NO	16.86	16.86		NO	NO
2000	552.01	552.01		NO	146.05	146.05		NO	16.04	16.04		NO	NO
2001	488.96	488.96		NO	154.76	154.76		NO	16.23	16.23		NO	NO
2002	503.35	503.35		NO	155.40	155.40		NO	17.76	17.76		NO	NO
2003	449.75	449.75		NO	151.94	151.94		NO	15.24	15.24		NO	NO
2004	489.32	489.32		NO	152.45	152.45		NO	17.81	17.81		NO	NO
2005	480.22	480.22		NO	119.13	119.13		NO	19.04	19.04		NO	NO
2006	475.74	475.74		NO	170.49	170.49		NO	17.42	17.42		NO	NO
2007	472.92	472.92		NO	162.22	162.22		NO	17.71	17.71		NO	NO
2008	444.55	444.55		NO	134.69	134.69		NO	24.22	24.22		NO	NO
2009	416.95	416.95		NO	112.66	112.66		NO	22.41	22.41		NO	NO
2010	432.73	432.73		NO	133.61	133.61		NO	24.59	24.59		NO	NO
2011	450.03	450.03		NO	123.86	123.86		NO	29.37	29.37		NO	NO
2012	439.57	439.57		NO	100.23	100.23		NO	29.91	29.91		NO	NO
2013	415.30	415.30		NO	101.59	101.59		NO	32.38	32.38		NO	NO
2014	423.27	423.27		NO	102.46	102.46		NO	29.37	29.37		NO	NO
2015	394.54	394.54		NO	122.80	122.80		NO	28.79	28.79		NO	NO
2016	416.68	416.68		NO	121.66	121.66		NO	30.32	30.32		NO	NO
2017	434.57	434.57		NO	109.48	109.48		NO	31.15	31.15		NO	NO
2018	432.14	432.14		NO	114.39	114.39		NO	32.86	32.86		NO	NO
2019	458.77	458.77		NO	105.99	105.99		NO	33.81	33.81		NO	NO
Trend 2018-2019	6.16%	6.16%		NA	-7.34%	-7.34%		NA	2.89%	2.89%		NA	NA
Trend 1990-2019	-22.63%	-22.63%		NA	-89.24%	-89.24%		NA	64.58%	64.58%		NA	NA

Source: Environment Agency

Source: Environment Agency

2 - Industrial Processes														
GHG emissions by source & sink category (Gg CO ₂ eq)														
Year	2F-Product uses as substitutes for ODS				2 - Industrial Processes					2 - Industrial Processes				
	Total	HFCs	PFC	Total	HFC	PFC	SF6	N ₂ O	Total	CO ₂	CH ₄	N ₂ O	F-gases	
1990	0.00	0.00	NO	9.92	NO	NO	0.73	9.19	1608.30	1598.38	NO	9.19	0.73	
1991	0.00	0.00	NO	9.61	NO	NO	0.74	8.86	1531.07	1521.46	NO	8.86	0.74	
1992	5.49	5.49	NO	9.28	NO	NO	0.76	8.52	1464.86	1450.10	NO	8.52	6.25	
1993	12.94	12.94	NO	8.98	NO	NO	0.78	8.20	1454.52	1432.60	NO	8.20	13.72	
1994	14.19	14.19	NO	8.71	NO	NO	0.81	7.90	1359.65	1336.75	NO	7.90	15.00	
1995	15.15	15.15	NO	9.34	NO	NO	1.75	7.58	1004.21	979.73	NO	7.58	16.90	
1996	17.33	17.33	NO	9.20	NO	NO	1.94	7.26	950.60	924.06	NO	7.26	19.27	
1997	20.10	20.10	NO	9.03	NO	NO	2.10	6.93	842.68	813.55	NO	6.93	22.19	
1998	22.96	22.96	NO	8.77	NO	NO	2.16	6.61	685.17	653.45	NO	6.61	25.11	
1999	26.21	26.21	NO	8.52	NO	NO	2.24	6.27	724.36	689.64	NO	6.27	28.45	
2000	31.08	31.08	NO	8.28	NO	NO	2.36	5.92	753.46	714.10	NO	5.92	33.45	
2001	38.25	38.25	NO	8.51	NO	NO	2.97	5.54	706.72	659.95	NO	5.54	41.23	
2002	41.51	41.51	NO	9.17	NO	NO	3.58	5.59	727.20	676.52	NO	5.59	45.09	
2003	41.75	41.75	NO	9.60	NO	NO	4.17	5.42	668.27	616.93	NO	5.42	45.92	
2004	41.93	41.93	NO	9.67	NO	NO	4.73	4.94	711.19	659.59	NO	4.94	46.66	
2005	40.47	40.47	NO	9.92	NO	NO	5.31	4.61	668.71	618.32	NO	4.61	45.78	
2006	43.37	43.37	NO	10.64	NO	NO	5.73	4.91	717.48	663.47	NO	4.91	49.10	
2007	47.76	47.76	NO	11.40	NO	NO	6.17	5.24	711.72	652.55	NO	5.24	53.92	
2008	50.25	50.25	NO	12.27	NO	NO	6.58	5.69	665.42	602.90	NO	5.69	56.83	
2009	51.40	51.40	NO	12.05	NO	NO	6.99	5.05	614.76	551.31	NO	5.05	58.39	
2010	53.67	53.67	NO	11.25	NO	NO	7.29	3.95	654.95	590.04	NO	3.95	60.97	
2011	56.55	56.55	NO	11.55	NO	NO	7.75	3.80	670.17	602.07	NO	3.80	64.30	
2012	58.91	58.91	NO	11.81	NO	NO	8.14	3.67	639.09	568.37	NO	3.67	67.05	
2013	59.89	59.89	NO	14.43	2.56	NO	8.51	3.36	622.17	547.85	NO	3.36	70.97	
2014	64.94	64.94	NO	14.18	1.71	NO	8.90	3.58	632.61	553.49	NO	3.58	75.55	
2015	64.74	64.74	NO	14.83	1.99	NO	9.37	3.48	624.02	544.44	NO	3.48	76.09	
2016	63.14	63.14	NO	15.87	2.02	NO	9.72	4.13	646.32	567.31	NO	4.13	74.89	
2017	63.68	63.68	NO	19.03	4.89	NO	9.90	4.24	656.72	574.01	NO	4.24	78.48	
2018	60.14	60.14	NO	19.20	4.56	NO	10.20	4.44	657.31	577.97	NO	4.44	74.90	
2019	59.48	59.48	NO	17.02	1.88	NO	10.43	4.71	675.07	598.57	NO	4.71	71.79	
Trend														
2018-2019	-1.10%	-1.10%	NA	-11.32%	-58.75%	NA	2.23%	6.21%	0.03	0.04	NA	0.06	-0.04	
Trend														
1990-2019	83182978.30%	83182978.30%	NA	71.61%	NA	NA	1321.12%	-48.68%	-0.58	-0.63	NA	-0.49	96.80	

Source: Environment Agency

Notes:

CH₄ emissions are converted in CO₂e by multiplying the emissions by 21, *i.e.* the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon.

N₂O emissions are converted in CO₂e by multiplying the emissions by 310, *i.e.* the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

The F-gases are those not covered by the Montreal Protocol, *i.e.* HFCs, PFCs and SF₆ expressed in CO₂e using the global warming potential (GWP) values based on the effects of GHG over a 100-year time horizon.

Figure 4-2 – GHG emission trends – indexes – for CRF Sector 2 – Industrial Processes: 1990-2019

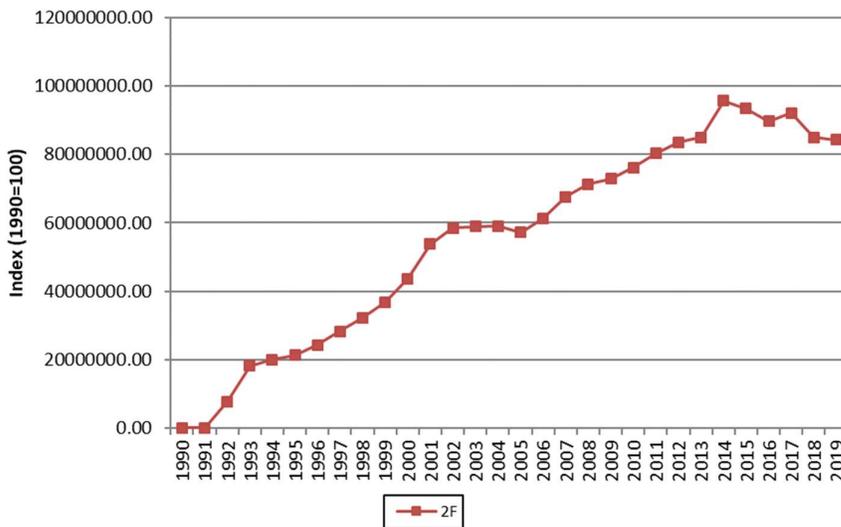
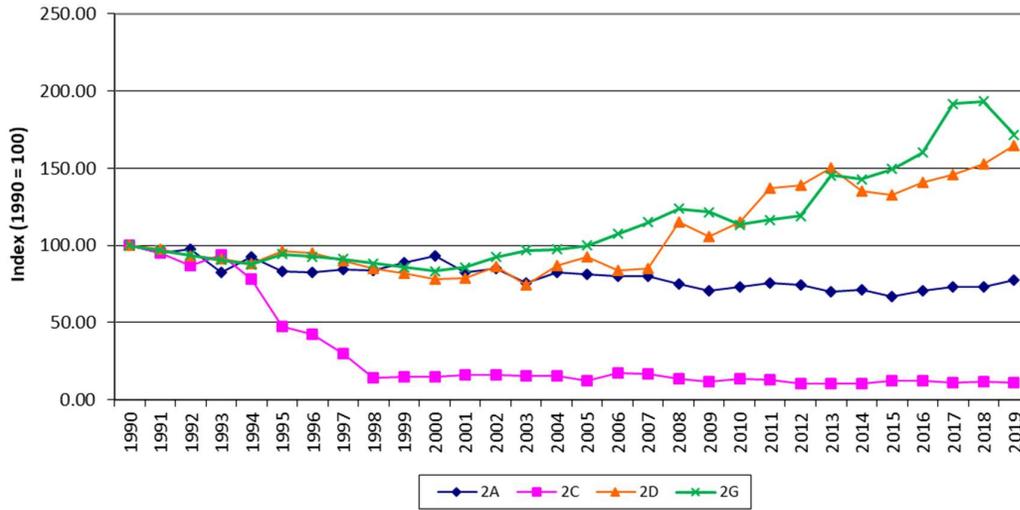
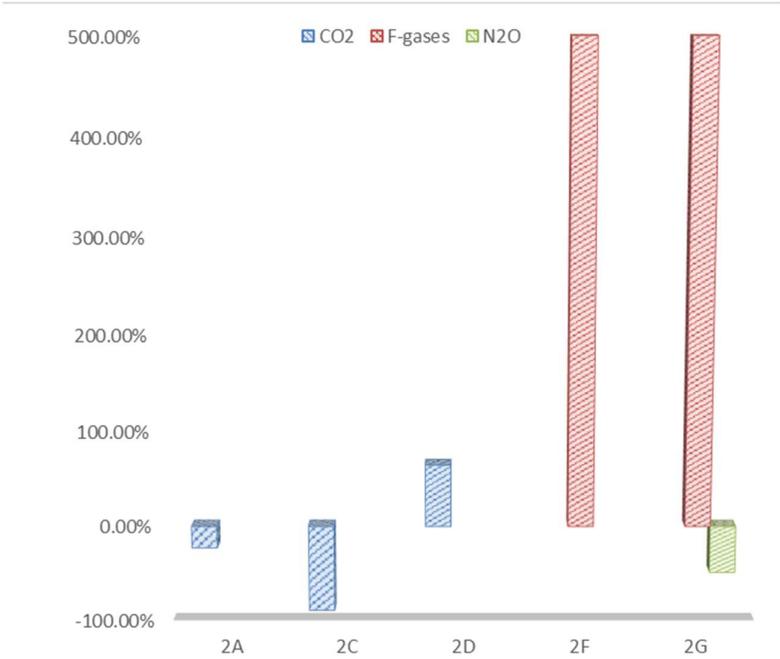


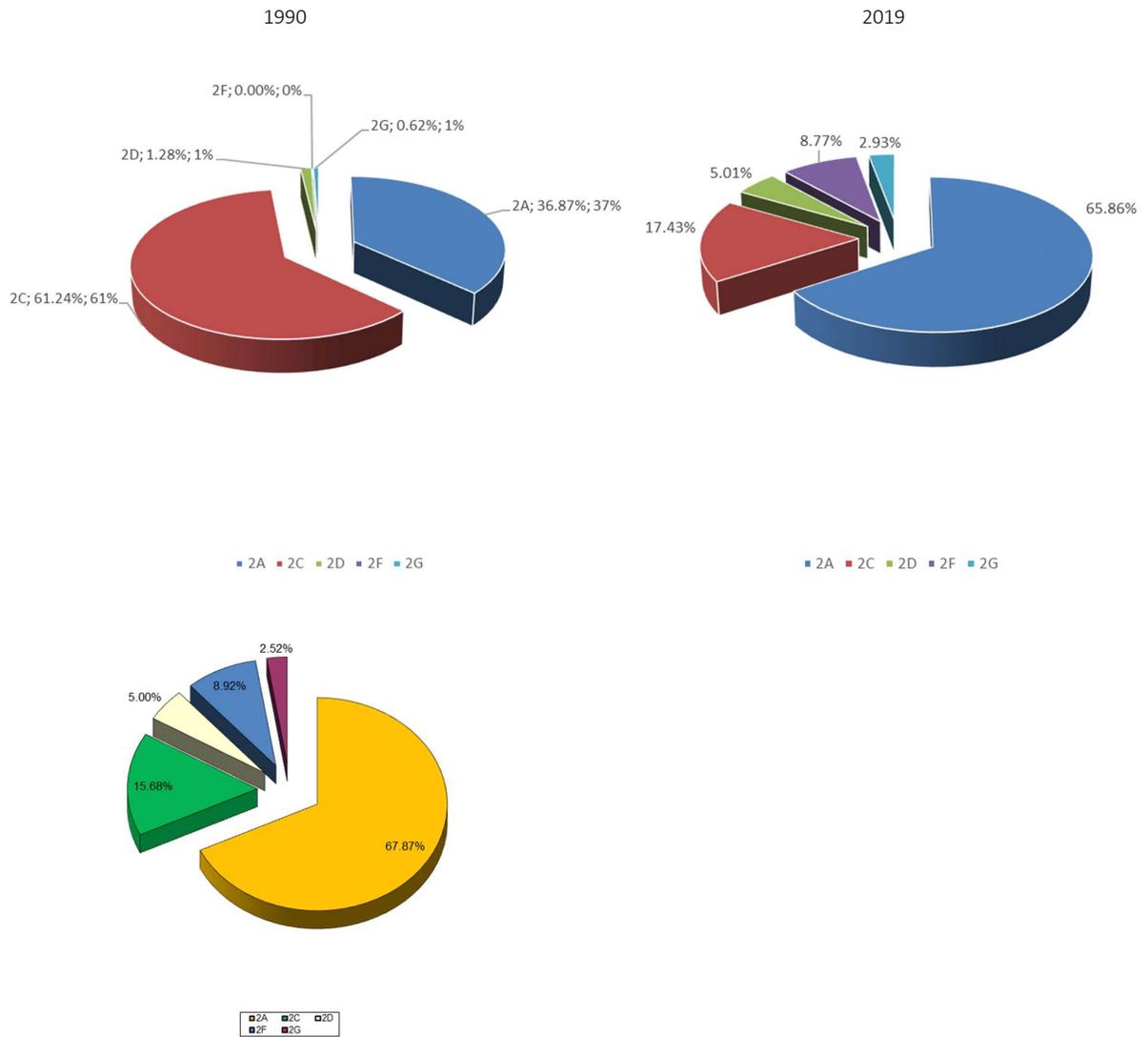
Figure 4-3 – GHG emission trends in % for CRF Sector 2 – Industrial Processes: 1990-2019



The emission trends briefly described above led to a significant change in the composition of industrial processes’ GHG emissions, as shown in

Figure 4-4.

Figure 4-4 – IPCC Categories weights in GHG emissions for CRF Sector 2 – Industrial Processes: 1990 and 2019



4.1.2 Key Categories

The methodology and results of the key source analysis are presented in Chapter 1.5. Table 4-2 presents the key source categories of IPCC Category 2 Industrial processes.

Table 4-2 – Key sources of IPCC category 2 - Industrial processes

2 - Industrial Processes and Product Use						
Key sources						
IPCC Category	Category Name	GHG	LA excl. LULUCF	LA incl. LULUCF	TA excl. LULUCF	TA incl. LULUCF
2A1	Cement Production	CO ₂	90-19	90-19		
2A3	Glass Production	CO ₂	96, 00, 10, 12, 14-17, 19	96, 00-01, 10-12, 14-19		
2C1	Iron & Steel Production	CO ₂	90-19	90-19	X	X
2F1	Refrigeration and air conditioning	F-gases	14-15	14-15		

Source: Environment Agency

Notes: LA = Level Assessment (Tier 1) including respectively excluding LULUCF

TA = Trend Assessment 2019 (Tier 1) including respectively excluding LULUCF, for F-gases 1995 is used as the base year

4.1.3 Completeness

Table 4-3 and Table 4-4 give an overview of the IPCC categories included under CRF Sector 2 and provide information on the status of emission estimates of all sub-categories.

Table 4-3 – Overview of sub-categories of CRF Sector 2 – Industrial Processes: status of emission estimates for CO₂, CH₄ and N₂O

GHG source & sink category	Description	Status		
		CO ₂	CH ₄	N ₂ O
2.A.1	mineral products - cement production	X		
2.A.2	mineral products - lime production	NO		
2.A.3	mineral products - glass production	X		
2.A.4	mineral products - other process uses of carbonates	NO		
2.A.4.a	Ceramics	NO		
2.A.4.b	Other uses of soda ash	NO		
2.A.4.c	Non-metallurgical magnesium production	NO		
2.A.4.d	Other	NO		
2.B.1	chemical industry - ammonia production	NO	NO	NO
2.B.2	chemical industry - nitric acid production			NO
2.B.3	chemical industry - adipic acid production	NO		NO
2.B.4	chemical industry - carbide production	NO	NO	

GHG source & sink category	Description	Status		
		CO ₂	CH ₄	N ₂ O
2.B.5	chemical industry - other	NO	NO	NO
2.B.4	chemical industry - caprolactam, glyoxal and glyoxylic acid production	NO	NO	NO
2.B.5	chemical industry - carbide production	NO	NO	NO
2.B.6	chemical industry - titanium dioxide production	NO	NO	NO
2.B.7	chemical industry - soda ash production	NO	NO	NO
2.B.8	chemical industry - petrochemical and carbon black production	NO	NO	NO
2.B.9	chemical industry - fluorochemical production	NO	NO	NO
2.B.10	chemical industry - other	NO	NO	NO
2.C.1	metal production - iron and steel production	X	NO	NO
2.C.1.a	Steel	X	NO	NO
2.C.1.b	Pig iron	NO	NO	NO
2.C.1.c	Direct reduced iron	NO	NO	NO
2.C.1.d	Sinter	NO	NO	NO
2.C.1.e	Pellet	NO	NO	NO
2.C.1.f	Other (please specify)	NO	NO	NO
2.C.2	metal production - ferroalloys production	NO	NO	NO
2.C.3	metal production - aluminium production	NO	NO	NO
2.C.4	metal production - magnesium production	NO	NO	NO
2.C.5	metal production - lead production	NO	NA	NA
2.C.6	metal production - zink production	NO	NO	NO
2.C.7	metal production - other	X	NO	NO
2.D.1	non-energy products from fuels and solvent use - lubricant use	X		
2.D.2	non-energy products from fuels and solvent use - paraffin wax use	X		
2.D.3	non-energy products from fuels and solvent use - other	X		
2.D.3	solvent use	X	NO	NO
2.D.3	road paving with asphalt	NO	NO	NO
2.D.3	asphalt roofing	NO	NO	NO
2.D.3	other (please specify) Urea-based catalysts	X	NO	NO
2.G	other product manufacture and use	NO	NO	X
2.G.3	other product manufacture and use - N ₂ O from product uses	NO	NO	X
2.G.3.a	Medical applications	NO	NO	X
2.G.3.b	other	NO	NO	X
	propellant for pressure and aerosol products	NO	NO	X
	other (please specify)	NO	NO	NO
2.H.1	other - pulp and paper	NO	NO	NO
2.H.2	other - food and beverages industry	NO	NO	NO
2.H.3	other - other (please specify)	NO	NO	NO

Note: A X indicates that emissions from this sub-category have been estimated, the grey shaded cells are those also shaded in the CRF tables.

Table 4-4 – Overview of subcategories of CRF Sector 2 – Industrial Processes: status of emission estimates for halocarbons, SF₆ and NF₃

GHG source & sink category	Description	Status			
		HFCs	PFCs	SF ₆	NF ₃
2.B	chemical industry	NO	NO	NO	NO
2.B.9	fluorochemical production	NO	NO	NO	NO
	by-product emissions	NO	NO	NO	NO
	fugitive emissions	NO	NO	NO	NO
2.B.10	other	NO	NO	NO	NO
2.C	metal industry	NO	NO	NO	NO
2.C.3	aluminium production	NO	NO	NO	NO
2.C.4	magnesium production	NO	NO	NO	NO
2.C.7	other	NO	NO	NO	NO
2.E	electronics industry	NO	NO	NO	NO
2.E.1	integrated circuit or semiconductor	NO	NO	NO	NO
2.E.2	TFT flat panel display	NO	NO	NO	NO
2.E.3	photovoltaics	NO	NO	NO	NO
2.E.4	heat transfer fluid	NO	NO	NO	NO
2.E.5	other	NO	NO	NO	NO
2.F	product uses as substitutes for ODS	X	NO	X	NO
2.F.1	refrigeration and air conditioning	X	NO	NO	NO
2.F.2	foam blowing agents	X	NO	NO	NO
2.F.3	fire protection	NO	NO	NO	NO
2.F.4	aerosols	X	NO	NO	NO
2.F.5	solvents	NO	NO	NO	NO
2.F.6	other applications	NO	NO	NO	NO
2.G	other product manufacture and use	X	NO	X	NO
2.G.1	electrical equipment	NO	NO	X	NO
2.G.2	SF ₆ and PFCs from other product use	NO	NO	X	NO
2.G.4	other	X	NO	NO	NO
2.H.1	other - pulp and paper	NO	NO	NO	NO
2.H.2	other - food and beverages industry	NO	NO	NO	NO
2.H.3	other - other (please specify)	NO	NO	NO	NO

Note: a X indicates that emissions from this sub-category have been estimated, the grey shaded cells are those also shaded in the CRF tables.

4.2 Mineral Products (2.A.)

This section describes the estimation of carbon dioxide emissions resulting from industrial processes used in clinker works and flat glass production installations. In 2019, this source category was responsible for 67.96% of GHG emissions in CO₂e from industrial processes – but only 36.85% in 1990. It represented 4.27% of the total GHG emissions in CO₂e (excluding LULUCF) in 2019 and 4.66% in 1990. Compared to 2018, emissions increased by 6.16% to attain the level of 458.77 Gg CO₂ in 2019. Compared to 1990, emissions decreased by 22.63%.

4.2.1 Cement Production (2.A.1.)

4.2.1.1 Source category description

In 2019, clinker production was responsible for 58.48% of GHG emissions in CO₂e from industrial processes – but only 33.52% in 1990. It represented 3.67% of the total GHG emissions in CO₂e (excluding LULUCF) in 2019 and 4.24% in 1990. Compared to 2019, emissions increased by 6.85% to attain the level of 394.79 Gg CO₂ in 2019. Compared to 1990, emissions decreased by 26.80%.

2A1 - Cement Production is a key source with regard to CO₂ emissions. It has been a key source without interruption since 1990: see Table 4-2.

4.2.1.2 Methodological issues

4.2.1.2.1 Activity data

In Luxembourg, one clinker production plant is operating. During the production of clinker, limestone, which is mainly calcium carbonate (CaCO₃), is calcined to produce lime (CaO) and CO₂ as a by-product.

Activity data, *i.e.* clinker production, is obtained annually from the plant operator (Table 4-6).

4.2.1.2.2 Methodology

1990-2013: For the estimation of CO₂ emissions, the ETS 2007 method using clinker production data is applied:

$$CO_2 \text{ Emissions} = EF_{clinker} \bullet CF_{clinker} \bullet \text{Clinker Production}$$

The conversion factor ($CF_{clinker}$) takes into account the amount of (non-carbonate) CaO and MgO in the raw materials. According to the operator of the plant, there is no calcined Cement Kiln Dust (CKD) to be lost from the system.

According to 2007 ETS Tier 3 method, the emission factor is based on the CaO and MgO content of the clinker:

$$EF_{clinker} = 0.785 \bullet \text{CaO Content} + 1.092 \bullet \text{MgO Content (Weight Fraction in Clinker)}$$

The CaO and MgO contents for the years for which no CaO and no MgO contents are available, are estimated by a linear interpolation (Table 4-6).

Starting 2014, emissions associated to dust in the production ovens have been determined by the operating company. Similar to previous years, the previously described approach according to ETS guidelines is applied and the following fluxes are considered:

-fluxes resulting from process generated dusts in the rotatif oven

-fluxes associated with used powders in the rotatif oven

For the years 1990-2013, these fluxes haven been extrapolated, based on the year 2014, and added to the emissions.

4.2.1.2.3 Emission factor

Emission estimates from the Tier 2 method, as well as activity data and IEFs, are summarized in

Table 4-5.

Table 4-5 - CO₂ emissions trend, activity data and IEFs for IPCC sub-category 2A1 – Cement Production: 1990-2019

2A1 - Clinker Production			
Activity data, emissions and implied emission factors			
Year	AD t	CO₂ Gg	IEF kg CO₂ / t clinker
1990	1'048'000	539.36	514.65
1991	1'001'637	514.96	514.12
1992	1'013'452	520.45	513.54
1993	842'855	432.35	512.95
1994	950'854	487.19	512.37
1995	848'455	434.23	511.79
1996	837'518	428.20	511.27
1997	865'659	442.13	510.75
1998	870'053	443.92	510.23
1999	913'265	465.50	509.71
2000	965'369	491.55	509.19
2001	843'608	428.56	508.00
2002	874'577	443.25	506.82
2003	769'754	389.22	505.64
2004	847'389	427.47	504.45
2005	833'798	419.63	503.27
2006	826'131	415.40	502.83
2007	816'688	410.29	502.38
2008	761'816	382.39	501.94
2009	708'048	357.91	505.49
2010	736'019	370.66	503.60
2011	770'232	389.22	505.32
2012	758'241	381.12	502.64
2013	743'260	371.56	499.91
2014	731'076	359.82	492.18
2015	677'731	329.48	486.15
2016	750'566	351.37	468.14
2017	761'255	370.70	486.96
2018	746'704	369.49	494.83
2019	802'488	394.79	491.96
Trend 2018-2019	7.47%	6.85%	-0.58%
Trend 1990-2019	-23.43%	-26.80%	-4.41%

Sources: AD: plant operator ; CO₂ and IEF: Environment Agency

Sources: AD: plant operator; CO₂ and IEF: Environment Agency

Table 4-6 – Effective and interpolated CaO content in % and EFs: 1990-2019

2A1 - Cement Production						
CaO content & emission factors						
Year	CaO (%)	CaO (%)	MgO (%)	MgO (%)	EF	CF
	operator	interpolation	operator	interpolation	kg CO ₂ / t clinker	-
1990	67.72	67.72	1.12	1.118	543.78	1.00
1991		67.67		1.1	543.21	1.00
1992		67.62		1.08	542.58	1.00
1993		67.56		1.06	541.95	1.00
1994		67.51		1.04	541.33	1.00
1995	67.46	67.46	1.02	1.02	540.70	1.00
1996		67.40		1.012	540.14	1.00
1997		67.34		1.004	539.58	1.00
1998		67.28		0.996	539.02	1.00
1999		67.22		0.988	538.47	1.00
2000	67.16	67.16	0.98	0.98	537.91	1.00
2001		67.03		0.96	536.64	1.00
2002		66.89		0.94	535.37	1.00
2003		66.76		0.92	534.10	1.00
2004		66.62		0.9	532.83	1.00
2005	66.49	66.49	0.88	0.88	531.56	1.00
2006		66.42		0.89	531.08	1.00
2007		66.35		0.89	530.60	1.00
2008	66.28	66.28	0.90	0.9	530.13	1.00
2009	66.78	66.78	0.89	0.89	533.94	1.00
2010	66.59	66.59	0.84	0.84	531.90	1.00
2011	66.84	66.84	0.83	0.83	531.90	1.00
2012	65.93	65.93	1.22	1.22	530.87	0.93
2013	65.93	65.93	1.22	1.22	530.87	0.93
2014	67.11	67.11	1.43	1.43	542.43	0.89
2015	67.17	67.17	1.86	1.86	547.60	0.87
2016	65.58	65.58	1.36	1.36	529.65	0.87
2017	66.23	66.23	1.19	1.19	532.90	0.90
2018	66.22	66.22	1.21	1.21	533.04	0.91
2019	66.27	66.27	1.17	1.17	460.43	0.91

Sources: plant operator and Environment Agency

Sources: plant operator and Environment Agency

4.2.1.2.4 Conversion factor (CF)

In 2012, the estimation method of raw material composition was changed. Before 2012, the operating company assumed that all the CaO and MgO came from carbonated source (CaCO₃ and MgCO₃), the amounts of which were known. Since 2012, the company started to measure and determine the actual content of carbon, organic carbon, CaO and MgO content in the different raw materials, because raw material contained some decarbonated materials (such as blast furnace slacks). To take into account the amount of (non-carbonate) CaO and MgO in the raw material and according to 2007 ETS method, the conversion factor (CF) is based on measurements twice a month of total carbon, organic carbon, CaO and MgO content in the raw material. As such, for the values prior to 2012, the conversion factors are based on the 2012 value of the conversion factor. The rationale is that the amount of already decarbonated CaO and MgO should be rather constant, due to the fact that the primary raw material comes from one single quarry, and that secondary raw materials (blast furnace slack) come from historical slack depots within the country, which one could assume to also possess constant CaO and MgO contents. Since 2014, the CF varies a little more as Luxembourg's blast furnace slack depots are almost exhausted, and other secondary raw materials need to be imported with varying decarbonated CaO and MgO contents.

4.2.1.3 Uncertainties and time-series consistency

Table 4-7 gives the error values which are assumed on the various calculation parameters for the uncertainty assessment.

Table 4-7 – Error values (%) for uncertainty assessment

Step	Error (%)	Error (%)
	IPCC GPG 2000 Table 3.1 (Tier 2)	Plant-specific estimation
1) Production data	1-2	1.5
2) Assume 100% carbonate source from CaCO ₃	1-3	2
3) CaO chemical analysis	1-2	1.5

Combined resulting errors (uncertain quantities are to be combined by multiplication):

- Activity data uncertainty1.5 %
- Emission factor uncertainty2.5 %
- Emissions uncertainty2.9 %

4.2.1.4 Source-specific QA/QC and verification

The calculated plant-specific emission factors are consistent with the 2004 ETS Tier 1 Guidelines default emission factor of 525 kg CO₂/t clinker.

4.2.1.5 Category-specific recalculations including changes made in response to the review process

Recalculations were done based on reviewer suggestions (ESD review 2020), as such for the years 1990-2011, the conversion factor was adapted from 1 to 0.93 as to avoid issues regarding overestimation. Furthermore, emissions resulting from various fluxes were extrapolated based on the year 2014 and added to the emissions of the years 1990-2013, which previously did not take into account these fluxes.

4.2.1.6 Category-specific planned improvements including those in response to the review process

There are no planned improvements to IPCC sub-category 2.A.1.

4.2.2 Lime Production (2.A.2)

This source category does not exist in Luxembourg.

4.2.3 Glass Production (2.A.3)

4.2.3.1 Source category description

In 2019, glass production was responsible for 9.48% of GHG emissions in CO₂e from industrial processes – but only 3.33% in 1990. It represented 0.60% of the total GHG emissions in CO₂e (excluding LULUCF) in 2019 and 0.42% in 1990. Compared to 2018, emissions

increased by 2.10% to attain the level of 63.98 Gg CO₂ in 2019. Compared to 1990, emissions increased by 19.43%. 2.A.3 - *Glass Production* is a key source with regard to CO₂ emissions. It has been a key source since for several years: see Table 4-2 in Section 0.

4.2.3.2 Methodological issues

4.2.3.2.1 Activity data

In Luxembourg, one company runs two flat glass production plants. CO₂ is released during melting in the kiln, from carbonates contained in mineral input materials (limestone, dolomite and soda ash).

Activity data, *i.e.* flat glass production, is obtained annually from the plant operators (Table 4-8).

4.2.3.2.2 Methodology

A country specific (CS) methodology is applied:

$$CO_2 \text{ emissions} = EF_{\text{glass}} \bullet \text{Glass Production}$$

Estimates from the CS method, as well as activity data and IEFs, are summarized in Table 4-8.

Table 4-8 – CO₂ emission trend, activity data and IEFs for IPCC sub-category 2.A.3 – Other – Glass Production: 1990-2019

2A3 - Glass Production			
Activity data, emissions and implied emission factors			
Year	AD t	AD Gg	kg CO ₂ / t glass
1990	377 240.00	53.57	142.00
1991	342 745.00	48.67	142.00
1992	403 328.00	57.27	142.00
1993	410 176.00	58.24	142.00
1994	426 991.00	60.63	142.00
1995	425 026.00	60.35	142.00
1996	420 750.00	59.75	142.00
1997	414 616.00	58.88	142.00
1998	361 401.00	51.32	142.00
1999	419 579.00	59.58	142.00
2000	425 751.00	60.46	142.00
2001	425 391.00	60.41	142.00
2002	423 240.00	60.10	142.00
2003	426 299.00	60.53	142.00
2004	435 595.00	61.85	142.00
2005	435 073.00	60.59	139.27
2006	435 806.00	60.34	138.45
2007	443 094.00	62.63	141.34
2008	440 538.00	62.16	141.10
2009	437 319.00	59.03	134.99
2010	430 140.00	62.07	144.31
2011	433 676.00	60.82	140.24
2012	423 081.00	58.45	138.15
2013	304 453.00	43.74	143.66
2014	430 098.00	63.44	147.51
2015	420 703.00	65.06	154.65
2016	430 103.00	65.31	151.85
2017	433 178.00	63.87	147.44
2018	422 077.50	62.65	148.42
2019	403 425.00	63.98	158.58
Trend 2018-2019	-4.42%	2.12%	6.84%
Trend 1990-2019	6.94%	19.43%	11.68%

Sources: AD: plant operator; CO₂ and IEF: Environment Agency

The use of soda ash for glass production is accounted for in 2A3. The amount of soda ash used in 2018 in the glass production was 73365.245 t (Source: verified ETS data). In 2019, the use of soda ash amounted to 72772.151 t.

4.2.3.2.3 Emission factors

The emission factor is based on the loss of ignition of the batch composition. Recycled glass is included in the calculation of the emission factor. The background data and the calculation of the emission factor are provided by the operator. The batch is composed of 1 t dry raw material and 0.25 t recycled glass. The loss of ignition of the dry raw material is 15.5%. Accordingly, the production of 1 t glass consumes 0.9132 t dry raw material and releases 141.5 kg CO₂ as loss of ignition. For each year, the plant-specific EF's of the two operating plants were determined based on the carbonate contents in the raw materials and the activity data for plant 1 and plant 2. The employed EF corresponds to the average EF of the two plants.

As no data is available for the years 1990-2004, an average EF of 142 kg CO₂/ t glass, based on the years 2005-2013, has been applied for those years. There is no indication of any change in product quality or batch composition over time, hence favouring the approach of an average emission factor that is kept constant for the whole time span from 1990-2004.

4.2.3.3 Uncertainties and time-series consistency

Estimations of uncertainties are based on the following study: W. Winiwarter, T. Köther, Austrian Research Centers, "Uncertainty related to Luxembourg's national greenhouse gas inventory", June 2008, ARC-sys-0162, as well as consultations with the producer

- Activity data uncertainty2.0 %
- Emission factor uncertainty5.0 %
- Cumulative emission uncertainty5.4 %

4.2.3.4 Source-specific QA/QC and verification

The calculated CO₂ emission is consistent with the calculated value according to the ETS methodology.

Concerning the use of soda ash in glass production, import and export values for Soda ash, provided by STATEC, have been compared to the use of soda ash in Glass Production to check for equivalence and exclude any other application.

4.2.3.5 Category-specific recalculations including changes made in response to the review process

No changes were made since the last submission.

4.2.4 Category-specific planned improvements including those in response to the review process

There are no planned improvements to IPCC sub-category 2.A.3.

4.2.5 Other Process Uses of Carbonates (2.A.4)

This source category does not exist in Luxembourg.

4.2.5.1 Ceramics (2.A.4.a)

This source category does not exist in Luxembourg.

4.2.5.2 Other Uses of Soda ash (2.A.4.b)

The use of soda ash is accounted for in IPCC sub-category 2A3 –*Glass Production*. There is no other soda ash use in Luxembourg.

4.2.5.3 Source-specific QA/QC and verification

Import and Export values for Soda ash, provided by STATEC, have been compared to the use of soda ash in IPCC sub-category 2A3 –*Glass Production* to check for equivalence.

4.2.5.4 Non Metallurgical Magnesia Production (2.A.4.c)

This source category does not exist in Luxembourg.

4.2.5.5 Other (2.A.4.d)

This source category does not exist in Luxembourg.

4.2.6 Asphalt Roofing (2.A.5)

This source category does not exist in Luxembourg.

4.2.7 Road Paving with Asphalt (2.A.6)

This source category does not exist in Luxembourg.

4.3 Chemical Industry (2.B)

There are no emissions to be reported for the chemical industry for Luxembourg.

CRF	Description	Notation key
2.B.1	Ammonia production	NO
2.B.2	Nitric acid production	NO
2.B.3	Adipic acid production	NO
2.B.4	Caprolactam, glyoxal and glyoxylic acid production	NO
2.B.5	Carbide production	NO
2.B.6	Titanium dioxide production	NO
2.B.7	Soda ash production	NO
2.B.8	Petrochemical and carbon black production	NO
2.B.9	Fluorochemical production	NO
2.B.10	Other	NO

4.4 Metal Production (2.C)

This section describes the estimation of carbon dioxide emissions resulting from industrial processes relating to iron and steel production (IPCC Sub-category 2C1). As a matter of fact, steel production combines process and energy related emissions. For pragmatic reasons (and to be as close as reasonable to the real situation), gaseous fuels have been considered causing energy related emissions⁸⁸ (this includes blast furnace gas derived from solid fuels), and solid fuels (coke, anthracite, residue oil and – for electric arc furnaces – carbon electrodes) process related emissions.

No other IPCC sub-categories under IPCC category 2C are reporting GHG emissions, hence IPCC category 2C = IPCC sub-category 2C1 – *Iron and Steel Production*.

4.4.1 Iron and Steel Production (2.C.1)

4.4.1.1 Source category description

In 2019, iron and steel production was responsible for 15.36% of GHG emissions in CO₂e from industrial processes – but 61.22% in 1990. It represented 0.97% of the total GHG emissions in CO₂e (excluding LULUCF) in 2019 and 7.74% in 1990. Compared to 2018, emissions decreased by 7.52% to attain the level of 103.7 Gg CO₂ in 2019. Compared to 1990, emissions decreased by 89.47% due to the technological shift from blast furnaces to electric arc furnaces operated in the mid-1990s. Furthermore, one of three electric furnaces stopped production in the year 2012.

An overview of the iron and steel related CO₂ emissions is provided in Table 4-9.

⁸⁸ Accounted for under IPCC Category 1A – Fuel Combustion Activities. See also Section 4.4.1.3 below.

Table 4-9 – CO₂ emissions trend, activity data and IEFs for IPCC sub-category 2C1 – Iron and Steel Production: 1990-2019

2C1 - Iron & Steel Production					
Year	Steel Production (t)				Filter Dust (t)
	SP	BF	BOF	EAF	Primus
1990	4'804'000	2'645'200	3'506'230	NO	NO
1991	4'567'000	2'463'000	3'379'440	NO	NO
1992	4'152'000	2'255'200	3'068'463	NO	NO
1993	4'561'000	2'412'000	3'288'847	4'095	NO
1994	3'747'000	1'926'890	2'627'278	445'990	NO
1995	1'977'700	1'028'230	1'410'469	1'202'668	NO
1996	1'810'970	829'010	1'168'070	1'333'758	NO
1997	1'002'815	438'030	597'814	1'982'405	NO
1998	NO	NO	NO	2'476'909	NO
1999	NO	NO	NO	2'600'324	NO
2000	NO	NO	NO	2'571'243	NO
2001	NO	NO	NO	2'724'679	NO
2002	NO	NO	NO	2'736'000	NO
2003	NO	NO	NO	2'675'000	NO
2004	NO	NO	NO	2'684'000	NO
2005	NO	NO	NO	2'194'485	29'263
2006	NO	NO	NO	2'802'049	38'942
2007	NO	NO	NO	2'845'872	46'446
2008	NO	NO	NO	2'584'341	35'717
2009	NO	NO	NO	2'103'281	16'514
2010	NO	NO	NO	2'633'613	NO
2011	NO	NO	NO	2'525'697	NO
2012	NO	NO	NO	2'208'000	NO
2013	NO	NO	NO	2'089'000	NO
2014	NO	NO	NO	2'192'999	NO
2015	NO	NO	NO	2'126'283	NO
2016	NO	NO	NO	2'175'409	NO
2017	NO	NO	NO	2'171'696	NO
2018	NO	NO	NO	2'227'951	NO
2019	NO	NO	NO	2'103'583	NO

Sources: AD: plant operator; Statec

Note: SATEC's 1990 value for BOF replaced by TÜV Rheinland 1992-1993 study reported value

2C1 - Iron & Steel Production CO2 Emissions						
Year	Total (Gg)	Pig Iron	Steel			Sinter
		BF (Gg)	BOF (Gg)	EAF (Gg)	Primus (Gg)	SP (Gg)
1990	984.91	200.00	404.48	NO	NO	380.43
1991	937.74	186.23	389.85	NO	NO	361.66
1992	853.29	170.52	353.98	NO	NO	328.80
1993	923.19	182.37	379.40	0.23	NO	361.19
1994	770.83	145.69	303.08	25.33	NO	296.72
1995	465.38	77.74	162.71	68.31	NO	156.61
1996	416.60	62.68	134.75	75.76	NO	143.41
1997	294.10	33.12	68.96	112.60	NO	79.41
1998	140.69	NO	NO	140.69	NO	NO
1999	147.70	NO	NO	147.70	NO	NO
2000	146.05	NO	NO	146.05	NO	NO
2001	154.76	NO	NO	154.76	NO	NO
2002	155.40	NO	NO	155.40	NO	NO
2003	158.94	NO	NO	151.94	7.00	NO
2004	172.45	NO	NO	152.45	20.00	NO
2005	152.92	NO	NO	119.13	33.79	NO
2006	209.79	NO	NO	170.49	39.30	NO
2007	203.49	NO	NO	162.22	41.27	NO
2008	169.30	NO	NO	134.69	34.61	NO
2009	128.66	NO	NO	112.66	16.00	NO
2010	133.61	NO	NO	133.61	NO	NO
2011	123.86	NO	NO	123.86	NO	NO
2012	100.23	NO	NO	100.23	NO	NO
2013	101.59	NO	NO	101.59	NO	NO
2014	102.46	NO	NO	102.46	NO	NO
2015	122.80	NO	NO	122.80	NO	NO
2016	119.33	NO	NO	119.33	NO	NO
2017	107.43	NO	NO	107.43	NO	NO
2018	112.14	NO	NO	112.14	NO	NO
2019	103.70	NO	NO	103.70	NO	NO
Trend 2018-2019	-7.52%	NA	NA	-7.52%	NA	NA
Trend 1990-2019	-89.47%	NA	NA	NA	NA	NA

Sources: AD: plant operator; Statec

Note: SATEC's 1990 value for BOF replaced by TÜV Rheinland 1992-1993 study reported value.

2C1 – Iron and Steel Production is a key source with regard to CO₂ emissions. It has been a key source since 1990: see Table 4-2 in Section

Key Categories0.

4.4.1.2 Methodological issues

4.4.1.2.1 Activity data

One sinter plant, two blast furnaces and three basic oxygen furnace steel plants (*BOF*) were operated in Luxembourg in 1990. The shift from *BOF* steel production to the *EAF* steel production occurred between 1993 and 1997 (see Figure 4-5). Three electric arc furnaces were operated between 1998 and 2011. One advanced multiple-heath furnace followed by a specially designed electric arc furnace (*PRIMUS* process) was operated between 2003 and 2009. Since 2013, only two of the three electric arc furnaces (*EAF*) are in operation.

A simplified country-specific methodology is used for the years 1993 to 2003 (as the first *EAF* was only introduced in 1993). It is important to mention that the base year 1990 is not concerned by this simplified methodology. In 1990, only blast furnaces were operated. Concerning time-series consistency, it is not possible to improve time-series consistency without losing the quality of the data. Indeed, the production processes changed over time and also more detailed methodologies were introduced over time which required a more detailed data collection. The required data for the time before the new methodologies do not exist, and cannot be extrapolated based on surrogates, without considerably increasing the uncertainties. Thus, it was opted to use the most detailed and verified data available to assess the emissions over time. In that sense, Luxembourg considers that the time series are constituent in an overall manner, as the carbon mass balance method was used for every technology used over time.

Concerning carbon mass balance, the NIR clearly indicates that for all production processes (*BF*, *EAF*, *PRIMUS*) a carbon mass balance is applied over the production process (see section 4.4.1.2.2). For the example of the electric arc furnace production, the carbon mass balance is the following:

$$E = (C_{\text{Carbon}} + C_{\text{Anthracite}}) * 3.664 + E_{\text{Electrodes}} + E_{\text{Pig iron}} + E_{\text{Petroleum coke}} + E_{\text{CaC}_2} + E_{\text{flux}}$$

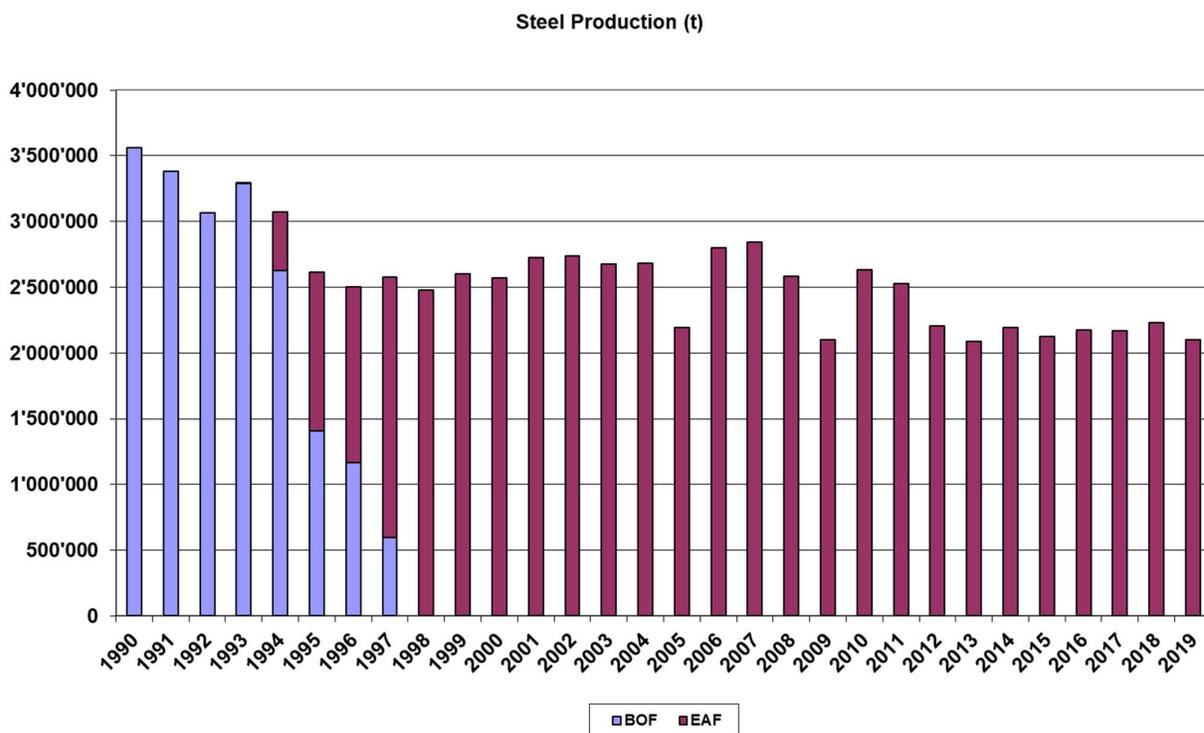
$$E_i = AD_i * EF_i \quad \text{with } i = \text{electrodes, pig iron, petroleum coke, CaC}_2, \text{ fluxes}$$

All materials introduced in the furnace and containing carbon are considered (carbon, anthracite, electrodes, pig iron, petroleum coke, CaC_2 and scrap) and it is assumed that the carbon content of the steel output equals to the scrap input.

Limestone and dolomite were not used as such in Luxembourg's *BF* and *BOF* steel production. In the sinter plant, the sinter was produced from two types of iron ore, "Minettes calcaires", i.e. iron ore containing carbonates and "Minettes silicieuses", i.e. siliceous iron ore. The carbon content of the iron ore is displayed in Table 4-11. The use of carbonate containing iron ore, and mixing it with siliceous ore, was advantageous in the sense that no limestone needed to be added to reach the optimal basicity of the final ore. Hence, decarbonisation of the ore is considered in the sinter plant and neither limestone nor dolomite was added to the ore to produce the agglomerate.

In the *BF* and *BOF* steel production, again neither limestone nor dolomite was added to the production process. Only burnt lime is used in the *BOF* steel production, for instance, to favour the slagging. All the C input is detailed in the methodological description.

Figure 4-5 – Steel production according to BOF and EAF: 1990-2019



Several plants are considered:

Sinter Plant (SP)

In the sinter plant iron ore and other iron-containing materials are agglomerated prior to the introduction into the blast furnace. Process emissions occur from the oxidation of the carbonates in the iron ore.

Blast furnace (BF)

Mainly sinter (iron oxides), coke and other fuels are supplied to the blast furnace. CO₂ process emissions are associated with the use of carbon to convert iron oxide to pig iron. Coke and other fuels serve not only as reducing agent but also to produce blast furnace gas as energy source which is recovered and used as fuel within the plant and in other steel industry processes and in a power station.

An energy balance serves to exclude double-counting of carbon from the consumption as reducing agent if this is already accounted for as fuel consumption in IPCC category 1A – Fuel Combustion Activities.

Basic oxygen furnace steel production (BOF)

In the basic oxygen furnace, pig iron (4% C) is transformed to steel (0.13% C). During the process, the reduced carbon is released as CO₂.

Electric arc furnace steel production (EAF)

In the electric arc furnaces anthracite and carbon, including the consumption of the electrodes, are used as reducing agent with the result of CO₂ process emissions. The consumption of natural gas in the EAF is accounted for as energy consumption and, consequently, reported under IPCC Sub-category 1A2a – Iron and Steel.

PRIMUS® process (PRIMUS)

The PRIMUS process consists of a combination of an advanced multiple-hearth furnace and a specially designed electric arc furnace. Steelmaking dust is transformed into iron. Process emissions occur from raw material (steelmaking dust) and reducing agents (anthracite, carbon and the consumption of the electrodes).

Activity data for iron production (*BF*) and steel production (*BOF & EAF*) are collected from STATEC's Statistical Yearbook. They have been supplemented by information received directly from the operator. This is the case for sinter production (*SP*) and for the steel production breakdown between BOF & EAF between 1993 and 1997.

The activity data for the PRIMUS® process is based on the introduced filter dust.

The production data for the steel production in 1990 (*BOF*) was corrected based on detailed information from the TÜV Rheinland 1992-1993 study. It is assumed that the 1990 value of 3 560 290 tonnes for BOF in STATEC's Statistical Yearbook is a typing error.

Table 4-10 summarizes iron and steel production by process.

Table 4-10 – Iron and steel production by process: 1990-2019

2C1 - Iron & Steel Production CO2 Emissions						
Year	Total (Gg)	Pig Iron	Steel			Sinter
		BF (Gg)	BOF (Gg)	EAF (Gg)	Primus (Gg)	SP (Gg)
1990	984.91	200.00	404.48	NO	NO	380.43
1991	937.74	186.23	389.85	NO	NO	361.66
1992	853.29	170.52	353.98	NO	NO	328.80
1993	923.19	182.37	379.40	0.23	NO	361.19
1994	770.83	145.69	303.08	25.33	NO	296.72
1995	465.38	77.74	162.71	68.31	NO	156.61
1996	416.60	62.68	134.75	75.76	NO	143.41
1997	294.10	33.12	68.96	112.60	NO	79.41
1998	140.69	NO	NO	140.69	NO	NO
1999	147.70	NO	NO	147.70	NO	NO
2000	146.05	NO	NO	146.05	NO	NO
2001	154.76	NO	NO	154.76	NO	NO
2002	155.40	NO	NO	155.40	NO	NO
2003	158.94	NO	NO	151.94	7.00	NO
2004	172.45	NO	NO	152.45	20.00	NO
2005	152.92	NO	NO	119.13	33.79	NO
2006	209.79	NO	NO	170.49	39.30	NO
2007	203.49	NO	NO	162.22	41.27	NO
2008	169.30	NO	NO	134.69	34.61	NO
2009	128.66	NO	NO	112.66	16.00	NO
2010	133.61	NO	NO	133.61	NO	NO
2011	123.86	NO	NO	123.86	NO	NO
2012	100.23	NO	NO	100.23	NO	NO
2013	101.59	NO	NO	101.59	NO	NO
2014	102.46	NO	NO	102.46	NO	NO
2015	122.80	NO	NO	122.80	NO	NO
2016	119.33	NO	NO	119.33	NO	NO
2017	107.43	NO	NO	107.43	NO	NO
2018	112.14	NO	NO	112.14	NO	NO
2019	103.70	NO	NO	103.70	NO	NO
Trend 2018-2019	-7.52%	NA	NA	-7.52%	NA	NA
Trend 1990-2019	-89.47%	NA	NA	NA	NA	NA

Sources: AD: plant operator ; Statec

Note: STATEC's 1990 value for BOF replaced by TÜV Rheinland 1992-1993 study reported value.

4.4.1.2.2 Methodology

Sinter Plant (SP)

The emissions in 1990 are calculated from the mass of carbon in the ore. It is therefore a country specific methodology. The data were collected directly from the operator.

Table 4-11 – Background data for the calculation of CO₂ emissions – Sinter Plant

Raw material	Tonnes (dry)	% C	Gg CO ₂
Minettes calcaires	2 043 408	4.38	328.16
Minettes silicieuses	908 957	1.57	52.27
Total	2 952 365	NA	380.43

A country specific methodology has been applied for the years 1991 to 1997 based on the emission factor determined for the year 1990:

$$CO_2 \text{ Emissions}_{SP} = EF_{SP} \bullet \text{Sinter Production}$$

Blast furnace (BF) and basic oxygen furnace steel production (BOF)

The 2000 IPCC-GPG Tier 2 methodology is applied for calculating the emissions in 1990.

The emissions from iron production in BF and from steel production in BOF are calculated separately based on a carbon balance over the production processes.

$$Emissions_{BF} = E_{Iron} = (C_{Reducing \ Agent} + C_{Ore} - C_{Iron}) \bullet 44/12$$

$$Emissions_{BOF} = E_{Steel} = (C_{Iron} + C_{Scrap} + C_{AddBOF} - C_{Steel}) \bullet 44/12$$

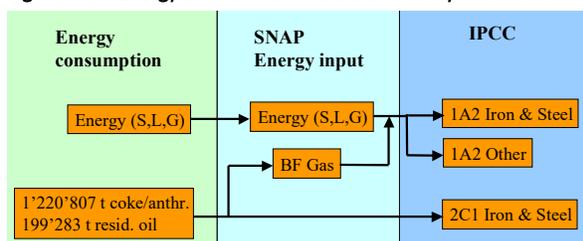
With:

$C_{Reducing \ Agent}$	= carbon serving as reducing agent: calculated from the energy balance over the iron and steel production, see below
C_{Ore}	= additional C-input from Iron ore and Iron scrap into the BF: 3 841 t iron ore (1.57% C, plant specific) + 6 222 t iron scrap (4% C, IPCC default)
C_{Iron}	= 2 645 200 t Iron (4% C, IPCC default)
C_{Scrap}	= 1 296 470 t Steel Scrap (0.4%, ETS default)
C_{AddBOF}	= Additional C-input in BOF: 19 532 t Ferromangan (4% C, plant specific), 1 688 t Carbon 95 (95% C, plant specific), 2 671 t Carbon 98 (98% C, plant specific)
C_{Steel}	= 5 506 230 t Steel (0.13% C, plant specific)

Activity data, as indicated above, were collected from the operator [TÜV Rheinland, 1992-1993].

The carbon accounted for reducing agent ($C_{Reducing \ Agent}$) in the blast furnace is determined from the energy balance over the iron and steel industry.

Figure 4-6 – Energy balance iron and steel industry – flow chart



In 1990, the overall energy consumption in the iron and steel industry was compared with the energy input into the different SNAP categories reported in the CORINAIR inventory. 1 180 646 t coke, 40 027 t anthracite and 199 283 t residual oil are accounted to be transformed partly into blast furnace gas which is then fed with the remaining solid, liquid and gaseous fuels into the CORINAIR SNAP categories and further on into the different IPCC Energy sub-categories 1A2a and 1A2f. The remaining part of the blast furnace gas carbon serves as reducing agent that is reported under IPCC sub-category 2C1:

$$C_{\text{Reducing Agent}} = C_{2C1} = C_{(1\,220\,807\text{ t coke/anthracite} + 199\,283\text{ t residual oil})} - C_{\text{BFGas}}$$

From the 1990 energy balance (Table 4-12), 160.05 Gg carbon (C) serves as reducing agent in the blast furnace.

Table 4-12 – Energy balance iron and steel industry: 1990

Energy	tonnes	% C		Gg C
Coke	1 180 646	90.33		1066.48
Anthracite	40 027	95.00		38.03
Oil	199 283	85.75		170.88

Energy	GJ	kg CO ₂ /GJ	kg C/GJ	Gg C
BFGas	15 851 000	258.00	70.36	1115.33
				Gg C
C Reducing Agent				160.05

Therefore, the resulting carbon dioxide emissions for the iron and steel production in 1990 equal:

$$CO_2 \text{ Emissions}_{BF} = 200.00 \text{ Gg } CO_2$$

$$CO_2 \text{ Emissions}_{BOF} = 404.48 \text{ Gg } CO_2$$

For the subsequent years (1991 to 1997), a country specific methodology has been applied based on the emission factor determined for the year 1990:

$$CO_2 \text{ Emissions}_{BF} = EF_{BF} \bullet \text{Pig Iron Production}$$

$$CO_2 \text{ Emissions}_{BOF} = EF_{BOF} \bullet \text{Steel Production}$$

Electric arc furnace steel production (EAF)

The mass balance approach according to 2007 ETS guidelines is applied for calculating the emissions for the years 2004 to 2014.

The emissions are calculated based on a carbon balance over the production process.

$$E = (C_{Carbon} + C_{Anthracite}) \bullet 3.664 + E_{Electrodes} + E_{Pig\ iron} + E_{Petroleum\ coke} + E_{CaC2} + E_{Scrap} - E_{Steel}$$

$$E_i = AD_i \bullet EF_i \quad \text{with } i = \text{electrodes, pig iron, petroleum coke, CaC}_2$$

It is assumed that E_{Scrap} equals E_{Steel} .

The activity data (C_{Carbon} , $C_{Anthracite}$, AD_i) are collected from the individual EAF (consumption of carbon, anthracite, electrodes, pig iron, petroleum coke and calcium carbide with their respective carbon contents).

The emission factors (EF) for electrodes, pig iron, petroleum coke and calcium carbide are taken from the 2007 guidelines - Tier1.

Starting 2015, better data collection allowed for a more specific approach regarding the calculations of EAF associate emissions. Similar to previous years, the mass balance approach, according to 2007 ETS guidelines, is applied, while the carbon balance over the production process has been expanded on:

$$E = (C_{Carbon} + C_{Anthracite}) \bullet 3.664 + E_{Electrodes} + E_{Pig\ iron} + E_{Petroleum\ coke} + E_{CaC2} + E_{flux}$$

Where E_{flux} corresponds to: $E_{flux} = E_{elements\ of\ fine\ alloying} + E_{scrap\ high\ in\ Carbon} + E_{scrap\ low\ in\ Carbon} + E_{actif\ carbon} + E_{forge\ carbon} - E_{steel} - E_{process\ residues}$

All emission factors are taken from the 2007 guidelines- Tier 1.

Regarding previous years, a lack of data doesn't make it possible to apply this new approach to the years preceding 2015.

The resulting emissions for the steel production are:

$$2019 - CO_2\ Emissions_{EAF} = 103.70\ Gg\ CO_2 \quad 2018 - CO_2\ Emissions_{EAF} = 112.14\ Gg\ CO_2$$

$$2017 - CO_2\ Emissions_{EAF} = 107.43\ Gg\ CO_2$$

$$2016 - CO_2\ Emissions_{EAF} = 119.33\ Gg\ CO_2$$

$$2015 - CO_2\ Emissions_{EAF} = 122.80\ Gg\ CO_2$$

$$2014 - CO_2\ Emissions_{EAF} = 102.46\ Gg\ CO_2$$

$$2013 - CO_2\ Emissions_{EAF} = 101.59\ Gg\ CO_2$$

$$2012 - CO_2\ Emissions_{EAF} = 100.23\ Gg\ CO_2$$

$$2011 - CO_2\ Emissions_{EAF} = 123.86\ Gg\ CO_2$$

$$2010 - CO_2\ Emissions_{EAF} = 133.61\ Gg\ CO_2$$

$$2009 - CO_2\ Emissions_{EAF} = 112.66\ Gg\ CO_2$$

$$2008 - CO_2\ Emissions_{EAF} = 134.69\ Gg\ CO_2$$

$$2007 - CO_2 \text{ Emissions}_{EAF} = 162.22 \text{ Gg } CO_2$$

$$2006 - CO_2 \text{ Emissions}_{EAF} = 170.49 \text{ Gg } CO_2$$

$$2005 - CO_2 \text{ Emissions}_{EAF} = 119.13 \text{ Gg } CO_2$$

$$2004 - CO_2 \text{ Emissions}_{EAF} = 152.45 \text{ Gg } CO_2$$

For the previous years (1993 to 2003), for which detailed data are not available, a simplified methodology has been applied based on the emission factor determined for the year 2004:

$$CO_2 \text{ Emissions}_{EAF} = EF_{EAF} \bullet \text{Steel Production}$$

It is assumed that the calculated emission factor for the year 2004 is the same for the previous years (1993 to 2003).

PRIMUS® process (PRIMUS)

The PRIMUS process was shut down in 2009. The ETS 2004 guidelines are applied for calculating the emissions in 2009.

$$E_{Primus} = (C_{Raw \text{ materials}} + C_{Electrodes} + C_{Carbon} + C_{Anthracite} - C_{Products}) \times 44/12$$

It is assumed that $C_{Products}$ equals zero (Source: ETS declaration).

The activity data are collected from the operator (consumption of electrodes, carbon and anthracite with their respective carbon contents).

The resulting emissions in 2009 are:

$$Emissions_{PRIMUS} = 16.00 \text{ Gg } CO_2$$

The same methodology is applied for the years 2005 to 2009.

The emissions for the years 2003 and 2004 are estimated based on the relative carbon consumption (Table 4-13) and the average ratio of the CO_2 emissions per carbon consumption for the years 2005-2008.

Table 4-13 – Carbon consumption of the Primus process

Year	Carbon consumption (t)
2003	2'376
2004	6'592
2005	11'781
2006	12'850
2007	13'302
2008	10'683
2009	NA
2010	NO
2011	NO
2012	NO
2013	NO
2014	NO
2015	NO
2016	NO
2017	NO
2018	NO
2019	NO

Source: plant operator

Note: Facility shut down in 2009

4.4.1.2.3 Emission factors

For **SP, BF and BOF**, EFs are calculated from the determined CO₂ emissions and the production data in 1990. The EF is kept constant for the subsequent years 1991 to 1997: see Table 4-14.

Table 4-14 – EFs for SP, BF and BOF

Production (1990)	Emissions (1990)	EF
4 804 000 t sinter	380.44 Gg CO ₂	EF _{SP} = 79.19 kg CO ₂ / t sinter
2 645 200 t iron	200.00 Gg CO ₂	EF _{BF} = 75.61 kg CO ₂ / t iron
3 506 230 t steel	404.48 Gg CO ₂	EF _{BOF} = 115.36 kg CO ₂ / t steel

For **EAF**, the EF_{EAF} is calculated from the determined CO₂ emissions and the production data. For the period from 1993 to 2004, the EF is equal to the one determined for the year 2004. For the years 2005 and 2006, EFs are recalculated for each year: see Table 4-15.

Table 4-15 – EFs for EAF

	Production	Emissions (2004)	EF
	2 684 000 t steel	152.45 Gg CO ₂	EF _{EAF} = 56.80 kg CO ₂ / t steel
Year	Production t steel	Emissions Gg CO ₂	EF _{EAF} (kg CO ₂ / t steel)
2005	2 194 485	119.13	54.29
2006	2 802 049	170.49	60.85
2007	2'845'872	162.22	57.00
2008	2'584'341	134.69	52.12
2009	2'103'281	112.66	53.56
2010	2'633'613	133.61	50.73
2011	2'525'697	123.86	49.04
2012	2'208'000	100.23	45.39
2013	2'089'000	101.59	48.63
2014	2'192'999	102.46	46.72
2015	2'126'283	122.8	57.75
2016	2'175'409	119.33	54.86
2017	2'171'696	107.43	49.47
2018	2'227'951	112.14	50.33
2019	2'103'583	103.70	49.30

The calculated emission factor for steel production in 2004 (EF_{EAF} = 56.80 kg CO₂ / t steel) and also applied for the previous years (1993 to 2003) is consistent with the calculated emission factors for the subsequent years (2005 to 2019).

For the PRIMUS® process, the implied emission factors EF_{PRIMUS}, for the years 2005-2009, are calculated from the determined CO₂ emissions and the introduced filter dust (Table 4-16).

Table 4-16 – AD, emissions and IEF for Primus

Year	Filter dust (t)	Emissions (Gg CO ₂)	EF PRIMUS (Mg CO ₂ / t dust)
2005	29'263	33.79	1.15
2006	38'942	39.30	1.01
2007	46'446	41.27	0.89
2008	35'717	34.61	0.97
2009	16'514	16.00	0.97
2010	NO	NO	NA
2011	NO	NO	NA
2012	NO	NO	NA
2013	NO	NO	NA
2014	NO	NO	NA
2015	NO	NO	NA
2016	NO	NO	NA
2017	NO	NO	NA
2018	NO	NO	NA
2019	NO	NO	NA

Note: Facility shut down in 2009

4.4.1.3 Uncertainties and time-series consistency

Table 4-17 gives the error values which are assumed on the various calculation parameters for the uncertainty assessment.

Table 4-17 – Error values (%) for uncertainty assessment

Step	Error (%)	Error (%)
	IPCC GPG 2000 Chap. 3.1.3.1	Plant-specific estimation
1) Amount of reducing agent for iron production	5	5
2) Pig iron activity data / Steel activity data	a few	2
3) Carbon content of pig iron and iron ore (plant-specific data are available)	5	5
4) emission factors uncertainties	5	5

Combined resulting errors (uncertain quantities are to be combined by multiplication):

- Emissions uncertainty (1990: 1), 2), 3), 4)) .. 8.9 %
- Emissions uncertainty (2004: 2), 4)5.4 %

4.4.1.4 Source-specific QA/QC and verification

Activity and energy data for 1990 have been cross-checked with the activity data available in STATEC's Statistical Yearbook as well as with those provided by the operator directly or through the TÜV Rheinland 1992-1993 study. The iron and steel IPCC Sub-categories 1A2a (fuel combustion) and 2C1 (process emissions) have been cross-checked to avoid double counting.

The calculated emission factor for steel production in 2004 ($EF_{EAF} = 56.80 \text{ kg CO}_2 / \text{t steel}$) and also applied for the previous years (1993 to 2003) is consistent with the calculated emission factors for the subsequent years (2005 to 2014).

4.4.1.5 Category-specific recalculations including changes made in response to the review process

No changes were made since the last submission.

4.4.1.6 Category-specific planned improvements including those in response to the review process

There are no planned improvements to IPCC sub-category 2.C.1.

4.4.2 Ferroalloys Production (2.C.2)

There are no dedicated plants for producing ferroalloys in Luxembourg.

4.4.3 Aluminium Production (2.C.3)

Aluminium production in Luxembourg is made out of aluminium scraps. There is, therefore, no primary aluminium production. The production from aluminium scraps is generating only fuel combustion emissions – hence, no process emissions – and is, therefore, reported under IPCC Sub-category 1.A.2.b – *Non-Ferrous Metals*.

4.4.4 Magnesium production (2.C.4)

This source category does not exist in Luxembourg.

4.4.5 Lead production (2.C.5)

This source category does not exist in Luxembourg.

4.4.6 Zinc production (2.C.6)

This source category does not exist in Luxembourg.

4.4.7 Other (as specified in table 2(I),A-H) (2.C.7)

Secondary aluminium production

In Luxembourg, one manufacturer is carrying activities belonging to the category 2.G.4. Activity data is directly obtained from the manufacturer. The data is limited to the one manufacturer and is considered confidential, thus the here described information is restricted to the activity data, which concerns CO₂ emissions related to the processing of lacquered or coated aluminium. Starting 2016, these emissions are estimated to equal 2.3231 kt, 2.0492 kt in 2017, 2.2473 kt in 2018 and 2.2834 kt in 2019.

4.4.7.1.1 Uncertainties and time-series consistency

The error values which are assumed on the various calculations are as given:

- Activity data uncertainty 0.4%, based on ETS reporting
- Emission factor uncertainty 50%, emission factor estimation was based on a single analysis campaign.

4.4.7.1.2 Source specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.6) of which important elements include:

- Are the correct values used (check for transcription errors, ...)?
- Check of plausibility of input data (time-series, order of magnitude, ...)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, ...)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, ...
- Are all references clearly made?
- Are all assumptions documented?

4.4.7.2 Category-specific recalculations including changes made in response to the review process

No revisions and recalculations have been done since the last submission.

4.4.7.3 Category-specific planned improvements including those in response to the review process

There are no planned improvements to IPCC sub-category 2.G.4

4.5 Non-energy products from fuels and solvent use (2.D)

This section describes the estimation of carbon dioxide emissions resulting from non-energy products like lubricants or waxes. In 2019, this source category was responsible for 5.01% of CO₂ emissions from industrial processes – but only 1.28% in 1990. It represented 0.31% of the total GHG emissions in CO₂e (excluding LULUCF) in 2019 and 0.16% in 1990. Compared to 2018, emissions increased by 7.56% to attain the level of 33.81 Gg CO₂ in 2019. Compared to 1990, emissions increased by 64.58%.

4.5.1 Lubricant use (2.D.1)

4.5.1.1 Source category description

No manufacturing of lubricants does occur in Luxembourg. Lubricants are either used in road transportation (motor oil and greases) or in the manufacturing and construction industry (mainly greases). Incineration of lubricants (waste oil) does not occur in Luxembourg. Waste oil is either recycled or exported.

Luxembourg reports emissions from lubricants exclusively under category 2.D.1. The activity data obtained from the national statistics institute (Statec) does not allow for a disaggregation of the lubricants consumption between 2-stroke engines and other applications. Furthermore, the number of 2-stroke engines in Luxembourg is very low; the gasoline consumption by this vehicle category in 2019 was 10 tonnes. Assuming a mixture of 1:50 as suggested by the IPCC 2006 Guidelines, the lubricant consumption of 2-stroke engines is about 0.2 tonnes, and the associated CO₂ emissions are 0.0006 kt CO₂ emissions, which is below the threshold of significance.

In 2019, this source category was responsible for 0.69% of CO₂ emissions from industrial processes – but only 0.39% in 1990. It represented 0.04% of the total GHG emissions in CO₂e (excluding LULUCF) in 2019 and 0.05% in 1990. Compared to 2018, emissions decreased by 12.89% to attain the level of 4.69 Gg CO₂ in 2019. Compared to 1990, emissions decreased by 24.42%.

An overview of the lubricant related CO₂ emissions, as well as of the amount of associated carbon stored is provided in Table 4-18.

Table 4-18 Emissions from 2.D.1 Lubricant Use

2D1 - Lubricant Use				
Activity data, emissions				
Year	AD t	CO ₂ Gg	Fraction of carbon stored	Carbon stored Gg C
1990	10524.00	6.20	0.8	6.7690368
1991	10696.00	6.31	0.8	6.8796672
1992	10199.00	6.01	0.8	6.5599968
1993	9655.00	5.69	0.8	6.210096
1994	10004.00	5.90	0.8	6.4345728
1995	10223.00	6.03	0.8	6.5754336
1996	10175.00	6.00	0.8	6.54456
1997	9038.00	5.33	0.8	5.8132416
1998	9061.00	5.34	0.8	5.8280352
1999	7648.00	4.51	0.8	4.9191936
2000	7102.00	4.19	0.8	4.5680064
2001	6745.00	3.98	0.8	4.338384
2002	7067.00	4.17	0.8	4.5454944
2003	6645.00	3.92	0.8	4.274064
2004	5040.00	2.97	0.8	3.241728
2005	6153.00	3.63	0.8	3.9576096
2006	4961.00	2.93	0.8	3.1909152
2007	4825.00	2.84	0.8	3.10344
2008	10218.00	6.02	0.8	6.5722176
2009	8207.00	4.84	0.8	5.2787424
2010	9425.00	5.56	0.8	6.06216
2011	8568.00	5.05	0.8	5.5109376
2012	8058.00	4.75	0.8	5.1829056
2013	7853.00	4.63	0.8	5.0510496
2014	7446.00	4.39	0.8	4.7892672
2015	7736.00	4.56	0.8	4.9757952
2016	8770.00	5.17	0.8	5.640864
2017	7923.00	4.67	0.8	5.0960736
2018	9131.00	5.38	0.8	5.8730592
2019	7954.42	4.69	0.8	5.11628555
Trend				
2018-2019	-12.89%	-12.89%	0.00%	-12.89%
1990-2019	-24.42%	-24.42%	0.00%	-24.42%

Sources: AD: STATEC; CO2: Environment Agency

4.5.1.2 Methodology

Generally speaking, lubricant emissions estimations in Luxembourg are based on the Tier 1 (Chap5, Tab.5.2, p5.7) methods described in the 2006 IPCC Guidelines for National Greenhouse Gas inventories. Activity data (import/export) for the years 1990 to 2018 were obtained from STATEC.

4.5.1.3 Uncertainties and time-series consistency

The error values which are assumed on the various calculations are as given:

- Activity data uncertainty 5%
- Emission factor uncertainty 50%

4.5.1.4 Source-specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.6) of which important elements include:

- Are the correct values used (check for transcription errors, ...)?
- Check of plausibility of input data (time-series, order of magnitude, ...)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, ...)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, ...
- Are all references clearly made?
- Are all assumptions documented?

4.5.1.5 Category-specific recalculations including changes made in response to the review process

No recalculations or changes were made since the last submission.

4.5.1.6 Category-specific planned improvements including those in response to the review process

There are no planned improvements for this category.

4.5.2 Paraffin wax use (2.D.2)

4.5.2.1 Source category description

No manufacturing of products from the paraffin wax category occurs in Luxembourg, as such all used products are imported. In 2019, this source category was responsible for 0.39% of CO₂ emissions from industrial processes – but only 0.01% in 1990. It represented 0.02% of the total GHG emissions in CO₂e (excluding LULUCF) in 2019 and 0.002% in 1990. Compared to 2018, emissions decreased by 16.81% to attain the level of 2.62 Gg CO₂ in 2019. Compared to 1990, emissions increased by 1143.31%. Starting 2010, activity data for paraffin wax strongly increases, which is due to the implementation of a new company. Similarly, the increase in 2012/2013 is also linked to the activity of the same company.

An overview of the paraffin wax related CO₂ emissions is provided in Table 4-19

Table 4-19 Emissions from 2.D.2 Paraffin Wax Use

2D2 - Paraffin Wax Use		
Activity data, emissions		
Year	AD	CO₂
	t	Gg
1990	357.16	0.21
1991	361.99	0.21
1992	366.82	0.22
1993	371.84	0.22
1994	376.95	0.22
1995	382.43	0.23
1996	387.36	0.23
1997	392.19	0.23
1998	397.11	0.23
1999	371.51	0.22
2000	413.31	0.24
2001	396.54	0.23
2002	397.54	0.23
2003	469.48	0.28
2004	441.56	0.26
2005	439.36	0.26
2006	295.88	0.17
2007	283.61	0.17
2008	424.01	0.25
2009	213.16	0.13
2010	2177.23	1.28
2011	1268.85	0.75
2012	1135.95	0.67
2013	4526.83	2.67
2014	2883.55	1.70
2015	2609.31	1.54
2016	4480.71	2.64
2017	4343.01	2.56
2018	3801.70	2.24
2019	4440.62	2.62
Trend 2018-2019	16.81%	16.81%
Trend 1990-2019	1143.31%	1143.31%

Sources: AD: STATEC ; CO₂: Envi

4.5.2.3 Methodology

The emissions of paraffin wax in Luxembourg were assessed in 2014 in order to assure compliance with the 2006 IPCC reporting guidelines.

Generally speaking, paraffin wax emissions estimations in Luxembourg are based on the Tier 1 (Chap5, Tab.5.3., p5.11) methods described in the 2006 IPCC Guidelines for National Greenhouse Gas inventories. Activity data (import/export) for the years 1999 to 2018 were obtained from STATEC. For the years 1990 to 1998, the data was extrapolated based population data and on the average import/export data for the years 1999-2005.

4.5.2.4 Uncertainties and time-series consistency

The error values were taken from the 2006 IPCC Guidelines for National Greenhouse Gas inventories (paraffin wax chapter) and are as follows:

- Activity data uncertainty 5%
- Emission factor uncertainty 100%

4.5.2.5 Source-specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.6) of which important elements include:

- Are the correct values used (check for transcription errors, ...)?
- Check of plausibility of input data (time-series, order of magnitude, ...)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, ...)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, ...
- Are all references clearly made?
- Are all assumptions documented?

4.5.2.6 Category-specific recalculations including changes made in response to the review process

The data for the years 2017 and 2018 has been updated.

4.5.2.7 Category-specific planned improvements including those in response to the review process

Obtaining country specific data for the years 1990 to 1998, alternatively improvements to the estimations of the activity data and emissions concerning those years will be performed.

4.5.3 Other (2.D.3)

4.5.3.1 Solvent use (2.D.3.1)

4.5.3.1.1 Sector Overview

Solvents are chemical compounds, which are used to dissolve substances as paint, glues, ink, rubber, plastic, pesticides or for cleaning purposes (degreasing). Solvents used in products such as coatings, inks, and consumer products generally emit substances classified as VOCs (Volatile Organic Compounds). Because solvents consist mainly of NMVOC, solvent use is a major source for anthropogenic NMVOC emissions in Luxembourg. Once released into the atmosphere NMVOCs react with reactive molecules (mainly HO-radicals) or high energetic light to finally form CO₂.

For more details on categories where emissions are not occurring and categories that are not estimated or included elsewhere, see Table 4-3.

4.5.3.1.2 Emission Trends

In 2019, this source category was responsible for 1.92% of the total CO₂ emissions of the industrial processes sector estimated for Luxembourg (0.88% in 1990). Furthermore, in 2019, 0.12% of total GHG emissions (excluding LULUCF) in Luxembourg originated from Solvent and Other Product Use, compared to 0.11% in 1990. Compared to 2018, GHG emissions from Solvent and Other Product Use increased by 18.92% in 2019. Compared to 1990, emissions decreased by 8.49%.

Figure 4-7 and Table 4-20 present the trend in total greenhouse gas emissions by subcategories.

Figure 4-7 - Emissions and trend from 1990 – 2019 by Sub-Categories of 2.D.3.1 - Solvent and Other Product Use.

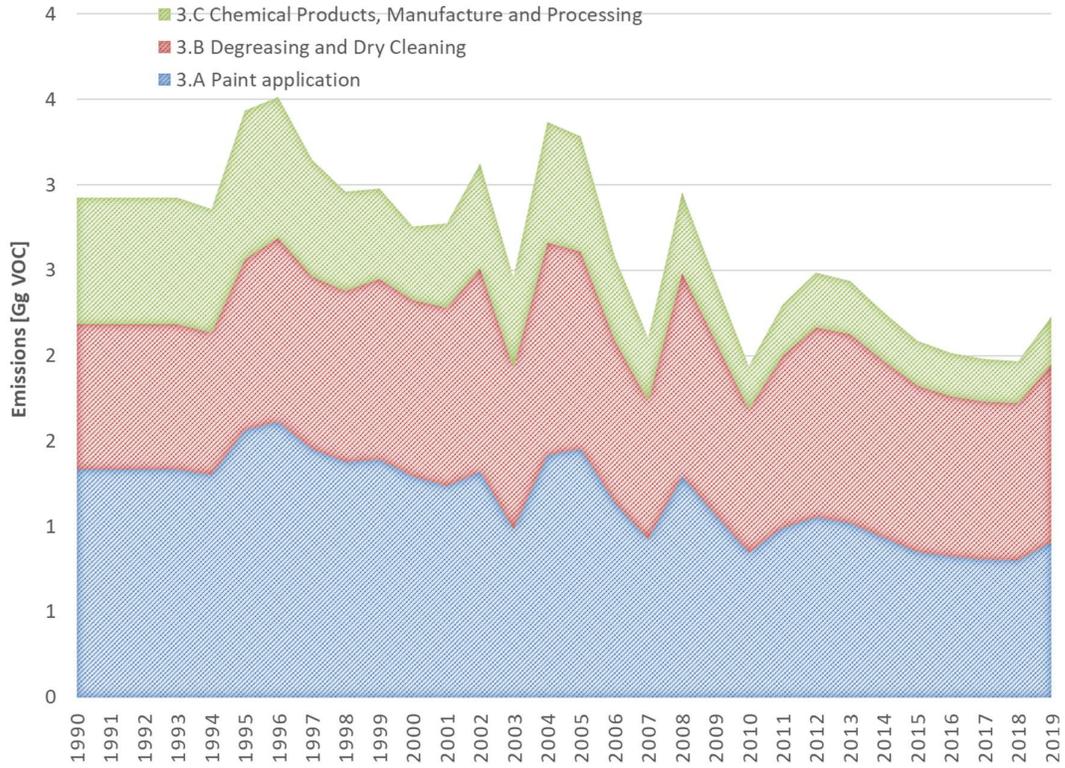


Table 4-20 - Emissions and trend from 1990 – 2019 by Sub-Categories of 2.D.3.1 - Solvent and Other Product Use.

Year	Total CO2 (kt)	Paint Application CO2 (kt)	Degreasing and Dry Cleaning CO2 (kt)	Chemical Products, Manufacture and Processing CO2 (kt)	Other CO2 (kt)
1990	14.13	3.95	4.02	2.03	4.12
1991	13.57	3.71	3.77	2.00	4.09
1992	12.86	3.45	3.49	1.93	3.98
1993	12.90	3.21	3.21	1.92	4.57
1994	11.97	2.89	2.85	1.83	4.41
1995	13.51	3.33	3.20	2.28	4.69
1996	13.29	3.31	3.23	2.03	4.72
1997	12.89	3.08	3.07	1.71	5.03
1998	11.94	2.96	3.00	1.43	4.55
1999	12.13	3.02	3.14	1.24	4.73
2000	11.61	2.88	3.06	1.01	4.67
2001	12.02	2.74	3.12	1.19	4.97
2002	13.36	2.91	3.57	1.54	5.34
2003	11.04	2.16	2.85	1.36	4.67
2004	14.58	3.11	3.55	1.83	6.09
2005	13.94	3.20	3.17	1.76	5.80
2006	11.34	2.60	2.66	1.26	4.83
2007	9.59	2.18	2.31	0.91	4.20
2008	13.78	3.14	3.43	1.11	6.11
2009	12.10	2.64	2.98	0.76	5.71
2010	10.80	2.14	2.49	0.48	5.70
2011	11.76	2.51	2.97	0.55	5.73
2012	13.27	2.68	3.23	0.58	6.77
2013	12.92	2.60	3.19	0.56	6.58
2014	11.17	2.38	2.97	0.51	5.31
2015	10.99	2.18	2.77	0.46	5.59
2016	10.70	2.10	2.67	0.44	5.49
2017	11.26	2.06	2.62	0.43	6.14
2018	10.87	2.05	2.61	0.43	5.78
2019	12.93	2.33	2.96	0.49	7.16
Trend 2018-2019	19%	13%	13%	13%	24%
Trend 1990-2019	-8%	-41%	-26%	-76%	73%

Greenhouse gas emissions in this sector decreased by 6% between 1990 and 2018, due to the positive impact of the enforced laws and regulations in Luxembourg:

- Solvent Ordinance: for limitation of emission of volatile organic compounds due to the use of organic solvents in certain paints and varnishes and vehicle refinishing products in order to combat acidification and ground-level ozone⁸⁹;
- Ordinance for paint finishing system (surface technology systems): for limitation of emission of volatile organic compounds due to the use of organic solvents by activities such as surface coating, painting or varnishing of different materials and products along the entire chain in the painting process in order to combat acidification and ground-level ozone⁹⁰
- Ordinance for industrial facilities and installations applying chlorinated hydrocarbon: for limitation of emission of chlorinated organic solvents from industrial facilities and installations applying chlorinated hydrocarbon;
- Convention on Long-range Transboundary Air Pollution (LRTAP)⁹¹, extended by eight protocols from which the following have relevance:

89 Règlement grand-ducal du 7 avril 2011 remplaçant l'annexe III du règlement grand-ducal modifié du 25 janvier 2006 relatif à la réduction des émissions de composés organiques volatils dues à l'utilisation de solvants organiques dans certains vernis et peintures et dans les produits de retouche de véhicules. (implementation of European Council Directive 2004/42/CE and European Council Directive 2010/79/EC).

90 Règlement grand-ducal du 20 décembre 1995 relatif à certaines modalités d'application et à la sanction du règlement CE N° 3093/94 du Conseil du 15 décembre 1994 relatif à des substances qui appauvrissent la couche d'ozone.

91 Loi du 18 juin 1981 portant approbation de la Convention sur la pollution atmosphérique transfrontière à longue distance, en date à Genève, du 13 novembre 1979. (Convention entered into force 16 March 1983; ratified by Luxembourg 15 July 1982)

- The 1988 Protocol concerning the Control of Nitrogen Oxides or their Transboundary Fluxes;⁹²
- The 1991 Protocol concerning the Control of Emissions of Volatile Organic Compounds or their Transboundary Fluxes;⁹³
- The 1998 Protocol on Persistent Organic Pollutants (POPs);⁹⁴
- The 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone; 21 Parties.⁹⁵
- Ordinance for volatile organic compounds (VOC) due to the use of organic solvents in certain activities and installations;⁹⁶
- European Council Directive 1999/13/EC of March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations;
- European Council Directive 2004/42/CE of the European Parliament and of the Council of 21 April 2004 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain paints and varnishes and vehicle refinishing products and amending Directive 1999/13/EC;
- Regulation on the limitation of emission during the use of solvents containing lightly volatile halogenated hydrocarbons in industrial facilities and installations.⁹⁷

4.5.3.1.3 Completeness

Table 4-21 gives an overview of the IPCC categories included in this chapter and presents the transformation matrix from SNAP categories. It also provides information on the status of emission estimates of all subcategories. A “✓” indicates that emissions from this sub-category have been estimated.

Table 4-21 - Overview of subcategories of IPCC Category 2.D.3.1 - Solvents and Other Product Use: correlation with SNAP codes and status of estimation.

IPCC Category		SNAP		CO2	N2O
3.A	Paint application	0601	Paint application	✓	NA
3.B	Degreasing and Dry Cleaning	0602	Degreasing, dry cleaning and electronics	✓	NA
3.C	Chemical Products, Manufacture and Processing	0603	Chemical products manufacturing and processing	✓	NA
3.D	Other	0604	Other use of solvents and related activities	✓	NA

4.5.3.1.4 CO2 Emissions from Solvent and Other Product Use

92 Loi du 31 juillet 1990 portant approbation du Protocole à la Convention sur la pollution atmosphérique transfrontière à longue distance de 1979, relatif à la lutte contre les émissions d'oxydes d'azote ou leurs flux transfrontières, fait à Sofia, le 31 octobre 1988. (Protocol entered into force 14 February 1991; ratified by Luxembourg 4 October 1990)

93 Loi du 29 juillet 1993 portant approbation du Protocole à la Convention sur la pollution atmosphérique transfrontière à longue distance, de 1979, relatif à la lutte contre les émissions de composés organiques volatils ou de leurs flux transfrontières, fait à Genève, le 18 novembre 1991. (Protocol entered into force 29 September 1997; ratified by Luxembourg 11.11.1993)

94 Loi du 24 décembre 1999 portant approbation du Protocole à la Convention sur la pollution atmosphérique transfrontière à longue distance, de 1979, relatif aux polluants organiques persistants, fait à Aarhus (Danemark), le 24 juin 1998. (Protocol entered into force on 23 October 2003; ratified by Luxembourg 01.05.2000)

95 Loi du 14 juin 2001 portant approbation du Protocole à la Convention de 1979 sur la pollution atmosphérique transfrontière à longue distance, relatif à la réduction de l'acidification, de l'eutrophisation et de l'ozone troposphérique, fait à Göteborg, le 30 novembre 1999. (Protocol entered into force on 17 May 2005; ratified by Luxembourg 07.08.2001)

96 Règlement grand-ducal du 3 décembre 2010 modifiant le règlement grand-ducal modifié du 4 juin 2001 portant - application de la directive 1999/13/CE du Conseil du 11 mars 1999 relative à la réduction des émissions de composés organiques volatils dues à l'utilisation de solvants organiques dans certaines activités et installations; - modification du règlement grand-ducal modifié du 16 juillet 1999 portant nomenclature et classification des établissements classes;

97 Règlement grand-ducal du 12 juillet 1995, relatif aux générateurs d'aérosols.

4.5.3.1.4.1 Methodology Overview

CO₂ emissions from solvent use were calculated from NMVOC emissions of this sector. As a first step the quantity of solvents used and the solvent emissions were calculated. To determine the quantity of solvents used, in Luxembourg, in the various applications, a bottom up and a top down approach were combined. Figure 4-8 to Figure 4-10 present an overview of the methodology.

The top down approach provides total quantities of solvents used in Luxembourg. The share of solvents used for the different applications and the solvent emission factors have been calculated on the basis of the bottom up approach. It was based on the economic structure in Luxembourg, applying solvent use and emission factors from the Austrian survey by linking the results of bottom up and top down approach, quantities of solvents annually used and solvent emissions for the different applications were obtained.

This model has been developed for Austria⁹⁸ (Windsperger et al. 2002a, 2004) and was in the meantime applied for different European countries within the network “non-energy use of fossils and CO₂ emissions” (Windsperger & Steinlechner, 2006). The application for Luxembourg is suitable as both countries show similar situation regarding economic and technical structure, and moreover as members of the EU similar legal framework conditions.

Figure 4-8 - Top-down-Approach compared to Bottom-up-Approach.

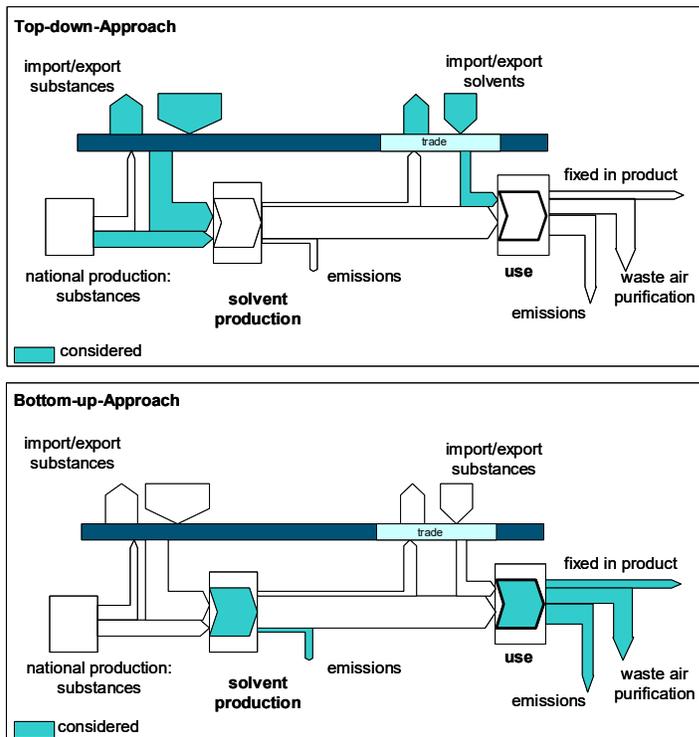


Figure 4-9 - Overview of the methodology for solvent emissions.

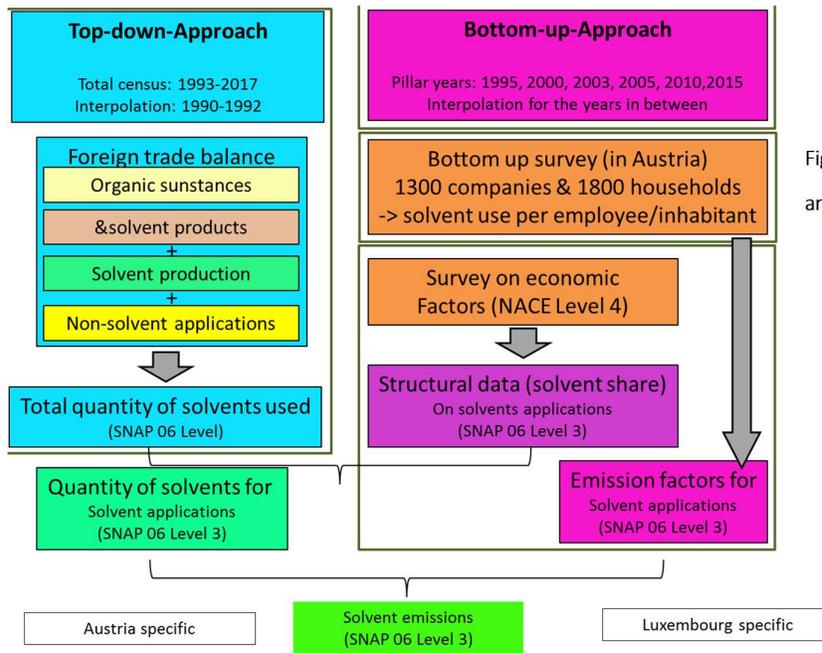


Figure 4-10 - Data of Top-down-Approach and Bottom-up-Approach for 2013.

Top-down				Bottom-up						Combination Top-down to Bottom-up						
CRF Sector 3				CRF Sector 3A-3D	SNAP Level 3		Solvent Share		Solvent Emission Factor		Solvent Activity			Solvent Emissions		
Imp/Exp Solvent products	2	Inland Solvent production	10	3 A, Paint application	060101	Manufacture of automobiles	0.3%	64%	1.9	0.1	0.0	0.0	0.0	0.1		
					060102	Car repairing	1.0%	86%		0.1	0.0	0.0	0.1			
					060103	Construction and buildings	6.6%	89%		0.5	0.0	0.0	0.4			
					060104	Domestic use	1.3%	89%		0.1	0.0	0.0	0.1			
					060105	Coil coating	2.4%	52%		0.2	0.0	0.0	0.1			
					060107	Wood coating	2.3%	90%		0.2	0.0	0.0	0.2			
					060108	Other industrial paint application	11.9%	50%		0.9	0.0	0.0	0.4			
					060201	Metal degreasing	13.6%	29%		1.0	0.0	0.0	0.3			
					060202	Dry cleaning	0.3%	84%		0.0	0.0	0.0	0.0			
					060203	Electronic components manufact.	0.0%	82%		0.0	0.0	0.0	0.0			
					060204	Other industrial cleaning	16.7%	68%		1.2	0.0	0.0	0.8			
					060305	Rubber processing	6.3%	93%		0.5	0.0	0.0	0.4			
					060306	Pharmaceutical products manufact.	0.7%	26%		0.1	0.0	0.0	0.0			
					060307	Paints manufacturing	0.5%	100%		0.0	0.0	0.0	0.0			
					060308	Inks manufacturing	0.7%	100%		0.0	0.0	0.0	0.0			
					060309	Glues manufacturing	0.0%	100%		0.0	0.0	0.0	0.0			
					060310	Asphalt blowing	0.7%	1%		0.0	0.0	0.0	0.0			
					060311	Adhesive, films & photographs	0.0%	94%		0.0	0.0	0.0	0.0			
					060312	Textile finishing	0.0%	90%		0.0	0.0	0.0	0.0			
					060314	Other manufacturing	0.9%	100%		0.1	0.0	0.0	0.1			
					060403	Printing industry	9.7%	65%		0.7	0.0	0.0	0.5			
					060404	Fat and oil extraction	0.3%	20%		0.0	0.0	0.0	0.0			
					060405	Application of glues and adhesives	0.0%	63%		0.0	0.0	0.0	0.0			
					060406	Preservation of wood	0.1%	99%		0.0	0.0	0.0	0.0			
					060407	Treatment & conservation of vehicles	0.3%	85%		0.0	0.0	0.0	0.0			
					060408	Domestic solvent use (other)	17.3%	84%		1.3	0.0	0.0	1.1			
					060411	Domestic use of pharmac. products	4.0%	94%		0.3	0.0	0.0	0.3			
					060412	Other (preservation of seeds,...)	2.1%	78%		0.2	0.0	0.0	0.1			

A study compiled for Austria (WINDSPERGER *et al.* 2002a) showed huge overestimation of NMVOC emissions when emission estimates are based on a top down approach only because a large amount of substances is used for “non-solvent-applications”. “Non-solvent applications” are applications where substances usually are used as feed stock in chemical, pharmaceutical or petrochemical industry (e.g. production of MTBE/ETBE, formaldehyde, polyester, biodiesel, pharmaceuticals *etc.*) and where therefore no emissions from “solvent use” arise. However, there might be emissions from the use of the produced products, such as MTBE/ETBE which is used as fuel additive and finally combusted; these emissions are considered in the transport sector.

Additionally, the comparison of the top-down and the bottom-up approaches helped to identify several quantitatively important applications like windscreens wiper fluids, antifreeze, moonlighting, hospitals, de-icing agents of aeroplanes, tourism, which were not considered in the top-down approach.

4.5.3.1.4.2 Top down Approach

The top-down approach is based on:

1. import-export statistics on solvent substances and solvent containing products (foreign trade balance) (STATEC);
2. production statistics on solvents in Luxembourg;
3. a survey on non-solvent-applications in companies in Austria (Windsperger *et al.* 2004a);
4. survey on the solvent content in products and preparations at producers and retailers in Austria (Windsperger *et al.* 2002a).

ad (1) and (2): Total quantity of solvents used in Luxembourg were obtained from import-export statistics and production statistics provided by STATEC.

Nearly a full top down investigation of substances of the import-export statistics from 1993 to 2008 was carried out (data 1990 – 1992 were interpolated). One problem is that the methodology of the import-export statistics changed over the years. In case of severe deviations between some years smoothing the time series with the mean values was used.

In Luxembourg, there are only few facilities producing solvents. The production of solvents considerably decreased, especially in the last years.

ad (3): In a study on the comparison of top down and bottom up approach in Austria (WINDSPERGER *et al.* 2002a), the amount of solvents used in “non-solvent-applications” was identified. The most important companies in Austria were identified and asked to report the quantities of solvents they used over the considered time period in „non-solvent-applications“. In combination with import-export statistic for these solvent substances the percentages of „non-solvent-applications“ were calculated.

For Luxembourg, these percentages of “non-solvent-applications” were adapted to the country's specific situation according to information from companies in Luxembourg.

ad (4): Relevant producers and retailers provided data on solvent content in products and preparations in Austria. These data were also adapted to Luxembourg due to the country specific situation.

4.5.3.1.4.3 Bottom up Approach

In a first step, an extensive survey on the use of solvents in the year 2000 was carried out in 1 300 Austrian companies (WINDSPERGER *et al.* 2002b). In this extensive survey data about the solvent content of paints, cleaning agents *etc.* and on solvents used (both substances and substance categories) like acetone or alcohols were collected.

Furthermore, information was gathered on:

- type of application of the solvents: “final application”, “cleaner” and “product preparation” as well as
- actual type of waste gas treatment: “open application”, “waste gas collection” and “waste gas treatment”.

For every category of application and waste gas treatment an emission factor was estimated to calculate solvent emissions in the year 2000; see Table 4-22.

The survey in 1 300 Austrian companies in the year 2000 was carried out at all industrial branches with solvent applications at NACE-level-4. Within these NACE-levels data on solvent use distinguished in substance categories was collected from the companies and a factor of “solvent use per employee” was calculated. For the calculation of the total amounts within the SNAP-digit (level 3) the number of employees in the respective NACE-levels in 2000 was used (WINDSPERGER *et al.* 2002b). In accordance with statistics in other European countries the structural business statistics (number of employees (NACE Rev.1.1)) were taken from EUROSTAT 2008 ⁹⁹.

Table 4-22 - Emission factors for NMVOC emissions from Solvent Use.

Category	Factor
final application	1.00
cleaner	0.85
product preparation	0.05
open application	1.00
waste gas collection	0.50
waste gas treatment	0.20

In a second step a survey in 1 800 households was made (WINDSPERGER *et al.* 2002a) for estimating the domestic solvent use (37 categories in 5 main groups: cosmetic, do-it-yourself, household cleaning, car, fauna and flora). Also, solvent use in the context of moonlighting besides commercial work and do-it-yourself was calculated.

The comparison of top down and bottom up approach helped to identify several additional applications that make an important contribution to the total amount of solvents used. Thus in a third step the quantities of solvents used in these applications such as windscreens wiper fluids, antifreeze, hospitals, de-icing agents of aeroplanes, tourism were estimated in surveys.

The outcome of these three steps was the total amount of solvents used for each application in the year 2000 (at SNAP level 3) in Austria (WINDSPERGER *et al.* 2002a).

99 <http://ecp.eurostat.ec.europa.eu>

To adapt the values for Luxembourg coefficients of the solvent consumption per employee (respective inhabitant) were used and applied to the employees of the industry sectors in Luxembourg (resp. Inhabitants). The outcome was the total amount of solvents for every application in the year 2000 in Luxembourg.

To achieve a time series, the development of the economic and technical situation in relation to the year 2000 was considered. It was distinguished between “general aspects” and “specific aspects” (see Table 4-23, Table 4-24 and Table 4-25). The information about these defined aspects were collected for two pillar years (1990 and 1995) and were taken from several studies (SCHMIDT *et al.* 1998, BARNERT 1998) and expert judgements from associations of industries (chemical industry, printing industry, paper industry) and other stakeholders. On the basis of this information calculation factors were estimated. With these factors and the data for solvent use and emission of 2000 data for the two pillar years was estimated. For the years in between, data was linearly interpolated. Since 2000, no new survey has been conducted so that the data remain constant since then.

For the pillar year 2005, 2010 and 2015 country specific data are used to update the bottom-up approach:

- update by of emission factors, type of waste gas treatment and solvent content by using information from solvents balances reported under the Solvent Ordinance.
- update of plant specific information from associations of industries and statistical data for “general aspects” and “specific aspects” .

Table 4-23 - General aspects and their development.

General aspects	1990	1995	2000	2005
efficiency factor solvent cleaning	150%	130%	100%	100%
efficiency factor application	110%	105%	100%	100%
solvent content of water-based paints	12%	10%	8%	8%
solvent content of solvent-based paints	58%	55%	55%	55%
efficiency of waste gas purification	75%	78%	80%	80%

Table 4-24 - Specific aspects and their development: distribution of the used paints (water based-paints – solvent-based paints) and part of waste gas purification (application – purification).

SNAP category	description	year	Distribution of used paints		Part of waste gas treatment	
			Solvent based paints	Water based paints	Application	Purification
060101	manufacture of automobiles	2005	73%	27%	10%	0%
		2000	73%	27%	10%	0%
		1995	80%	20%	8%	0%
		1990	90%	10%	5%	0%
060102	car repairing	2005	51%	49%	62%	1%
		2000	51%	49%	62%	1%
		1995	55%	45%	60%	0%
		1990	75%	25%	10%	0%
060107	wood coating	2005	46%	54%	46%	3%
		2000	46%	54%	46%	3%

SNAP category	description	year	Distribution of used paints		Part of waste gas treatment	
			Solvent based paints	Water based paints	Application	Purification
		1995	60%	40%	45%	2%
		1990	85%	15%	10%	0%
060108	Other industrial paint application	2005	97%	3%	90%	46%
		2000	97%	3%	90%	46%
		1995	99%	1%	87%	45%
		1990	100%	0%	26%	20%
060201	Metal degreasing	2005	92%	8%	75%	0%
		2000	92%	8%	75%	0%
		1995	95%	5%	65%	0%
		1990	100%	0%	10%	0%
060403	Printing industry	2005			44%	17%
		2000			44%	17%
		1995			29%	10%
		1990			10%	5%
060405	Application of glues and adhesives	2005			58%	0%
		2000			58%	0%
		1995			53%	0%
		1990			15%	0%
060103	Paint application : construction and buildings	2005	91%	9%	19%	4%
		2000	91%	9%	19%	4%
		1995	93%	7%	15%	2%
		1990	100%	0%	5%	0%
060105	Paint application : coil coating	2005	100%	0%	63%	0%
		2000	100%	0%	63%	0%
		1995	100%	0%	60%	0%
		1990	100%	0%	25%	0%
060406	Preservation of wood	2005	83%	17%	0%	0%
		2000	83%	17%	0%	0%
		1995	85%	15%	0%	0%
		1990	95%	5%	0%	0%
060412	Other (preservation of seeds,...)	2005	100%	0%	90%	0%
		2000	100%	0%	90%	0%
		1995	100%	0%	80%	0%
		1990	100%	0%	10%	0%

Table 4-25 - Specific aspects and their development: changes in the number of employees compared to the year 2000

SNAP	Description	Changes in the number of employees compared to the year 2000				
		1990	1995	2000	2003	2005
0601	Paint application					
060101	manufacture of automobiles	106%	106%	100%	134%	163%
060102	car repairing	93%	93%	100%	120%	125%
060103	construction and buildings	93%	93%	100%	120%	128%
060104	domestic use	separate analysis				
060105	coil coating	106%	106%	100%	32%	38%
060107	wood coating	93%	93%	100%	117%	126%
060108	industrial paint application	93%	93%	100%	100%	110%
0602	Degreasing, dry cleaning and electronics					
060201	Metal degreasing	117%	117%	100%	100%	88%
060202	Dry cleaning	94%	94%	100%	103%	106%
060203	Electronic components manufacturing	3%	3%	100%	96%	165%
060204	Other industrial cleaning	76%	76%	100%	134%	143%
0603	Chemical products manufacturing and processing					
060305	Rubber processing	190%	190%	100%	199%	198%
060306	Pharmaceutical products manufacturing	88%	88%	100%	194%	134%
060307	Paints manufacturing	133%	133%	100%	111%	111%
060308	Inks manufacturing	89%	89%	100%	94%	93%
060309	Glues manufacturing	NO	NO	NO	NO	NO
060310	Asphalt blowing	218%	218%	100%	103%	104%
060311	Adhesive, magnetic tapes, films and photographs	84%	84%	100%	70%	70%
060312	Textile finishing	119%	119%	100%	6%	7%
060314	Other	88%	88%	100%	87%	132%
0604	Other use of solvents and related activities					
060403	Printing industry	90%	90%	100%	111%	103%
060404	Fat, edible and non edible oil extraction	0%	0%	100%	155%	177%
060405	Application of glues and adhesives	NO	NO	NO	NO	NO
060406	Preservation of wood	91%	91%	100%	245%	125%
060407	Under seal treatment and conservation of vehicles	71%	71%	100%	102%	102%
060408	Domestic solvent use (other than paint application)	analysed separately				
060411	Domestic use of pharmaceutical products (k)	analysed separately				
060412	Other (preservation of seeds,...)	32%	32%	100%	48%	24%

Because of unavailability of data of employees in 1990 in the European database, the number of employees was taken out from 1995.

4.5.3.1.4.4 Combination Top-down – Bottom-up approach and updating

To verify and adjust the data, the solvents given in the top down approach and the results of the bottom up approach were differentiated in the pillar years (1995, 2000, 2003, 2005) (see Table 4-26). The differences between the quantities of solvents from the top down approach and bottom up approach respectively are lower than 10%. Table 4-26 shows the range of the differences in the considered pillar years broken down to the 15 substance categories.

Table 4-26 - Differences between the results of the bottom up and the top down approach for Luxembourg.

Year	Differences [t/a]
2005	-760
2003	0
2000	54
1995	-549

As the data of the top down approach were obtained from national statistics, they are assumed to be more reliable than the data of the bottom up approach. That's why the annual quantities of solvents used were taken from the top down approach while the share of the solvents for the different applications (on SNAP level 3) and the solvent emission factors have been calculated on the basis of the bottom up approach. The following tables (

Table 4-27,

Tables **4-28** and Figure 4-11) present activity data and NMVOC emissions.

Table 4-27 - Activity data of Category 2.D.3.1 Solvent and other product use [Mg] 1990-2019

Year	Solvents used (Gg)									
	2D3	2D3a	2D3b	2D3c	2D3d	2D3e	2D3f	2D3g	2D3h	2D3i
	TOTAL	Dometics solvent use including fungicides	Road paving with asphalt	Asphalt roofing	Coating applications	Degreasing	Dry cleaning	Chemical products	Printing	Other solvent use
1990	6.532	1.20	NA	NO	1.708	1.733	0.020	0.973	0.710	0.187
1991	6.532	1.200	NA	NO	1.708	1.733	0.020	0.973	0.710	0.187
1992	6.532	1.200	NA	NO	1.708	1.733	0.020	0.973	0.710	0.187
1993	6.532	1.200	NA	NO	1.708	1.733	0.020	0.973	0.710	0.187
1994	6.390	1.174	NA	NO	1.671	1.696	0.020	0.952	0.695	0.183
1995	7.677	1.411	NA	NO	2.007	2.037	0.024	1.144	0.834	0.220
1996	8.058	1.532	NA	NO	2.117	2.186	0.026	1.080	0.871	0.246
1997	7.411	1.455	NA	NO	1.957	2.054	0.024	0.883	0.797	0.241
1998	7.174	1.454	NA	NO	1.904	2.030	0.024	0.748	0.767	0.247
1999	7.424	1.551	NA	NO	1.980	2.144	0.025	0.663	0.790	0.270
2000	7.079	1.524	NA	NO	1.897	2.087	0.025	0.527	0.749	0.271
2001	7.032	1.509	NA	NO	1.791	2.105	0.024	0.597	0.751	0.254
2002	7.828	1.675	NA	NO	1.889	2.379	0.026	0.747	0.845	0.267
2003	6.091	1.300	NA	NO	1.389	1.879	0.020	0.645	0.664	0.194
2004	8.101	1.797	NA	NO	2.053	2.255	0.028	0.852	0.865	0.252
2005	7.749	1.785	NA	NO	2.161	1.924	0.028	0.809	0.810	0.234
2006	6.271	1.485	NA	NO	1.679	1.609	0.023	0.600	0.627	0.247
2007	5.252	1.278	NA	NO	1.349	1.392	0.019	0.457	0.501	0.256
2008	7.554	1.887	NA	NO	1.858	2.065	0.028	0.592	0.687	0.437
2009	6.357	1.629	NA	NO	1.494	1.791	0.024	0.443	0.550	0.427
2010	5.134	1.349	NA	NO	1.150	1.489	0.020	0.314	0.421	0.392
2011	6.083	1.659	NA	NO	1.339	1.771	0.024	0.365	0.468	0.457
2012	6.573	1.856	NA	NO	1.421	1.922	0.026	0.388	0.474	0.486
2013	6.434	1.878	NA	NO	1.366	1.888	0.026	0.374	0.433	0.469
2014	5.959	1.795	NA	NO	1.243	1.755	0.024	0.340	0.374	0.428
2015	5.504	1.708	NA	NO	1.128	1.628	0.023	0.309	0.320	0.389
2016	5.319	1.650	NA	NO	1.090	1.573	0.022	0.299	0.309	0.376
2017	5.223	1.621	NA	NO	1.070	1.544	0.021	0.293	0.304	0.369
2018	5.192	1.611	NA	NO	1.064	1.535	0.021	0.292	0.302	0.367
2019	5.887	1.826	NA	NO	1.206	1.741	0.024	0.331	0.342	0.416
Trend 1990-2019	-9.87%	52.15%	NA	NA	-29.36%	0.43%	18.39%	-66.03%	-51.78%	122.78%
2005-2019	-24.03%	2.34%	NA	NA	-44.17%	-9.54%	-12.14%	-59.11%	-57.72%	77.80%
2018-2019	13.38%	13.38%	NA	NA	13.38%	13.38%	13.38%	13.38%	13.38%	13.38%

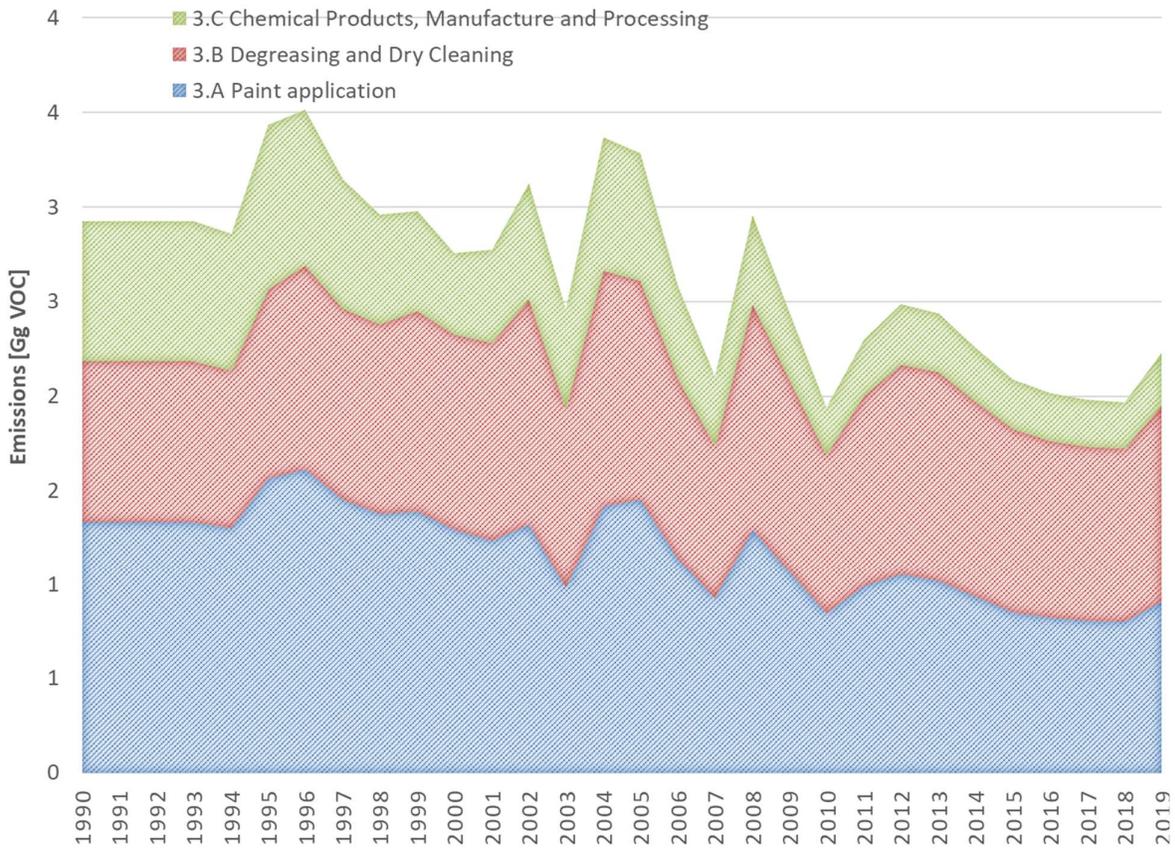
2D3 - Solvent and Product Use										
NMVOC emissions (Gg)										
Year	2D3 TOTAL	2D3a Dometics solvent use including fungicides	2D3b Road paving with asphalt	2D3c Asphalt roofing	2D3d Coating applications	2D3e Degreasing	2D3f Dry cleaning	2D3g Chemical products	2D3h Printing	2D3i Other solvent use
1990	4.60	1.04	0.009	NO	1.33	0.83	0.018	0.74	0.49	0.14
1991	4.60	1.04	0.008	NO	1.33	0.83	0.018	0.74	0.49	0.14
1992	4.60	1.04	0.009	NO	1.33	0.83	0.018	0.74	0.49	0.14
1993	4.89	1.33	0.007	NO	1.33	0.83	0.018	0.74	0.49	0.14
1994	4.84	1.35	0.013	NO	1.30	0.82	0.018	0.72	0.48	0.14
1995	5.59	1.40	0.007	NO	1.56	0.98	0.021	0.87	0.57	0.17
1996	5.77	1.47	0.010	NO	1.61	1.05	0.023	0.83	0.59	0.18
1997	5.47	1.60	0.009	NO	1.45	0.99	0.021	0.68	0.54	0.17
1998	5.07	1.42	0.008	NO	1.38	0.98	0.021	0.58	0.51	0.17
1999	5.18	1.48	0.013	NO	1.39	1.04	0.022	0.53	0.52	0.18
2000	4.90	1.46	0.012	NO	1.30	1.01	0.021	0.43	0.49	0.17
2001	5.04	1.59	0.011	NO	1.23	1.03	0.020	0.49	0.49	0.17
2002	5.57	1.70	0.011	NO	1.32	1.17	0.022	0.61	0.55	0.18
2003	4.59	1.54	0.018	NO	0.98	0.93	0.017	0.53	0.43	0.14
2004	6.13	2.02	0.004	NO	1.42	1.22	0.023	0.70	0.56	0.18
2005	5.93	1.94	0.005	NO	1.45	1.13	0.023	0.67	0.53	0.17
2006	4.73	1.61	0.005	NO	1.14	0.93	0.019	0.49	0.37	0.17
2007	3.93	1.40	0.005	NO	0.92	0.80	0.016	0.37	0.27	0.16
2008	5.55	2.03	0.004	NO	1.29	1.17	0.024	0.47	0.32	0.23
2009	4.79	1.93	0.003	NO	1.07	1.00	0.020	0.35	0.23	0.19
2010	4.24	2.00	0.003	NO	0.85	0.82	0.017	0.25	0.15	0.15
2011	4.61	1.97	0.005	NO	0.99	0.99	0.020	0.30	0.16	0.17
2012	5.23	2.39	0.004	NO	1.06	1.09	0.022	0.32	0.17	0.18
2013	5.12	2.35	0.004	NO	1.02	1.08	0.022	0.31	0.15	0.18
2014	4.43	1.88	0.005	NO	0.93	1.02	0.020	0.28	0.13	0.16
2015	4.39	2.04	0.004	NO	0.85	0.96	0.019	0.26	0.11	0.15
2016	4.28	2.00	0.005	NO	0.82	0.92	0.018	0.25	0.11	0.15
2017	4.51	2.28	0.005	NO	0.81	0.91	0.018	0.25	0.11	0.14
2018	4.37	2.13	0.026	NO	0.80	0.90	0.018	0.25	0.11	0.14
2019	5.20	2.66	0.028	NO	0.91	1.02	0.020	0.28	0.12	0.16
Trend 1990-2019	13.08%	156.95%	205.35%	NA	-31.75%	22.45%	13.55%	-62.23%	-75.45%	13.04%
2005-2019	-12.26%	37.17%	488.39%	NA	-37.52%	-9.80%	-12.14%	-58.59%	-77.27%	-5.54%
2018-2019	19.00%	24.97%	6.53%	NA	13.38%	13.38%	13.38%	13.38%	13.38%	13.98%

Amounts correspond to amounts of solvent used.

Tables 4-28 - Implied NMVOC emission factors for Solvent Use 1990–2018 and NMVOC emissions

Year	NMVOC implied emission factor (g NMVOC/g solvents)									
	2D3 TOTAL	2D3a Dometics solvent use including fungicides	2D3b Road paving with asphalt	2D3c Asphalt roofing	2D3d Coating applications	2D3e Degreasing	2D3f Dry cleaning	2D3g Chemical products	2D3h Printing	2D3i Other solvent use
1990	0.704	0.863	NA	NA	0.780	0.482	0.880	0.760	0.688	0.774
1991	0.704	0.863	NA	NA	0.780	0.482	0.880	0.760	0.688	0.774
1992	0.704	0.863	NA	NA	0.780	0.482	0.880	0.760	0.688	0.774
1993	0.749	1.110	NA	NA	0.780	0.482	0.880	0.760	0.688	0.774
1994	0.758	1.152	NA	NA	0.780	0.482	0.880	0.760	0.688	0.774
1995	0.728	0.993	NA	NA	0.780	0.482	0.880	0.760	0.688	0.774
1996	0.716	0.960	NA	NA	0.761	0.482	0.874	0.764	0.681	0.746
1997	0.738	1.100	NA	NA	0.742	0.483	0.868	0.771	0.675	0.719
1998	0.707	0.976	NA	NA	0.722	0.484	0.862	0.781	0.669	0.692
1999	0.697	0.955	NA	NA	0.703	0.484	0.856	0.795	0.663	0.667
2000	0.692	0.960	NA	NA	0.683	0.485	0.850	0.816	0.657	0.641
2001	0.717	1.056	NA	NA	0.689	0.488	0.848	0.818	0.655	0.667
2002	0.711	1.014	NA	NA	0.697	0.492	0.846	0.819	0.653	0.691
2003	0.753	1.182	NA	NA	0.707	0.497	0.844	0.820	0.651	0.713
2004	0.757	1.121	NA	NA	0.690	0.542	0.844	0.827	0.651	0.726
2005	0.765	1.087	NA	NA	0.673	0.589	0.844	0.834	0.651	0.739
2006	0.755	1.085	NA	NA	0.677	0.581	0.844	0.813	0.591	0.678
2007	0.748	1.098	NA	NA	0.684	0.573	0.844	0.799	0.531	0.608
2008	0.735	1.078	NA	NA	0.696	0.566	0.844	0.791	0.470	0.533
2009	0.754	1.186	NA	NA	0.713	0.560	0.844	0.792	0.410	0.455
2010	0.825	1.481	NA	NA	0.736	0.553	0.844	0.808	0.350	0.376
2011	0.758	1.190	NA	NA	0.739	0.561	0.844	0.815	0.350	0.372
2012	0.796	1.290	NA	NA	0.743	0.568	0.844	0.822	0.350	0.376
2013	0.795	1.251	NA	NA	0.746	0.575	0.844	0.829	0.350	0.380
2014	0.744	1.046	NA	NA	0.750	0.581	0.844	0.837	0.350	0.384
2015	0.797	1.193	NA	NA	0.753	0.587	0.844	0.844	0.350	0.388
2016	0.804	1.214	NA	NA	0.753	0.587	0.844	0.844	0.350	0.388
2017	0.863	1.404	NA	NA	0.753	0.587	0.844	0.844	0.350	0.388
2018	0.838	1.322	NA	NA	0.753	0.587	0.844	0.844	0.350	0.390
2019	0.880	1.457	NA	NA	0.753	0.587	0.844	0.844	0.350	0.393
Trend 1990-2019	24.89%	68.88%	NA	NA	-3.38%	21.92%	-4.09%	11.17%	-49.09%	-49.26%
2005-2019	14.96%	34.04%	NA	NA	11.90%	-0.28%	0.00%	1.29%	-46.24%	-46.87%
2018-2019	5.01%	10.23%	NA	NA	0.00%	0.00%	0.00%	0.00%	0.00%	0.53%

Figure 4-11 - NMVOC emissions and trend from 1990–2019 by subcategories of Category 2.D.3.1 - Solvent and Other Product Use



4.5.3.1.4.5 Calculation of CO₂ emissions from Solvent Emissions

The basis for the calculation of the carbon dioxide emissions were the quantities of solvent emissions differentiated by the 15 groups of substances (acetone, methanol, propanol, solvent naphtha, paraffins, alcohols, glycols, ester, aromates, ketones, aldehydes, amines, organic acids, cyclic hydrocarbons, and others). Substance specific carbon dioxide factors for these 15 substance groups have been created in Austria (see Table 4-29) on the basis of the carbon content and the stoichiometrically formed CO₂.

Table 4-29 - Substance specific carbon dioxide emission factors

Substances	CO ₂ factor [kg CO ₂ /kg substance]	Substances	CO ₂ factor [kg CO ₂ /kg substance]
Acetone	2.28	Glycols	1.82
Aldehydes	2.44	Ketones	2.45
Alcohols	1.91	Methanol	1.38
Alcohols/Propanols	2.20	Paraffins	3.14
Aromates	3.33	Residuals	0.92
Cyclic Hydrocarbons	3.14	Solvent naphtha	3.14
Ester	2.16	Glycols	1.82

In Austria the amount of carbon dioxide emissions was disaggregated to SNAP level 3 according to the share of solvents used and solvent emissions that were calculated in the context of the bottom up approach. In Table 4-29, the implied CO₂ Emission factors of Austria, which were also used for Luxembourg, as well as in

Table 4-30, the carbon dioxide emissions of Category 3-Solvent and Other Product Use for the years 1990 to 2018 are shown.

Table 4-30 - CO₂ emission of Category 2.D.3.1 Solvent and Other Product Use 1990–2019.

SNAP	0601	060101	060102	060103	060104	060105	060107	060108
Unit Gg								
1990	3.95	0.04	0.17	1.20	0.19	0.82	0.49	1.04
1991	3.71	0.03	0.17	1.19	0.19	0.76	0.46	0.90
1992	3.45	0.03	0.17	1.16	0.18	0.70	0.43	0.78
1993	3.21	0.03	0.17	1.12	0.18	0.64	0.40	0.66
1994	2.89	0.02	0.16	1.05	0.18	0.57	0.36	0.55
1995	3.33	0.03	0.19	1.25	0.23	0.64	0.42	0.57
1996	3.31	0.03	0.19	1.22	0.23	0.68	0.39	0.57
1997	3.08	0.03	0.17	1.12	0.22	0.67	0.34	0.53
1998	2.96	0.02	0.16	1.06	0.22	0.68	0.31	0.51
1999	3.02	0.02	0.16	1.07	0.23	0.73	0.29	0.52
2000	2.88	0.02	0.15	1.00	0.23	0.73	0.25	0.49
2001	2.74	0.02	0.16	1.03	0.22	0.55	0.26	0.48
2002	2.91	0.03	0.18	1.19	0.24	0.43	0.30	0.54
2003	2.16	0.02	0.15	0.96	0.19	0.19	0.24	0.42
2004	3.11	0.04	0.20	1.34	0.26	0.28	0.34	0.66
2005	3.20	0.04	0.20	1.35	0.26	0.29	0.34	0.72
2006	2.60	0.03	0.16	1.14	0.21	0.25	0.30	0.51
2007	2.18	0.02	0.14	0.99	0.18	0.23	0.26	0.36
2008	3.14	0.03	0.20	1.48	0.26	0.35	0.40	0.41
2009	2.64	0.03	0.16	1.29	0.22	0.31	0.36	0.27
2010	2.14	0.02	0.13	1.08	0.18	0.26	0.31	0.15
2011	2.51	0.02	0.16	1.29	0.22	0.29	0.36	0.17
2012	2.68	0.02	0.17	1.39	0.24	0.29	0.39	0.18
2013	2.60	0.02	0.17	1.36	0.24	0.26	0.38	0.17
2014	2.38	0.02	0.15	1.26	0.22	0.22	0.35	0.15
2015	2.18	0.02	0.14	1.17	0.21	0.19	0.32	0.13
2016	2.10	0.02	0.14	1.13	0.20	0.18	0.31	0.13
2017	2.06	0.02	0.13	1.11	0.20	0.18	0.30	0.12
2018	2.05	0.02	0.13	1.10	0.20	0.18	0.30	0.12
2019	2.33	0.02	0.15	1.25	0.22	0.20	0.34	0.14

SNAP	0602	060201	060202	060203	060204
Unit	Gg				
1990	4.02	2.90	0.02	0.0002	1.10
1991	3.77	2.64	0.02	0.0001	1.11
1992	3.49	2.37	0.03	0.0001	1.10
1993	3.21	2.11	0.03	0.0001	1.07
1994	2.85	1.81	0.03	0.0001	1.00
1995	3.20	1.97	0.03	0.0001	1.20
1996	3.23	1.86	0.03	0.0004	1.33
1997	3.07	1.66	0.03	0.0007	1.38
1998	3.00	1.52	0.03	0.0010	1.45
1999	3.14	1.48	0.04	0.0013	1.62
2000	3.06	1.35	0.04	0.0015	1.67
2001	3.12	1.29	0.04	0.0014	1.79
2002	3.57	1.38	0.04	0.0015	2.14
2003	2.85	1.04	0.03	0.0011	1.78
2004	3.55	1.01	0.04	0.0018	2.50
2005	3.17	0.61	0.04	0.0019	2.51
2006	2.66	0.50	0.03	0.0013	2.13
2007	2.31	0.42	0.03	0.0009	1.86
2008	3.43	0.60	0.04	0.0009	2.78
2009	2.98	0.51	0.04	0.0005	2.44
2010	2.49	0.41	0.03	0.0002	2.04
2011	2.97	0.47	0.04	0.0002	2.46
2012	3.23	0.49	0.04	0.0002	2.70
2013	3.19	0.46	0.04	0.0002	2.69
2014	2.97	0.41	0.04	0.0001	2.53
2015	2.77	0.36	0.03	0.0001	2.37
2016	2.67	0.35	0.03	0.0001	2.29
2017	2.62	0.35	0.03	0.0001	2.25
2018	2.61	0.34	0.03	0.0001	2.23
2019	2.96	0.39	0.04	0.0001	2.53

SNAP	0603	060305	060306	060307	060308	060309	060310	060311	060312	060314
Unit	Gg									
1990	2.03	1.61	0.03	0.20	0.10	0.000	0.0065	0.0027	0.0116	0.09
1991	2.00	1.61	0.03	0.17	0.09	0.000	0.0065	0.0027	0.0115	0.08
1992	1.93	1.59	0.02	0.15	0.08	0.000	0.0065	0.0027	0.0114	0.08
1993	1.92	1.57	0.02	0.16	0.08	0.000	0.0064	0.0027	0.0113	0.07
1994	1.83	1.50	0.02	0.15	0.08	0.000	0.0062	0.0025	0.0110	0.06
1995	2.28	1.82	0.02	0.23	0.11	0.000	0.0075	0.0030	0.0137	0.07
1996	2.03	1.61	0.02	0.20	0.11	0.000	0.0064	0.0035	0.0124	0.08
1997	1.71	1.31	0.02	0.18	0.11	0.000	0.0049	0.0036	0.0105	0.07
1998	1.43	1.08	0.02	0.14	0.10	0.000	0.0038	0.0039	0.0090	0.07
1999	1.24	0.92	0.02	0.11	0.09	0.000	0.0028	0.0044	0.0082	0.08
2000	1.01	0.70	0.02	0.10	0.10	0.000	0.0017	0.0046	0.0068	0.08
2001	1.19	0.88	0.03	0.10	0.09	0.000	0.0016	0.0040	0.0046	0.07
2002	1.54	1.20	0.04	0.11	0.10	0.000	0.0018	0.0039	0.0028	0.08
2003	1.36	1.10	0.04	0.09	0.07	0.000	0.0014	0.0025	0.0003	0.06
2004	1.83	1.49	0.04	0.12	0.10	0.000	0.0019	0.0035	0.0005	0.07
2005	1.76	1.45	0.03	0.11	0.10	0.000	0.0018	0.0034	0.0005	0.06
2006	1.26	0.98	0.02	0.09	0.10	0.000	0.0015	0.0029	0.0004	0.06
2007	0.91	0.66	0.02	0.07	0.10	0.000	0.0012	0.0026	0.0003	0.06
2008	1.11	0.72	0.02	0.10	0.17	0.000	0.0017	0.0039	0.0003	0.10
2009	0.76	0.41	0.01	0.08	0.16	0.000	0.0014	0.0035	0.0002	0.10
2010	0.48	0.17	0.01	0.06	0.14	0.000	0.0011	0.0030	0.0001	0.09
2011	0.55	0.17	0.01	0.09	0.18	0.000	0.0012	0.0032	0.0001	0.10
2012	0.58	0.15	0.01	0.11	0.19	0.000	0.0012	0.0032	0.0002	0.11
2013	0.56	0.12	0.01	0.12	0.19	0.000	0.0010	0.0029	0.0001	0.11
2014	0.51	0.08	0.01	0.12	0.18	0.000	0.0008	0.0024	0.0001	0.10
2015	0.46	0.05	0.01	0.13	0.17	0.000	0.0007	0.0020	0.0001	0.09
2016	0.44	0.05	0.01	0.12	0.17	0.000	0.0006	0.0019	0.0001	0.09
2017	0.43	0.05	0.01	0.12	0.16	0.000	0.0006	0.0019	0.0001	0.09
2018	0.43	0.05	0.01	0.12	0.16	0.000	0.0006	0.0019	0.0001	0.09
2019	0.49	0.05	0.01	0.14	0.18	0.000	0.0007	0.0021	0.0001	0.10

SNAP	0604	060403	060404	060405	060406	060407	060408	060411	060412
Unit									
Gg									
1990	4.12	1.41	0.00	0.00	0.02	0.04	1.7619	0.55786533	0.33
1991	4.09	1.34	0.00	0.00	0.02	0.04	1.8078	0.568956	0.31
1992	3.98	1.26	0.00	0.00	0.02	0.04	1.8049	0.56873922	0.28
1993	4.57	1.18	0.00	0.00	0.02	0.04	2.4992	0.56281058	0.26
1994	4.41	1.07	0.00	0.00	0.02	0.04	2.5044	0.53585604	0.23
1995	4.69	1.25	0.00	0.00	0.03	0.05	2.4567	0.64828101	0.26
1996	4.72	1.23	0.00	0.00	0.03	0.05	2.4668	0.66298514	0.28
1997	5.03	1.14	0.00	0.00	0.02	0.05	2.9033	0.63562505	0.28
1998	4.55	1.09	0.00	0.00	0.02	0.05	2.4809	0.62874401	0.28
1999	4.73	1.11	0.01	0.00	0.02	0.05	2.5782	0.66182883	0.31
2000	4.67	1.05	0.01	0.00	0.02	0.05	2.5830	0.64841815	0.31
2001	4.97	1.05	0.01	0.00	0.03	0.05	2.9188	0.63489322	0.28
2002	5.34	1.19	0.01	0.00	0.05	0.05	3.0729	0.69655373	0.28
2003	4.67	0.93	0.01	0.00	0.05	0.04	2.9222	0.53407922	0.19
2004	6.09	1.21	0.01	0.00	0.05	0.05	3.7801	0.73525669	0.25
2005	5.80	1.14	0.01	0.00	0.03	0.05	3.6064	0.72718972	0.24
2006	4.83	0.88	0.01	0.00	0.02	0.04	3.0001	0.59873405	0.27
2007	4.20	0.70	0.01	0.00	0.02	0.04	2.6257	0.51014333	0.29
2008	6.11	0.96	0.01	0.00	0.03	0.05	3.7923	0.74612406	0.51
2009	5.71	0.77	0.01	0.00	0.02	0.04	3.7104	0.6383795	0.51
2010	5.70	0.59	0.01	0.00	0.02	0.04	4.0476	0.52398977	0.48
2011	5.73	0.66	0.01	0.00	0.02	0.04	3.7475	0.69922081	0.56
2012	6.77	0.67	0.01	0.00	0.02	0.05	4.5938	0.83835684	0.60
2013	6.58	0.61	0.00	0.00	0.02	0.04	4.4172	0.9000292	0.59
2014	5.31	0.52	0.00	0.00	0.01	0.04	3.2830	0.90556675	0.54
2015	5.59	0.45	0.00	0.00	0.01	0.04	3.6955	0.90162781	0.49
2016	5.49	0.43	0.00	0.00	0.01	0.04	3.6587	0.87121045	0.48
2017	6.14	0.43	0.00	0.00	0.01	0.03	4.3426	0.85558482	0.47
2018	5.78	0.42	0.00	0.00	0.01	0.03	3.9934	0.85051367	0.47
2019	7.16	0.48	0.00	0.00	0.01	0.04	5.1301	0.96427759	0.53

Table 4-31 - Implied CO2 Emission factors for Category 2.D.3.1 Solvent and Other Product Use 1990–2019.

SNAP	060101	060102	060103	060104	060105	060107	060108
Unit	kg/Mg Solvent						
1990	2.61	2.57	2.61	2.36	2.39	2.50	1.91
1991	2.42	2.58	2.58	2.29	2.21	2.36	1.66
1992	2.22	2.56	2.52	2.23	2.03	2.21	1.43
1993	2.02	2.52	2.44	2.19	1.86	2.06	1.22
1994	1.82	2.45	2.33	2.19	1.68	1.91	1.03
1995	1.70	2.47	2.30	2.35	1.59	1.84	0.90
1996	1.59	2.33	2.23	2.26	1.50	1.74	0.82
1997	1.60	2.37	2.31	2.32	1.51	1.77	0.81
1998	1.57	2.35	2.35	2.34	1.49	1.76	0.78
1999	1.54	2.33	2.39	2.35	1.47	1.74	0.75
2000	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2001	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2002	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2003	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2004	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2005	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2006	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2007	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2008	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2009	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2010	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2011	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2012	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2013	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2014	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2015	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2016	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2017	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2018	1.53	2.34	2.45	2.39	1.47	1.75	0.73
2019	1.53	2.34	2.45	2.39	1.47	1.75	0.73

SNAP		060201	060202	060203	060204
Unit		kg/Mg Solvent			
1990		2.47	1.10	1.94	1.96
1991		2.25	1.18	1.75	1.98
1992		2.02	1.25	1.56	1.95
1993		1.80	1.29	1.38	1.91
1994		1.58	1.31	1.20	1.83
1995		1.43	1.38	1.08	1.82
1996		1.31	1.34	1.01	1.74
1997		1.29	1.39	1.00	1.79
1998		1.24	1.42	0.98	1.79
1999		1.20	1.44	0.96	1.79
2000		1.16	1.47	0.94	1.80
2001		1.16	1.47	0.94	1.80
2002		1.16	1.47	0.94	1.80
2003		1.16	1.47	0.94	1.80
2004		1.16	1.47	0.94	1.80
2005		1.16	1.47	0.94	1.80
2006		1.16	1.47	0.94	1.80
2007		1.16	1.47	0.94	1.80
2008		1.16	1.47	0.94	1.80
2009		1.16	1.47	0.94	1.80
2010		1.16	1.47	0.94	1.80
2011		1.16	1.47	0.94	1.80
2012		1.16	1.47	0.94	1.80
2013		1,16	1,47	0,94	1,80
2014		1.16	1.47	0.94	1.80
2015		1.16	1.47	0.94	1.80
2016		1.16	1.47	0.94	1.80
2017		1.16	1.47	0.94	1.80
2018		1.16	1.47	0.94	1.80
2019		1.16	1.47	0.94	1.80

SNAP		060305	060306	060307	060308	060309	060310	060311	060312	060314
Unit		kg/Mg Solvent								
1990		2.88	0.99	2.77	1.78	2.68	0.03	2.18	2.11	1.40
1991		2.88	0.90	2.46	1.61	2.45	0.03	2.23	2.11	1.32
1992		2.85	0.80	2.09	1.38	2.11	0.03	2.22	2.09	1.23
1993		2.81	0.71	2.24	1.49	2.27	0.03	2.19	2.07	1.15
1994		2.75	0.61	2.23	1.47	2.24	0.03	2.12	2.05	1.06
1995		2.79	0.54	2.71	1.76	2.65	0.03	2.13	2.14	1.02
1996		2.66	0.52	2.49	1.62	2.45	0.03	2.05	2.04	0.95
1997		2.71	0.54	2.77	1.80	2.72	0.03	2.12	2.09	0.95
1998		2.72	0.54	2.53	1.65	2.50	0.03	2.14	2.11	0.93
1999		2.73	0.54	2.34	1.53	2.32	0.03	2.15	2.13	0.91
2000		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2001		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2002		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2003		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2004		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2005		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2006		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2007		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2008		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2009		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2010		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2011		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2012		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2013		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2014		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2015		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2016		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2017		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2018		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89
2019		2.77	0.55	2.69	1.78	2.68	0.03	2.18	2.19	0.89

SNAP	060403	060404	060405	060406	060407	060408	060411	060412
Unit	kg/Mg Solvent							
1990	1.98	0.66	2.55	2.70	1.89	1.87	2.15	2.13
1991	1.88	0.67	2.42	2.72	1.95	1.92	2.19	1.98
1992	1.77	0.66	2.29	2.69	1.96	1.92	2.19	1.82
1993	1.66	0.65	2.16	2.66	1.96	1.89	2.17	1.67
1994	1.54	0.64	2.02	2.59	1.93	1.82	2.11	1.52
1995	1.49	0.66	1.97	2.61	1.96	1.82	2.12	1.43
1996	1.41	0.63	1.86	2.51	1.88	1.74	2.04	1.36
1997	1.43	0.64	1.88	2.58	1.94	1.79	2.10	1.37
1998	1.42	0.65	1.86	2.60	1.96	1.80	2.11	1.36
1999	1.40	0.65	1.84	2.61	1.98	1.80	2.12	1.35
2000	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2001	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2002	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2003	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2004	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2005	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2006	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2007	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2008	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2009	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2010	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2011	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2012	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2013	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2014	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2015	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2016	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2017	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2018	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35
2019	1.40	0.66	1.84	2.65	2.03	1.82	2.15	1.35

4.5.3.1.5 Uncertainties and time-series consistency

The error values which are assumed on the various calculations are as given:

- Activity data uncertainty 50%
- Emission factor uncertainty 50%

4.5.3.1.6 Source specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.6) of which important elements include:

- Are the correct values used (check for transcription errors, ...)?
- Check of plausibility of input data (time-series, order of magnitude, ...)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, ...)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, ...
- Are all references clearly made?
- Are all assumptions documented?

Source-specific elements of QA/QC for Solvent and Other Product Use include:

a) Bottom-up checks on:

Input data and emission factors:

- check for the plausibility of the activity data and their trend and check for plausibility of the emission factors as well as the related input data and their trends
- check documentation of the most important reasons for changes and non-changes of activity data
- check if these changes or non-changes of activity data fit to trends of underlying conditions
- if checks do not allow any explanation, further check of the used statistics and their estimates and/or communication with the data providers
- check of input data for completeness

Emissions:

- check the correctness of all equations in the calculation files
- check the correctness of all intermediate results
- check the plausibility of the results and their trends related to activity data and emission factors
- check the correctness of the transfer of all data and results

b) Top-down checks include:

- Comparison of the used activity data with those from other statistics: STATEC publication and EUROSTAT database.
- Comparison of the used activity data with those from relevant plant operators.
- Comparison of the used emission factors and underlying input data with those of other data sources (e.g. from literature, results in NIRs of other comparable regions, IPCC default values).

4.5.3.1.7 Category-specific recalculations including changes made in response to the review process

The method for calculating solvent emissions has been modified. The modifications concern Deicing products and take into account the recent guidelines elaborated in the EMEP/EEA air pollutant emission inventory guidebook 2019. While previously, emission from deicing products were calculated alongside all other solvents, in the new approach, emissions from deicing products are calculated separately and the emissions are added to the emissions of SNAP category 0604.

GHG source & sink category	Revisions 2019v1 → 2020v1	Type of revision
2.D.3.1	update of data of production statistics, import and export statistics update of emission factors and solvent content update of plant specific, information from associations of industries and statistical data for “general aspects” and “specific aspects” .	updated 2.D.3.1

4.5.3.1.8 Category-specific planned improvements including those in response to the review process

There are currently no planned improvements to IPCC sub-category 2.D.3.1.

4.5.3.2 Road Paving with Asphalt (2D3b)

Previously, emissions from road paving with asphalt were reported in 1A2g^{viii}, and have now been moved to 2.D.3.1. An overview of road paving with asphalt related NMVOC emissions is provided in the following table:

Road Paving with Asphalt			
year	Activity Data (kt) Asphalt produced	Emissions (t) NMVOC	Implied Emission Factors (kg/t asphalt)
1990	608.880	0.009	15.000
1991	529.120	0.008	15.000
1992	583.052	0.009	15.000
1993	455.934	0.007	15.000
1994	864.349	0.013	15.000
1995	452.471	0.007	15.000
1996	684.634	0.010	15.000
1997	623.154	0.009	15.000
1998	555.976	0.008	15.000
1999	859.039	0.013	15.000
2000	827.880	0.012	15.000
2001	740.321	0.011	15.000
2002	722.684	0.011	15.000
2003	1200.022	0.018	15.000
2004	539.700	0.004	8.259
2005	560.490	0.005	8.457
2006	564.883	0.005	8.249
2007	630.567	0.005	7.211
2008	606.886	0.004	7.076
2009	688.418	0.003	4.197
2010	627.093	0.003	4.281
2011	783.181	0.005	5.836
2012	703.165	0.004	6.217
2013	607.814	0.004	6.208
2014	690.515	0.005	7.377
2015	607.760	0.004	6.832
2016	768.686	0.005	6.086
2017	685.024	0.005	6.639
2018	671.173	0.026	39.003
2019	642.210	0.028	43.426
Trend 2018-2019	-4.32%	6.53%	11.34%
2005-2019	14.58%	488.39%	413.52%
1990-2019	5.47%	205.35%	189.50%

As CO emissions are considered negligible (IPCC guidelines 2006, Volume 3 Industrial Processes and Product Use, 5.4 Asphalt Production And Use) they were not estimated.

4.5.3.3 Asphalt Roofing (2D3c)

This source category does not exist in Luxembourg.

4.5.3.4 Urea-based catalysts (2.D.3.2)

4.5.3.4.1 Source category description

In 2019, CO₂ emissions resulting from the use of urea-based catalysts in SCR-equipped vehicles was responsible for 2.01% of GHG emissions CO₂e from industrial processes and product use and for 0.13% of the total GHG emissions in CO₂e (excluding LULUCF). Compared to 2018, emissions increased by 4.93% to reach 13.57 Gg CO₂ in 2019. An overview of the related CO₂ emissions is provided in

Table 4-32.

2.D.3.2 – Urea-based catalysts is not a key source with regard to CO₂ emissions.

Table 4-32 - CO₂ emissions trend, activity data and IEFs for IPCC sub-category 2.D.3.2 – Urea-based catalysts: 1990-2019.

2D3 - Urea-based catalysts			
Year	activity data (t)	CO₂ emissions (Gg)	implied emission factor (t CO₂/t)
1990	NO	NO	NA
1991	NO	NO	NA
1992	NO	NO	NA
1993	NO	NO	NA
1994	NO	NO	NA
1995	NO	NO	NA
1996	NO	NO	NA
1997	NO	NO	NA
1998	NO	NO	NA
1999	NO	NO	NA
2000	NO	NO	NA
2001	NO	NO	NA
2002	NO	NO	NA
2003	NO	NO	NA
2004	NO	NO	NA
2005	4'795	1.14	0.238
2006	11'751	2.80	0.238
2007	20'200	4.81	0.238
2008	30'282	7.22	0.238
2009	31'404	7.48	0.238
2010	39'386	9.39	0.238
2011	44'154	10.52	0.238
2012	42'577	10.15	0.238
2013	44'916	10.71	0.238
2014	44'300	10.56	0.238
2015	42'830	10.21	0.238
2016	43'759	10.43	0.238
2017	47'953	11.43	0.238
2018	54'280	12.94	0.238
2019	56'955	13.57	0.238
Trend 1990-2019	NA	NA	
Trend 2018-2019	4.93%	4.93%	

Total sales volumes or import/export data for urea-based catalysts are not available for Luxembourg. Therefore the NEMO model (details in Chapter 3.2.9.3.2.2) was used to estimate the consumption of AdBlue® by SCR-equipped vehicles (domestic and transiting/commuting fleet). Urea-based catalysts have been consumed by heavy duty vehicles since 2005 (EURO IV and higher) and since 2013 also by passenger cars (EURO 6).

4.5.3.4.1.1 Methodology

CO₂ emissions from urea-based catalysts used in SCR-equipped vehicles are calculated separately by the NEMO model (described in chapter 3.2.9.3.2.2.). This approach considers the specific operating condition of the SCR exhaust gas after-treatment system in any driving condition¹⁰⁰. The calculation is based on the assumption that one mole of urea generates one mole of CO₂ and converts 0.9 mole of NO_x as illustrated by Equation 4-1.

¹⁰⁰ Rexeis M., Schwingshackl M., Dippold M., Hausberger S.: Emissionen aus Kalt- und Kühlstarts sowie aus AdBlue-Verwendung in SCR-Katalysatoren von Lkw, LNF, 2-Rädern sowie von mobilen Maschinen. Erstellt im Auftrag des Umweltbundesamtes GmbH. Bericht Nr.: I-24/201313/Rex Em 11/2013-679 vom 16.9.2013

Equation 4-1: Formula used by the NEMO model to determine CO₂ emissions from the use of AdBlue® in SCR-equipped vehicles.

$$\text{CO}_2 [g] = \frac{(\text{NO}_{x,\text{EO}} - \text{NO}_{x,\text{TP}})[g]}{\left(46 \frac{g}{\text{mol}}\right)} \cdot \left(\frac{1}{1 - s_{\text{NH}_3,\text{loss}}}\right) \cdot \left(\frac{1}{2}\right) \cdot \left(44 \frac{g}{\text{mol}}\right)$$

molar mass NO₂
CO₂ / NH₃ mole ratio
molar mass CO₂

With:

NO_{x,EO}: NO_x emissions (in NO₂ mass equivalent) at engine out

NO_{x,TP}: NO_x emissions (in NO₂ mass equivalent) at tailpipe

s_{NH₃,loss}: share of NH₃ losses caused by NH₃ slip through SCR catalyst without NO_x conversion and by NH₃ not generated from urea. The value used for s_{NH₃,loss} is 10% (expert judgment by IVT Graz).

4.5.3.4.1.2 Emission factors

The CO₂ implied emission factor for urea-based catalysts is 0.238 t/t for the entire timeseries. This is equivalent to the default emission factor proposed in the IPCC guidelines¹⁰¹.

4.5.3.4.2 Uncertainties and time-series consistency

The uncertainty for activity data is estimated to be +/-20% (expert judgement by TU Graz, 2015). The timeseries is considered to be consistent.

4.5.3.4.3 Source-specific QA/QC and verification

There are no statistical recordings of activity data for AdBlue®.

The emission factor used by the NEMO model was compared to the default value proposed in the IPCC guidelines.

101 2006 IPCC Guidelines, Volume 2, Chapter 3, p. 3.12

4.5.3.4.4 Category-specific recalculations including changes made in response to the review process

NO_x emissions factors have been update for non-road mobile machinery (1.A.2.g.vii, 1.A.3.c, 1.A.4.c.ii), as such the emissions for the years 2014 to 2018 have been revised.

4.5.3.4.5 Category-specific planned improvements including those in response to the review process

There are currently no planned improvements to IPCC sub-category 2.D.3.2.

4.6 Electronics industry (2.E)

4.6.1 Integrated circuit or semiconductor (2.E.1)

This source category does not exist in Luxembourg.

4.6.2 TFT flat panel display (2.E.2)

This source category does not exist in Luxembourg.

4.6.3 Photovoltaics (2.E.3)

This source category does not exist in Luxembourg.

4.6.4 Heat transfer fluid (2.E.4)

This source category does not exist in Luxembourg.

4.6.5 Other (as specified in table 2(II)) (2.E.5)

4.7 Product uses as substitutes for ODS (2.F)

Consumption of Halocarbons and SF₆ (2F)

The following sources have been identified:

- Refrigeration and air-conditioning (2.F.1)
 - Commercial refrigeration
 - Domestic refrigeration
 - Industrial refrigeration
 - Transport refrigeration
 - Mobile air-conditioning
 - Stationary air-conditioning
- Foam blowing agents (2.F.2)
 - Closed cells
 - Open cells
- Fire protection (2.F.3)
- Aerosols (2.F.4)
 - Metered dose inhalers
 - Other (please specify - one row per substance)
- Solvents (2.F.5)
- Other applications(9) (2.F.6)
 - Emissive
 - Contained

4.7.1 Source category description

This section describes the estimation of products uses as substitutes for ODS resulting from industrial processes (production, consumption). In 2019, this category represented 8.81% of the GHG emissions in CO₂e from industrial processes and 0.55% of the total GHG emissions in CO₂e (excluding LULUCF). This percentage was only 0.15% in 1995. As shown in Figure 4-12, the related emissions experienced an increase between 1995 and 2019 (+293%). Compared to 2018, emissions decreased by 1.10 % to attain the level of 59.48 Gg CO₂ in 2019. This reduction is mainly due to the Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006. The regulation restricts and bans the usage of various F-gases popularly used in stationary refrigeration and air conditioning, as such the amount of F-gases on the market was reduced and prices increased strongly. The impact of these restrictions becomes visible in 2014 and 2015, which show increases due to stock increment and system refillments being done before the entry into force of the restrictions. These is followed by a decline. Both observations are corroborate with the general observations made by the European Environmental Agency in their F-gas report No 20/2017. The decrease will gradually continue as suppliers are in possession of ample stocks and prices continue to increase. Furthermore, the Directive 2006/40/EC of the European parliament and of the council of 17 May 2006 prohibits new passenger vehicles to use air-conditioning system designed to contain fluorinated greenhouse gases with a global warming potential higher than 150. As such, most manufactures have switched from R134a (GWP=1430) to R1234yf (GWP=4), and as mobile air condition from passenger vehicles represents the biggest source of emissions in 2.F, a decline in emissions can be observed starting in the year 2016.

F-gas emission estimates are presented in Table 4-33.

Figure 4-12 – GHG emission trends for CRF Sector 2F – HFCs: 1990-2019

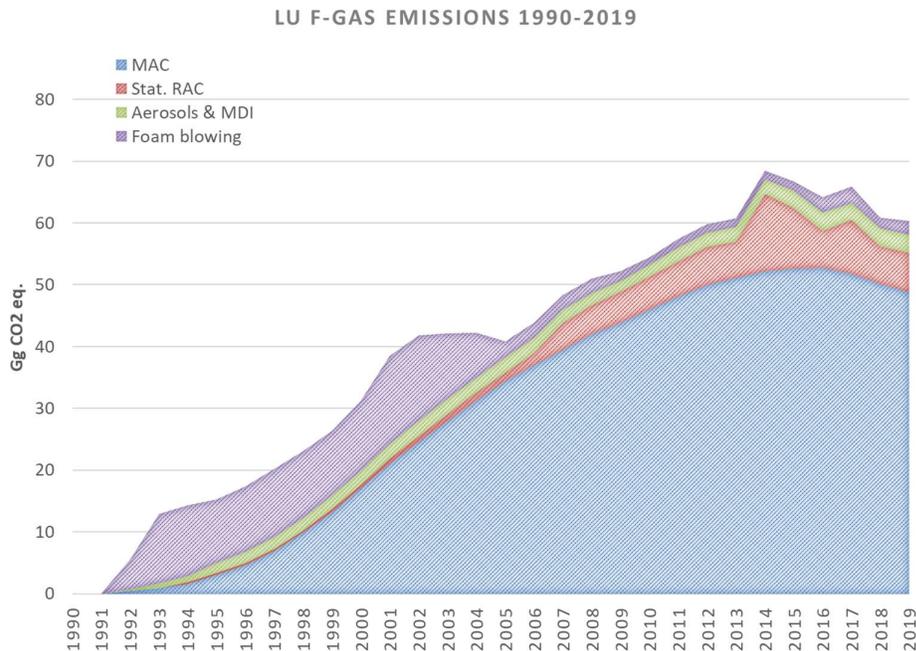


Table 4-33 – Estimated emissions of HFCs: 1990-2019

Year	2F -Product uses as substitutes for ODS	2F1 - Refrigeration and Air Conditioning Equipment (HFC)	2F1 - Stationary refrigeration and air conditioning	2F1 - Mobile refrigeration and air conditioning	2F2 - Foam Blowing (HFC)	2 F4 - Aerosols/ Metered Dose Inhalers (HFC)
	Gg CO ₂ e					
1990	0.00	0.00	0.00	0.00	0.00	0.00
1991	0.00	0.00	0.00	0.00	0.00	0.00
1992	5.49	0.47	0.02	0.45	4.79	0.23
1993	12.94	0.90	0.03	0.87	11.34	0.70
1994	14.19	1.76	0.16	1.60	11.45	0.99
1995	15.15	3.28	0.17	3.11	10.22	1.65
1996	17.33	4.90	0.21	4.69	10.63	1.80
1997	20.10	7.15	0.24	6.91	11.02	1.92
1998	22.96	10.13	0.26	9.86	10.79	2.04
1999	26.21	13.63	0.37	13.26	10.42	2.15
2000	31.08	17.46	0.42	17.04	11.36	2.27
2001	38.25	21.68	0.63	21.04	14.21	2.37
2002	41.51	25.28	0.69	24.59	13.82	2.41
2003	41.75	28.75	0.85	27.90	10.53	2.46
2004	41.93	32.21	0.95	31.26	7.31	2.40
2005	40.47	35.47	1.08	34.39	2.54	2.46
2006	43.37	38.38	1.36	37.02	2.53	2.45
2007	47.76	43.23	3.76	39.47	2.41	2.12
2008	50.25	45.97	3.98	41.99	2.35	1.93
2009	51.40	48.12	4.25	43.87	1.55	1.73
2010	53.67	50.49	4.52	45.97	1.23	1.95
2011	56.55	52.95	4.83	48.12	1.33	2.27
2012	58.91	55.29	5.38	49.91	1.40	2.22
2013	59.89	56.16	5.08	51.08	1.39	2.34
2014	64.94	61.19	9.02	52.17	1.43	2.32
2015	64.74	60.40	7.78	52.62	1.54	2.80
2016	63.14	57.73	4.95	52.78	2.43	2.99
2017	63.68	58.37	6.64	51.73	2.71	2.61
2018	60.14	55.55	5.44	50.11	1.63	2.96
2019	59.48	54.39	5.62	48.78	2.22	2.87
Trend						
Trend 1995-2019	293%	1557%	3111%	1470%	-78%	74%
Trend						
Trend 2018-2019	-1.10%	-2.08%	3.26%	-2.66%	35.68%	-3.12%

Source: Environment Agency

2F1 – Refrigeration and air conditioning is a key source with regard to F-gas emissions for the years 2014 and 2015: see Table 4-2 in Section 0.

Finally, although Luxembourg now reports emissions from 1990 onwards, it should be highlighted that 1995 was chosen as the base year for HFCs.

4.7.1.1 Methodology

The emissions of fluorinated greenhouse gases in Luxembourg were thoroughly re-assessed in 2014 in order to assure compliance with the 2006 IPCC reporting guidelines, to streamline data acquisition and processing, to include previously neglected applications and sub-applications, and to increase transparency of emissions estimations.

Generally speaking, the estimations of emissions in Luxembourg are based on emission-factor approaches. Due to highly incomplete records of chemical sales data (Econotec consultants 2010, importers inquiry 2014), mass-balance approaches are mostly inapplicable. Emission factors are predominantly derived from regional to global estimates. In some cases, it was possible to calculate country-specific emission factors. Activity data consisted in direct emission records (e.g. refrigeration manufacturing, industrial and commercial refrigeration), country-specific life-cycle approach data (e.g. mobile air conditioning) or, in the absence of country-specific records, regionally derived data (e.g. aerosols). For the first time, emissions from fluorinated ethers used as anaesthetics are estimated for Luxembourg as complementary information. Note, however, that fluorinated ethers are not among the mandatory sources of greenhouse gas emissions to be reported under the 2006 IPCC Reporting Guidelines, and were thus excluded from Luxembourg halocarbon and SF₆ emissions compilations. In the medical applications considered here, fluorinated ethers are completely emitted after use. Thus, consumption of fluorinated ethers was considered equal to emission. The used Tier method for each application is given in the following table:

Application sub-application subdivision	Method
Sub-application	
Subdivision	
Refrigeration and air conditioning	Tier 2a/3
Mobile air conditioning (MAC)	Tier 2a
Car MACs	Tier 2a
Bus and coach MACs	Tier 2a
Truck MACs	Tier 2a
Tractor and engine MACs	Tier 2a
Rail vehicle MACs	Tier 2a
Refrigerated transport	Tier 2a
Stationary refrigeration and air conditioning	Tier 2a/3
Fridge production	Tier 2a
Commercial and industrial refrigeration	Tier 2a/3
Residential and commercial air conditioning	Tier 2a/3
Aerosols	Tier 2a
Metered dose inhalers (MDI)	Tier 2a
Other aerosols	Tier 2a
Foam blowing	Tier 1
Electrical switchgear	Tier 2a
Particle accelerator	Tier 1
Manufacture solvents	Tier 3
Soundproof windows	Tier 2a

4.7.1.1.1 Refrigeration and air-conditioning (2.F.1)

The following sub-applications have been identified:

- Fridge production
- Commercial and industrial refrigeration
- Stationary air conditioning
- Refrigerated transport
- Mobile air conditioning:
 - cars
 - buses
 - trucks
 - trains
 - agricultural and construction engines

Domestic refrigeration plays no significant role here. In fact, , the share of domestic fridges containing fluorinated greenhouse gases has been very low in Luxembourg since 1995, and considering an average refrigerant charge of 0,1 kg and an operation emission factor of 0,3% (Schwarz 2005), emissions from the domestic refrigeration sub-application are, indeed, negligible and therefore omitted here.

Fridge production: A single fridge production plant, run by Dometic S.à.r.l., is currently being exploited in Luxembourg. The equipment produced is predominantly used for medical and other non-domestic purposes. Almost the entire production (99.5%) is exported. Thus, the only relevant emissions to be considered are those occurring during manufacture.

On the basis of a six month emissions survey by Dometic in 2006, a manufacture emission of 2 kg of R134a was calculated for 2006. The manufacture emission was reinvestigated with the producer in 2018, after which it was determined to be equal to the value of 2006, thus amounting to 2kg, based on the activity data. The resulting manufacture emissions factor was extrapolated to the years before and after 2006. Discussions with the fridge manufacturer revealed that an additional source of emission are accidental releases, which for 2017, as an example, amounted to a total of 1.4kg, as measured by the manufacturer. These emissions are accounted for in the total emission resulting from fridge production.

Commercial and industrial refrigeration: As part of the obligations introduced by Regulation (EC) No 842/2006 of the European Parliament and of the Council of 17 May 2006 on certain fluorinated greenhouse gases, leak checks are to be performed regularly for all equipment containing at least 3 kg of fluorinated greenhouse gases (The regulation No 842/2006 has meanwhile been replaced by the regulation 517/2014, which continues to impose leak checks). Luxembourgian legislation requires the reports of the leak checks to be transmitted to the authorities at the Luxembourg Environmental Agency. Since almost all non-domestic refrigeration and air conditioning devices contain more than 3 kg of refrigerant, the leak tightness reports contribute to an extensive database covering almost the entire sector. This database was used as a basis for the emissions estimations. In order to account for the refrigeration devices containing less than 3 kg of refrigerant and thus not covered by the leak detection database, all emission values were increased by 10%, which was assumed to adequately represent the share of the devices in question taking into account their low individual charges.

Given the nature of the information provided by the leak detection reports, stand-alone commercial refrigeration, medium and large commercial refrigeration and industrial refrigeration were lumped as commercial and industrial refrigeration.

In previous years, the record of leak detection reports was too patchy to be used as source of evidence. Significant efforts were made since to achieve a more thorough enforcement of the reporting obligation, with the result that a much more complete database is available. In order to test for the exhaustiveness of the reports, the retail refrigeration sector was chosen as a model system. In fact, the number of supermarkets and retail stores can be easily monitored, in contrast to the number of buildings equipped with air conditioning for example. Comparison with the leak detection coverage of the retail sector then provides an estimation of the database completeness.

A total of 65,8% of the retail sector existing at the end of 2013 (except for small shops at service stations which mostly lack devices containing more than 3 kg of refrigerant) are covered by a leak detection report for 2013. Subtracting supermarkets equipped with refrigeration devices exclusively using natural refrigerants, accounting for an estimated 18% of the Luxembourgian retail sector, a completeness of 72% can be assumed. The remaining 28% are extrapolated in the present emissions estimations. The 72% completeness quota is extended to all other refrigeration and air conditioning sub-applications covered by the leak inspection database, provided that the retail sector is representative in terms of reports exhaustiveness. Completeness has been revaluated for the years 2014 (80%), 2015 (89%), 2016 (95%) and 2017 (100%).

Assuming a life span of 20 years per device (Schwarz 2005), the evolution of the refrigeration equipment population could be approximated rather faithfully. All equipment constructed before 1993 is assumed to have been converted to hydrofluorocarbon (HFC) refrigerants in 1993 (which approximates the time of introduction of the HFCs as alternatives to the ozone depleting refrigerants), and the respective HFC charges to have entered the population in 1993. The charges of the devices for which the leak inspection reports provided no year of construction were totalled, divided by the number of years since the first appearance of the respective refrigerant in the Luxembourgian refrigeration population and added to the charges of the years in question. These measures are deemed temporary awaiting improvement of the reporting accuracy.

The non-domestic refrigeration sector presents an overwhelming span of refrigerant charges, ranging from a few kilograms to more than half a metric ton. Thanks to the leak inspection reports which indicate the charge of the device checked, the total amount of refrigerant being used in a particular year can be directly monitored rather than approximated on the basis of average refrigerant charges. In combination with the year of manufacture as indicated by the tightness reports and an assumed 20 years life span, the total amount of refrigerant entering the Luxembourgian refrigeration device population per year can be directly monitored as well.

Leak inspection reporting precisely indicates the amount of refrigerant emitted per device. As a result, operation emissions could be directly monitored rather than implied through application of an emission factor, at least since 2012 when the database attained satisfying completeness. On the basis of the total amount of refrigerant used per year and the total amount of refrigerant emitted during operation in the same year, implied emission factor were calculated for individual refrigerants and applied to the respective pre-2012 stocks.

Emissions during manufacture and decommissioning: Most of the non-domestic refrigeration devices are assembled (or at least filled with refrigerant for the first time) and decommissioned in Luxembourg. Since the share of pre-filled importations and decommissioned but non-emptied exportations is unknown, is assumed.

Unfortunately, the leak inspection reports provide no insights on emissions during manufacture and decommissioning. In line with the default emission factors of the 2006 IPCC reporting guidelines for developed countries, and assuming a conservative 100 % rate of

manufacture and decommissioning of equipment in Luxembourg, a manufacture emission factor of 0,5 % and a decommissioning emission factor of 30 % were adopted. Furthermore, decommissioned equipment is exported to neighbouring countries, as such a part of the decommissioning process does not take place in Luxembourg.

Stationary air conditioning: Since data on residential and commercial air conditioning are extracted from the same leak inspection database as the data on commercial and industrial refrigeration, the approaches employed were the same. In line with the default emission factors of the 2006 IPCC reporting guidelines for developed countries, and following an analysis by various experts from the field, a manufacture emission factor of 0,2 % and a decommissioning emission factor of 20 % were adopted. Furthermore, decommissioned equipment is exported to neighbouring countries, as such a part of the decommissioning process does not take place in Luxembourg.

Refrigerated transport (RT): As a result of the recent re-assessment of fluorinated greenhouse gas emissions, annual registration figures of RT vehicles for the years 1995-2016 were acquired. No data exist for the years 1990-1994, as such the data was extrapolated based on the data of the years 1995-2014. The here-employed approach is based on the weight-class-specific characteristics used by Schwarz (2005) for the German model combined with Luxembourg-specific registration figures and the relative shares of the weight classes. In order to comply with this model, relative shares of weight classes in the Luxembourgian general truck and van population were applied to annual RT vehicle registrations data. The average life span of a RT vehicle is assumed to equal seven years.

Manufacture and decommissioning of RT equipment does occur in Luxembourg but at a very low level compared to importations and exportations (Carrosserie Comes & Cie 2014). Corresponding emissions are thus considered negligible.

Evolution of the RT vehicle population: are undifferentiated in terms of weight class. by Schwarz (2005), who subdivided German RT vehicles into the classes < 2 - 5 t, 5 - 9 t, 9 - 22 t and > 22 t. These shares are assumed to approximate the composition of the Luxembourgian RT vehicle population. As for the truck MAC model,

Refrigerant type and average charge per RT vehicle: Schwarz (2005) elaborated a model taking into account the average charge per vehicle for each weight class and the respective shares of the predominantly used refrigerants (R134a, R404A and, since 1997, R410A):

Refrigerant type, average charge and share in RT equipment for the different weight classes

Weight class	< 2 - 5 t		5 - 9 t		9 - 22 t			> 22 t	
Refrigerant	134a	134a	404A	134a	404A	410A	410A	134a	404A
Average charge (kg)	2,0	2,5	2,5	5	4	4	9	6,75	6,75
Share	100 %	50 %	50 %	10 %	10 %	80 %	10 %	5 %	85 %

Since no country-specific data in this respect were available and since there was no reason to assume that the Luxembourgian situation significantly deviates from the German one, the model by Schwarz (2005) was applied to the Luxembourgian RT vehicle population.

Given the exclusively commercial use of RT vehicles and the often highly temperature-sensitive freight, thorough and regular technical maintenance is assumed, implying a 100 % filling level. RT vehicles were assumed to leave the population with a filling of 85 %, in line with the annual loss through operation emission of 15 % (Schwarz 2005).

Mobile air conditioning (MAC):

Car MACs: In spite of relatively low average refrigerant charges (generally less than 1 kg), car MACs count among the most important sources of fluorinated greenhouse gas emissions. Luxembourg is no exception in this respect, considering its large and comparatively modern and thus well-equipped car population. A noteworthy particularity, however, is the lack of car manufacture and decommissioning facilities. All new cars are imported and almost all used cars are exported before scrapping. As a result, the only emissions to take into account for the Luxembourg car MAC sector are operation emissions.

The number of newly entering cars is provided as the number of new registrations by the STATEC records. The mean lifespan of a car in Luxembourg was found to be approximately 7 years by Econotec consultants (2010). Given the similarity between the Luxembourgian and the German car populations, the evolution of the MAC share suggested by Schwarz and Fischer (2009) is adopted here and considered to have reached saturation at 96% since 2005.

Schwarz (1996, 2005) traced a continuous decrease in the average refrigerant charge per car between 1992 until 2002, as a result of an increasing number of smaller cars being equipped with MAC but also as a result of technical progress. For the trend beyond 2002, the data provided by Clodic (2006) was used and extrapolated. Here, advantage is taken of the brand-specific STATEC record of new registrations for the years 2005 until 2012, combined with the Behr Hella Service GmbH (2012) record of refrigerant charges per car model. Individual charges were averaged per brand, considering the models manufactured between 2005 and 2012. The average refrigerant charge per brand was then used in combination with the share of the individual brands in the Luxembourgian car population to calculate the average refrigerant charge per car of the Luxembourgian population for each year from 2005 to 2012.

The country specific results document a slight decrease from 654 g per car in 2005 to 647 g in 2009, followed by a slight increase to 652 g per car in 2012. These values are well in line with the trend from 1992 to 2002 (Schwarz 1996, 2005) and a population with a high share of large, high-capacity cars. Unless significant shifts in the brand-specific composition of the population occur, the 2012 value of 652 g per car was here considered to hold true for 2013, at least preliminarily (see below).

During the first two years following manufacture, annual refilling of car ACs was assumed for guarantee service reasons. During the following years, car ACs were assumed to be only refilled when considered necessary, i.e. upon tangibly reduced performance. As shown by Clodic (2006), car AC performance only drops after the loss of approximately half of the refrigerant. With an annual regular emission rate of 8,8 % (see below), and a mean life span of seven years, cars in Luxembourg can be assumed to be exported before refilling after the two years guarantee is deemed necessary. In order to take this refilling pattern into account, an average filling level of 81 % is assumed, resulting from two years of 100 % filling, followed by five years of continuous loss without refilling. For the same reason, cars leaving the population after seven years are assumed to contain 59 % of the original refrigerant charge.

Schwarz (2007) used an operation emission factor of 10 %, resulting from an empirically determined factor of 8,8 % for intact ACs taking into account leakage from defective systems. Since there is no reason to assume that the Luxembourgian car population significantly differs from the car population used to determine the operation emission factor, the 10 % value is adopted here.

As a result of the EU MAC Directive (Directive 2006/40/EC of the European Parliament and of the Council of 17 May 2006 relating to emissions from air-conditioning systems in motor vehicles and amending Council Directive 70/156/EEC) banning refrigerants with a GWP exceeding 150 for ACs of newly registered car types, with a temporary exemption until 31 December 2012 (European Commission 2012), 5 % of all newly registered cars with an AC in 2013 were assumed to use a refrigerant other than R134a (such as R1234yf) and were thus excluded from the emissions estimations. The 5 % assumption results from expert judgment implying an average 10 years

life span of a car type and taking into account the resilience of certain car manufacturers to abandon R134a. This population was estimated to have increased over time as such values correspond to 15% for 2014, 25% for 2015, 55% for 2016, 94% for 2017 and, starting in 2018, 100%.

Bus and coach MACs: Emissions estimations for bus and coach MACs are basically similar to those of car MACs, with a few exceptions. As for cars, no manufacturing or decommissioning activities take place in Luxembourg. Accordingly, no manufacturing or decommissioning emissions are to be taken into account. The average life span of buses and coaches in Luxembourg was found to evolve around 7 years, as suggested by expert judgment from bus company representatives.

The bus operating companies furthermore confirmed that the vast majority of buses and coaches operated since 1995 have been equipped with MAC. One operator reached the 100 % MAC quota for his bus population in 1997, starting with 25 % in 1995, and a second one had no bus with MAC in 1995, reaching the 100 % quota only in 2007. As a result, a MAC quota of 70 % is assumed for the Luxembourg bus and coach population in 1995, increasing to 80 % in 1997 and then gradually increasing to 100 % in 2007. In order to account for the rise of R134a since its introduction in the bus MAC domain in 1993 (Schwarz 2005), an extrapolated quota evolution of 0 % in 1992, 30 % in 1993 and 70% in 1994 was adopted.

Bus and coach MACs contain much higher amounts of refrigerant than car MACs, owing to the much longer pipes. Individual charges, however, vary considerably, depending on the size and the type of the bus. Minibuses generally contain around 2 kg of refrigerant per vehicle, while the large high standard coaches require 15 kg of refrigerant. According to the information provided by the bus companies in Luxembourg, however, even within the same type of standard 14 m coach, charges range from 4,9 kg to 15 kg per vehicle, depending on technical specificities. Buses with separate conductor air conditioning for example generally contain more refrigerant.

In order to account for the high diversity of refrigerant charges per vehicle, an average value of 10 kg is adopted here, in line with the estimated average provided by the bus companies. Minibuses were assumed to range among the bus and coach figures rather than the car estimations. Although this is likely to result in overestimated emission values, a conservative approach is warranted in the absence of a more type-specific bus and coach population survey.

According to the bus company representatives, MACs of buses and coaches are generally refilled every year. In some cases, annual refilling is even part of maintenance obligations imposed by the manufacturers. This implies a 100 % filling level from registration to removal from service. Buses are assumed to leave the population with a 86 % filling level, in line with an annual loss of 14 %.

Figures of refrigerant consumption for maintenance provided by the bus companies suggest annual operation emission factors between 10 and 14 %. Ökorecherche (2007) found operation emission rates of 15 % for older buses and 13,7 % for younger ones (registered after 2000). An emission factor of 14 % is therefore adopted here to account for both the published figures and the empirical data provided by operators.

Truck MACs: Truck MACs follow the same principles of emissions estimations as car and bus/coach MACs. Again, only operation emissions are relevant in the case of Luxembourg. Estimations were based on a subdivision in three weight classes (vans, small trucks, large trucks) with individual MAC quota, refrigerant charge and operation emission factor figures respectively, following the model employed by Schwarz (2005).

Data on new weight-class specific truck registrations are extracted from the STATEC database. For the years since 1997, registration figures are subdivided into several weight classes. For the years before 1997, the trend of the relative shares in new registrations of the three weight classes of Schwarz (2005) is extrapolated to the weight-unspecific truck and van registrations of the respective years. In the absence of specific data, an average life span of seven years is assumed for trucks, in analogy to the car and bus/coach models.

Schwarz (2005) provided MAC quota figures for all three truck weight classes in Germany for the years 1993-2002. For the large trucks, the trend seems to meaningfully reflect the situation in Luxembourg and is therefore applied here in the absence of country-specific data. MAC quota figures after 2002 are extrapolated to attain a hypothetical saturation value of 90 % in 2005.

Since the equipment standard of the Luxembourgian vehicle population is generally above the European average, MAC quota figures for smaller trucks and vans provided by Schwarz (2005) seem too low. Country-specific data could not be collected because the presence or absence of a MAC is not recorded upon registration (SNCT pers. comm.). It was assumed that the MAC quota evolution of smaller trucks in Luxembourg was best reflected by that of the larger trucks. In the case of the vans, in contrast, the same trend as for cars was assumed.

According to Schwarz (2005), refrigerant charges have remained at constant values of 1 kg for small trucks and 1,2 kg for large trucks since 1993. Van MACs, in contrast, have undergone a decrease in refrigerant charge from 1,2 kg in 1993 to 0,85 kg in 2002. In line with the Behr Hella Service GmbH (2012) refrigerant charge data for various vehicle types, a further decrease to 0,8 kg per van by 2013 was adopted. Intermediate values between 2002 and 2013 were interpolated. A truck is assumed to leave the population with an average filling level of 86,5 %, in line with a combined average operation emission factor of 13,5 %.

Due to the predominantly commercial use of trucks, a more thorough and regular technical maintenance than for cars was assumed, resulting in an annual refilling of MACs and thus an effective charge of 100%, except for the last year before leaving the population.

Again, in the absence of country-specific data on refrigerant loss during operation, the emission factors determined by Schwarz (2005) on the basis of a survey on the German truck population were adopted. Vans were assumed to have the same operation emission factor as cars (10 %), as a result of technical similarity. Truck MACs, in contrast, are confronted with longer operation times and higher mechanical stress, and are thus assigned an emission factor of 15 %.

Tractor and engine MACs: Emissions estimations for MACs of tractors and engines (e.g. harvesters) are basically similar to those of truck MACs, with two different categories (tractors and engines) each with individual MAC quotas, refrigerant charges and emission factors. A similar approach to that of truck MACs, including calculation of combined variables, is therefore proposed.

All data on newly registered tractors and engines are extracted from the STATEC database. In the absence of specific data, an average life span of seven years is assumed for tractors and engines, in analogy to the car and bus/coach models.

Data on MAC quota were adopted from Schwarz (2005), who found a very steep rise since the introduction of R134a in the MAC sector to 75 % in 1994 and eventually 95 % in 2002 for engines, and a more gentle and gradual rise to 70 % in 2002 for tractors. These trends were assumed to hold true for the Luxembourgian tractor and engine populations, with pre-1994 data extrapolated to 0 % in 1992 in line with an introduction of R134a as standard MAC refrigerant in 1993 (Schwarz 2005), and post-2002 data assumed constant at 95 % for engines and extrapolated to reach 95 % in 2005 for tractors.

The average refrigerant charges of 1,44 kg per tractor and 1,6 kg per engine provided by Schwarz (2005) were adopted in the absence of country-specific data. Due to the largely commercial use of tractors and engines and the strong seasonal concentration of operation time, technical maintenance was assumed to be more thorough and regular than for cars, resulting in an annual refrigerant refilling and thus a 100 % filling level. Tractors and engines were assumed to leave the population with a filling level of 83 %, in line with an average operation emission factor of 17 % for the combined tractor and engine sector.

No country-specific data on operation emission factors were available, which is why the figures for the German tractor and engine populations provided by Schwarz (2005) (15 % for tractors and 25 % for engines) were adopted.

Rail vehicle MACs: Detailed annual data on rail vehicles with MAC entering and leaving the population, indicating individual refrigerant charges, were provided by the sole national railway operator as well as Luxtram

It is assumed that all rail vehicles are subject to regular technical maintenance and thus refilled at least annually, implying a filling level of 100 %.

No construction or dismantling of rail vehicles takes place in Luxembourg. As a result, only emissions during operation are relevant. No country-specific data were available for operation emission factors. Schwarz (2005) used 15 % for German rail vehicles. Since there was no reason to assume a different operation emission factor for Luxembourgian rail vehicles, the 15 % value is adopted.

4.7.1.1.2 Foam blowing agents (2.F.2)

In spite of significant efforts to collect country-specific data, no improvement in the estimation of fluorinated greenhouse gas emissions related to foam blowing could be achieved. In fact, in the absence of a local producer, sales data are the most promising source of data but have remained unavailable by the end of the last re-assessment of emissions estimations. Waste treatment data, including an analysis of household garbage to search for erroneously disposed polyurethane (PU) cans, resulted in unrealistically low consumption figures for PU cans (approximately half the figures of the neighbouring countries). Therefore, as in the previous reports, the PU spray emissions (HFC 134a, HFC 152a) and the extruded polystyrene (XPS) emissions (HFC 134a) are estimated using the reported quantities used per habitant and year in Belgium, Germany as well as France, and their average HFC content, expressed per capita with the relative population in Luxembourg.

4.7.1.1.3 1.8.1.1. Fire extinguisher (2.F.3)

This source category does not exist in Luxembourg.

4.7.1.1.4 Aerosols (2.F.4)

Metered Dose Inhalers (MDI)

Emissions from MDIs were estimated on the basis of country specific data provided by IMS Health for the years 2001 to 2005, indicating the number of doses sold in Luxembourgian pharmacies. The share of doses sold in hospitals was assumed to amount to 5 %, in line with Belgian hospital sales. It was furthermore assumed that R134a was the only fluorinated greenhouse gas used in MDIs sold in Luxembourg, and that each dose contained 75 mg of R134a. For the years before 2001, a gradual ingress of R134a-using MDIs, from the first appearance in 1996 onwards, was assumed, in line with the German MDI evolution (Schwarz 2005). In order to estimate the total number of MDIs sold before 2001 and after 2005 (the period covered by IMS Health data), per capita MDI dose sales for 2001 and 2005 were extrapolated to the pre-2001 and the post-2005 years respectively on the basis of the population evolution. This approach admittedly neglected possible effects of dry powder injection (DPI) as an alternative to MDIs, and of population-independent variations in the number of asthmatic patients. In the absence of robust evidence, however, these factors could not be accounted for in the here-employed model.

In line with the 2006 IPCC reporting guidelines, emissions of MDIs sold in year x are assumed to be emitted at 50 % in the course of year x and at 50 % in the course of the following year x+1.

Other aerosols

No country-specific data on emissions from aerosols other than MDIs could be collected owing to the absence of aerosol manufacturing plants and the unavailability of importation data. As a result, the German per capita aerosol emissions were applied to Luxembourg.

4.7.1.1.5 Solvents (2.F.5)

This source category does not exist in Luxembourg.

4.7.1.2 Uncertainties and time-series consistency

The uncertainties estimated for activity data and emission factors for the different sub-categories are presented in table xx.

Sub-category	AD uncertainty	Explanation/source	EF uncertainty	Explanation/source
2.F.1.a - Commercial refrigeration	25%	AD are taken from AEV's Leak database, uncertainty is based on expert judgement from the administrator of the database	25%	EFs are derived from AEV Leak database, uncertainty is based on expert judgement from the administrator of the database
2.F.1.b - Domestic refrigeration	1%	Data directly received from the only fridge manufacturer.	1%	Data directly received from the only fridge manufacturer.
2.F.1.d - Transport refrigeration	2%	Expert judgement from data provider (SNCA)	25%	Uncertainty expected to be „high“ according to Schwarz (2005)
2.F.1.e - Mobile air-conditioning	2%	Expert judgement from data provider (Statec)	25%	Germany's GHG inventory 2020
2.F.1.f - Stationary air-conditioning	25%	AD are taken from AEV's Leak database, uncertainty is based on expert judgement from the administrator of the database	25%	EFs are derived from AEV Leak database, uncertainty is based on expert judgement from the administrator of the database
2.F.2 - Foam blowing agents	25%	Belgium's GHG inventory 2020	5%	Belgium's GHG inventory 2020
2.F.4.a - Meter dose inhalers	25%	Relatively high uncertainty because data are extrapolated from neighbouring countries	0%	IPCC 2006 Guidelines (EF=100%)
2.F.4.b - Other	25%	Relatively high uncertainty because of different varieties available and because data are extrapolated from neighbouring countries	0%	IPCC 2006 Guidelines (EF=100%)

4.7.1.3 Source-specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.6) of which important elements include:

- Are the correct values used (check for transcription errors, ...)?
- Check of plausibility of input data (time-series, order of magnitude, ...)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, ...)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, ...
- Are all references clearly made?
- Are all assumptions documented?

4.7.1.4 Category-specific recalculations including changes made in response to the review process

2F1 Stationary refrigeration and air conditioning: error in the data calculation has been fixed for the years 2014-2018. 2F2 Foam blowing: data has been revised for the year 2018.

4.7.1.5 Category-specific planned improvements including those in response to the review process

The following improvements to category 2F - *Product uses as substitutes for ODS* are planned, or will be explored for the next submission depending on the availability of data and resources (Table 4-34).

Table 4-34 – Planned improvements for IPCC Category 2F – Product uses as substitutes for ODS

GHG source & sink category	Planned improvement	Recommendation
2F2 – Foam blowing	continue the quest for country-specific data	
2F4 – Aerosols	continue the quest for country-specific data	

4.8 Other product manufacture and use (2.G)

4.8.1 Source category description

This section describes the estimation of F-gas emissions resulting from the category *2.G - Other product manufacture and use* from industrial processes (production, consumption). In 2019, the category 2.G represented 2.52% of the GHG emissions in CO₂e from industrial processes and 0.16% of the total GHG emissions in CO₂e (excluding LULUCF). This percentage was 0.09% in 1995. As shown in Figure 4-13, emissions from category 2.G experienced an increase of 82% between 1995 and 2019. Compared to 2018, emissions decreased by 11.32% to attain the level of 17.02 Gg CO₂ in 2019.

F-gas emission estimates are presented in Table 4-35

Figure 4-13 - GHG emission trends for CRF Sector 2G : 1990-2019

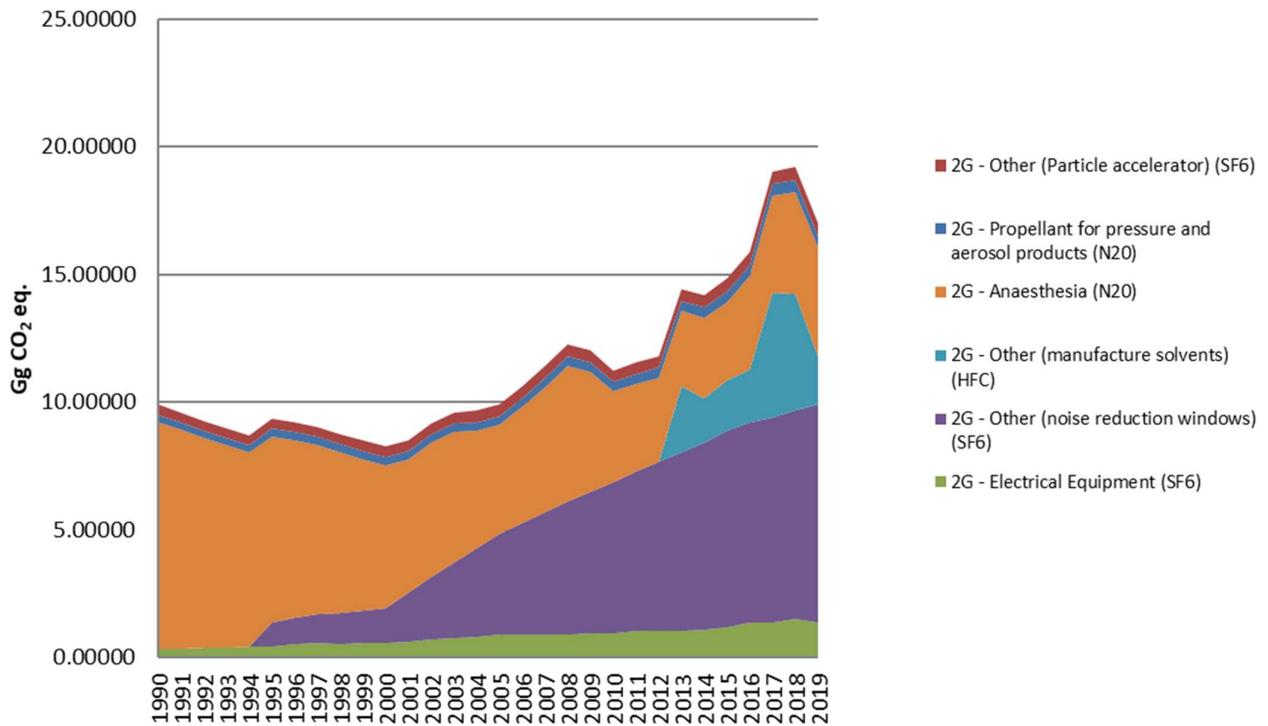


Table 4-35 - Estimated emissions for CRF Sector 2F: 1990-2019

Year	2G - Other product manufacture and use	2G - Electrical Equipment (SF6)	2G - Other Particle accelerator) (SF6)	2G - Other (noise reduction windows) (SF6)	2G - Other (manufacture solvents) (HFC)	2G - Anaesthesia (N ₂ O)	2G - Propellant for pressure and aerosol products (N ₂ O)
	Gg CO ₂ e						
1990	9.91976	0.32674	0.40719	NO	NO	8.9052128	0.2806171
1991	9.60593	0.34959	0.39255	NO	NO	8.5793827	0.2844131
1992	9.28240	0.37386	0.39097	NO	NO	8.2293531	0.2882092
1993	8.98463	0.39985	0.38236	NO	NO	7.91027	0.2921513
1994	8.71001	0.42770	0.38430	NO	NO	7.6018485	0.2961664
1995	9.33518	0.43270	0.36082	0.95677	NO	7.28442	0.3004734
1996	9.20375	0.51693	0.38709	1.04069	NO	6.9546944	0.3043425
1997	9.03438	0.57227	0.40236	1.12486	NO	6.6267596	0.3081386
1998	8.76556	0.54137	0.41702	1.19964	NO	6.2955238	0.3120076
1999	8.51501	0.55880	0.41820	1.26745	NO	5.9540141	0.3165337
2000	8.27579	0.57696	0.43476	1.34875	NO	5.5948431	0.3204758
2001	8.51099	0.64117	0.42650	1.90311	NO	5.2160844	0.3241259
2002	9.17120	0.70499	0.43437	2.44418	NO	5.2604111	0.3272649
2003	9.59544	0.76747	0.43962	2.96457	NO	5.091628	0.332156
2004	9.67268	0.81738	0.44680	3.46503	NO	4.606782	0.3366821
2005	9.91860	0.92638	0.45581	3.92689	NO	4.267062	0.3424492
2006	10.64155	0.90764	0.46490	4.36227	NO	4.559102	0.3476323
2007	11.40428	0.91493	0.47425	4.77710	NO	4.884816	0.3531804
2008	12.27264	0.92546	0.48558	5.17102	NO	5.330326	0.3602615
2009	12.04646	0.95066	0.49661	5.54422	NO	4.688434	0.3665396
2010	11.24579	0.95691	0.42230	5.91369	NO	3.579278	0.3736208
2011	11.54552	1.02907	0.44164	6.27946	NO	3.413888	0.3814642
2012	11.80813	1.04139	0.45364	6.64158	NO	3.281576	0.3899359
2013	14.43382	1.05091	0.46324	7.00007	2.56332	2.972848	0.3834332
2014	14.18309	1.07354	0.47308	7.35498	1.70560	3.166846	0.4090357
2015	14.83382	1.17747	0.48161	7.70781	1.98768	3.058672	0.4205772
2016	15.87019	1.36849	0.48785	7.86449	2.02376	3.696094	0.4295034
2017	19.02777	1.38902	0.49517	8.01960	4.88884	3.797414	0.4377198
2018	19.19654	1.52590	0.50330	8.17316	4.55592	3.9918888	0.4463724
2019	17.02353	1.36900	0.51195	8.54906	1.87944	4.2588312	0.4552489
Trend 1995-2019	82%	216%	42%	794%	NA	-42%	52%
Trend 2018-2019	-11.32%	-10.28%	1.72%	4.60%	-58.75%	6.69%	1.99%

4.8.1.1 Methodology

The emissions of fluorinated greenhouse gases in Luxembourg were thoroughly re-assessed in 2014 in order to assure compliance with the 2006 IPCC reporting guidelines, to streamline data acquisition and processing, to include previously neglected applications and sub-applications, and to increase transparency of emissions estimations.

Generally speaking, emissions estimations in Luxembourg are based on emission-factor approaches. Due to highly incomplete records of chemical sales data (Econotec consultants 2010, importers inquiry 2014), mass-balance approaches are mostly inapplicable.

Emission factors are predominantly derived from regional to global estimates. In some cases, it was possible to calculate country-specific emission factors.

4.8.1.2 Uncertainties and time-series consistency

The error values which are assumed on the various calculations are as given:

- Activity data uncertainty 30%
- Emission factor uncertainty 20%

4.8.1.3 Source-specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.6) of which important elements include:

- Are the correct values used (check for transcription errors, ...)?
- Check of plausibility of input data (time-series, order of magnitude, ...)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, ...)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, ...
- Are all references clearly made?
- Are all assumptions documented?

4.8.1.4 Category-specific recalculations including changes made in response to the review process

For category Propellant for pressure and aerosol products (2.G.3.b) data for the years 2016 and 2017 have been revised.

For category Particle accelerators (2.G.2.b), the category was created following the suggestion made during the Luxembourgish in country review of 2018.

4.8.1.5 Category-specific planned improvements including those in response to the review process

No improvements are planned for category 2G – *Other product manufacture and use*.

4.8.2 Electrical equipment (2.G.1)

One of the major applications of fluorinated greenhouse gases outside the ODS substitute sector (air conditioning and refrigeration, aerosols, etc.) is sulphur hexafluoride (SF₆) used as insulator in electrical switchgears. There are different types of switchgear, in particular depending on the voltage (20 kV, 65 kV and 220 kV), with a high diversity of SF₆ charges per device. In terms of emissions estimation modalities the switchgear can be divided into medium voltage (MV), for 20kV switchgears, and high voltage (HV) devices (65 kV and 220 kV).

In Luxembourg, there is one main operator of electrical switchgear devices (Creos), covering an estimated 80 % of the equipment, and a few smaller operators, four of which provided data on their equipment. As such the data are obtained directly from the operators and cover all HV devices. In order to account for possibly unreported MV equipment, 2 % were added to the reported stock of SF₆ MV equipment.

Individual charges typically vary between less than 1 kg of SF₆ in MV devices to several 100 kg in HV equipment. Data on type-specific charges were provided by the equipment operators.

MV equipment is pre-filled in the manufacture plant, which is not occurring in Luxembourg since all MV devices are imported. HV equipment, in contrast, is filled on site which entails manufacture or initial emissions that are relevant for Luxembourg. Since no reports on the amounts of SF₆ emitted during such operations are available, the figures provided by Schwarz (2005) documenting the evolution of on-site filling emissions of HV equipment in Germany from 1997 to 2002 were used to calculate initial emission factors for Luxembourg for the period in question. The initial emission factors of 1997 and 2002 are extended to the preceding and the following years respectively.

Operation emissions are not reported by the equipment operators, which is why, again, regionally derived factors in line with the 2006 IPCC reporting guidelines and the recommendations of the VDN, VIK, ZVEI and Solvay (2003) report are used. For the MV devices, an operation emission factor of 0,1 % is assumed. For the HV equipment, operation emissions vary depending on the year of manufacture: 0,9 % for devices installed before 1997, 0,8 % for devices installed between 1997 and 2003, and 0,5 % for those installed since 2004. No refilling is assumed to occur over the equipment lifetime.

Emissions at decommissioning are assumed to be relevant only for the HV equipment, and are assumed to amount for 2 % of the initial charge (2006 IPCC reporting guidelines, Schwarz 2005).

4.8.2.1 SF₆ and HFCs from other product use (2.G.2)

Particle accelerators (2.G.2.b)

In Luxembourg, particle accelerators are currently only used in radiation therapy. Due to a lack of data concerning the total amount of SF₆ present in the devices as well as the corresponding refill rates/amounts. The corresponding emissions are based on the reported data of Germany, applied to the Luxembourgish population. The resulting emissions in 2018 correspond to 0.50 Gg CO₂-eq

Noise reduction windows (2.G.2.C)

A life-cycle approach is applied:

$$\text{Emissions} = EF \bullet AR + D$$

The activity rate (*AR*) is the calculated SF₆ stock on the basis of the estimated installed noise reduction windows, based on imported double glassed windows into Luxembourg with noise reduction fraction from Germany. The annual leakage rate of SF₆ is assumed to be 1% (EF=1%) and the lifespan 25 years. Disposal emissions (*D*) of the remaining SF₆ stock occur after a lifetime of 25 years. The resulting emissions in 2018 are 8.17 Gg CO₂-eq.

4.8.3 N₂O from product uses (2.G.3)

4.8.3.1 Medical applications (2.G.3.a)

N₂O emissions from Anaesthesia

In 2019, 0.04% of total GHG emissions (excluding LULUCF) in Luxembourg originated from 2G3 - N₂O emissions from anaesthesia, compared to 0.63% in 1990. Compared to 2018, N₂O emissions from anaesthesia for the year 2019 increased by 6.69% and decreased by 52.18% compared to 1990.

It was assumed that all the N₂O used for anaesthesia is completely released to the atmosphere. Emissions are shown in Table 4-36 and Figure 4-14.

For the period 1990-2002, no data from the hospitals on the consumption of N₂O could be obtained. Hence, N₂O emissions from anaesthesia usage were estimated by combining reported emissions in Germany with the relative population in Luxembourg. From 2003 to 2018, the use of N₂O in hospitals for anaesthesia was directly obtained from the "Entente des hôpitaux luxembourgeois". Thus, country-specific data was used. The data obtained covers the use of N₂O for anaesthesia in all hospitals of Luxembourg. The revised data from Germany (CRF 2015) for N₂O use in anaesthesia have been implemented and taken into account for the comparison.

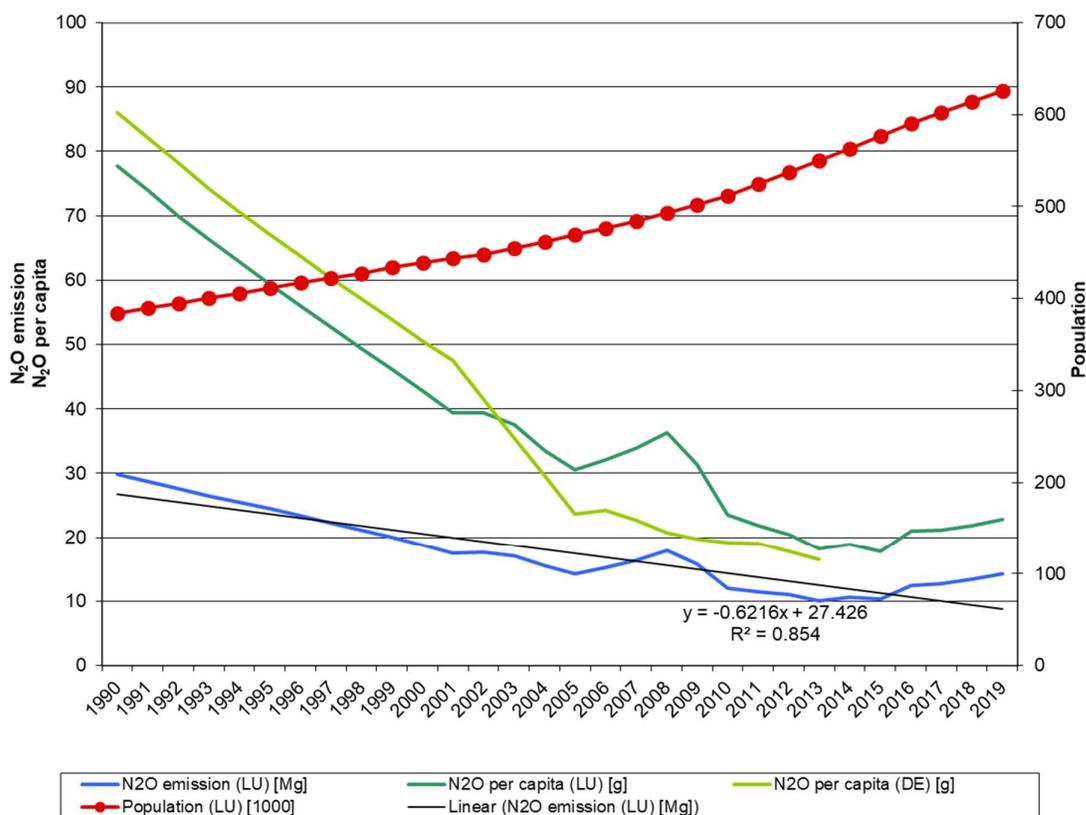
Although two different methods for the estimation of N₂O from anaesthesia are used over the time period (1990-2002 and 2003-2018), it is estimated that the time-series consistency is ensured. Indeed, when comparing the 2002 and 2003 values of emissions per capita of Germany with Luxembourg's value, these are relatively similar (Table 4-34). From 2004 onwards, the German per capita emissions seem to decrease much more rapidly than Luxembourg's values thus avoiding a potential underestimation by applying a country-specific method. However, the general trend of decreasing emissions is consistent between the German and Luxembourgish figures thus ensuring time-series consistency. As such, direct comparison between German and Luxembourgish figures are only carried out until 2013.

Based on data provided by the "Lëtzebuurger Associatioun vun de Klengdéierepraktiker", which is an association representing all the veterinaries active in Luxembourg, no N₂O is used as anaesthesia in veterinary cabinets or clinics in Luxembourg.

Table 4-36 – 2.G.3.a - Use of N₂O for Anaesthesia: 1990–2019.

	Luxembourg			Germany
	N ₂ O emission (LU) [Mg]	Population (LU) [1000]	N ₂ O per capita (LU) [g]	N ₂ O per capita (DE) [g]
1990	29.88	384.4	77.74	86.07
1991	28.79	389.6	73.90	82.03
1992	27.62	394.8	69.95	78.17
1993	26.54	400.2	66.33	74.19
1994	25.51	405.7	62.88	70.58
1995	24.44	411.6	59.39	67.12
1996	23.34	416.9	55.98	63.68
1997	22.24	422.1	52.68	60.32
1998	21.13	427.4	49.43	57.07
1999	19.98	433.6	46.08	53.86
2000	18.77	439.0	42.77	50.55
2001	17.50	444.0	39.42	47.48
2002	17.65	448.3	39.38	41.45
2003	17.09	455.0	37.55	35.47
2004	15.46	461.2	33.52	29.55
2005	14.32	469.1	30.52	23.62
2006	15.30	476.2	32.13	24.17
2007	16.39	483.8	33.88	22.73
2008	17.89	493.5	36.25	20.69
2009	15.73	502.1	31.33	19.71
2010	12.01	511.8	23.47	19.15
2011	11.46	524.9	21.83	19.07
2012	11.01	537.0	20.51	17.83
2013	9.98	549.7	18.15	16.49
2014	10.63	563.0	18.88	15.55
2015	10.26	576.2	17.81	14.23
2016	12.40	590.7	21.00	13.14
2017	12.74	602.0	21.17	12.07
2018	13.40	613.9	21.82	10.67
2019	14.29	626.1	22.83	9.62

Figure 4-14 – N₂O emissions and N₂O consumption for anaesthesia per capita and trend: 1990–2019



4.8.3.1.1 Uncertainties and time-series consistency

Direct use of N₂O has been specifically collected from the hospitals in Luxembourg. According to WINIWARTER (2008) pursuant to RAMIREZ ET AL. 2006, an uncertainty of 20% for the amount of N₂O is used Table 4-37. In contrast to Ramirez, it is assumed that virtually all of the N₂O actually used is also fully released, thus no additional uncertainty is applied.

Table 4-37 - Uncertainties for category 2.G.3.a - N₂O emissions from anaesthesia.

IPCC Source category	Gas	AD	EF	Combined
	Uncertainty [%]			
2G3a - N ₂ O emissions from anaesthesia	N ₂ O	20.0	0	20.0

4.8.3.1.3 Source specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.6) of which important elements include:

- Are the correct values used (check for transcription errors, ...)?
- Check of plausibility of input data (time-series, order of magnitude, ...)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, ...)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, ...
- Are all references clearly made?
- Are all assumptions documented?

4.8.3.2 Category-specific recalculations including changes made in response to the review process

No changes have been made.

4.8.3.3 Category-specific planned improvements including those in response to the review process

There are no planned improvements to IPCC sub-category 2.G.3.a.

4.8.3.4 Other (2.G.3.b)

Propellant for pressure and aerosol products

For the period 1990-2019, no data regarding exclusively the consumption of food aerosol cans, and the related N₂O emission in Luxembourg, could be obtained. Hence, N₂O emissions from propellant for pressure and aerosol products usage were estimated by combining reported emissions in Belgium with the relative population in Luxembourg. In 2019, 0.004% of total GHG emissions (excluding LULUCF) in Luxembourg originated from 2.G.3.b - Propellant for pressure and aerosol products compared to 0.002% in 1990. Compared to 2018, N₂O emissions from Propellant for pressure and aerosol products, for the year 2019, increased by 1.99% and by 62.23% compared to 1990 (Table 4-38).

Table 4-38- 2.G.3.b - Use of N2O for Propellant for pressure and aerosol products: 1990–2019.

1.8.4.2 Other (2.G.3.b)		
Propellant for pressure and aerosol products		
	N₂O emission [Gg]	Population (LU) [1000]
1990	0.000942	384.4
1991	0.000954	389.6
1992	0.000967	394.8
1993	0.000980	400.2
1994	0.000994	405.7
1995	0.001008	411.6
1996	0.001021	416.9
1997	0.001034	422.1
1998	0.001047	427.4
1999	0.001062	433.6
2000	0.001075	439.0
2001	0.001088	444.0
2002	0.001098	448.3
2003	0.001115	455.0
2004	0.001130	461.2
2005	0.001149	469.1
2006	0.001167	476.2
2007	0.001185	483.8
2008	0.001209	493.5
2009	0.001230	502.1
2010	0.001254	511.8
2011	0.001280	524.9
2012	0.001309	537.0
2013	0.001287	549.7
2014	0.001373	563.0
2015	0.001411	576.2
2016	0.001441	590.7
2017	0.001469	602.0
2018	0.001498	613.9
2019	0.001528	626.1

4.8.3.4.1 Uncertainties and time-series consistency

The error values which are assumed on the various calculations are as given:

- Activity data uncertainty 30%
- Emission factor uncertainty 20%

4.8.3.4.2 Source specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.6) of which important elements include:

- Are the correct values used (check for transcription errors, ...)?
- Check of plausibility of input data (time-series, order of magnitude, ...)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, ...)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, ...
- Are all references clearly made?
- Are all assumptions documented?

4.8.3.4.3 Category-specific recalculations including changes made in response to the review process

No changes were made for this submission.

4.8.3.4.4 Category-specific planned improvements including those in response to the review process

There are no planned improvements to IPCC sub-category 2.G.3.b

4.8.3.5 Other (2.G.4)

In Luxembourg, one manufacturer is producing solvents belonging to the category 2.G.4. The aforementioned production started in 2013. Activity data is directly obtained from the manufacturer. The data is limited to the one manufacturer and is considered confidential, thus the here described information is restricted to the activity data.

4.8.3.5.1 Uncertainties and time-series consistency

The error values were obtained from the manufacturer and are the following:

- Activity data uncertainty 6.6%
- Emission factor uncertainty 6.6%

4.8.3.5.2 Source specific QA/QC and verification

The calculations of the data for category 3 are embedded in the overall QA/QC-system of the GHG inventory (see Chapter 1.6) of which important elements include:

- Are the correct values used (check for transcription errors, ...)?
- Check of plausibility of input data (time-series, order of magnitude, ...)
- Is the data set complete for the whole time series?
- Check of calculations, units ...
- Check of plausibility of results (time-series, order of magnitude, ...)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks, ...
- Are all references clearly made?
- Are all assumptions documented?

4.8.3.5.3 Category-specific recalculations including changes made in response to the review process

No revisions and recalculations have been done since the last submission.

4.8.3.5.4 Category-specific planned improvements including those in response to the review process

There are no planned improvements to IPCC sub-category 2.G.4

4.9 Other (2.H)

This source category exists in Luxembourg, but no emissions associated with the national inventories are produced. N₂O emissions coupled to certain processes used in the beverage and food industry are not occurring in Luxembourg.

5 Agriculture (CRF Sector 3)

5.1 Sector Overview

This chapter gives information about the estimation of greenhouse gas (GHG) emissions from agriculture activities (CRF Sector 3 - Agriculture) in Luxembourg for the period 1990-2019.

Emissions from the agriculture sector comprise emissions from the following categories:

- Methane emissions from enteric fermentation (CRF 3A)
- Methane emissions from manure management (CRF 3Ba)
- N₂O emissions from manure management (CRF 3Bb)
- N₂O emissions from managed soils (CRF 3D)
- CO₂ emissions from liming (CRF 3G)
- CO₂ emissions from urea applicationLiming (CRF 3H)
- CO₂ emissions from other carbon containing fertilizer (CRF 3I)

For categories where emissions are not occurring, not estimated or included elsewhere, see Table 5-4 below. More details are presented under each source category in the following sections.

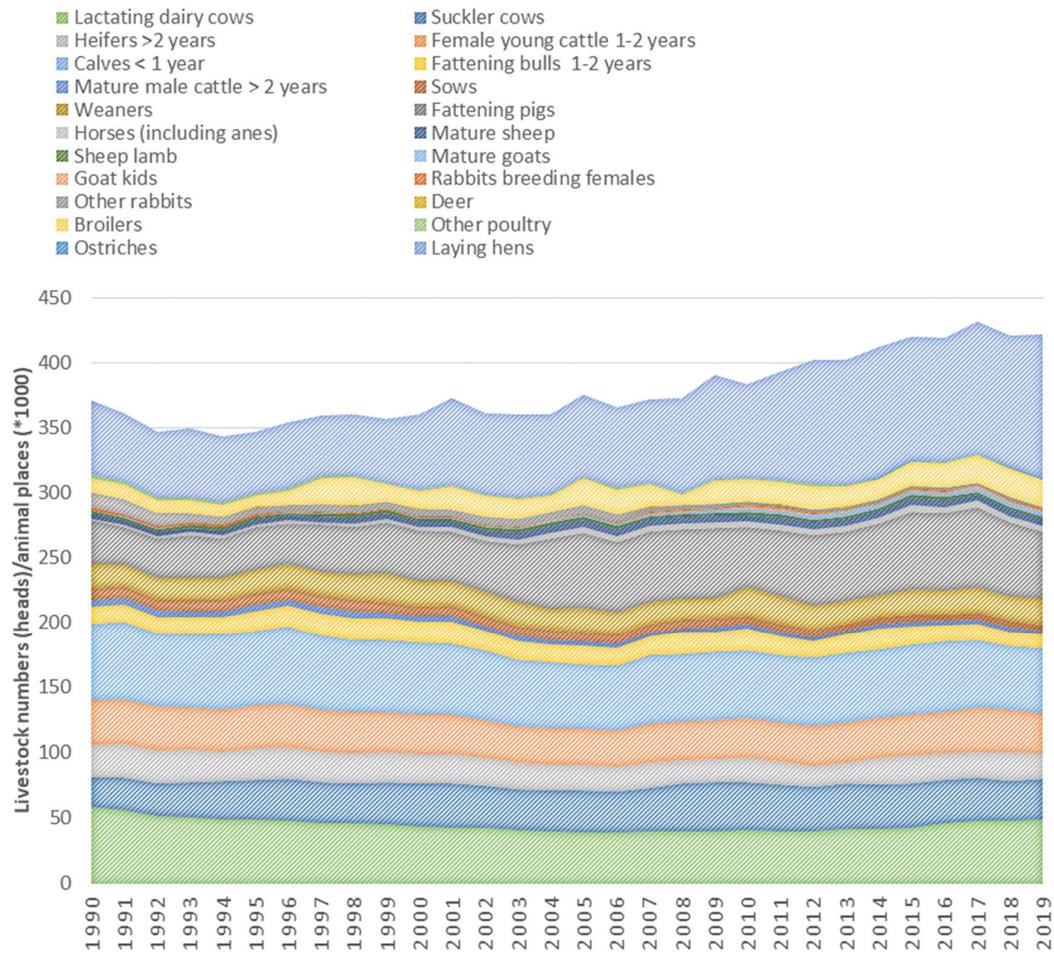
Hereafter a short overview of the Luxemburgish agricultural sector.

The country of Luxembourg is lying in a cool climate region, with both moderate winters and summers. More than 50% of the used agriculture surface in Luxembourg is permanent grassland (STATEC, 2020). Cattle, and in particularly dairy cattle, was and is therefore the most important livestock sector in Luxembourg. With the introduction of a dairy produce quota (also referred to as milk quota system) in 1983 in the European Union, and hence in Luxembourg, as well as an increasing milk yield/dairy cow over the years, had the number of dairy cows decreased over time, partly compensated by an increased number of suckler cows. However, this trend has changed with the abolishment of the milk quota system in Europe in spring 2015, and the number of dairy cows is increasing since then, with an accelerated increase in the first 2-3 years, and is slowing down in the last two years, see Figure 5-1 (STATEC, 2020). Suckler cows and fattening bulls have decreased since then.

Swine and poultry are in Luxembourg of far less importance than cattle, and are now-a-days for the majority of the production in the hands of a few professional farmers. Although, in recent years, cattle farmers tend to install mobile laying hen stables, resulting in a sharp increase of laying hens (Note: the produced eggs are sold on a deficitary local market). Sheep, goats and other livestock is in Luxembourg a niche production (STATEC, 2020).

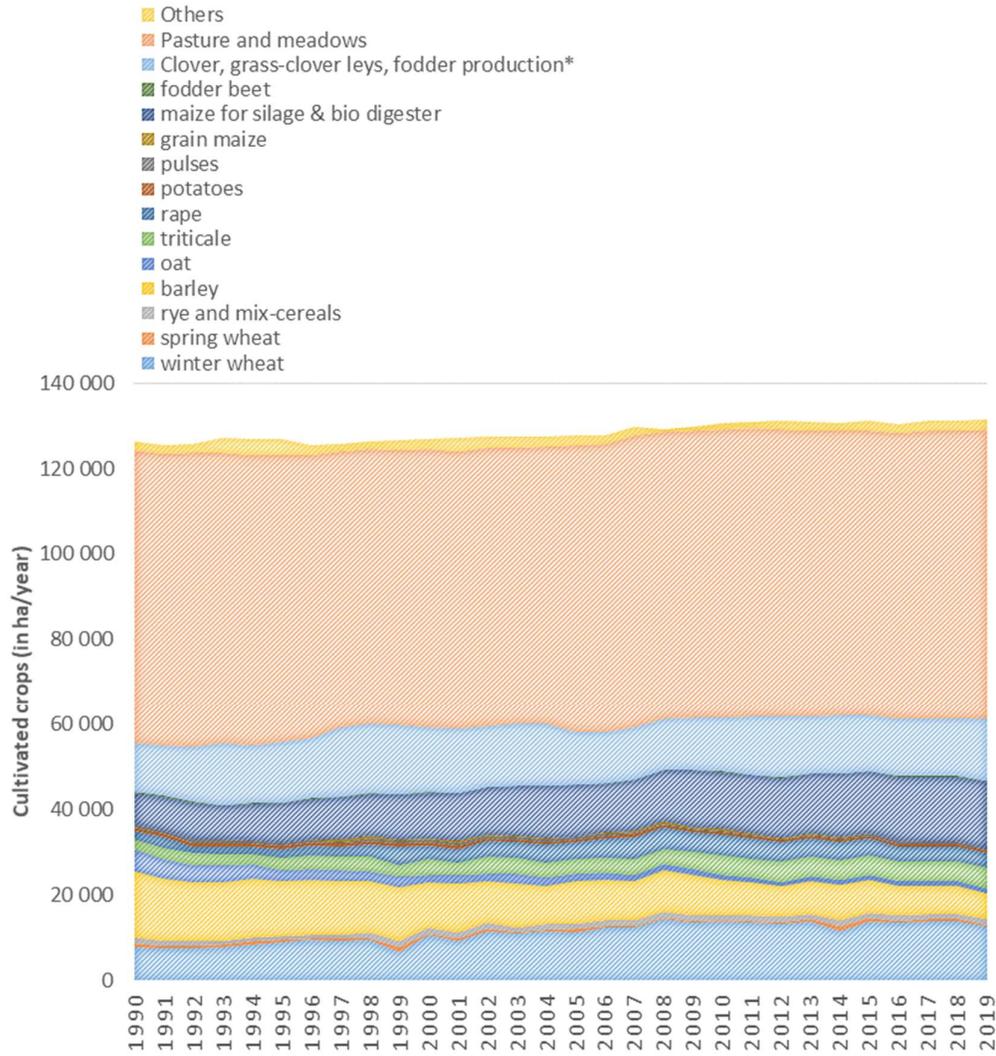
Permanent grassland is with more than 50% of the used agriculture surface predominant in Luxembourg. Grass, cover-grass and maize for silage (whole plant) are and were the main forage crops grown in Luxembourg, see Figure 5-2 (STATEC, 2020). Grains such as wheat, barley and triticale, but also rapeseed were the major cash crops cultivated in Luxembourg. In particularly the cultivated area for wheat and maize increased over the years, whereas barley and oat decreased.

Figure 5-1 – Average animal population (heads/animal places) per year for the different livestock categories for the period 1990-2019



Source : (STATEC, 2020)

Figure 5-2 – Cultivated crops (ha/year) for the period 1990-2019

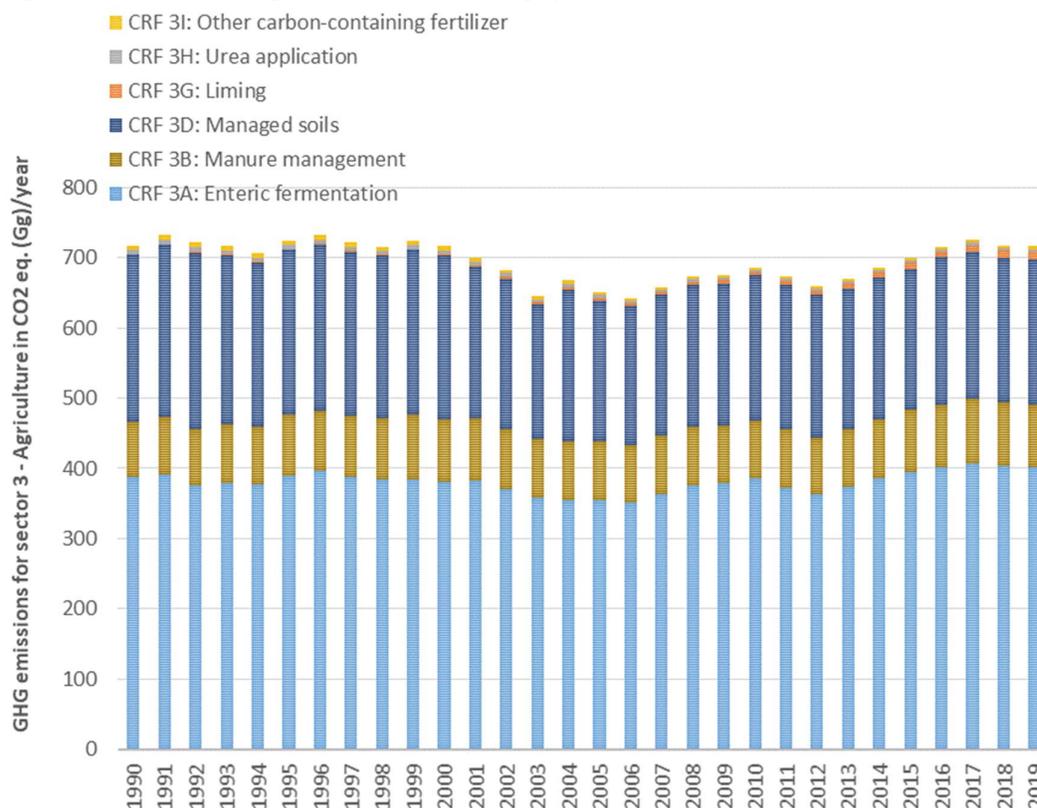


Source: (STATEC, 2020)

5.1.1 Emission Trends

In 2019, the agricultural sector contributed 6.63% to the total of Luxembourgish greenhouse gas emissions without LULUCF. The GHG emissions for agriculture increased by 0.14% when comparing 1990 to 2019 (see Figure 5-3 and Table 5-1, Table 5-2).

Figure 5-3 – Emissions from Agriculture, total and per category (CO₂ eq.): 1990 - 2019



Source: Service d'Economie Rurale (SER)

The overall trend in greenhouse gas emissions from agriculture, which used to decrease over time, was reversed in 2013 until 2017, and tends to decline lately, see Figure 5-3. The main drivers for this trend are i) the livestock numbers, in particularly dairy cows (see Figure 5-1), and ii) lower amounts of N-fertilizers applied on agricultural soils (see emissions in Figure 5-3). With the introduction of the milk quota system in 1983 in the European Union (i.e. a restriction on milk production), and an increasing milk yield per dairy cow over time, the number of dairy cows decreased over the years, although partly compensated by a parallel increase in the number of suckler cows. However, this trend has changed with the abolishment of the milk quota system in Europe in spring 2015, and the number of dairy cows is increasing since then, with an accelerated increase in the first 2-3 years, and is slowing down in the last two years, see Figure 5-1. Suckler cows and fattening bulls have decreased since then.

Fluctuations which can be seen for agricultural soils (in particular CRF 3D & CRF 3I (see Table 5-1)) resulted mostly from the variability of mineral fertilizer use, either because of high prices and/or due to weather conditions hampering their application. Fluctuations which can be seen for enteric fermentation and manure management are partly the result of bad weather conditions hampering the growth and/or the harvest of forages, with consequently a shortage in forage, initiating an increased selling of cattle, followed by a temporary reduction of the cattle population, but also affecting the offered feed ratio with consequently higher milk urea than in

average years; and in a smaller part also the volatility of either piglet prices and/or pork prices that might result in a temporary reduction/increase of the pig production.

The increase of CO₂ emissions over the years is mainly due to an increase of CO₂ emissions from liming (see Table 5-1). A consequence of the closure of blast furnaces and the re-structure of the iron industry in Luxembourg in the eighties/nineties, and the replacement of Thomas slag by other types of liming fertilizers.

Table 5-1– GHG emission trends in Gg CO2 eq. for CRF Sector 3 – Agriculture (without LULUCF): 1990-2019

3 - Agricultural Sector																								
GHG emissions by source & sink category (Gg CO2 eq)																								
Year	3A - Enteric fermentation				3B -Manure management				3D - Agricultural soils (without LULUCF)				3G- Liming				3H - Urea application				3I - Carbon-containing fertilizer			
	Total	CO2	CH4	N2O	Total	CO2	CH4	N2O	Total	CO2	CH4	N2O	Total	CO2	CH4	N2O	Total	CO2	CH4	N2O	Total	CO2	CH4	N2O
1990	387.8	NA	387.8	NA	78.5	NA	47.7	30.7	238.7	NA	NA	238.7	0.26	0.26	NA	NA	0.0000	0.0000	NA	NA	6.04	6.04	NA	NA
1991	390.5	NA	390.5	NA	82.8	NA	53.0	29.7	245.4	NA	NA	245.4	0.46	0.46	NA	NA	0.0000	0.0000	NA	NA	6.29	6.29	NA	NA
1992	375.3	NA	375.3	NA	81.0	NA	53.0	28.0	250.5	NA	NA	250.5	0.66	0.66	NA	NA	0.0000	0.0000	NA	NA	6.79	6.79	NA	NA
1993	379.4	NA	379.4	NA	82.6	NA	54.5	28.1	240.8	NA	NA	240.8	1.02	1.02	NA	NA	0.0000	0.0000	NA	NA	6.19	6.19	NA	NA
1994	376.9	NA	376.9	NA	82.5	NA	54.9	27.6	233.4	NA	NA	233.4	1.49	1.49	NA	NA	0.0000	0.0000	NA	NA	5.88	5.88	NA	NA
1995	389.6	NA	389.6	NA	86.0	NA	57.7	28.3	235.3	NA	NA	235.3	1.22	1.22	NA	NA	0.0000	0.0000	NA	NA	5.77	5.77	NA	NA
1996	395.5	NA	395.5	NA	86.9	NA	58.2	28.7	236.6	NA	NA	236.6	1.07	1.07	NA	NA	0.0000	0.0000	NA	NA	5.75	5.75	NA	NA
1997	387.9	NA	387.9	NA	87.0	NA	59.0	28.1	233.3	NA	NA	233.3	1.59	1.59	NA	NA	0.0000	0.0000	NA	NA	5.66	5.66	NA	NA
1998	384.1	NA	384.1	NA	87.8	NA	60.1	27.6	230.3	NA	NA	230.3	2.19	2.19	NA	NA	0.0000	0.0000	NA	NA	5.55	5.55	NA	NA
1999	384.1	NA	384.1	NA	92.2	NA	65.3	26.8	234.5	NA	NA	234.5	1.22	1.22	NA	NA	0.0000	0.0000	NA	NA	5.73	5.73	NA	NA
2000	380.0	NA	380.0	NA	89.9	NA	63.6	26.3	232.9	NA	NA	232.9	2.04	2.04	NA	NA	0.0000	0.0000	NA	NA	5.67	5.67	NA	NA
2001	382.5	NA	382.5	NA	89.4	NA	63.2	26.2	215.3	NA	NA	215.3	2.48	2.48	NA	NA	0.0000	0.0000	NA	NA	4.83	4.83	NA	NA
2002	369.8	NA	369.8	NA	86.6	NA	61.2	25.4	213.2	NA	NA	213.2	3.15	3.15	NA	NA	0.0000	0.0000	NA	NA	5.04	5.04	NA	NA
2003	358.4	NA	358.4	NA	83.9	NA	58.9	25.0	191.2	NA	NA	191.2	3.05	3.05	NA	NA	0.0000	0.0000	NA	NA	4.10	4.10	NA	NA
2004	354.4	NA	354.4	NA	83.9	NA	58.5	25.4	215.9	NA	NA	215.9	2.62	2.62	NA	NA	0.0000	0.0000	NA	NA	5.21	5.21	NA	NA
2005	354.9	NA	354.9	NA	83.6	NA	58.4	25.2	199.5	NA	NA	199.5	4.23	4.23	NA	NA	0.0004	0.0004	NA	NA	4.27	4.27	NA	NA
2006	351.4	NA	351.4	NA	81.3	NA	56.3	25.0	198.3	NA	NA	198.3	3.30	3.30	NA	NA	0.0004	0.0004	NA	NA	4.22	4.22	NA	NA
2007	363.7	NA	363.7	NA	83.0	NA	57.0	26.0	199.8	NA	NA	199.8	3.34	3.34	NA	NA	0.0004	0.0004	NA	NA	4.00	4.00	NA	NA
2008	375.7	NA	375.7	NA	83.7	NA	57.1	26.7	202.3	NA	NA	202.3	3.10	3.10	NA	NA	0.0004	0.0004	NA	NA	4.00	4.00	NA	NA
2009	378.1	NA	378.1	NA	83.0	NA	56.5	26.6	202.1	NA	NA	202.1	4.41	4.41	NA	NA	0.0004	0.0004	NA	NA	4.03	4.03	NA	NA
2010	385.1	NA	385.1	NA	83.5	NA	56.3	27.2	205.8	NA	NA	205.8	3.81	3.81	NA	NA	0.0004	0.0004	NA	NA	4.01	4.01	NA	NA
2011	372.8	NA	372.8	NA	81.9	NA	55.5	26.4	205.5	NA	NA	205.5	5.29	5.29	NA	NA	0.0004	0.0004	NA	NA	4.22	4.22	NA	NA
2012	364.0	NA	364.0	NA	80.1	NA	54.4	25.6	202.6	NA	NA	202.6	5.48	5.48	NA	NA	0.0003	0.0003	NA	NA	4.01	4.01	NA	NA
2013	373.2	NA	373.2	NA	81.8	NA	55.7	26.1	201.2	NA	NA	201.2	6.29	6.29	NA	NA	0.0003	0.0003	NA	NA	3.92	3.92	NA	NA
2014	385.2	NA	385.2	NA	84.6	NA	57.8	26.8	201.4	NA	NA	201.4	6.95	6.95	NA	NA	0.0002	0.0002	NA	NA	3.74	3.74	NA	NA
2015	395.4	NA	395.4	NA	87.5	NA	60.4	27.1	201.6	NA	NA	201.6	7.36	7.36	NA	NA	0.0002	0.0002	NA	NA	3.89	3.89	NA	NA
2016	401.8	NA	401.8	NA	89.4	NA	61.8	27.6	209.1	NA	NA	209.1	6.99	6.99	NA	NA	0.0002	0.0002	NA	NA	4.17	4.17	NA	NA
2017	407.3	NA	407.3	NA	91.5	NA	63.3	28.3	209.7	NA	NA	209.7	8.80	8.80	NA	NA	0.0001	0.0001	NA	NA	4.13	4.13	NA	NA
2018	403.4	NA	403.4	NA	90.7	NA	62.8	27.9	204.9	NA	NA	204.9	10.97	10.97	NA	NA	0.0001	0.0001	NA	NA	3.85	3.85	NA	NA
2019	401.5	NA	401.5	NA	89.5	NA	62.1	27.4	206.7	NA	NA	206.7	10.38	10.38	NA	NA	0.0001	0.0001	NA	NA	4.17	4.17	NA	NA
Trend 1990 -2019	3.6%	NA	3.6%	NA	14.0%	NA	30.1%	-10.9%	-13.4%	NA	NA	-13.4%	3960%	3960%	NA	NA	NA	NA	NA	NA	-30.9%	-31%	NA	NA
Trend 2018 -2019	-0.5%	NA	-0.5%	NA	-1.3%	NA	-1.0%	-1.8%	0.9%	NA	NA	0.9%	-5.3%	-5.3%	NA	NA	-34.6%	-34.6%	NA	NA	8.3%	8.3%	NA	NA

Source: Service d'Economie Rurale (SER)

Note: CH4 emissions were converted in CO2-eq. by multiplying the emissions by 25 and N2O emissions were converted in CO2-eq. by multiplying the emissions by 298

Table 5-2– GHG emission trends in Gg CO₂ eq. for CRF Sector 3 – Agriculture without and without LULUCF

3 - Agricultural Sector GHG emissions (Gg CO ₂ eq)								
Year	Agriculture (without LULUCF)				Agriculture (with LULUCF)			
	Total	CO ₂	CH ₄	N ₂ O	Total	CO ₂	CH ₄	N ₂ O
1990	711.3	6.29	435.5	269.5	711.3	6.29	435.5	269.5
1991	725.4	6.75	443.5	275.1	725.4	6.75	443.5	275.2
1992	714.3	7.45	428.4	278.5	714.4	7.45	428.4	278.6
1993	710.0	7.22	433.8	268.9	710.0	7.22	433.8	269.0
1994	700.2	7.37	431.8	261.0	700.2	7.37	431.8	261.0
1995	717.9	6.98	447.3	263.6	718.0	6.98	447.3	263.7
1996	725.8	6.82	453.8	265.3	725.9	6.82	453.8	265.3
1997	715.4	7.25	446.8	261.4	715.5	7.25	446.8	261.4
1998	709.9	7.74	444.3	257.9	710.0	7.74	444.3	258.0
1999	717.7	6.95	449.4	261.3	717.7	6.95	449.4	261.4
2000	710.6	7.71	443.6	259.3	710.7	7.71	443.6	259.3
2001	694.5	7.31	445.7	241.5	694.6	7.31	445.7	241.6
2002	677.7	8.18	431.0	238.5	677.8	8.18	431.0	238.6
2003	640.7	7.16	417.3	216.2	640.7	7.16	417.3	216.3
2004	661.9	7.83	412.8	241.3	662.0	7.83	412.8	241.3
2005	646.5	8.51	413.3	224.7	646.5	8.51	413.3	224.7
2006	638.5	7.52	407.7	223.3	638.5	7.52	407.7	223.3
2007	653.8	7.34	420.7	225.8	653.9	7.34	420.7	225.8
2008	668.9	7.10	432.8	229.0	668.9	7.10	432.8	229.1
2009	671.7	8.44	434.6	228.7	671.8	8.44	434.6	228.7
2010	682.2	7.82	441.4	233.0	682.2	7.82	441.4	233.0
2011	669.7	9.51	428.3	231.9	669.7	9.51	428.3	231.9
2012	656.1	9.49	418.4	228.2	656.2	9.49	418.4	228.3
2013	666.4	10.22	428.9	227.3	666.5	10.22	428.9	227.3
2014	681.9	10.69	443.0	228.3	681.9	10.69	443.0	228.3
2015	695.7	11.25	455.7	228.8	695.8	11.25	455.7	228.8
2016	711.5	11.16	463.6	236.7	711.5	11.16	463.6	236.7
2017	721.5	12.92	470.6	238.0	721.6	12.92	470.6	238.0
2018	713.7	14.82	466.1	232.8	713.7	14.82	466.1	232.8
2019	712.3	14.55	463.7	234.1	712.3	14.55	463.7	234.1
Trend 1990 -2019	0.1%	131%	6.5%	-13.1%	0.1%	131%	6.5%	-13.1%
Trend 2018 -2019	-0.2%	-1.8%	-0.5%	0.6%	-0.2%	-1.8%	-0.5%	0.6%

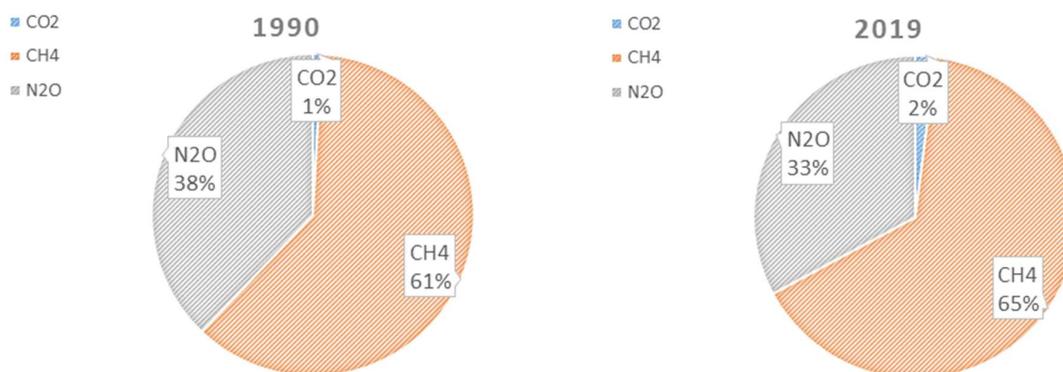
Source: Service d'Economie Rurale (SER)

5.1.1.1 Emission trends per gas

From 1990 to 2019 CO₂ emissions from agriculture increased by 131%, although they account for only 2% of the emissions from agriculture in 2019. CH₄ emissions from agriculture increased by 6.5%. Whereas N₂O emissions decreased in the same time by 13.1%. The trends are presented in Table 5-1 without LULUCF, and in Table 5-2 with and without LULUCF.

The share of gases has slightly changed over time (see Figure 5-4). In 2019 about 65% of emissions from agriculture originate from CH₄ (in 1990 61%), 33% from N₂O (in 1990 38%) and 2% from CO₂ (in 1990 1%).

Figure 5-4 – Share of gases from Agriculture (CO₂ eq.): 1990 and 2019



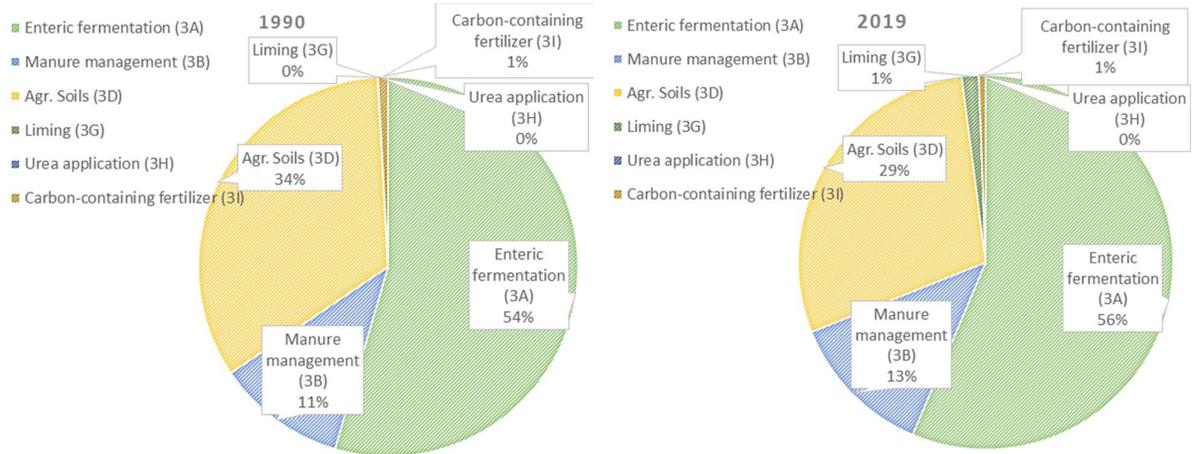
Source: Service d’Economie Rurale (SER)

5.1.1.2 Emission trends per subcategory

GHG emissions by subcategories are presented in Figure 5-3 and Table 5-1. Important categories were 3A enteric fermentation (Trend 1990-2019: +3.6%) and 3.D agricultural soils (Trend 1990-2019: -13.4%) followed by 3.B manure management (Trend 1990-2019: +14%). Although of less importance, liming (3 G) associated CO₂ emissions were increasing since 1990 to 2019 by 3960%. Note this artifact was a consequence of the closure of blast furnaces and the re-structure of the iron industry in Luxembourg in the eighties/nineties, and the replacement of Thomas slag by other types of liming fertilizers. Whereas carbon-containing fertilizer (3I) associated CO₂ emissions were decreasing (-30.9%). Urea application (3H) associated CO₂ emissions were/are insignificant (i.e. representing <0.0001% of the emissions from agriculture sector (CRF 3) at any moment in time).

Enteric fermentation (3A) emissions are responsible for 56% of the emissions from agriculture in 2019 (in 1990 54%), followed by N₂O emissions from agricultural soils (3D) (29% versus 34% in 1990) and manure management (3B) (13% versus 11% in 1990), see Figure 5-5. Liming- associated emissions (3G) are responsible for <2% of the emissions from agriculture in 2019 (in 1990 0.04%). Carbon-containing (3I) associated CO₂ emissions are responsible for 0.6% of the emissions from agriculture in 2019 (in 2019 0.8%). Urea application (3H) associated CO₂ emissions are only marginal.

Figure 5-5 – Share of categories from Agriculture (CO₂ eq.): 1990 and 2019



5.1.2 Key Categories

The methodology and results of the key source analysis are presented in Chapter 1.5. Table 5-3 presents the key source categories of Sector 3 – Agriculture.

Table 5-3 – Key sources of IPCC Sector 3 – Agriculture

3 - Agriculture						
Key sources						
IPCC Category	Category Name	GHG	LA excl. LULUCF	LA incl. LULUCF	TA excl. LULUCF	TA incl. LULUCF
3A	Enteric Fermentation	CH ₄	90-19	90-19	X	X
3B	Manure Management	CH ₄	97-02, 18	97-02, 14-19		
3D1	Direct N ₂ O Emissions from Managed Soils	N ₂ O	90-19	90-19		

Source: Environment Agency

Notes: LA = Level Assessment (Tier 1) including respectively excluding LULUCF
 TA = Trend Assessment 2019 (Tier 1) including respectively excluding LULUCF

5.1.3 Completeness

Table 5-4 gives an overview of the IPCC categories included under CRF Sector 3 and provides information on the status of emission estimates of all subcategories..

Table 5-4 –Overview of subcategories of CRF 3 – Agriculture: Status

CRF source category		CO ₂		CH ₄		N ₂ O	
		Method	EF	Method	EF	Method	EF
3. Agriculture							
A.	Enteric fermentation	NA	NA	T1, T2	D, CS	NA	NA
B.	Manure management	NA	NA	T1, T2	D, CS	T2	D
C.	Rice cultivation	NA	NA	NO	NO	NA	NA
D.	Agricultural soils	NA	NA	NA	NA	T1, T2	D
E.	Prescribed burning of savannahs	NO	NO	NA	NA	NA	NA
F.	Field burning of agricultural residues	NO	NO	NA	NA	NA	NA
G.	Liming	T1	D	NA	NA	NA	NA
H.	Urea application	T1	D	NA	NA	NA	NA
I.	Other carbon-containing fertilizers	T1	D	NA	NA	NA	NA
J.	Other	NO	NO	NA	NA	NA	NA

Used abbreviations: NA = not applicable; NO=not occurring. T1=IPCC Tier 1; T2=IPCC Tier 2; D=IPCC default; CS=Country-specific.

5.2 General aspects

Animal categories, livestock numbers, manure management system (MMS), N excretion (N.ex) and the N flows in the manure management system are used in several categories in the emission calculations and were therefore described in this chapter. Other required information are presented under each source category review.

5.2.1 Animal categories

Cattle was and is the major livestock in Luxemburg. In the emission calculations seven categories were distinguished:

Calves	Comprising calves <1 year, from both dairy and suckler herds. Where necessary, further distinguishing between male and female calves.
Female young cattle 1-2 years	Comprising 1-2 years old female cattle from both dairy and suckler herds
Fattening bulls 1-2 years	Comprising 1-2 year old male cattle, from both dairy and suckler herds. In the majority fattening bulls kept and fed inside stables. The remaining animals were growing breeding males and young oxes, but for simplicity reasons treated in the agricultural emission calculations as being 100% fattening bulls.
Heifers >2 years	Comprising heifers >2 years from both dairy and suckler herds. The majority of the heifers were kept for breeding purposes. Heifers for slaughtering were/are raised, fed and kept in the same way as breeding heifers, why no further distinction was made.
Mature male cattle >2 years	Comprising male cattle >2 years from both dairy and suckler herds. Mostly breeding animals; a few fattening bulls who took longer than the useable 20-24 months for finishing; and a few fattening oxes. In the nineties, the distribution might have been slightly other, but for simplicity all animals in this category were treated as being mature male breeding cattle.
Lactating dairy cows	Comprising <i>only</i> lactating dairy cows. In the census up to the year 2007 there were three “cow” categories distinguished, namely “dairy cows” comprising only lactating dairy cows; “cull cows” comprising non-lactating dairy cows kept for fattening purposes and “suckler cows”. Since 2008, however, both lactating and non-lactating dairy cows (i.e. cull cows) are reported together in one single category. For 1990-2007 cull cows accounted on average for 9.15% (range 7.1%-10.8%) of the total consisting of lactating dairy cows and non-lactating dairy cows ($P_{\text{cull cows}}$) (STATEC 2019c). Assuming the same distribution of lactating and non-lactating dairy cows for the year 2008 and onwards, the number of lactating dairy cows ($N_{\text{lactating dairy cows}} = N_{\text{dairy cows (total)}} - N_{\text{cull cows}}$) and the number of cull cows ($N_{\text{non-lactating dairy cows}} = [N_{\text{dairy cows (total)}} * P_{\text{cull cows}}]$) was estimated.
Suckler cows	Comprising suckler cows (>90%) and “cull cows” i.e. non-lactating dairy cows. Numbers of cull cows were partly based on statistics (1990-2007), partly estimated (2008-2018), for more details see livestock category “lactating dairy cows”.

Note in the CRF tables female calves and male calves were summarized and reported as one category, namely “calves”; furthermore female young cattle 1-2 years and heifers >2 years were summarized and reported as one category, namely “young cattle”.

For sheep the distinction was made between mature sheep and sheep lambs:

Mature sheep	Comprising all sheep ≥ 1 year; in the majority breeding females (~90%) (STATEC 2019c). The remaining animals are other mature sheep, but for simplicity reasons treated in the agricultural emission calculations as being 100% female breeding animals.
Sheep lambs	Comprising only lambs <1 year. Sheep lambs are born in early spring. The majority of them are fattened and slaughtered at the age of 5-7 months, (Kirchgeßner M. , 2014c) and remaining animals are raised as replacement stock. Approximately 80% (range 75%-85% (Vaessen Personal communication; December 2018)) of the fattening lambs were assumed to be slaughtered at the age of 6 months. The average animal population was corrected following IPCC guidelines (IPCC 2006a) ¹⁰² .

For swine we distinguished between sows, fattening pigs and weaners.

Sows	Comprising mated sows, sows with piglets and mated young sows.
Weaners	Comprising piglets with a weight between 10-30 kg, i.e. weaners.
Fattening pigs	Comprising fattening pigs >30 kg (>90%) (STATEC 2019c) and growing not mated female breeding swines >30 kg and all male breeding swines >30 kg. For simplicity reason, these swine’s’ are treated in the emission calculations as being fattening pigs.

Note: Emissions from piglets <10 kg were considered within the “sow” category, respectively “breeding pigs” in the CRF tables.

For poultry (reported in the CRF tables as one category) we distinguish between laying hens, broilers and other poultry:

Laying hens	Comprising laying hens and chicks up to 6 months
Broilers	Comprising only broilers
Other poultry	Comprising all other poultry categories, but subtracting ostriches, which were considered in a separate category.

For goats (reported in the CRF tables as one category) we distinguished between mature goats and goat kits:

Mature goats	Comprising all goats ≥ 1 year, in the majority goat ewes (STATEC 2019c). The remaining animals are other mature goats, but for simplicity reasons treated in the agricultural emission calculations as being 100% goat ewes.
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¹⁰² Annual average population = (Number of lambs reported in census * 20%) + ((6*30) * ((Number of lambs reported in census * 80%)/365)). Note the number of sheep lambs reported in the census is approximately the number of sheep lambs produced annually.

Goat kits Comprising goat kids <1 year. Goat kids are born in early spring. Male goats kits (assumption to be 50%) are fattened and slaughtered at the age of 5-7 weeks. Female goat kits are raised as replacement stock (own survey)¹⁰³. It was therefore assumed that ~50% of the kits would be slaughtered at the age of 6 weeks, and adapted the average animal population following IPCC guidelines (IPCC 2006a)¹⁰⁴.

Horses, including mules and asses:

Horses Comprising horses, mules and asses. For horses, it was further distinguished, between heavy agriculture horses, riding horses and ponies. Mules and asses were considered together with the ponies.

Note emissions from mules and asses were considered together with horses, why using in the CRF tables the notation key "IE".

For rabbits (reported in the CRF tables as one category) we distinguished between breeding female animals and other rabbits:

Breeding female animals Comprising breeding female animals. Estimated emissions include the raising of young stock, but no fattening.

Other rabbits Comprising all other rabbits, mainly fattening rabbits

Other animal categories considered were deer and ostriches:

Deer All other registered animals are considered in this category, the majority (>90%) were deer's.

Ostriches Comprising only ostriches

103 Own survey conducted in November 2018 between goat farmers keeping in 2017 approximately 70% of the goat ewes in Luxembourg, and confirmed by unpublished data collected by the "landwirtschaftliche Testbetriebsnetz" (LTBN), i.e. the Luxembourgish Farm accounting data network (FADN)-partner (Pers. communication Marc Schmit and Paul Jacqué, SER - Comptabilité, December 2018). For more details on the LTBN see: <https://agriculture.public.lu/de/betriebsfuhrung/buchfuhrung/testbetriebsnetz.html>, and on the FADN see <http://ec.europa.eu/agriculture/rica/>.

104 Annual average population = (Number of goat kits reported in census * 50%) + ((6*7) * ((Number of kits reported in census * 50%)/365)). Note the number of goat kits reported in the census is approximately the number of goat kits produced annually.

5.2.2 Activity data

5.2.2.1 Livestock numbers

Activity data on animals numbers were based on the agricultural census conducted annually in spring¹⁰⁵ by STATEC (Institut national de la statistique et des études économiques du Grand-Duché de Luxembourg) (STATEC, 2020) in later years in collaboration with SER (Service d'Economie Rurale) (STATEC 2018)¹⁰⁶, and since 2017 only by SER, and are summarized in Table 5-5. In the Agriculture census, all farms situated in Luxembourg with either ≥ 10 horses, or ≥ 10 cattle, or ≥ 20 small ruminants, or ≥ 50 fattening pigs, or ≥ 10 breeding female pigs (> 50 kg), or ≥ 1000 poultry birds or ≥ 1000 rabbits were taken into account. The response rate was $\sim 95\%$. However, since 2012 is the number of cattle – the most important livestock category in Luxembourg – no longer self-reported by the farmers, but are these data extracted from the “SANITEL” database, whereby taking the number of cattle as registered on April 1st; and hence a 100% coverage of farmers with ≥ 10 cattle. In Luxembourg each single cattle has to be registered and is followed from birth or import until end of life (slaughter or natural death) or export, whatever comes first. All those movements are registered in the “SANITEL” database (ASV, 2018).

¹⁰⁵ Up to 2011 this was the 15th of May, and since 2012 it is the 1st of April

¹⁰⁶ A short description of the underlying legislation and other details can be found on: <https://statistiques.public.lu/en/methodology/methodes/entreprises/Agriculture/agriculture/index.html> accessed on 24-02-2019.

Table 5-5 – Average animal numbers (heads/animal places) per year per livestock category for the period 1990-2019*

3 - Agriculture																						
Activity data - annual average population (heads/animal places per year (* 1000)) ^a																						
Year	Calves < 1 year	Female young cattle 1-2 years ^b	Heifers >2 years	Fattening bulls 1-2 years	Mature male cattle > 2 years	Lactating dairy cows ^c	Suckler cows ^c	Sows	Fattening pigs ^d	Weaners ^{d,e}	Mature sheep	Sheep lambs < 1 year ^f	Mature goats ^g	Goat kids < 1 year ^{f,g}	Horses ^h	Broilers	Laying hens ⁱ	Other poultry ^j	Ostriches ^j	Rabbits - Breeding animals ^k	Other rabbits ^k	Deer
1990	59.6	34.0	24.6	13.0	5.4	58.8	22.0	9.0	33.2	19.2	3.7	2.1	0.30	0.12	1.7	11.2	57.8	2.26	0.00	2.31	11.2	0.09
1991	59.3	34.4	25.7	13.6	5.6	55.6	25.3	8.5	28.4	17.0	3.9	2.3	0.33	0.13	1.8	10.9	52.7	2.06	0.00	1.83	11.7	0.16
1992	56.2	33.8	25.0	12.7	4.7	51.1	25.7	8.6	30.6	16.4	3.8	1.9	0.27	0.09	1.8	9.5	50.8	1.82	0.00	1.65	10.4	0.13
1993	55.7	32.3	25.0	13.7	4.7	50.2	27.3	8.6	33.6	16.9	3.3	2.1	0.30	0.12	1.9	9.9	53.6	1.62	0.00	1.48	7.1	0.13
1994	58.0	31.9	22.6	14.1	4.2	49.0	28.9	8.6	30.9	17.0	4.1	2.2	0.27	0.13	2.1	9.3	51.1	1.52	0.00	1.34	6.4	0.18
1995	57.6	33.0	23.7	15.3	4.9	48.6	30.7	8.9	33.0	17.8	4.1	2.0	0.22	0.10	2.2	8.5	47.1	1.80	0.00	1.39	5.8	0.18
1996	59.1	33.0	24.6	16.2	5.1	48.0	32.0	8.6	31.6	18.7	3.8	2.0	0.17	0.07	2.2	10.3	51.6	1.59	0.00	1.13	4.8	0.14
1997	57.0	32.7	23.2	16.7	5.6	46.3	30.8	8.7	36.1	18.1	4.0	2.4	0.21	0.08	2.3	19.6	46.7	1.94	0.00	1.27	6.0	0.17
1998	55.3	31.4	23.0	17.1	5.3	46.0	30.7	8.7	36.6	20.3	4.5	2.2	0.17	0.07	2.3	21.3	47.1	1.39	0.00	1.07	5.7	0.28
1999	55.4	30.8	23.1	16.6	4.8	45.1	32.1	8.3	39.2	22.0	4.3	2.4	0.15	0.06	2.8	13.5	48.6	0.98	0.00	0.97	5.2	0.33
2000	54.8	30.6	22.6	16.4	4.4	43.3	32.9	7.6	38.5	19.7	4.3	2.2	0.18	0.07	3.2	14.2	57.6	0.85	0.00	1.44	5.2	0.38
2001	54.3	30.3	22.7	16.7	4.8	42.9	33.4	7.8	38.4	18.9	4.8	2.2	0.19	0.07	3.1	17.6	66.7	1.00	0.00	1.00	5.5	0.34
2002	53.7	28.1	21.4	15.0	4.2	42.1	32.8	7.6	39.7	19.1	4.7	2.7	0.55	0.31	3.1	16.0	61.9	0.96	0.00	1.13	5.9	0.32
2003	51.3	28.0	20.1	14.3	3.8	40.6	31.5	7.4	44.4	18.9	5.6	2.3	1.02	0.49	3.4	15.3	64.0	1.01	0.20	0.97	5.5	0.24
2004	50.8	27.7	19.8	13.8	3.6	39.9	31.1	7.2	54.7	16.6	5.6	2.5	1.34	0.38	3.7	12.2	60.9	1.08	0.27	0.86	5.7	0.29
2005	49.2	27.6	19.6	14.5	3.4	39.3	31.7	7.4	58.0	18.9	5.2	3.0	1.47	0.42	4.2	20.3	63.1	1.12	0.21	0.92	5.6	0.25
2006	49.5	27.8	19.0	14.0	3.2	38.6	31.6	7.1	54.7	16.9	5.8	2.3	1.35	0.34	4.3	19.3	62.0	1.15	0.17	0.88	6.0	0.25
2007	52.7	29.1	20.0	14.4	2.8	40.0	32.8	6.9	54.2	17.4	5.2	2.5	1.62	0.67	4.3	17.5	64.4	0.81	0.18	0.77	4.0	0.19
2008	52.1	29.3	18.4	16.5	3.2	39.6	36.6	6.6	54.0	16.0	5.0	2.1	2.01	0.51	4.5	8.1	73.3	0.63	0.21	0.68	3.4	0.34
2009	52.4	29.4	18.3	15.4	3.8	40.3	36.8	6.6	54.2	15.7	5.1	2.2	2.15	0.55	4.6	17.3	80.1	0.83	0.23	0.76	3.4	0.34
2010	52.2	30.3	18.6	16.5	3.7	40.9	36.6	6.5	46.2	21.9	5.1	2.4	2.99	1.18	4.6	17.2	72.4	0.54	0.20	0.67	2.8	0.33
2011	52.3	29.7	17.2	14.3	3.2	40.1	35.8	6.0	50.8	22.2	5.2	2.3	3.19	1.48	4.6	17.5	84.1	0.68	0.33	0.65	2.1	0.43
2012	52.5	29.8	16.3	13.1	2.8	39.5	34.5	5.7	54.3	19.1	4.9	2.0	3.70	0.67	4.9	17.8	95.0	1.54	0.21	0.71	2.9	0.38
2013	53.3	30.2	16.3	14.4	3.1	42.0	34.4	5.4	53.7	17.5	5.2	2.0	3.23	0.69	4.7	15.6	95.7	0.85	0.34	0.73	2.7	0.27
2014	53.3	30.6	20.5	15.7	3.5	42.0	33.3	5.3	54.8	17.4	5.2	2.1	3.01	0.74	4.7	15.4	100.1	1.01	0.18	0.74	2.3	0.27
2015	54.1	31.6	21.3	14.2	3.7	42.6	33.5	4.9	60.0	19.9	5.6	2.3	3.40	0.77	4.7	18.4	95.3	0.96	0.26	0.76	2.0	0.24
2016	54.7	31.5	20.1	12.5	3.1	46.4	33.2	4.9	60.0	18.5	5.2	2.2	3.40	0.97	4.5	18.9	95.3	0.87	0.25	0.61	2.2	0.17
2017	52.6	33.3	20.1	12.3	3.3	47.9	32.8	5.3	61.8	19.9	5.1	2.0	3.48	1.09	4.7	20.9	101.7	1.26	0.20	0.54	1.9	0.12
2018	49.0	31.8	22.1	11.3	3.3	47.8	30.9	5.2	57.1	19.2	5.1	2.2	3.56	0.85	4.7	22.1	101.4	0.77	0.21	0.57	2.2	0.15
2019	50.6	30.3	19.8	10.1	3.2	49.0	30.8	4.5	51.9	20.0	5.1	2.1	3.38	1.11	4.7	21.4	110.7	0.60	0.24	0.60	1.8	0.05
Trend 1990-2019	-15%	-11%	-20%	-22%	-41%	-17%	40%	-50%	56%	4%	37%	0%	1030%	857%	171%	91%	92%	-73%	NA	-74%	-83%	-46%
Trend 2018-2019	3%	-5%	-11%	-11%	-2%	2%	0%	-14%	-9%	4%	1%	0%	-5%	30%	0%	-3%	9%	-22%	15%	7%	-18%	-67%

Explication notes for Table 5-5:

- a) Source: (STATEC, 2020) with additional unpublished information available at Service d'économie rurale (SER), Division des statistiques agricoles, des relations extérieurs et des marchés agricoles.
- b) In the CRF Tables were female young cattle 1-2 years and heifers >2 years reported as one category, namely "young cattle".

- c) Up to 2007 were dairy cows registered in two categories, i) lactating dairy cows, and ii) cull cows (i.e. non-lactating dairy cows with the purpose to be fattened and slaughtered), but no further distinction since 2008 (STATEC, 2020). From 1990-2007, did cull cows account on average for 9.15% of the total dairy cow population (range 7.1%-10.8%). Assuming that the percentage of culled cows remained the same, the number of cull cows were estimated for the years 2008-2018 and subtracted from the total number of dairy cows in order to obtain the number of “lactating dairy cows”. Cull cows were considered together with suckler cows in the animal category “suckler cows”.
- d) For the period 1990-2009 there was a subcategory of fattening pigs from 20 kg-50 kg. To suit our animal categories, this category was split up and it was assumed that 2/3 would have been fattening pigs >30 kg and 1/3 would have been weaners. From 2010 onwards, statistics are collected accordingly to the live weights used in the current inventory, i.e. fattening pigs >30 kg and weaners 10-30 kg. Note the number of pig farmers and the number of pigs is relatively low in Luxemburg compared to our neighboring countries. This fact together with a strong reorientation of the sector in the whole period, and the fact that some of the pig farmers work on contract basis - in particularly those raising weaners and fattening pigs – is an explanation for the observed fluctuations between years.
- e) Piglets staying with the sow up to 10 kg weight were not considered as a separate category in the emission calculation - a category also registered in the census. Since 2010 were those registered as a separate category. For the time period 1990-2009, it was assumed that 50% of the piglets <20 kg would be weaners, and the other 50% would be newborn piglets <10 kg staying with the sows. The total for swine from the inventory differs therefore from the one reported by STATEC (STATEC, 2020), and other international statistical institutes such as EUROSTAT.
- f) The majority of sheep lambs and goat kids are fattened and sold previous to one year of age. Following the IPCC guidelines from 2006, (IPCC 2006a) the average number of animals were corrected, why the total for sheep, respectively for goats from the inventory differs from the one reported by STATEC (STATEC, 2020), and other international statistical institutes.
- g) From 2007 there were three categories, namely goat-ewes; goat kits and other mature goats (i.e. mainly breeding males and other goats older than 1 year). Previous to 2007, there exist only two categories, namely goat-ewes and “others”. This latter category was split into lambs and others. Based on the data from 2007-2018 (for the Source see footnote a), we assumed that on average 18% (range: 7%-30%) would have been “other mature goats” and the remaining would have been goat kits. Note in the CRF table goats are reported as one category.
- h) Mules and asses are included in the category “horses”.
- i) There were two categories, namely laying hens and chicks older than 6 months up to 2004. Since 2005, however are chicks older than 6 months and laying hens considered as one category.
- j) In the published statistics were ostriches included in “other poultry”. Ostriches were considered as a separate category and therefore subtracted from this category.
- k) In the CRF tables reported as one category, but for the emission calculations the distinction is made between breeding female animals and other rabbits (i.e. fattening rabbits).

5.2.3 Manure management system

For the emission calculations information were required on:

- a) The proportion of excreta deposited during grazing, referred hereafter as manure management system (MMS) – pasture ($MMS\text{-}pasture_{(i)}$) for animal category i . Data for the years 1990-2019 is summarized in

- b) Table 5-6, whereby i are all the different animal categories considered in the emission calculations.
- c) and proportion of excreta deposited during housing, whereby distinguishing further between:
- the proportion of excreta deposited during housing in stables with livestock i kept on solid manure, hereafter referred to as MMS- solid_(i) and summarized in Table 5-7.
 - the proportion of excreta deposited during housing in stables with a liquid/slurry management system, whereby slurry remains on the farm, hereafter referred to as MMS- liquid_(i) and summarized in Table 5-8.
 - the proportion of excreta deposited during housing in stables with a liquid/slurry management system, whereby slurry is used as feeding material for bio digester, hereafter referred to as MMS- feed_(i) and summarized in Table 5-9.

Further information required for the emission calculations were:

- a) the fraction (or proportion) of the year that animals spend in:
- a. buildings (X_{build})¹⁰⁷,
 - b. and grazing (X_{grazing}).
- b) the proportion of livestock manure handled as:
- a. slurry (X_{slurry}),
 - b. and as solid (X_{solid}).
- c) for slurry further was required, what proportion of slurry¹⁰⁸:
- a. was spread directly ($X_{\text{spread_direct_slurry}}$)
 - b. was stored before application ($X_{\text{store_slurry}}$)
 - c. was used as feedstocks in biogas facilities ($X_{\text{feed_slurry}}$).
- d) for solid manure was further required, what proportion of solid manure¹⁰⁹:
- a. was stored before application ($X_{\text{store_solid}}$).

These different fractions/proportions were derived from the above mentioned MMS, whereby:

$$\begin{aligned}
 X_{\text{grazing}(i)} &= \text{MMS- pasture}_{(i)}. \\
 X_{\text{build}(i)} &= (1 - X_{\text{grazing}(i)}). \\
 X_{\text{slurry}(i)} &= ((\text{MMS-liquid}_{(i)} + \text{MMS-digest}_{(i)}) / (\text{MMS-liquid}_{(i)} + \text{MMS-digest}_{(i)} + \text{MMS-solid}_{(i)})) \\
 X_{\text{solid}(i)} &= (1 - X_{\text{slurry}(i)}). \\
 X_{\text{biogas_slurry}(i)} &= ((\text{MMS-digest}_{(i)}) / (\text{MMS-liquid}_{(i)} + \text{MMS-digest}_{(i)})). \\
 X_{\text{store_slurry}(i)} &= (1 - X_{\text{feed_slurry}(i)}) \\
 X_{\text{store_solid}(i)} &= \text{MMS-solid}_{(i)}.
 \end{aligned}$$

¹⁰⁷ Note: Yards, where than existing, are integrated in the building, and therefore not considered in the emission calculations as a separate category, but in xbuild.

¹⁰⁸ Note: Slurry is either stored on the farm or used as feedstocks. Direct spreading of slurry is not occurring in Luxembourg.

¹⁰⁹ Note: Solid manure is stored on the farm before spreading. Direct spreading is not occurring in Luxembourg. Also is it not common practice to use solid manure as feedstocks, why assumed to be zero.

Please note that

- yards are uncommon in Luxembourg, and where then existing, integrated in the building with similar liquid/slurry management system as the rest of the housing. Yards were therefore not considered in the emission calculations as a separate category, but as building;
- direct spreading of slurry is not occurring in Luxembourg;
- direct spreading of solid manure is not occurring in Luxembourg;
- solid manure as feedstock is not common practice, and was therefore assumed to not occur.

The first manure management systems were based on expert judgment. The percentage of each manure system had been estimated by Administration des service technique de l'agriculture (ASTA) on the basis of diverse unpublished in-house information and its knowledge on the agricultural practices in Luxembourg.

ASTA provided some additional information together with the manure management estimates:

- liquid system: liquid manure storage is present around 6 months/year – during the winter season – for a certain number of farms. It is present the whole year for porcine breeding;
- solid storage: manure storage is present around 6 months/year – during the winter season – for a certain number of farms;
- pasture: this system is present around 6 months/year when the animals are grazing (summer season);
- anaerobic digester: since the end of the last century, biogas installations are more and more frequent at farms (and/or manure is more regularly collected to supply municipal or private bio-methanization units). Hence, if the percentages presented in Table 5-9 could be seen as reasonable for the latest years, this would not be the case for the early 1990s. Indeed, as most of the installations producing biogas from manure are operating in Luxembourg since around the year 2000, they are usually very efficient and a gas tight coverage is present (expert judgment). Therefore emissions to be accounted for in CRF Sector 3 (leakages, as well as emissions due to storage in the digester) are very low (the methane produced should be recorded under the waste sector).

In 2010 the yearly agricultural census had been completed by a dedicated survey on agricultural production methods (SAPM). Based on the results from the SAPM, interpolated manure management system for the years 2000-2011 were produced by using the shares as derived from the 2010 SAPM (Gargano, L., Zangerlé G., Hauptert J., & Hoffmann J.-P., 2014).

In 2016 data on animal grazing was collected for dairy cows, for suckler cows, for horses, for sheep and for goats in the 2016 agriculture census. These data were linked at the level of individual herd sizes¹¹⁰ to estimate average grazing time (or the proportion of excreta deposited during grazing (MMS-pasture)) for an average animal of livestock category *i* for the year 2016. The 2016 data were used as such, whereas for the years 2011-2015, data were interpolated by assuming that the observed decrease/increase between 2010 and

¹¹⁰ Opposite to EUROSTAT where data are linked to the agricultural holding [https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Farm_structure_survey_\(FSS\)](https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Farm_structure_survey_(FSS))

2016 would have been linear, except for goats. For goats, where for simplicity reason it had been assumed that since the installation of the first professional dairy farmer with a few hundred dairy goats in 2001/2002 and a few additional farmers to follow, 100% of the goats would be kept inside (and hence MMS-pasture would be 0%), here the 2016 data were used starting from 2002 onwards (i.e. MMS- pasture being 0.3%). The proportion of excreta deposited during housing was adapted accordingly to the new MMS-pasture. Whereas within $X_{\text{build}(i)}$, the same distribution between MMS-liquid (i) ; MMS-feed (i) and MMS-solid (i) were assumed as observed in 2010. (Gargano, L., Zangerlé G., Hauptert J., & Hoffmann J.-P., 2014).

Without new data, the manure management systems for the years 2017-2019 were assumed to be the same as derived for 2016.

New data collected in the 2020 agriculture census will, allow an update, and interpolation, of the manure management system in the next submissions.

5.2.4 Slurry storage system

In the emissions calculations, the distinction is made between three slurry storage systems, namely:

- Slurry tank without cover;
- Slurry tank with cover (plastic film or solid cover);
- Slurry stored underneath slatted floor.

The available data was collected in the 2010 SPAM for the year 2010. In 2010 10.8% of the slurry was stored in slurry tanks without cover; 14.8% in slurry tank with cover (plastic film or solid cover), and 74.4% of the slurry was stored underneath slatted floor (Gargano, L., Zangerlé G., Hauptert J., & Hoffmann J.-P., 2014). The frequencies apply to the cattle and pig slurry as a whole. It was therefore assumed that cattle slurry stored in slurry tanks without cover would have in 80% a natural crust and in 20% no natural crust, similar to the assumption made in the manure management N-flow tool from the European Environment Agency version 10 February 2020. Whereas swine slurry stored in slurry tanks without cover would have no natural crust.

Based on expert judgment, it was assumed that in earlier years, the frequency distributions would have been similar to the one found in 2010. Without no data, the frequency distribution was kept constant for all following years. However, an update is planned in one of the following submissions, as these information will be collected again in the 2020 SPAM.

Table 5-6 – Manure management system pasture (MMS-pasture) for all animal categories: 1990-2019.

3 -Agriculture																			
Manure management system - pasture (MMS-pasture) for animal category <i>i</i> (i.e. the proportion of excreta deposited during grazing)																			
Year	Calves < 1 year	Female young cattle 1-2 years	Heifers > 2 years	Fattening bulls 1-2 years	Mature male cattle > 2 years	Lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners	Sheep	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deers
1990	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	75%	0%	75%
1991	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	75%	0%	75%
1992	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	75%	0%	75%
1993	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	75%	0%	75%
1994	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	75%	0%	75%
1995	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	75%	0%	75%
1996	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	75%	0%	75%
1997	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	75%	0%	75%
1998	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	75%	0%	75%
1999	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	75%	0%	75%
2000	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	75%	0%	75%
2001	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	75%	49%	0%	0%	0%	75%	0%	75%
2002	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2003	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2004	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2005	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2006	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2007	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2008	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2009	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2010	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2011	37%	49%	49%	0%	0%	24%	50%	0%	0%	0%	75%	0%	51%	0%	0%	0%	75%	0%	75%
2012	37%	49%	49%	0%	0%	23%	51%	0%	0%	0%	75%	0%	52%	0%	0%	0%	75%	0%	75%
2013	37%	49%	49%	0%	0%	23%	52%	0%	0%	0%	75%	0%	54%	0%	0%	0%	75%	0%	75%
2014	37%	49%	49%	0%	0%	22%	53%	0%	0%	0%	75%	0%	55%	0%	0%	0%	75%	0%	75%
2015	37%	49%	49%	0%	0%	21%	54%	0%	0%	0%	75%	0%	56%	0%	0%	0%	75%	0%	75%
2016	37%	49%	49%	0%	0%	20%	55%	0%	0%	0%	75%	0%	58%	0%	0%	0%	75%	0%	75%
2017	37%	49%	49%	0%	0%	20%	55%	0%	0%	0%	75%	0%	58%	0%	0%	0%	75%	0%	75%
2018	37%	49%	49%	0%	0%	20%	55%	0%	0%	0%	75%	0%	58%	0%	0%	0%	75%	0%	75%
2019	37%	49%	49%	0%	0%	20%	55%	0%	0%	0%	75%	0%	58%	0%	0%	0%	75%	0%	75%

Source: Expert judgement (ASTA) prepared on 19 June 2007, and SER & ASTA calculations based on partly unpublished data from the 2010 SAPM survey (Gargano, L., Zangerlé G., Hauptert J., & Hoffmann J.-P., 2014); 2016 agriculture census data (unpublished data).

Table 5-7 – Manure management system solid (MMS-solid) for all animal categories: 1990-2019.

3 -Agriculture																			
Manure management system - solid (MMS-solid) for animal category <i>i</i>																			
(i.e. the proportion of excreta deposited during housing in stables with livestock kept on solid manure and manure being stored on the farm)																			
Year	Calves < 1 year	Female young cattle 1-2 years	Heifers > 2 years	Fattening bulls 1-2 years	Mature male cattle > 2 years	Lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners	Sheep	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deers
1990	44%	32%	32%	81%	81%	52%	32%	5%	5%	5%	25%	25%	51%	100%	100%	100%	25%	100%	25%
1991	39%	27%	27%	77%	77%	46%	27%	5%	5%	5%	25%	25%	51%	100%	100%	100%	25%	100%	25%
1992	38%	26%	26%	75%	75%	45%	26%	5%	5%	5%	25%	25%	51%	100%	100%	100%	25%	100%	25%
1993	38%	26%	26%	75%	75%	44%	26%	5%	5%	5%	25%	25%	51%	100%	100%	100%	25%	100%	25%
1994	37%	25%	25%	74%	74%	43%	25%	5%	5%	5%	25%	25%	51%	100%	100%	100%	25%	100%	25%
1995	36%	24%	24%	73%	73%	42%	24%	5%	5%	5%	25%	25%	51%	100%	100%	100%	25%	100%	25%
1996	36%	24%	24%	73%	73%	42%	24%	5%	5%	5%	25%	25%	51%	100%	100%	100%	25%	100%	25%
1997	35%	23%	23%	73%	73%	41%	23%	5%	5%	5%	25%	25%	51%	100%	100%	100%	25%	100%	25%
1998	34%	22%	22%	72%	72%	40%	22%	5%	5%	5%	25%	25%	51%	100%	100%	100%	25%	100%	25%
1999	31%	19%	19%	68%	68%	35%	19%	5%	5%	5%	25%	25%	51%	100%	100%	100%	25%	100%	25%
2000	31%	19%	19%	68%	68%	35%	19%	5%	5%	5%	25%	25%	51%	100%	100%	100%	25%	100%	25%
2001	31%	19%	19%	68%	68%	35%	19%	5%	5%	5%	25%	25%	51%	100%	100%	100%	25%	100%	25%
2002	31%	19%	19%	68%	68%	35%	19%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2003	32%	20%	20%	69%	69%	36%	20%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2004	33%	20%	20%	69%	69%	36%	21%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2005	35%	20%	20%	69%	69%	36%	23%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2006	38%	19%	19%	69%	69%	35%	26%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2007	40%	19%	19%	68%	68%	34%	29%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2008	42%	18%	18%	68%	68%	33%	32%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2009	45%	18%	18%	68%	68%	32%	35%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2010	47%	18%	18%	67%	67%	31%	38%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2011	46%	18%	18%	66%	66%	32%	37%	5%	5%	5%	25%	100%	49%	100%	100%	100%	25%	100%	25%
2012	46%	18%	18%	67%	67%	32%	36%	5%	5%	5%	25%	100%	48%	100%	100%	100%	25%	100%	25%
2013	46%	18%	18%	67%	67%	32%	36%	5%	5%	5%	25%	100%	46%	100%	100%	100%	25%	100%	25%
2014	46%	18%	18%	67%	67%	33%	35%	5%	5%	5%	25%	100%	45%	100%	100%	100%	25%	100%	25%
2015	46%	18%	18%	67%	67%	33%	34%	5%	5%	5%	25%	100%	44%	100%	100%	100%	25%	100%	25%
2016	46%	18%	18%	67%	67%	33%	34%	5%	5%	5%	25%	100%	42%	100%	100%	100%	25%	100%	25%
2017	46%	18%	18%	67%	67%	33%	34%	5%	5%	5%	25%	100%	42%	100%	100%	100%	25%	100%	25%
2018	46%	18%	18%	67%	67%	33%	34%	5%	5%	5%	25%	100%	42%	100%	100%	100%	25%	100%	25%
2019	46%	18%	18%	67%	67%	33%	34%	5%	5%	5%	25%	100%	42%	100%	100%	100%	25%	100%	25%

Source: Expert judgement (ASTA) prepared on 19 June 2007, and SER & ASTA calculations based on partly unpublished data from the 2010 SAPM survey (Gargano, L., Zangerlé G., Hauptert J., & Hoffmann J.-P., 2014); 2016 agriculture census data (unpublished data).

Table 5-8 – Manure management system – liquid (MMS-liquid) for all animal categories: 1990-2019.

3 -Agriculture																			
Manure management system - liquid (MMS-liquid) for animal category <i>i</i>																			
(i.e. the proportion of excreta deposited during housing in stables with a liquid/slurry management system and manure being stored on the farm)																			
Year	Calves < 1 year	Female young cattle 1-2 years	Heifers > 2 years	Fattening bulls 1-2 years	Mature male cattle > 2 years	Lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners	Sheep	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deers
1990	19%	19%	19%	19%	19%	23%	19%	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1991	24%	24%	24%	24%	24%	29%	24%	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1992	25%	25%	25%	25%	25%	31%	25%	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1993	25%	25%	25%	25%	25%	31%	25%	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1994	26%	26%	26%	26%	26%	32%	26%	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1995	27%	27%	27%	27%	27%	33%	27%	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1996	27%	27%	27%	27%	27%	33%	27%	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1997	28%	28%	28%	28%	28%	34%	28%	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1998	29%	29%	29%	29%	29%	36%	29%	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1999	32%	32%	32%	32%	32%	40%	32%	95%	95%	95%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2000	31%	31%	31%	31%	31%	40%	31%	93%	94%	94%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2001	31%	31%	31%	31%	31%	39%	31%	91%	93%	93%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2002	30%	30%	30%	30%	30%	38%	30%	89%	91%	91%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2003	29%	29%	29%	29%	29%	37%	29%	87%	90%	90%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2004	28%	28%	28%	28%	28%	36%	28%	85%	89%	89%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2005	25%	27%	27%	27%	27%	36%	24%	82%	88%	88%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2006	22%	27%	27%	27%	27%	36%	21%	80%	87%	87%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2007	19%	27%	27%	27%	27%	36%	17%	78%	86%	86%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2008	16%	27%	27%	26%	26%	36%	14%	76%	84%	84%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2009	13%	27%	27%	26%	26%	37%	11%	74%	83%	83%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2010	10%	27%	27%	26%	26%	37%	7%	72%	82%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2011	11%	27%	27%	27%	27%	37%	7%	72%	82%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2012	11%	26%	26%	26%	26%	37%	7%	72%	82%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2013	11%	26%	26%	26%	26%	38%	7%	72%	82%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2014	11%	26%	26%	26%	26%	38%	7%	72%	82%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2015	11%	26%	26%	26%	26%	39%	7%	72%	82%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2016	11%	26%	26%	26%	26%	39%	6%	72%	82%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2017	11%	26%	26%	26%	26%	39%	6%	72%	82%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2018	11%	26%	26%	26%	26%	39%	6%	72%	82%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2019	11%	26%	26%	26%	26%	39%	6%	72%	82%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Source: Expert judgement (ASTA) prepared on 19 June 2007, and SER & ASTA calculations based on partly unpublished data from the 2010 SAPM survey (Gargano, L., Zangerlé G., Hauptert J., & Hoffmann J.-P., 2014); 2016 agriculture census data (unpublished data).

Table 5-9 – Manure management system – digester (MMS-digester) for all animal categories: 1990-2019.

3 -Agriculture																			
Manure management system - digester (MMS-digester) for animal category <i>i</i>																			
(i.e. the proportion of excreta deposited during housing in stables with a liquid/slurry management system and slurry being used as feeding material for bio digesters)																			
Year	Calves < 1 year	Female young cattle 1-2 years	Heifers > 2 years	Fattening bulls 1-2 years	Mature male cattle > 2 years	Lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners	Sheep	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deers
1990	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1991	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1992	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1993	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1994	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1995	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1996	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1997	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1998	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
1999	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2000	1%	1%	1%	1%	1%	1%	1%	2%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2001	1%	1%	1%	1%	1%	1%	1%	4%	2%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2002	2%	2%	2%	2%	2%	2%	2%	6%	4%	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2003	2%	2%	2%	2%	2%	3%	2%	8%	5%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2004	3%	3%	3%	3%	3%	3%	3%	11%	6%	6%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2005	3%	3%	3%	4%	4%	4%	3%	13%	7%	7%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2006	4%	4%	4%	4%	4%	5%	4%	15%	8%	8%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2007	4%	5%	5%	5%	5%	5%	4%	17%	9%	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2008	5%	5%	5%	5%	5%	6%	5%	19%	11%	11%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2009	5%	6%	6%	6%	6%	6%	5%	21%	12%	12%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2010	6%	6%	6%	7%	7%	7%	6%	23%	13%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2011	6%	6%	6%	7%	7%	7%	6%	23%	13%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2012	6%	6%	6%	7%	7%	7%	6%	23%	13%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2013	6%	6%	6%	7%	7%	7%	5%	23%	13%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2014	6%	6%	6%	7%	7%	7%	5%	23%	13%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2015	6%	6%	6%	7%	7%	7%	5%	23%	13%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2016	6%	6%	6%	7%	7%	8%	5%	23%	13%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2017	6%	6%	6%	7%	7%	8%	5%	23%	13%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2018	6%	6%	6%	7%	7%	8%	5%	23%	13%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2019	6%	6%	6%	7%	7%	8%	5%	23%	13%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Source: Expert judgement (ASTA) prepared on 19 June 2007, and SER & ASTA calculations based on partly unpublished data from the 2010 SAPM survey (Gargano, L., Zangerlé G., Hauptert J., & Hoffmann J.-P., 2014); 2016 agriculture census data (unpublished data)

5.2.5 Nitrogen excretion

5.2.5.1 Dairy cows

For dairy cows the Nitrogen excretion (N.ex) per cow per year was calculated according to the following equation (DLG., 2008) that was based on Bannink and Hindle, 2003:

$$N. ex = \left(320 * \left(124 + \left(1320 * \text{milk urea } N \left[\frac{g}{\text{day}} \right] \right) + \left(1.87 * \text{milk } N \left[\frac{g}{\text{day}} \right] \right) - (6.9 * \text{daily milk yield}) \right) \right) + (45 * 256)$$

with

- assuming that an average dairy cow is 320 days on lactation and 45 days dry;
- using country-specific data for milk urea (Source: Tom Engel, pers. communication 26th November 2019; Tom Engel, personal communication Administration des service technique de l'agriculture (ASTA) - Service d'analyse du lait), see Table 5-10.
- assuming an N-ratio in urea of 46% (DLG., 2008) ;
- using country-specific milk protein (SER 2019), see Table 5-10.
- dividing milk protein by 6.38 to obtain N (DLG., 2008);
- using a country-specific daily milk yield, see Table 5-10, which is calculated by dividing the annual milk production (SER 2018) by the number of lactating dairy cows (see Table 5-9).

The annual milk production, see Table 5-10, consist of i) the official amount of milk delivered from the farms to dairy industries (>90%)¹¹¹; ii) the amount of milk and milk products sold by the farmers and iii) estimates on milk used at the farm for the farmers family and for feeding the calves (SER 2019).

Data on milk urea were obtained from the Administration des service technique de l'agriculture (ASTA) - Service d'analyse du lait, (Engel, 26-11-2019) for the years 2001-2018. ASTA is the only organization in Luxembourg responsible to test the milk collected by the dairy industry. There were no data on milk urea for the years 1990-2000, why using the average as observed for the years 2001-2005. For the years 2001-2005 only average of the tested milk samples were available and used as such, and for the years 2006-2018 weighted averages were used, i.e. weighted by the delivered amount of milk, and representing >80% of produced and delivered milk in Luxemburg. (Engel, 26-11-2019). For the year 2019 weighted averages as derived by ASTA were published in the annual activity report of the agriculture ministry (Ministère de l'agriculture, 2020).

The estimated N.ex per lactating dairy cow and per year for the years 1990-2019 is summarized in Table 5-10.

1.1.1 ¹¹¹ The dairy industry reports on a monthly basis the amount of milk collected at farm-gate, the milk fat and milk protein contain and the farm gate price to the SER – Statistiques agricoles, marches agricoles et relations extérieures on a monthly basis (Source: Fränk Steichen, personal communication December 2018; SER – Statistiques agricoles, marches agricoles et relations extérieures).

Table 5-10 – Annual milk production (*1000 tons), milk fat, milk protein, milk urea, daily milk yield and N.ex in kg N per dairy cow per year

3 - Agriculture						
Annual milk production (*1000 tons), milk fat, milk protein, milk urea, daily milk yield and N.ex in kg N per dairy cow per year						
Year	Annual milk (* 1000 tons) ^a	Milk fat (%) ^a	Milk (%) ^a	Milk urea (ppm) ^b	Daily milk (kg/day) ^c	N.ex (kg N per head per year) ^d
1990	281.7	4.09	3.26	235	15.0	110.2
1991	265.1	4.16	3.33	235	14.9	111.1
1992	260.4	4.16	3.34	235	15.9	112.3
1993	268.2	4.22	3.35	235	16.7	113.1
1994	261.6	4.16	3.34	235	16.7	113.0
1995	268.6	4.20	3.35	235	17.3	113.8
1996	265.5	4.25	3.38	235	17.3	114.2
1997	263.9	4.23	3.36	235	17.8	114.4
1998	264.0	4.25	3.37	235	18.0	114.7
1999	266.6	4.20	3.38	235	18.5	115.4
2000	264.5	4.19	3.36	235	19.1	115.7
2001	269.7	4.17	3.37	219	19.7	113.2
2002	270.7	4.18	3.37	221	20.1	114.3
2003	267.1	4.20	3.38	237	20.6	118.0
2004	268.5	4.20	3.39	262	21.0	123.5
2005	269.7	4.19	3.40	237	21.4	119.1
2006	268.1	4.21	3.40	250	21.7	121.9
2007	274.2	4.19	3.41	257	21.4	123.3
2008	277.7	4.21	3.40	254	21.9	122.9
2009	283.9	4.18	3.37	231	22.0	118.0
2010	295.3	4.18	3.40	246	22.6	122.0
2011	292.2	4.15	3.37	252	22.8	122.7
2012	289.4	4.16	3.39	234	22.9	119.9
2013	295.9	4.13	3.36	222	22.0	116.1
2014	317.0	4.09	3.38	219	23.6	117.3
2015	346.3	4.11	3.37	211	25.4	117.4
2016	376.2	4.12	3.39	218	25.4	119.1
2017	387.2	4.11	3.41	226	25.3	121.2
2018	407.6	4.12	3.43	232	26.6	124.3
2019	421.1	4.16	3.44	221	26.9	122.7
Trend 1990 -2019	49%	2%	6%	-6%	79%	11%
Trend 2018 -2019	3%	1%	0%	-5%	1%	-1%

- a) Source: (SER, 2020). Note: Until 1976 only milk delivered to dairy industries. Since 1977 the annual milk production consist of i) the official amount of milk delivered by the producers to the dairy industry (>90% (Source: Fränk Steichen, personal communication December 2018; SER - Statistiques agricoles, marches agricoles et relations extérieures)); ii) the amount of milk and milk products sold by the farmers and iii) milk consumed at the farm by the farmers family and/or used for its animals as derived from unpublished LTBN data (SER 2019).
- b) Note: There were no data for the years 1990-2000, why using the average as observed for the years 2001-2005. For the years 2001-2005 only the average of all tested milk samples were available, and for the years 2006-2018 weighted averages were used. ASTA is in Luxemburg the only institute responsible for testing milk that is delivered to dairy industries in Luxemburg and also for the majority of the milk delivered to dairy industries in Neighbouring countries. In 2017, ~95% of all delivered milk that was produced in Luxemburg was tested by ASTA. For >80% of the delivered milk was also the delivered quantity per tested sample known, allowing to estimate a weighted average representing >80% of the delivered milk in 2017. Urea data: Source: Administration des service technique de l'agriculture (ASTA) - Service d'analyse du lait, Tom Engel, pers. communication 26th November 2019; for confidential details of the delivered quantities to dairy industry: Source: SER - Statistiques agricoles, marches agricoles et relations extérieures; Fränk Steichen, personal communication 11th January 2019. For 2019; weighted averages as published in the annual activity report (Ministère de l'agriculture, 2020)
- c) Calculated by dividing the milk production by the number of lactating dairy cows (see Table 5-9) and assuming 320 days in lactation
- d) Calculated according to the equation shown above.

5.2.5.2 Other livestock categories than dairy cows

Having no own measurements, and having no information on feed ratio for all other livestock categories that would allow to estimate the N_{ex} based on an N-balance, the N_{ex} data were taken from the technical literature from Germany, Belgium, the Netherlands and France and were summarized in Table 5-11. Belgium, Germany and France (here in particular the Northern part) have direct borders with Luxembourg (Figure 2-1), and similar climate condition, feeding systems and animal husbandry systems as the one found in Luxembourg. And although the Netherlands does not have a direct border to Luxembourg, the distance between Wemperhardt (village in the North of Luxembourg) and Eijsden (village in the Sought of the Netherlands) is less than 100 km, and in particularly in the south-east of the Netherlands are climate condition, feeding systems and animal husbandry systems for certain livestock categories similar to one found in Luxembourg.

The starting point for this technical literature review were the corresponding emission inventories (NIR, IIR or both), respectively the underlying methodology reports (Lagerwerf, et al., 2019), (CITEPA, 2019), (Rösemann, et al., 2019), (Wever, 2019), (Ruysenaars, 2019), (Anonymous, Informative Inventory Report about Belgium's air emissions submitted under the Convention on Long Range Transboundary Air Pollution CLRTAP and National Emission Ceiling Directive NECD., 2019a). According to the snowball methodology additional relevant literature were retrieved. Relevant findings were summarized in an Excel-file (available on request). Using this excel-file, the final selection was made by two animal specialist (RB and MJJM). A detailed description of the choices made was provided in Annex 3:A in the NIR 2020 (Schuman, Becker, Hadzic, Mangen, & Mirgain, 2020)

However, in the current submission, the N_{ex} for suckler cows had to be revised, as the old value turned out to be an underestimation (Haenel H.-D., et al., 2020). With 90.7 kg N/year per suckler cow, is the N_{ex} per suckler cow the same as in the German inventory (Haenel H.-D., et al., 2020)

Table 5-11 – N excretion per head/place per year for the different livestock categories for 1990-2018

	N excretion (kg N per head/animal place per year)	Sources/Notes
Calves < 1 year	Calculated*	Based on the proportion of i) female calves and ii) males calves and the corresponding N.ex*
- Female calves < 1 year*	33	(CBS, 2018), VLM 2019, 2018, (VLM, NORMEN EN RICHTWAARDEN 2017 versie januari 2017, 2017), (VLM, NORMEN EN RICHTWAARDEN 2016 versie januari 2016, 2016), (VLM, NOG GEEN MAP 5: WAT ZIJN DE BEMESTINGSNORMEN IN 2015?, 2015), (VLM, NORMEN EN RICHTWAARDEN 2014, 2014), (VLM, NORMEN EN RICHTWAARDEN 2013 - december 2012, 2013), (VLM, NORMEN EN RICHTWAARDEN 2012 – editie maart 2012, 2012))
- Male calves < 1 year*	31.5	(CBS, 2018)
Female young female cattle 1-2 years	58	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012)
Heifers > 2 years	77	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012); “Other cattle older than 2 years”
Fattening bulls 1-2 years	58	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012)
Mature male cattle > 2 years	77	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012); “Other cattle older than 2 years”
Suckler cows	90.7	(Haenel H.-D. , et al., 2020)
Sows	23.5	(VLM 2017, 2016, 2015, 2014, 2013, 2012)
Fattening pigs	11.1	(Horlacher, 2018) page 488-489
Weaners	3.6	(Horlacher, 2018) page 488-489
Mature sheep	10.5	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012)
Sheep lambs < 1 year	4.36	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012)
Mature goats	18.7	(CBS 2018)
Goat kids < 1 year	-	Considered with does
Horses	Calculated*	Based on the proportion of i) agriculture horses; ii) riding horses and iii) horses<200 kg, anes and mules and the corresponding N.ex
- Agr. Horses > 6 months	65	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012); Horses > 600 kg;
- Riding horses > 6 months	50	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012); Horses 200-600 kg;
- Horses < 200 kg	33	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012); Ponys; horses < 6 months; mules & anes;
Broilers	0.3	(CITEPA, 2019)
Laying hens	0.81	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012)
Other poultry	0.38	(CITEPA, 2019)
Ostriches	15.6	(Rösemann et al. 2019)
Rabbits - Breeding female animals	3.16	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012); Breeding female animal, including raising of young stock (but no fattening);
Other rabbits (i.e. fattening rabbits)	0.658	(VLM 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012); Fattening rabbits
Deer	16	((Haenel H.-D. , et al., 2018) et al. 2018, Rösemann et al. 2019)

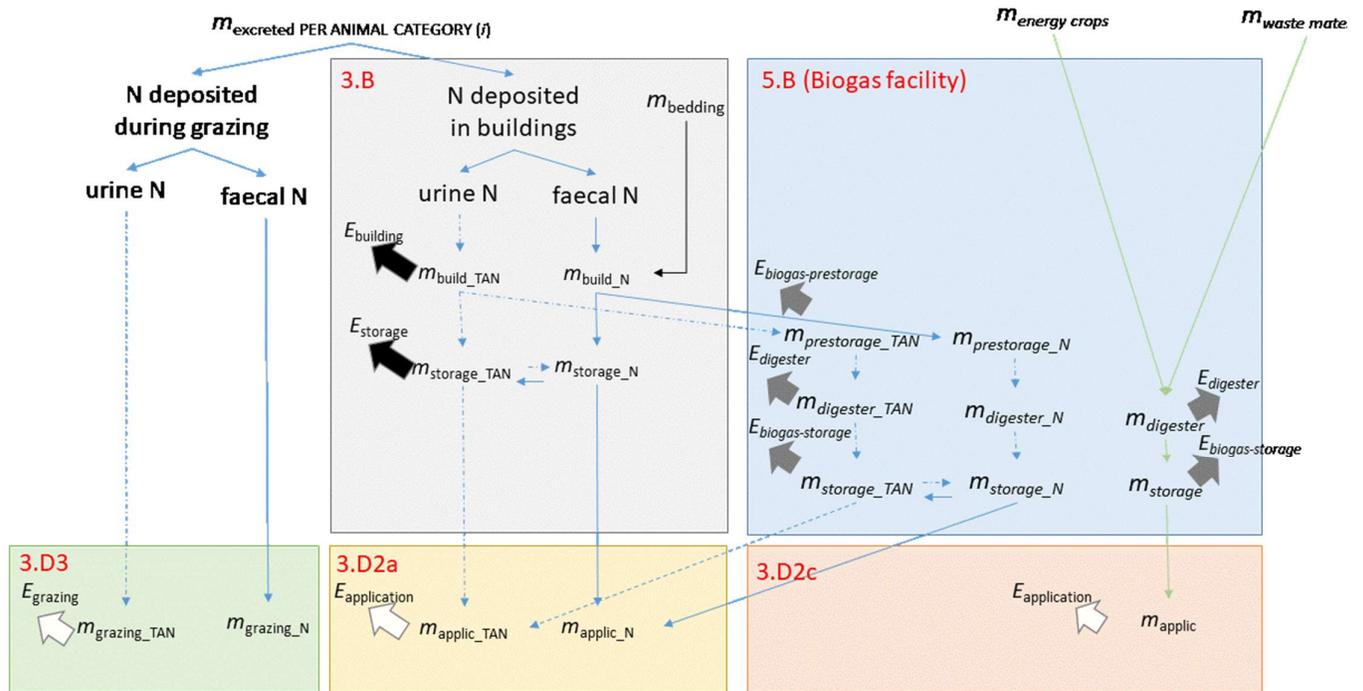
* Using more detailed statistics than the one provided in Table 5-5.

Using the French N.ex for ducks (0.4 kg n/ bird place/year), turkeys (1.0 kg N/bird place/year), geese (1.3 kg N/bird place/year) and broilers (as proxy for all other poultry, i.e. 0.3 kg N/bird place/year), assuming that places for ducks, turkeys and geese would only be occupied for half a year, and using the distribution as observed in 2005 (i.e. 25% ducks, 9% turkeys, 25% geese and 41% others), the N.ex for “other poultry” was calculated to be 0.38 kg N/bird place/year.

5.2.6 N flows in the manure management system

For the calculations of N emissions a Tier 2 technological approach was taken. The Tier 2 uses a mass-flow approach based on the concept of a flow of total ammoniacal nitrogen (TAN) through the manure management, and is summarized in Figure 5-6.

Figure 5-6 – N flow in the manure management system



Note: m : mass from which emissions may occur. Narrow broken arrows: TAN; narrow continuous arrows: organic N. The horizontal arrows denote the process of immobilisation in systems with bedding occurring in the house, and the process of mineralisation during storage. Broad black hatched arrows denote emissions assigned to manure management: $E_{building}$ emissions of N species ($E_{building}$ NH_3 emissions from buildings; $E_{storage}$ NH_3 , N_2O , NO_x and N_2 emissions from storage). Broad grey hatched arrows denote emissions assigned to biogas facility: $E_{biogas-prestorage}$ NH_3 emissions from prestorage; $E_{digester}$ NH_3 emissions from digester; $E_{biogas-storage}$ NH_3 emissions from biogas storage); Broad white arrows mark emissions from manure application/from soil: ($E_{application}$ NH_3 emissions during and after spreading; N_2O , NO_x and N_2 emissions from soil resulting from manure input; $E_{grazing}$ NH_3 , N_2O , NO_x and N_2 emissions during and after grazing).

The Tier 2 uses a mass-flow approach based on the concept of a flow of total ammoniacal nitrogen (TAN) through the manure management, which was determined following fifteen steps described in the 2019 guidelines (EMEP, EMEP/EEA air pollutant emission inventory Guidebook 2019 - 5B Manure management., 2019).

The first step is the definition of livestock subcategories “that are homogeneous with respect to feeding, excretion and age/weight range” (EMEP, EMEP/EEA air pollutant emission inventory Guidebook 2019 - 5B Manure management., 2019), see section 5.2.5 for full details.

As second step, is the total annual N.ex for livestock category i ($N_{ex(i)}$), expressed in kg N per year per head, respectively per year per animal place determined, with i being the i th livestock category. For details see section 5.2.5

In Step 3, the amount of the annual N excreted that is deposited within buildings in which livestock are housed ($m_{build_N(i)}$) and during grazing ($m_{grazing_N(i)}$), expressed in kg N per year per head/place for animal category i , was determined using the following equations (EMEP, EMEP/EEA air pollutant emission inventory Guidebook 2019 - 5B Manure management., 2019):

$$m_{grazing_N(i)} = x_{grazing(i)} * N_{ex(i)}$$

$$m_{build_N(i)} = x_{build(i)} * N_{ex(i)}$$

with $x_{grazing(i)}$ and $x_{build(i)}$ being defined in section 5.2.3.

Note. Yards, where than existing in Luxembourg, were integrated in the building with same manure management systemr, and were therefore not considered as a separate category, but as building.

In Step 4 the proportion of N excreted as TAN ($x_{TAN(i)}$) expressed as kg TAN per kg $N_{ex(i)}$, was calculated, whereby the amount of TAN deposited in buildings ($m_{build_TAN(i)}$) and during grazing ($m_{grazing_TAN(i)}$) was calculated using the following equations (EMEP, 2019):

$$m_{grazing_TAN(i)} = x_{TAN(i)} * m_{grazing_N(i)}$$

$$m_{build_TAN(i)} = x_{TAN(i)} * m_{build_N(i)}$$

No national data was available on the proportion of TAN, why using the default values for $x_{TAN(i)}$ as provided in Table 3.9 in the EMEP guidelines (EMEP, 2019)and summarized in Table 5-12.

Table 5-12 – TAN contents (X_{TAN}) used for emission estimates, expressed as kg TAN per kg $N_{ex(i)}$

	$X_{TAN(i)}$	Notes
Calves < 1 year;	0.6	Default value for non-dairy cattle (Table 3.9; (EMEP, 2019))
Female young female cattle 1-2 years	0.6	Default value for non-dairy cattle (Table 3.9; (EMEP, 2019))
Heifers > 2 years	0.6	Default value for non-dairy cattle (Table 3.9; (EMEP, 2019))
Fattening bulls 1-2 years	0.6	Default value for non-dairy cattle (Table 3.9; (EMEP, 2019))
Mature male cattle > 2 years	0.6	Default value for non-dairy cattle (Table 3.9; (EMEP, 2019))
Lactating dairy cows	0.6	Default value for dairy cattle (Table 3.9; (EMEP, 2019))
Suckler cows	0.6	Default value for non-dairy cattle (Table 3.9; (EMEP, 2019))
Sows	0.7	Default value for sows and piglets to 8 kg (Table 3.9; (EMEP, 2019))
Fattening pigs	0.7	Default value for fattening pigs, 8- 110 kg (Table 3.9; (EMEP, 2019))
Weaners	0.7	Default value for fattening pigs, 8-110 kg (Table 3.9; (EMEP, 2019))
Sheep (mature sheep and lambs)	0.5	Default value for sheep (Table 3.9; (EMEP, 2019))
Goats (mature goats and kids)	0.5	Default value for goats (Table 3.9; (EMEP, 2019))
Horses (including assess and mules)	0.6	Default value for horses (Table 3.9; (EMEP, 2019))
Broilers	0.7	Default value for broilers (Table 3.9; (EMEP, 2019))
Laying hens	0.7	Default value for laying hens (Table 3.9; (EMEP, 2019))
Other poultry	0.7	Default values for turkeys, ducks and geese (Table 3.9; (EMEP, 2019))
Ostriches	0.7	Default value for geese (Table 3.9; (EMEP, 2019)), similar as (Haenel H.-D. , et al., 2018)
Rabbits (breeding female animals and other rabbits)	0.6	Default value for horses (Table 3.9; (EMEP, 2019)), similar as (Haenel H.-D. , et al., 2018)
Deer	0.5	Default value for sheep and goats (Table 3.9; (EMEP, 2019))

In Step 5 the amounts of TAN and total N deposited in buildings handled as liquid slurry ($m_{build_slurry_TAN(i)}$ and $m_{build_slurry_N(i)}$) or as solid manure ($m_{build_solid_TAN(i)}$ and $m_{build_solid_N(i)}$) were calculated using the following equations (EMEP, 2019) :

$$\begin{aligned}
 m_{build_slurry_TAN(i)} &= x_{slurry(i)} * m_{build_TAN(i)} \\
 m_{build_slurry_N(i)} &= x_{slurry(i)} * m_{build_N(i)} \\
 m_{build_solid_TAN(i)} &= (1 - x_{slurry(i)}) * m_{build_TAN(i)} \\
 m_{build_solid_N(i)} &= (1 - x_{slurry(i)}) * m_{build_N(i)}
 \end{aligned}$$

with $x_{slurry(i)}$ being defined in section 5.2.3.

In step 6, the NH_3 -N losses (in kg NH_3 -N per animal per year) from the livestock buildings is calculated, following equation 15 and equation 16 from the 2019 guidelines (EMEP, 2019):

$$\begin{aligned}
 E_{build_slurry_NH3-N(i)} &= m_{build_slurry_TAN(i)} * EF_{build_slurry_NH3-N(i)} \\
 E_{build_solid_NH3-N(i)} &= m_{build_solid_TAN(i)} * EF_{build_solid_NH3-N(i)}
 \end{aligned}$$

with

$E_{build_slurry_NH3-N(i)}$	Emissions of NH_3 -N from livestock buildings with a liquid manure system;
$E_{build_solid_NH3-N(i)}$	Emissions of NH_3 -N from livestock buildings with a solid manure system;
$EF_{build_slurry_NH3-N(i)}$	Emissions factors for NH_3 -N emissions in livestock buildings with a liquid manure system;
$EF_{build_solid_NH3-N(i)}$	Emissions factors for NH_3 -N emissions from livestock buildings with a solid manure system;

More details are provided in the Informative Inventory Report (IIR) 2021 (IIR, 2021) in section 5.3.3. The NH_3 emissions are reported in NFR category 3B.

In step 7, the N in animal bedding in litter-based housing systems, an additional N input applicable **only** to solid manure, is considered, whereby accounting for the consequent immobilisation of TAN (f_{imm}) in that bedding.

The mass of bedding ($m_{bedding(i)}$), expressed as kg fresh weight per year per head/animal place, and the mass of nitrogen in that bedding ($m_{bedding_N(i)}$), expressed as kg N added per year per head/animal place were estimated using the figures provided in Table 3.7 in the 2019 guidelines (EMEP, 2019) and the country-specific housing period in days ($x_{housing(i)}$) and calculated by multiplying $x_{build(i)}$ with 365 (for $x_{build(i)}$ see section 5.2.3.), and is summarized in Table 5-13.

The estimates for N added straw in animal bedding for livestock category i in litter-based housing systems are summarized in Table 5-13. In the emission calculations the N added in straw in animal bedding was only considered for the proportion of animals kept in litter-based housing systems.

Table 5-13 – Estimated N added in straw in animal bedding ($m_{\text{bedding_N}(i)}$) for livestock category i^* (kg N/year/head or place)

3 - Agriculture														
Assumed N (kg N/head) in animal bedding for livestock category i														
Year	Calves < 1 year	Female young cattle 1-2 years	Heifers > 2 years	Fattening bulls 1-2 years	Mature male cattle > 2 years	Lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners	Sheep	Goats	Horses	Deers
1990	1.79	1.29	1.29	3.29	3.29	6.36	1.29	0.12	0.04	0.04	0.24	0.24	2.05	0.24
1991	1.60	1.10	1.10	3.10	3.10	5.63	1.10	0.12	0.04	0.04	0.24	0.24	2.05	0.24
1992	1.55	1.05	1.05	3.05	3.05	5.44	1.05	0.12	0.04	0.04	0.24	0.24	2.05	0.24
1993	1.54	1.04	1.04	3.04	3.04	5.38	1.04	0.12	0.04	0.04	0.24	0.24	2.05	0.24
1994	1.50	1.00	1.00	3.00	3.00	5.23	1.00	0.12	0.04	0.04	0.24	0.24	2.05	0.24
1995	1.48	0.98	0.98	2.98	2.98	5.13	0.98	0.12	0.04	0.04	0.24	0.24	2.05	0.24
1996	1.48	0.98	0.98	2.98	2.98	5.13	0.98	0.12	0.04	0.04	0.24	0.24	2.05	0.24
1997	1.44	0.94	0.94	2.94	2.94	5.00	0.94	0.12	0.04	0.04	0.24	0.24	2.05	0.24
1998	1.40	0.90	0.90	2.90	2.90	4.84	0.90	0.12	0.04	0.04	0.24	0.24	2.05	0.24
1999	1.25	0.75	0.75	2.75	2.75	4.26	0.75	0.12	0.04	0.04	0.24	0.24	2.05	0.24
2000	1.26	0.76	0.76	2.76	2.76	4.26	0.76	0.12	0.04	0.04	0.24	0.24	2.05	0.24
2001	1.27	0.77	0.77	2.77	2.77	4.30	0.77	0.12	0.04	0.04	0.24	0.24	2.05	0.24
2002	1.28	0.77	0.77	2.77	2.77	4.28	0.78	0.12	0.04	0.04	0.24	0.97	2.05	0.24
2003	1.31	0.81	0.81	2.80	2.80	4.37	0.81	0.12	0.04	0.04	0.24	0.97	2.05	0.24
2004	1.33	0.82	0.82	2.82	2.82	4.42	0.83	0.12	0.04	0.04	0.24	0.97	2.05	0.24
2005	1.43	0.81	0.81	2.80	2.80	4.32	0.95	0.12	0.04	0.04	0.24	0.97	2.05	0.24
2006	1.52	0.79	0.79	2.79	2.79	4.22	1.06	0.12	0.04	0.04	0.24	0.97	2.05	0.24
2007	1.62	0.77	0.77	2.77	2.77	4.12	1.18	0.12	0.04	0.04	0.24	0.97	2.05	0.24
2008	1.71	0.75	0.75	2.76	2.76	4.02	1.30	0.12	0.04	0.04	0.24	0.97	2.05	0.24
2009	1.81	0.73	0.73	2.74	2.74	3.92	1.41	0.12	0.04	0.04	0.24	0.97	2.05	0.24
2010	1.90	0.71	0.71	2.73	2.73	3.83	1.53	0.12	0.04	0.04	0.24	0.97	2.05	0.24
2011	1.88	0.73	0.73	2.67	2.67	3.86	1.50	0.12	0.04	0.04	0.24	0.97	2.00	0.24
2012	1.88	0.74	0.74	2.71	2.71	3.90	1.47	0.12	0.04	0.04	0.24	0.97	1.94	0.24
2013	1.88	0.74	0.74	2.71	2.71	3.93	1.44	0.12	0.04	0.04	0.24	0.97	1.88	0.24
2014	1.88	0.74	0.74	2.71	2.71	3.97	1.42	0.12	0.04	0.04	0.24	0.97	1.83	0.24
2015	1.88	0.74	0.74	2.71	2.71	4.01	1.39	0.12	0.04	0.04	0.24	0.97	1.77	0.24
2016	1.88	0.74	0.74	2.71	2.71	4.04	1.36	0.12	0.04	0.04	0.24	0.97	1.71	0.24
2017	1.88	0.74	0.74	2.71	2.71	4.04	1.36	0.12	0.04	0.04	0.24	0.97	1.71	0.24
2018	1.88	0.74	0.74	2.71	2.71	4.04	1.36	0.12	0.04	0.04	0.24	0.97	1.71	0.24
2019	1.88	0.74	0.74	2.71	2.71	4.04	1.36	0.12	0.04	0.04	0.24	0.97	1.71	0.24

*Note : Given the low numbers of poultry, ostriches and rabbits, and given that no data were provided in Table 3.7 in the 2019 Guidelines (EMEP, 2019) for these categories, no estimates of additional N in animal bedding in litter-based housing systems were made for poultry, ostriches and rabbits. For deer data provided in Table 3.7 for sheep and goats were used

The amounts of total-N and total-TAN in solid manure that were removed from buildings were calculated ($m_{\text{ex-build_solid_TAN}}$ and $m_{\text{ex-build_solid_N}}$), whereby following equation 18 and equation 19 from the 2019 guidelines (EMEP, 2019) :

$$m_{\text{ex-build_solid_TAN}(i)} = \{m_{\text{bui_solid_TAN}(i)} - (E_{\text{build_solid_NH3-N}(i)} + (m_{\text{bedding_N}(i)} * f_{\text{imm}}))\}$$

$$m_{\text{ex-build_solid_N}(i)} = \{m_{\text{build_solid_N}(i)} + m_{\text{bed_N}(i)} - E_{\text{build_solid}(i)}\}$$

with f_{imm} assumed to be 0.0067, according to the 2019 guidelines (EMEP, 2019)

In step 8, the amounts of total-N and TAN stored before application to land was estimated. Total manure was corrected for the proportion of manure that was used as feedstock for anaerobic digestions in biogas facilities ($x_{biogas_slurry(i)}$, and $x_{biogas_solid(i)}$), for details see section 5.2.3). Further was assumed that all manure (solid manure and slurry) would be stored before spreading (for details see section 5.2.3). The remainders, i.e. the proportion of slurry stored on farms ($x_{store_slurry(i)}$) and the proportion of solid manure stored on farms ($x_{store_solid(i)}$), which were presented in section 5.2.3, were used to estimate the amounts ($m_{storage}$) of total-N and TAN stored before application to land, following equation 20-23 and 26-29, respectively from the 2019 guidelines (EMEP, 2019) namely:

whereby for slurry:

$$m_{storage_slurry_TAN(i)} = \{(m_{build_slurry_TAN(i)} - E_{build_slurry_NH3-N(i)})\} * x_{store_slurry(i)}$$

$$m_{storage_slurry_N(i)} = \{(m_{build_slurry_N(i)} - E_{build_slurry_NH3-N(i)})\} * x_{store_slurry(i)}$$

$$m_{biogas_slurry_TAN(i)} = \{(m_{build_slurry_TAN(i)} - E_{build_slurry_NH3-N(i)})\} * x_{biogas_slurry(i)}$$

$$m_{biogas_slurry_N(i)} = \{(m_{build_slurry_N(i)} - E_{build_slurry_NH3-N(i)})\} * x_{biogas_slurry(i)}$$

and for solid manure:

$$m_{storage_solid_TAN(i)} = m_{ex-build_solid_TAN(i)} * x_{store_solid(i)}$$

$$m_{storage_solid_N(i)} = m_{ex-build_solid_N(i)} * x_{store_solid(i)}$$

$$m_{biogas_solid_TAN(i)} = m_{ex-build_solid_TAN(i)} * x_{biogas_solid(i)}$$

$$m_{biogas_solid_N(i)} = m_{ex-build_solid_N(i)} * x_{biogas_solid(i)}$$

The masses of TAN and total N ($m_{biogas_slurry_TAN}$ and $m_{biogas_slurry_N}$) are used in the Tier 2 methodology for calculating NH_3 emission from anaerobic digestion facilities (biogas production) and reported in NFR Category 5B2. It is uncommon to use solid manure in biogas facilities, why assuming that $x_{biogas_solid(i)}$ would be equal to zero (Not occurring).

Step 9 was applied only to slurry, with the aim to calculate the amount of TAN from which emissions will occur from slurry stores, whereby a fraction of the organic N is mineralised (f_{min}). The modified mass ($mm_{storage_slurry}$), from which emissions were calculated, was derived following equation 32 from the 2019 guidelines (EMEP, 2019), namely:

$$mm_{storage_slurry_TAN(i)} = m_{storage_slurry_TAN(i)} + \{(m_{storage_slurry_N(i)} - m_{storage_slurry_TAN(i)}) * f_{min}\}$$

with f_{min} assumed to be 0.1, according to the 2019 guidelines (EMEP, 2019).

In Step 10, the emissions of NH_3-N , N_2O-N , $NO-N$ and N_2-N were calculated using the corresponding's emission factors (EFs) for storage and the amounts of total TAN stored before application to land, whereby following equation 33 and 34 from the 2019 guidelines (EMEP, 2019), namely:

for slurry:

$$E_{storage_slurry(i)}$$

$$= E_{storage_slurry_NH3-N(i)} + E_{storage_slurry_N2O-N(i)} + E_{storage_slurry_NO-N(i)} + E_{storage_slurry_N2-N(i)}$$

$$= mm_{storage_slurry_TAN(i)} * (EF_{storage_slurry_NH3-N(i)} + EF_{storage_slurry_N2O-N(i)} + EF_{storage_slurry_NO-N(i)} + EF_{storage_slurry_N2-N(i)})$$

and for solid:

$$\begin{aligned}
 E_{storage_solid}(i) &= E_{storage_solid_NH_3-N}(i) + E_{storage_solid_N_2O-N}(i) + E_{storage_solid_NO-N}(i) + E_{storage_solid_N_2-N}(i) \\
 &= m_{storage_solid_TAN}(i) * (EF_{storage_solid_NH_3-N}(i) + EF_{storage_solid_N_2O-N}(i) + EF_{storage_solid_NO-N}(i) + EF_{storage_solid_N_2-N}(i))
 \end{aligned}$$

Detailed information on the calculations and the used EFs for the N₂O emissions are provided in section 5.4.3 in the current report, and for the other N emissions in section 5.3.3 in the Informative Inventory Report (IIR, 2021) . The N₂O emissions are reported in CRF category 3B, and the NH₃ and NO_x emissions are reported in NFR category 3B.

In Step 11, the total-N and TAN (m_{applic_N} and m_{applic_TAN}) that is applied to the field was calculated, according to equations 35-38 from the 2019 guidelines (EMEP, 2019) , namely:

for slurry:

$$\begin{aligned}
 m_{applic_slurry_TAN}(i) &= mm_{storage_slurry_TAN}(i) + mm_{dig_TAN}(i) - E_{storage_slurry}(i) \\
 m_{applic_slurry_N}(i) &= mm_{storage_slurry_N}(i) + mm_{dig_N}(i) - E_{storage_slurry}(i)
 \end{aligned}$$

and for solid:

$$\begin{aligned}
 m_{applic_solid_TAN}(i) &= m_{storage_solid_TAN}(i) - E_{storage_solid}(i) \\
 m_{applic_solid_N}(i) &= m_{storage_solid_N}(i) - E_{storage_solid}(i)
 \end{aligned}$$

Note the added digestate created by the anaerobic digestion of manure ($mm_{dig_TAN}(i)$ and $mm_{dig_N}(i)$ is returned from NRF 5.B.2.

In Step 12, the emissions of NH₃-N during and immediately after field application was calculated , according to equation 39 and 40 from the 2019 guidelines (EMEP, 2019), namely:

for slurry:

$$E_{applic_slurry_NH_3-N}(i) = m_{applic_slurry_TAN}(i) * EF_{applic_slurry_NH_3-N}(i)$$

and for solid:

$$E_{applic_solid_NH_3-N}(i) = m_{applic_solid_TAN}(i) * EF_{applic_solid_NH_3-N}(i)$$

Detailed information on the calculations and the used EFs are provided in section 5.4.3. in the Informative Inventory Report (IIR, 2021). The NH₃ emissions are reported in NFR category 3Da2a.

In Step 13, the net amount of N returned to soil from manure ($m_{returned_N}$ and $m_{returned_TAN}$) after losses of NH₃-N were calculated, according to equations 41-44 from the 2019 guidelines (EMEP, 2019), namely:

for slurry:

$$m_{returned_slurry_TAN}(i) = m_{applic_slurry_TAN}(i) - E_{applic_slurry_NH_3-N}(i)$$

$$m_{returned_slurry_N(i)} = m_{applic_slurry_N(i)} - E_{applic_slurry_NH3-N(i)}$$

and for solid:

$$m_{returned_solid_TAN(i)} = m_{applic_solid_TAN(i)} - E_{applic_solid_NH3-N(i)}$$

$$m_{returned_solid_N(i)} = m_{applic_solid_N(i)} - E_{applic_solid_NH3-N(i)}$$

Note: $m_{returned}$ does not account for NO and N₂O

In Step 14, the NH₃-N emissions from grazing ($E_{grazing_NH3-N(i)}$) for livestock category i were calculated, using $m_{grazing_TAN(i)}$ as estimated in Step 4 and following equation 45 from the 2019 guidelines (EMEP, 2019), namely:

$$E_{grazi_NH-N(i)} = m_{grazing_TAN(i)} * EF_{grazing_NH3-N(i)}$$

Detailed information on the calculations and the used EFs are provided in section 5.4.3 in the Informative Inventory Report (IIR, 2021). The NH₃ emissions are reported in NFR category 3D2.

And as last step were all the emissions from the manure management system that are to be reported in the NFR category 3B summed and converted to the mass of the relevant compound.

5.2.7 Category-specific recalculations including changes made in response to the review process

In the current submission the following changes were applied, namely:

- The manure management system were updated using more recent data.
- The assumption for cattle slurry stored in open tanks with respect of having a natural crust was revised.
- The used N excretion (N.ex) for suckler cow were revised
- The Tier 2 N mass-flow in the manure management systems was updated according to the 2019 EMEP guidelines, i.e. revisions of some formulas and used EFs. Additionally was the N quantity which is added via bedding material corrected (step 7). And in step 11 was the digestate created by the anaerobic digestion of manure, that is returned from 5.B.2 added.d.

A detailed description is provided in Annex 3:A, including recalculations. There are more improvements to follow in the following submissions. Lack of data requiring additional data collection, confidential data requiring legal contracts (i.e. MMS update), and available manpower were the reason for not fully implementing all desired changes in the current submission.

5.2.8 Category specific uncertainty

Models are not an exact representation of real life and therefore their estimates are to a certain extent uncertain. Uncertainty was modelled using Monte-Carlo techniques. A detailed description of the assumed uncertainties for animal population numbers, N.ex and manure management systems is provided in Annex 3:B.

5.2.9 Category-specific QA/QC and verification

Consistency and completeness checks have been performed directly while building and calculating GHG emissions from the agriculture sector.

The plausibility of the estimates, as well as the calculation methods, were discussed and developed by the sector experts in the country.

Planned improvement

With additional data on MMS collected during the 2020 agriculture census - additional changes will be made in future submissions, ones analysed.

With the publication of the future IPCC guidelines, the necessary changes will be made where applicable in future submissions.

5.3 Enteric Fermentation (IPCC Source Category 3.A)

This section describes the estimation of methane emissions resulting from enteric fermentation. In 2019, this source category was responsible for 87% of agricultural methane emissions and for 68.96% of the total methane emissions estimated for Luxembourg. It represented 56% of the total GHG emissions from the agriculture sector and 3.74% of the total GHG emissions in CO₂eq (excluding LULUCF).

5.3.1 Key source

With 3.74% of the total GHG emissions in CO₂ eq., excluding LULUCF in 2019, methane emissions from enteric fermentation (IPCC category 3A) is a key source, whether LULUCF is included or excluded (Table 5-3). It has been a key source in both cases without interruption since 1990.

Table 5-14 – CH₄ emission trends for IPCC Category 3A – Enteric Fermentation: 1990-2019 (Gg)

3 - Agriculture Sector																					
CH ₄ emissions (Gg)																					
Year	3.A - Enteric fermentation																				
	Total	Calves <1 year	Female young Heifers >2 years	Fattening bulls 1-2 years	Mature male cattle >2 years	Lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners 10-30 kg	Mature sheep	Sheep lambs <1 year	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deer	
1990	15.51	1.70	2.05	1.39	1.02	0.43	6.61	2.15	0.013	0.050	0.029	0.035	0.008	0.002	0.031	NO	NO	NO	NO	NE	0.002
1991	15.62	1.69	2.08	1.45	1.08	0.44	6.25	2.46	0.013	0.043	0.026	0.037	0.009	0.002	0.033	NO	NO	NO	NO	NE	0.003
1992	15.01	1.60	2.04	1.41	1.01	0.37	5.91	2.50	0.013	0.046	0.025	0.036	0.007	0.002	0.033	NO	NO	NO	NO	NE	0.003
1993	15.17	1.59	1.95	1.41	1.08	0.37	5.95	2.66	0.013	0.050	0.025	0.031	0.008	0.002	0.035	NO	NO	NO	NO	NE	0.003
1994	15.08	1.65	1.93	1.27	1.12	0.33	5.79	2.81	0.013	0.046	0.025	0.039	0.008	0.002	0.038	NO	NO	NO	NO	NE	0.004
1995	15.59	1.64	1.99	1.34	1.21	0.39	5.85	2.99	0.013	0.050	0.027	0.039	0.008	0.002	0.039	NO	NO	NO	NO	NE	0.004
1996	15.82	1.68	1.99	1.39	1.28	0.40	5.79	3.11	0.013	0.047	0.028	0.036	0.008	0.001	0.040	NO	NO	NO	NO	NE	0.003
1997	15.51	1.62	1.97	1.31	1.32	0.44	5.66	3.00	0.013	0.054	0.027	0.038	0.009	0.001	0.041	NO	NO	NO	NO	NE	0.003
1998	15.36	1.58	1.89	1.30	1.35	0.41	5.64	2.99	0.013	0.055	0.030	0.043	0.008	0.001	0.042	NO	NO	NO	NO	NE	0.006
1999	15.36	1.58	1.86	1.30	1.31	0.38	5.60	3.12	0.012	0.059	0.033	0.041	0.009	0.001	0.051	NO	NO	NO	NO	NE	0.007
2000	15.20	1.56	1.84	1.28	1.30	0.34	5.46	3.20	0.011	0.058	0.030	0.041	0.008	0.001	0.057	NO	NO	NO	NO	NE	0.008
2001	15.30	1.55	1.83	1.28	1.32	0.38	5.47	3.25	0.012	0.058	0.028	0.045	0.008	0.001	0.056	NO	NO	NO	NO	NE	0.007
2002	14.79	1.53	1.70	1.21	1.19	0.33	5.43	3.19	0.011	0.060	0.029	0.045	0.010	0.004	0.056	NO	NO	NO	NO	NE	0.006
2003	14.34	1.46	1.69	1.14	1.13	0.30	5.31	3.07	0.011	0.067	0.028	0.053	0.009	0.008	0.062	NO	NO	NO	NO	NE	0.005
2004	14.17	1.45	1.67	1.12	1.09	0.28	5.27	3.03	0.011	0.082	0.025	0.053	0.009	0.009	0.066	NO	NO	NO	NO	NE	0.006
2005	14.20	1.40	1.66	1.11	1.15	0.27	5.25	3.08	0.011	0.087	0.028	0.049	0.011	0.009	0.075	NO	NO	NO	NO	NE	0.005
2006	14.06	1.41	1.68	1.07	1.11	0.25	5.19	3.08	0.011	0.082	0.025	0.055	0.009	0.008	0.078	NO	NO	NO	NO	NE	0.005
2007	14.55	1.50	1.76	1.13	1.14	0.22	5.34	3.19	0.010	0.081	0.026	0.050	0.009	0.011	0.078	NO	NO	NO	NO	NE	0.004
2008	15.03	1.48	1.77	1.04	1.30	0.25	5.35	3.56	0.010	0.081	0.024	0.048	0.008	0.013	0.082	NO	NO	NO	NO	NE	0.007
2009	15.13	1.49	1.77	1.03	1.22	0.30	5.44	3.59	0.010	0.081	0.023	0.049	0.008	0.014	0.082	NO	NO	NO	NO	NE	0.007
2010	15.40	1.49	1.83	1.05	1.30	0.29	5.60	3.56	0.010	0.069	0.033	0.049	0.009	0.021	0.083	NO	NO	NO	NO	NE	0.007
2011	14.91	1.49	1.79	0.97	1.13	0.25	5.50	3.49	0.009	0.076	0.033	0.049	0.008	0.023	0.083	NO	NO	NO	NO	NE	0.009
2012	14.56	1.50	1.80	0.92	1.04	0.22	5.43	3.36	0.009	0.081	0.029	0.046	0.007	0.022	0.088	NO	NO	NO	NO	NE	0.008
2013	14.93	1.52	1.82	0.92	1.14	0.24	5.65	3.36	0.008	0.081	0.026	0.049	0.008	0.020	0.084	NO	NO	NO	NO	NE	0.005
2014	15.41	1.52	1.85	1.16	1.24	0.28	5.84	3.25	0.008	0.082	0.026	0.050	0.008	0.019	0.085	NO	NO	NO	NO	NE	0.005
2015	15.81	1.54	1.91	1.20	1.12	0.29	6.17	3.28	0.007	0.090	0.030	0.053	0.009	0.021	0.085	NO	NO	NO	NO	NE	0.005
2016	16.07	1.56	1.90	1.14	0.99	0.25	6.71	3.25	0.007	0.090	0.028	0.049	0.008	0.022	0.082	NO	NO	NO	NO	NE	0.003
2017	16.29	1.50	2.01	1.14	0.97	0.26	6.91	3.21	0.008	0.093	0.030	0.048	0.008	0.023	0.084	NO	NO	NO	NO	NE	0.002
2018	16.13	1.39	1.92	1.25	0.89	0.26	7.12	3.02	0.008	0.086	0.029	0.048	0.008	0.022	0.084	NO	NO	NO	NO	NE	0.003
2019	16.06	1.44	1.83	1.12	0.79	0.25	7.35	3.01	0.007	0.078	0.030	0.049	0.008	0.022	0.084	NO	NO	NO	NO	NE	0.001
Trend 1990 -2019	4%	-15%	-11%	-20%	-22%	-41%	11%	40%	-50%	56%	4%	37%	0%	981%	171%	NO	NO	NO	NO	NE	-46%
Trend 2018 -2019	0%	3%	-5%	-11%	-11%	-2%	3%	0%	-14%	-9%	4%	1%	0%	2%	0%	NO	NO	NO	NO	NE	-67%

Source: Service d'économie rurale (SER).

Note: Asses and mules are included in the category horses. Turkey are included in the category other poultry.

5.3.2 Source category description

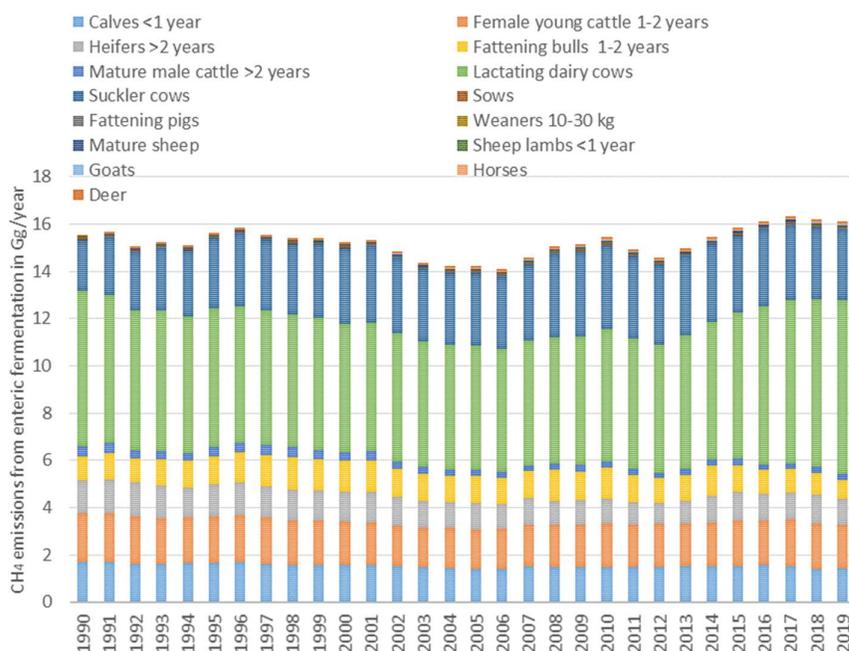
Livestock statistics in Luxembourg were detailed enough to go for option C. Cattle, the main livestock category in Luxembourg was split into 7 categories, namely calves <1 year; young female cattle 1-2 years; heifers >2years; fattening bulls 1-2 years, mature male >2 years, lactating dairy cows and suckler cows. For swine the distinction was made between sows, weaners 10-30 kg and fattening pigs >30 kg. Poultry was split in laying hens, broilers and other poultry. Sheep was split in mature animals and lambs. Mules and asses were included in the category horses. The remaining categories were goats, ostriches, rabbits and deer (see details in section 5.2.1).

Goats, although a niche production in Luxembourg, have experienced the biggest increase in their population for the whole period 1990-2019 (Table 5-5), and consequently also the biggest increase in methane emission from enteric fermentation for the same time period (>981%), see Table 5-14. However, methane emission from enteric fermentation from goats represent <0.15% of the total methane emission from enteric fermentation in 2019 (see Table 5-14). Cattle as a whole group is over the whole period the main methane emitting animal category with regard to enteric fermentation, and was, in 2019, responsible for 98% of the total methane emission from enteric fermentation (Table 5-14 and Figure 5-7). Lactating dairy cows is the subgroup with the highest emission over the whole period (Figure 5-8). In 2019, 46% of the methane emission from enteric fermentation were from lactating dairy cows (Figure 5-7 and Table 5-14).

On the whole, methane emissions from enteric fermentation increased by 4% over the period 1990-2019. This results mainly from raising emission of dairy cows (+11%) and suckler cows (+40%). Raising emissions of other livestock categories, such as horses (+171%) and fattening pigs (+56%) had only a marginal impact on the total methane emissions from enteric fermentation.

With regard to cattle, its total population and its evolution are strongly influenced by changes in agricultural policy and, more precisely, in the Common Agricultural Policy of the EU (CAP). This is the case for dairy cows. Due to a quota system for milk production in place from 1983-31st March 2015, and an increasing milk yield per cow was the population of dairy cows declining over time. But with the abolishment of the milk quota system in Europe in spring 2015, is the number of dairy cows increasing since then, with an accelerated increase in the first 2-3 years, and a slowing down in the last two years. Another factor influencing cattle population is/was, availability of fodder, respectively fodder and milk prices. As an example, the peak in the non-dairy cattle population observed in 1991 can be explained by a sharp price fall of the bovine meat price that year. This price fall led farmers to postpone slaughtering until early 1992.

Figure 5-7 – Enteric fermentation per animal category: 1990 - 2019



Source: SER.

Note: Asses and mules were included in the category horses.

5.3.3 Methodological issues

Table 5-15 gives an overview of the status, the methods and emission factors (EF) used for the IPCC Source Category 3.A.

The 2006 IPCC guidelines do not provide an EF for poultry, because of “insufficient data” (IPCC 2006a). Why it was assumed that there would be no emissions occurring (“NO”), neither in poultry, nor in ostriches. And although rabbits are, like horses, mono-gastric animals causing some methane emissions, there was no EFs for rabbits in the 2006 IPCC guidelines provided, why not estimated (“NE”).

An IPCC Tier 2 methodology was used for cattle and sheep, and an IPCC Tier 1 methodology was applied for all other animal categories.

Table 5-15 – Overview of IPCC Source Category 3.A: Status, methods and emission factors (EF) used.

GHG source & sink category	Description	CH ₄		
		Status	Method	EF
3.A.1 opt. C	Calves < 1 year	x	T2	CS
3.A.1	Female young cattle 1-2 years ^a	x	T2	CS
3.A.1	Heifers > 2 years	x	T2	CS
3.A.1	Fattening bulls 1-2 years	x	T2	CS
3.A.1	Mature male cattle >2 years	x	T2	CS
3.A.1	Lactating dairy cows	x	T2	CS
3.A.1	Suckler cows	x	T2	CS
3.A.2	Mature sheep	x	T2	CS
3.A.2	Sheep lamb < 1 year	x	T2	CS
3.A.3	Sows	x	T1	D
3.A.3	Fattening pigs >30 kg	x	T1	D
3.A.3	Weaners (10-30 kg)	x	T1	D
3.A.4	Horses ^b	x	T1	D
3.A.4	Goats ^c	x	T1	D
3.A.4	Poultry ^d	NO		
3.A.4	Ostrich ^d	NO		
3.A.4	Rabbits ^d	NE		
3.A.4	Deer	X	T1	D

Notes: An “x” indicates that emissions from this sub-category had been estimated.

- In the CRF reported as one category. For the emission calculations a distinction was made between young female cattle 1-2 years and heifers >2 years.
- Including also ponys, mules and asses.
- Goats were split in 2 sub-categories: i) mature goats and ii) goat kits for the calculations, but reported in the CRF as one category.
- In the 2006 IPCC guidelines, no EFs were developed for poultry, ostrich and rabbits, why assumed to not occur (NO), respectively not estimated (NE).

Used abbreviations: CS = country-specific value EF; D = IPCC default EF; NE=not estimated; NO=not occurring; T1 = IPCC Tier 1; T2 = IPCC Tier 2.

5.3.3.1 Activity data

Livestock numbers were the activity data for this emission source. Livestock numbers were presented in section 5.2.2.1.

5.3.3.2 Emission factors

Emission factors used for the calculation of enteric fermentation, are detailed in following sections dealing with all livestock categories, excluding cattle and sheep.

Emission factors for swine, goats, horses and deer

For the Tier 1 methodology, default emission factors (EF) for enteric fermentation related methane emissions in kg CH₄ per head per year were derived from Table 10.10 in the 2006 IPCC guidelines (IPCC 2006a), namely 1.5 kg for swine, 5 for goats, 18 for horses and 20 for deer (=deer). For the assumed uncertainties, see Annex 3: B.

The live weight for those animal categories are summarized in Table 5-16.

Table 5-16 - Live weight for other animal categories than cattle and sheep.

Animal category	Weight (kg)				Note
	Begin weight	End weight	Mature weight	Average weight	
Sows			250-300 kg (KTBL 2018f)	275 kg ^a	Mature weights were taken from literature for breeds present in Luxemburg.
Fattening pigs	30 kg	120 kg (KTBL 2018g) (Kirchgessner M. , 2014f)	-	75 kg ^b	Similar breeds and feeding conditions in Germany and in Luxembroug
Weaners	10 kg	30 kg		20 kg ^b	Begin weight is the defined starting age for this category, and the 30 kg is the defined end weight
Mature goats ^c			50-55 kg (KTBL 2018g, Weiss 1985)	52.5 kg ^a	Similar breeds and feeding conditions in Germany and in Luxemburg
Goat kits ^c	3.5-5 kg ^a (KTBL 2018a)	13 kg (own survey) / 52.5 kg ^a (mature weight)	50-55 kg (KTBL 2018b) (Weiss, 1985)	19 kg ^{a, b}	Taken into consideration the average animal population of slaughtered goat kits (13 kg end weight) and replacement female goat kits (52.5 kg end weight).
Horses - heavy ^e			600-800 kg (Anonymous, 2019b) (Kirchgessner M. , 2014g)	700 kg ^a	Mature weights were taken from literature for breeds present in Luxemburg
Riding horses ^d			500-700 kg (Kirchgessner 2014g)	600 kg ^a	Mature weights were taken from literature for breeds present in Luxemburg
Ponys, including anes and mules ^d			100-400 kg (Kirchgessner 2014g)	250 kg ^a	Mature weights were taken from literature for breeds present in Luxemburg
Laying hens ^e			1.8-2.3 kg (Scholtyssek, 1987)	2.05 kg ^a	
Broilers ^e	0.04 kg (KTBL 2018f)	1.5-2 kg ^a (KTBL 2018a, Scholtyssek et al. 1987)		0.9 kg ^{a, b}	
Other poultry ^e	0.04 -0.2 kg ^a (KTBL 2018a)	3-15 kg ^a (KTBL 2018a)		5 kg ^{a, b}	The range covers the different other poultry categories considered in this category
Ostriches	1.5-1.9 kg ^a (Kirchgessner M. , 2014g) (Kirchgessner M. , 2014h)		90-135 kg ^a	57 kg ^{a, b}	
Rabbits – breeding female animals ^f			3 kg (Haenel et al. 2018)	3 kg	
Other rabbits ^f	0.1 kg (KTBL 2018a,	2.4-2.7 kg ^a (KTBL 2018a)		1.33 kg ^{a, b}	

	Kirchgesner 2014f)				
Deer	4.6-4.9 kg ^a (KTBL 2018a)	42.5-72.5 kg ^a (KTBL 2018a)		31 kg ^{a,b}	

Note: The breeds present in Luxembourg are also very common in Germany. Climate, feeding and housing conditions are similar between Germany and Luxembourg. References to KTBL and Kirchgesner, both standard references for the German agriculture, apply also to the Luxembourgish agriculture.

- a) The middle of the range is used as most likely value in the stochastic calculations, and as “the value” for the deterministic calculations.
- b) Calculated: (begin weight + end weight) /2.
- c) The average weight for “goats” reported in the CRF tables varies over the years and is calculated using the weights presented in the above table and the average animal population for mature goats and goat kits.
- d) The average weight for “horses” reported in the CRF tables varies over the years and is calculated using the weights presented in the above table and the average animal population for heavy horses, riding horses, ponys, anes and mules.
- e) The average weight for “poultry” reported in the CRF tables varies over the years and is calculated using the weights presented in the above table and the average animal population for broilers, laying hens and other poultry.
- f) The average weight for “rabbits” reported in the CRF tables varies over the years and is calculated using the weights presented in the above table and the average animal population for breeding female animals and for other rabbits.

Emission factors for cattle and sheep

For cattle and sheep a Tier 2 approach was used to calculate country- and year-specific emission factors. The general EF for enteric fermentation related methane emissions in kg CH₄ per head per year was estimated following equation 10.21 from the 2006 IPCC guidelines (IPCC 2006a):

$$EF_{CH_4} 3A_i = \left(\frac{GE_i * \left(\frac{Y_{mi}}{100} \right) * 365}{55.65} \right)$$

with:

- Y_{mi} : Methane conversion factor for livestock category (*i*), per cent of gross energy in feed converted to methane
- GE_i : Gross energy (MJ/animal/day) for animal category *i*

Based on the 2006 IPCC guidelines (IPCC 2006a), we used the default value of 6.5% for Y_m for cattle and mature sheep, and the default value of 4.5% for Y_m for sheep lambs <1 year.

The GE_i in MJ/day/animal is calculated for cattle and sheep according to equation 10.16 in the 2006 IPCC guidelines (IPCC 2006a):

$$GE_i = \left(\frac{\left(\frac{NE_m + NE_a + NE_l + NE_p}{REM} \right) + \left(\frac{NE_g + NE_{wool}}{REG} \right)}{\frac{DE\%_i}{100}} \right)$$

with:

- NE_m = net energy required by the animal for maintenance, MJ/day
- NE_a = net energy for animal activity, MJ/day
- NE_l = net energy for lactation, MJ/day
- NE_p = net energy required for pregnancy, MJ/day

- REM = ratio of net energy available in a diet for maintenance to digestible energy consumed
- NE_g = net energy needed for growth, MJ/day
- NE_{wool} = net energy required to produce a year of wool, MJ/day
- REG = ratio of net energy available for growth in a diet to digestible energy consumed
- DE% = digestibility energy expressed as a percentage of gross energy.

Note, net energy for work was not considered, as not applicable in Luxembourg, neither for cattle, nor for sheep.

The net energy for maintenance (NE_m) in MJ/day was calculated according to equation 10.3 of the 2006 IPCC guidelines (IPCC 2006a):

$$NE_m = Cf_i * (Weight)^{0.75}$$

with:

- Cf_i = a coefficient which varies for each animal category, MJ/day/kg
- Weight = live-weight of animal, kg

Note the default values provided in Table 10.4 of the 2006 IPCC guidelines (IPCC 2006a) were used, namely 0.386 for lactating dairy cows; 0.370 for fattening bulls 1-2 years and for mature male cattle >2 years and 0.322 for all other cattle categories; further 0.236 for sheep lamb <1 year and 0.217 for mature sheep.

The used live weights for the different cattle and sheep categories are summarized in Table 5-17.

The net energy for animal activity (NE_a) in MJ/day for cattle was calculated according to equation 10.4 of the 2006 IPCC guidelines (IPCC 2006a):

$$NE_a = C_a * NE_m$$

with:

- C_a = coefficient corresponding to animal's feeding situation.

The C_a according to Table 10.5 from the 2006 IPCC guidelines (IPCC 2006a) was 0.17 for the percentage of the year that cattle were grazing (x_{grazing}¹¹²), and 0 for the percentage of the year that cattle were kept in the stall (x_{stall} = 1 - x_{grazing}).

The net energy for animal activity (NE_a) in MJ/day for sheep was calculated according to equation 10.5 of the 2006 IPCC guidelines (IPCC 2006a):

$$NE_a = C_a * (live - weight (kg))$$

The C_a according to Table 10.5 from the 2006 IPCC guidelines (IPCC 2006a) was 0.009 for housed ewes, 0.0107 for sheep grazing on pasture (lambs and mature sheep) and 0.067 for housed fattened lambs. The used live-weights are summarized in Table 5-17.

¹¹² x_{grazing} is equal to the proportion of excreta deposited during grazing (MMS – pasture).

Table 5-17 – Cattle and sheep: live weight, daily weight gain and digestibility of feed.

Animal category	Weight (kg)				Daily weight gain (kg/day)	Digestible energy (DE%) ^e
	Begin weight	End weight	Live weight	Mature weight		
Calves < 1 year	40 (KTBL 2018a)	325 (KTBL 2018a, Kirchgessner 2014a)	183 ^a	794 ^c	0.78 ^b	70%
Female young cattle 1-2 years	End weight of calves <1 year	550 (KTBL 2018a, Kirchgessner 2014a)	438 ^a	650 (KTBL 2018a)	0.62 ^b	70%
Heifers > 2 years	End weight of female young cattle	600 (KTBL 2018a, Kirchgessner 2014a)	575 ^a	650 (KTBL 2018a)	0.14 ^b	70%
Fattening bulls 1-2 years	430 (Kirchgessner 2014b)	700 (Kirchgessner 2014b, KTBL 2018b)	565 ^a	1075 (KTBL 2018b)	1.33 (KTBL 2018b)	70%
Mature male cattle >2 years	End weight of fattening bulls	900 (KTBL 2018a)	800 ^a	1075 (KTBL 2018b)	0.55 ^b	70%
Lactating dairy cows			650 (KTBL 2018a)	650 (KTBL 2018a)	-	70%
Suckler cows			700 (KTBL 2018a)	700 (KTBL 2018a)	-	70%
Mature sheep			75 (KTBL 2018b)	75 (KTBL 2018b)	-	70%
Sheep lamb <1 year	5 (KTBL 2018a, Kirchgessner, 2014e)	45 /55 ^d (Kirchgessner, 2014d)	26 ^{a,d}	75 (KTBL 2018b)	0.21 ^{b,d}	70%

Notes: The dominant breed in dairy cattle in Luxembourg is Holstein, one of the breeds also common in Germany. Climate, feeding and housing conditions are similar between Germany and Luxembourg. References to KTBL and Kirchgessner, both standard references for the German agriculture, apply also to the Luxembourgish agriculture.

- a) Calculated: (begin weight + end weight) /2.
- b) Calculated: (end weight- begin weight)/365.
- c) Weighted average based on mature cows (650 kg) and mature bulls (1075 kg) and assuming that 66% of calves are female calves (STATEC 2018b).
- d) Lambs slaughter obtain an end live-weight of 45 kg (~80% of the lambs) and replacement animals obtain an end live-weight of 55 kg, resulting in an weighted average live weight of 26 kg and a weighted daily growth of 0.21 kg. Note: An “x” indicates that emissions from this sub-category have been estimated.
- e) Category 2 in Table 10.2 of the 2006 IPCC guidelines (IPCC 2006a) fits best the Luxembourgish situation. For more details, see further down in this section.

The net energy for growth (NE_g) in MJ/day for cattle (i.e. all cattle categories except for cows) was calculated according to equation 10.6 of the 2006 IPCC guidelines (IPCC 2006a):

$$NE_g = 22.02 * \left(\frac{Live - weight}{C * Mature weight} \right)^{0.75} * WG^{1.097}$$

with:

C = a coefficient with a value of 0.8 for females and 1.2 for bulls (IPCC 2006a).

WG = average daily weight gain in kg/day and as summarized in Table 5-17.

Note: Male calves from dairy cows are often sold and exported at the age of ~10 days for veal production. Consequently ~66% of the calves were female calves (STATEC 2018b).

The net energy for growth (NE_g) in MJ/day for sheep lambs was calculated according to equation 10.7 of the 2006 IPCC guidelines (IPCC 2006a):

$$NE_g = \frac{WG_{lamb} * (a + 0.5 * b * (BW_i + BW_f))}{365}$$

with:

WG_{lamb} = the weight gain ($BW_f - BW_i$) in kg per year

BW_i = the live body weight at weaning, namely 30 kg (Kirchgessner M. , 2014c)

BW_f = the live body weight at 1-year old (55 kg) or at slaughter (45 kg), see Table 5-17.

a being a constant and being 2.1 for females (assumption: ~50% of all lambs) and 2.5 for intact males, see Table 10.6 of the 2006 IPCC guidelines (IPCC 2006a)

b being a constant and being 0.45 for females and 0.35 for intact males, see Table 10.6 of the 2006 IPCC guidelines (IPCC 2006a).

The net energy for lactation (NE_l) in MJ/day for dairy cows and suckler cows was calculated according to equation 10.8 of the 2006 IPCC guidelines (IPCC 2006a):

$$NE_l = Milk * (1.47 + 0.4 * Fat)$$

with:

Milk = amount of milk produced in kg per day.

Fat = Fat content of milk in %/kg.

Daily milk yield and fat contents of dairy cows are summarized in Table 5-10.

Daily milk yield for suckler cows varies between 8-14 kg/day (Kirchgessner M. , 2014a), (KTBL, 2018a) and during 7-10 months (Kirchgessner M. , 2014d). For the emissions calculations an average of 11 kg per day was assumed for a period of 243 days, resulting in 2677 kg milk/suckler cow per year. Having no data, the average fat content as estimated for dairy cows for the years 1990-2018, namely 4.1%, was used as proxy.

The net energy for lactation (NE_l) in MJ/day for sheep was calculated according to equation 10.10 of the 2006 IPCC guidelines (IPCC 2006a):

$$NE_l = \left[\frac{5 * WG_{wean}}{365} \right] * EV_{milk}$$

with:

WG_{wean} = the weight gain of the lamb between birth and weaning, namely 25 kg = 30 kg (BW_i) – 5 kg (birth weight).

EV_{milk} = the energy required to produce 1 kg of milk in MJ/kg. The default value used was 4.6 MJ/kg (IPCC 2006a)

The net energy for wool production (NE_{wool}) in MJ/day for sheep was calculated according to equation 10.12 of the 2006 IPCC guidelines (IPCC 2006a):

$$NE_{wool} = \left[\frac{EV_{wool} * Production_{wool}}{D} \right]$$

with:

$Production_{wool}$ = annual wool production per sheep in kg/year.

EV_{wool} = the energy value of each kg of wool produced in MJ/kg. The default value, namely 24 MJ/kg is used (IPCC 2006a).

The annual wool production was 2.5-3 kg per sheep per year (Vaessen Personal communication; December 2018). For the emissions calculations, an annual wool production of 2.75 kg/year per mature sheep, and 1.7 kg for sheep lambs (note 80% of the lambs would be slaughtered at 6 months) was assumed.

The net energy for pregnancy (NE_p) in MJ/day for cattle and sheep was calculated according to equation 10.13 of the 2006 IPCC guidelines (IPCC 2006a):

$$NE_p = C_{pregnancy} * NE_m$$

with:

$C_{pregnancy}$ = pregnancy coefficient. The default value, namely 0.10 is used.

NE_m = net energy required by the animal for maintenance, MJ/day.

The default value for cattle for $C_{pregnancy}$, namely 0.10 was used (IPCC 2006a). The default value for sheep was 0.077 for single birth and 0.126 for twins (IPCC 2006a). With on average 1.5 lambs born per year per ewe (Vaessen Personal communication; December 2018), it was assumed that 50% of the ewes would give birth to one lamb and 50% would give birth to twins.

NE_p was weighted by the portion of females that would be pregnant in a year. For simplification it was assumed that 100% of lactating dairy cows would be pregnant and 100% of the heifers >2 years. Within the category “suckler cows”, it was assumed that 100% of the suckler cows would be pregnant, but non-lactating cows (i.e. 9.2% of cows in this category) would not be pregnant, resulting in a weighted average of 91.8% pregnancy for the livestock category “suckler cows”. For female young cattle 1-2 years, it was assumed, similar as Germany, that 30% would be pregnant (Haenel et al. 2018). For mature sheep, it was assumed for simplicity reason, that 100% would be pregnant.

The ratio of net energy available in diet for maintenance to digestible energy consumed (REM) was estimated according to equation 10.14 of the 2006 IPCC guidelines (IPCC 2006a):

$$REM = \left(1.123 - (4.092 * 10^{-3} * DE\%) + [1.126 * 10^{-5} * (DE\%)^2] - \left(\frac{25.4}{DE\%} \right) \right)$$

with:

DE% = digestible energy expressed as a percentage of gross energy.

In Table 10.2 in the 2006 IPCC guidelines (IPCC 2006a), there were three references, whereby category 2, “pasture fed animals” describes best the Luxemburg situation. There are three main forage sources used in Luxemburg for cattle and other ruminants, those are fresh grass, grass silage and corn silage (whole plant) with an average digestibility of 68.6% (range: 62.4%-73.1%); 71.1% (68.2%-73.2%) and 74.7% (73.9%-76.5%), respectively.¹¹³

In the summer, fresh grass was/is the main forage source for older calves, young cattle; bulls >2 (mostly sires kept with suckler cows or heifers) and suckler cows. Calves receive in addition some concentrated feed (up to 1-1.5 kg/day). In the winter were/are the majority of the animals kept in the stable, and was/is grass silage and corn silage the main forage source, supplemented with concentrated feed. Feed concentrates in Luxemburg were/are based on fodder cereals, such as barley and wheat, and supplemented with soybean meal and rapeseed meal (both are extruded meals).

Fattening bulls are kept the whole year in the stable and fed with corn silage, supplemented with some grass silage and concentrated feed.

For dairy cows and the introduction of milking robots, the situation has changed over time. There are now-a-days dairy cows kept the whole year around in stables, whereas on other dairy farms, dairy cows are put in the summer months on pasture varying from a few hours to the majority of the day. Nevertheless, even if on pasture or not, dairy cows would mostly be fed in stable with grass silage, corn silage and concentrated feed, whereby the milk yield is dictating the amount of concentrated feed.

Given the high digestibility of the three main forage sources, and the fact that the cattle diet is supplemented with concentrated feed, animal experts at the SER and ASTA recommended to use for feed digestibility 70% (which is slightly higher than the digestibility of fresh grass, but lower than the average digestibility of grass silage and corn silage).

Sheep, goats, horses and deer are other ruminants kept in Luxemburg, why for simplification the same feed digestibility was assumed as for cattle, namely 70%.

The ratio of net energy available for growth in a diet to digestible energy consumed (REG) is estimated according to equation 10.15 from the 2006 IPCC guidelines (IPCC 2006a):

$$REG = \left(1.164 - (5.160 * 10^{-3} * DE\%) + [1.308 * 10^{-5} * (DE\%)^2] - \left(\frac{37.44}{DE\%} \right) \right)$$

¹¹³ Based on measurements conducted by the Laboratoire de Contrôle et d'Essais de l'ASTA (Administration des Services Techniques de l'Agriculture), Ettelbruck for the years 2012-2017; Christelle Schmit (head of department), personnel communication (3-10-2018). Feed digestibility is determined in the laboratory. The laboratory is following international recognized norms (for details see https://agriculture.public.lu/de/publications/pflanzen-boden/Labo_Ettelbruck/labo_ettelbruck_analysen.html)

Table 5-18 – Estimated gross energy (GE) for cattle and sheep categories for the years 1990-2019

3 - Agriculture									
Activity data - Estimated gross energy (GE)/head/year									
Year	Calves <1 year	Female young cattle 1-2 years	Heifers >2 years	Fattening bulls 1-2 years	Mature male cattle >2 years	Lactating dairy cows	Suckler cows	Mature sheep	Sheep lambs <1 year
1990	66.8	141.5	132.4	185.4	184.5	263.3	228.3	22.3	12.6
1991	66.8	141.5	132.4	185.4	184.5	263.9	228.3	22.3	12.6
1992	66.8	141.5	132.4	185.4	184.5	271.4	228.3	22.3	12.6
1993	66.8	141.5	132.4	185.4	184.5	278.2	228.3	22.3	12.6
1994	66.8	141.5	132.4	185.4	184.5	277.2	228.3	22.3	12.6
1995	66.8	141.5	132.4	185.4	184.5	282.1	228.3	22.3	12.6
1996	66.8	141.5	132.4	185.4	184.5	283.2	228.3	22.3	12.6
1997	66.8	141.5	132.4	185.4	184.5	286.6	228.3	22.3	12.6
1998	66.8	141.5	132.4	185.4	184.5	288.1	228.3	22.3	12.6
1999	66.8	141.5	132.4	185.4	184.5	291.1	228.3	22.3	12.6
2000	66.8	141.5	132.4	185.4	184.5	295.3	228.3	22.3	12.6
2001	66.8	141.5	132.4	185.4	184.5	299.4	228.3	22.3	12.6
2002	66.8	141.5	132.4	185.4	184.5	302.9	228.3	22.3	12.6
2003	66.8	141.5	132.4	185.4	184.5	306.7	228.3	22.3	12.6
2004	66.8	141.5	132.4	185.4	184.5	310.2	228.3	22.3	12.6
2005	66.8	141.5	132.4	185.4	184.5	312.8	228.3	22.3	12.6
2006	66.8	141.5	132.4	185.4	184.5	315.3	228.3	22.3	12.6
2007	66.8	141.5	132.4	185.4	184.5	312.7	228.3	22.3	12.6
2008	66.8	141.5	132.4	185.4	184.5	316.9	228.3	22.3	12.6
2009	66.8	141.5	132.4	185.4	184.5	317.3	228.3	22.3	12.6
2010	66.8	141.5	132.4	185.4	184.5	321.2	228.3	22.3	12.6
2011	66.8	141.5	132.4	185.4	184.5	322.0	228.5	22.3	12.6
2012	66.8	141.5	132.4	185.4	184.5	323.0	228.7	22.3	12.6
2013	66.8	141.5	132.4	185.4	184.5	315.7	228.9	22.3	12.6
2014	66.8	141.5	132.4	185.4	184.5	326.3	229.2	22.3	12.6
2015	66.8	141.5	132.4	185.4	184.5	339.7	229.4	22.3	12.6
2016	66.8	141.5	132.4	185.4	184.5	339.6	229.6	22.3	12.6
2017	66.8	141.5	132.4	185.4	184.5	338.7	229.6	22.3	12.6
2018	66.8	141.5	132.4	185.4	184.5	349.0	229.6	22.3	12.6
2019	66.8	141.5	132.4	185.4	184.5	351.6	229.6	22.3	12.6

Source: SER

Table 5-19 – Implied emission factor (IEF) for enteric fermentation related methane emissions in kg CH₄ per head per year for the different cattle and sheep categories for the years 1990-2019

3 - Agriculture									
Implied emission factor (IEF) - Enteric fermentation related methane emissions (kg CH ₄ /head/year) for animal category <i>i</i>									
Year	Calves <1 year	Female young cattle 1-2 years	Heifers >2 years	Fattening bulls 1-2 years	Mature male cattle >2	Lactating dairy cows	Suckler cows	Mature sheep	Sheep lambs <1 year
1990	28.5	60.3	56.5	79.1	78.7	112.3	97.3	9.5	3.7
1991	28.5	60.3	56.5	79.1	78.7	112.5	97.3	9.5	3.7
1992	28.5	60.3	56.5	79.1	78.7	115.7	97.3	9.5	3.7
1993	28.5	60.3	56.5	79.1	78.7	118.6	97.3	9.5	3.7
1994	28.5	60.3	56.5	79.1	78.7	118.2	97.3	9.5	3.7
1995	28.5	60.3	56.5	79.1	78.7	120.3	97.3	9.5	3.7
1996	28.5	60.3	56.5	79.1	78.7	120.7	97.3	9.5	3.7
1997	28.5	60.3	56.5	79.1	78.7	122.2	97.3	9.5	3.7
1998	28.5	60.3	56.5	79.1	78.7	122.8	97.3	9.5	3.7
1999	28.5	60.3	56.5	79.1	78.7	124.1	97.3	9.5	3.7
2000	28.5	60.3	56.5	79.1	78.7	125.9	97.3	9.5	3.7
2001	28.5	60.3	56.5	79.1	78.7	127.6	97.3	9.5	3.7
2002	28.5	60.3	56.5	79.1	78.7	129.1	97.3	9.5	3.7
2003	28.5	60.3	56.5	79.1	78.7	130.8	97.3	9.5	3.7
2004	28.5	60.3	56.5	79.1	78.7	132.3	97.3	9.5	3.7
2005	28.5	60.3	56.5	79.1	78.7	133.4	97.3	9.5	3.7
2006	28.5	60.3	56.5	79.1	78.7	134.4	97.3	9.5	3.7
2007	28.5	60.3	56.5	79.1	78.7	133.3	97.3	9.5	3.7
2008	28.5	60.3	56.5	79.1	78.7	135.1	97.3	9.5	3.7
2009	28.5	60.3	56.5	79.1	78.7	135.3	97.3	9.5	3.7
2010	28.5	60.3	56.5	79.1	78.7	136.9	97.3	9.5	3.7
2011	28.5	60.3	56.5	79.1	78.7	137.3	97.4	9.5	3.7
2012	28.5	60.3	56.5	79.1	78.7	137.7	97.5	9.5	3.7
2013	28.5	60.3	56.5	79.1	78.7	134.6	97.6	9.5	3.7
2014	28.5	60.3	56.5	79.1	78.7	139.1	97.7	9.5	3.7
2015	28.5	60.3	56.5	79.1	78.7	144.8	97.8	9.5	3.7
2016	28.5	60.3	56.5	79.1	78.7	144.8	97.9	9.5	3.7
2017	28.5	60.3	56.5	79.1	78.7	144.4	97.9	9.5	3.7
2018	28.5	60.3	56.5	79.1	78.7	148.8	97.9	9.5	3.7
2019	28.5	60.3	56.5	79.1	78.7	149.9	97.9	9.5	3.7

Source: SER

These IEFs were multiplied with annual livestock numbers to obtain annual emissions per livestock category, and summarized over all livestock categories to obtain total emissions per year. For the assumed uncertainties, see Annex 3: B.

5.3.4 Category-specific recalculations including changes made in response to the review process

The GEi in MJ/day/animal was calculated for cattle and sheep according to equation 10.16 in the 2006 IPCC guidelines (IPCC 2006a): However, in the spreadsheet was the reference for $NE_{a(i)}$ erroneously fixed, why using the same value throughout the whole time period. This was corrected.

The manure management system was adapted, see section 5.2.3.

A detailed description is provided in Annex 3: A, and the recalculations are provided in Table A3-3 in Annex 3: A.

5.3.5 Category specific uncertainty

Models are not an exact representation of real life and therefore their estimates are to a certain extent uncertain. Uncertainty was model using Monte-Carlo technique. A detailed description of the assumed uncertainties for animal population numbers, manure management systems, emission factors, and in case of IPCC Tier 2, GE and DE% is provided in Annex 3: B.

5.3.6 Category-specific QA/QC and verification

Consistency and completeness checks have been performed directly while building and calculating GHG emissions from the agriculture sector.

The plausibility of the estimates, as well as the calculation methods, were discussed and developed by the sector experts in the country.

5.3.7 Planned improvement

Investigation on country-specific data for GE and DE% are planned, and if data and manpower available, will both be improved in future submissions. Further, with the publication of new IPCC guidelines and/or emissions factors will the necessary changes, where appropriated, be incorporated.

5.4 Manure Management (IPCC Source Category 3.B)

This section describes the estimation of methane and nitrous oxide emissions resulting from manure management. In 2019, this source category was responsible for 13% of the total GHG emissions from the agriculture sector and represented 0.83% of the total GHG emissions in CO₂e (excluding LULUCF). For each of the two gases reported, excluding LULUCF, in 2018:

- CH₄ represented 13.4% of agricultural methane emissions and 10.67% of the total methane emissions estimated for Luxembourg;
- N₂O represented 11.7% of agricultural nitrous oxide emissions and 8.13% of the total nitrous oxide emissions estimated for Luxembourg.

5.4.1 Key source

With 0.49% of the total GHG emissions in CO₂e, excluding LULUCF in 2019, methane emissions from cattle (IPCC Sub-category 3Ba) were a key source from 1997 to 2002 and for 2018, excluding LULUCF, and from 1997-2002 and 2014-2019 when LULUCF is included (see section 1.5.1.1).

5.4.2 Source category description

Livestock statistics in Luxembourg are detailed enough to go for option C. Cattle, the main livestock category in Luxembourg is split into 7 categories, namely calves <1 year; young female cattle 1-2 years; heifers >2years; fattening bulls 1-2 years, mature male >2 years, lactating dairy cows and suckler cows. For swine do we distinguish between sows, weaners 10-30 kg and fattening pigs>30 kg. Poultry is split in laying hens, broilers and other poultry. Sheep is split in mature animals and lambs. Mules and asses are included in the category horses. The remaining categories are goats, ostriches, rabbits and deer (see details in section 5.2.1).

Goats, although a niche production in Luxembourg, have experienced the biggest increase in their population for the whole period 1990-2019 (Table 5-5), and consequently also the biggest increase in methane (981%) from manure management, see Table 5-20. For N₂O emission the increase was even higher (4 471%), whereby the increase of the goat population was only one factor. The second factor driving those emissions were the switch from extensive pasture management to in-house stabilisation for the whole year around, see Table 5-21. However, methane emission from enteric fermentation from goats represented only 0.02% of the total methane emission from manure management in 2019 (see Table 5-20 and Figure 5-8), and 0.8% of the total N₂O emission from manure management (Table 5-21 and Figure 5-9).

Cattle as a whole group was over the whole period the main methane emitting animal category with regard to manure management, and was in 2019 responsible for 84% of the total methane emission from manure management (Table 5-20 and Figure 5-8) and for 93% of the total N₂O emission from manure management (Table 5-21 and Figure 5-9). Lactating dairy cows is the subgroup with the highest emission over the whole period for both methane and N₂O emission from manure management (Figure 5-8 and Figure 5-9). In 2019 51% of the methane emission from manure management (Table 5-20 and Figure 5-8) and 44% of the total N₂O emission from manure management (Table 5-21 and Figure 5-9) were from lactating dairy cows.

On the whole, methane emissions from manure management increased by 30% over the period 1990-2019, a result mainly due to raising emission of dairy cows (+75%). Raising emissions of other livestock categories, such as goats (+981%), horses (+171%) and laying hens (+92%) had only a marginal impact on the total methane emissions from enteric fermentation.

Direct N₂O emissions from manure management decreased by 13.5% over the period 1990-2019, see Table 5-21 and Table 5-22. CRF requires reporting emissions by manure management system categories rather than by livestock, see Table 5-22. Solid storage is the main source of N₂O. With fewer cattle now-a-days on straw, emissions were decreasing over time.

Indirect atmospheric N₂O emissions decreased by 5% (Table 5-23).

Combining both gases – CH₄ and N₂O (direct and indirect) – manure management related emissions, expressed in CO₂e, show an increase of 14% (Table 5-23).

With regard to cattle, its total population and its evolution are strongly influenced by changes in agricultural policy and, more precisely, in the Common Agricultural Policy of the EU (CAP). This is the case for dairy cows. Due to a quota system for milk production in place from 1983-31st March 2015, and an increasing milk yield per cow was the population of dairy cows declining over time. But with the abolishment of the milk quota system in Europe in spring 2015, is the number of dairy cows increasing since then, with an accelerated increase in the first 2-3 years, and a slowing down in the last two years. Another factor influencing cattle population is/was, availability of fodder, respectively fodder and milk prices.

Table 5-20 – CH₄ emission trends for IPCC Category 3B – Manure Management: 1990-2019 (Gg)

3 - Agriculture Sector																					
CH ₄ emissions (Gg)																					
Year	3.Ba - Manure management																				
	Total	Calves <1 year	Female youn >2 years	Heifers bulls 1-2 years	Fattening 1-2 years	Mature male cattle >2 years	Lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners 10-30 kg	Mature sheep	Sheep lambs <1 year	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deer
1990	1.91	0.16	0.19	0.13	0.11	0.04	0.73	0.20	0.074	0.18	0.10	0.001	0.0002	0.0001	0.003	0.0001	0.002	0.00006	NO	0.0011	0.00002
1991	2.12	0.18	0.22	0.15	0.13	0.05	0.81	0.26	0.069	0.15	0.09	0.001	0.0002	0.0001	0.003	0.0001	0.002	0.00005	NO	0.0011	0.00003
1992	2.12	0.18	0.22	0.16	0.12	0.04	0.79	0.28	0.071	0.16	0.09	0.001	0.0002	0.0000	0.003	0.0001	0.001	0.00005	NO	0.0009	0.00003
1993	2.18	0.18	0.22	0.16	0.13	0.05	0.81	0.30	0.071	0.18	0.09	0.001	0.0002	0.0001	0.003	0.0001	0.002	0.00004	NO	0.0007	0.00003
1994	2.20	0.19	0.22	0.15	0.14	0.04	0.80	0.32	0.070	0.17	0.09	0.001	0.0002	0.0001	0.003	0.0001	0.001	0.00004	NO	0.0006	0.00004
1995	2.31	0.19	0.23	0.16	0.15	0.05	0.83	0.35	0.073	0.18	0.10	0.001	0.0002	0.0000	0.003	0.0001	0.001	0.00005	NO	0.0006	0.00004
1996	2.33	0.20	0.23	0.16	0.16	0.05	0.82	0.36	0.071	0.17	0.10	0.001	0.0002	0.0000	0.003	0.0001	0.001	0.00004	NO	0.0005	0.00003
1997	2.36	0.20	0.23	0.16	0.17	0.06	0.82	0.36	0.071	0.19	0.10	0.001	0.0002	0.0000	0.004	0.0003	0.001	0.00005	NO	0.0006	0.00004
1998	2.41	0.20	0.23	0.16	0.18	0.05	0.84	0.36	0.071	0.20	0.11	0.001	0.0002	0.0000	0.004	0.0003	0.001	0.00004	NO	0.0005	0.00006
1999	2.61	0.21	0.25	0.17	0.19	0.05	0.92	0.42	0.068	0.21	0.12	0.001	0.0002	0.0000	0.004	0.0002	0.001	0.00003	NO	0.0005	0.00007
2000	2.54	0.21	0.24	0.17	0.19	0.05	0.89	0.42	0.061	0.20	0.10	0.001	0.0002	0.0000	0.005	0.0002	0.002	0.00002	NO	0.0005	0.00008
2001	2.53	0.21	0.24	0.17	0.19	0.05	0.88	0.42	0.062	0.20	0.10	0.001	0.0002	0.0000	0.005	0.0002	0.002	0.00003	NO	0.0005	0.00007
2002	2.45	0.20	0.22	0.16	0.17	0.05	0.87	0.41	0.060	0.21	0.10	0.001	0.0003	0.0001	0.005	0.0002	0.002	0.00003	NO	0.0005	0.00007
2003	2.36	0.19	0.21	0.14	0.15	0.04	0.84	0.38	0.057	0.23	0.10	0.001	0.0002	0.0002	0.005	0.0002	0.002	0.00003	0.001	0.0005	0.00005
2004	2.34	0.18	0.21	0.14	0.15	0.04	0.82	0.37	0.055	0.28	0.09	0.001	0.0002	0.0002	0.006	0.0002	0.002	0.00003	0.002	0.0005	0.00006
2005	2.34	0.17	0.21	0.14	0.15	0.04	0.82	0.35	0.056	0.30	0.10	0.001	0.0003	0.0002	0.007	0.0003	0.002	0.00003	0.001	0.0005	0.00005
2006	2.25	0.15	0.21	0.13	0.15	0.03	0.82	0.32	0.053	0.28	0.09	0.001	0.0002	0.0002	0.007	0.0003	0.002	0.00003	0.001	0.0005	0.00006
2007	2.28	0.15	0.22	0.14	0.15	0.03	0.86	0.30	0.050	0.27	0.09	0.001	0.0002	0.0003	0.007	0.0002	0.002	0.00002	0.001	0.0004	0.00004
2008	2.28	0.14	0.22	0.13	0.18	0.03	0.87	0.30	0.048	0.27	0.08	0.001	0.0002	0.0003	0.007	0.0001	0.002	0.00002	0.001	0.0003	0.00008
2009	2.26	0.13	0.23	0.13	0.17	0.04	0.89	0.27	0.047	0.27	0.08	0.001	0.0002	0.0004	0.007	0.0002	0.002	0.00002	0.001	0.0003	0.00008
2010	2.25	0.12	0.23	0.13	0.18	0.04	0.93	0.23	0.045	0.23	0.11	0.001	0.0002	0.0006	0.007	0.0002	0.002	0.00001	0.001	0.0003	0.00007
2011	2.22	0.12	0.23	0.12	0.16	0.04	0.92	0.23	0.042	0.25	0.11	0.001	0.0002	0.0006	0.007	0.0002	0.002	0.00002	0.002	0.0002	0.00009
2012	2.18	0.12	0.23	0.12	0.14	0.03	0.91	0.22	0.040	0.27	0.09	0.001	0.0002	0.0006	0.008	0.0002	0.003	0.00004	0.001	0.0003	0.00008
2013	2.23	0.12	0.23	0.12	0.16	0.03	0.96	0.21	0.038	0.26	0.09	0.001	0.0002	0.0005	0.007	0.0002	0.003	0.00002	0.002	0.0003	0.00006
2014	2.31	0.12	0.23	0.15	0.17	0.04	1.00	0.20	0.037	0.27	0.09	0.001	0.0002	0.0005	0.007	0.0002	0.003	0.00003	0.001	0.0002	0.00006
2015	2.41	0.12	0.24	0.15	0.15	0.04	1.06	0.20	0.034	0.29	0.10	0.001	0.0002	0.0006	0.007	0.0002	0.003	0.00003	0.001	0.0002	0.00005
2016	2.47	0.12	0.24	0.14	0.14	0.03	1.16	0.20	0.034	0.29	0.09	0.001	0.0002	0.0006	0.007	0.0002	0.003	0.00002	0.001	0.0002	0.00004
2017	2.53	0.12	0.25	0.14	0.13	0.04	1.20	0.20	0.037	0.30	0.10	0.001	0.0002	0.0006	0.007	0.0003	0.003	0.00003	0.001	0.0002	0.00003
2018	2.51	0.11	0.24	0.16	0.12	0.04	1.23	0.18	0.036	0.28	0.09	0.001	0.0002	0.0006	0.007	0.0003	0.003	0.00002	0.001	0.0002	0.00003
2019	2.48	0.11	0.23	0.14	0.11	0.03	1.27	0.18	0.031	0.25	0.10	0.001	0.0002	0.0006	0.007	0.0003	0.003	0.00002	0.001	0.0002	0.00001
Trend 1990-2019	30%	-29%	22%	10%	4%	-21%	75%	-7%	-57%	44%	-4%	37%	0%	981%	171%	91%	92%	-73%	NA	-82%	-46%
Trend 2018-2019	-1%	3%	-5%	-11%	-11%	-2%	3%	0%	-14%	-9%	4%	1%	0%	2%	0%	-3%	9%	-22%	15%	-13%	-67%

Source: SER.

Notes: Mules and asses are include with horses

Table 5-21 – N₂O emission trends for IPCC Category 3B – Manure Management: 1990-2019(Gg)

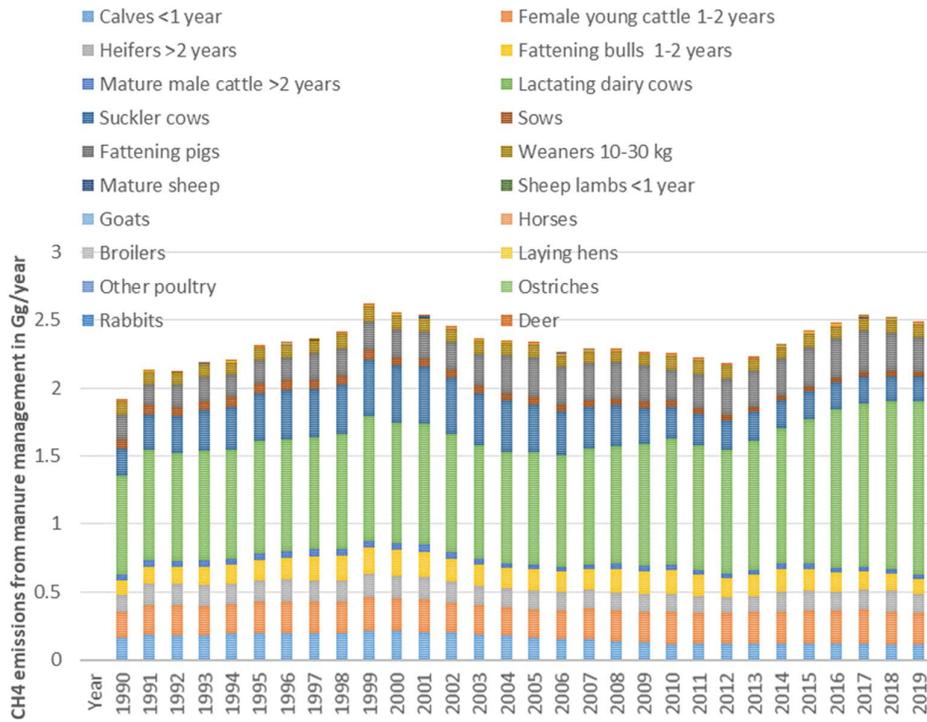
3 - Agriculture Sector																					
N ₂ O emissions (Gg)																					
Year	3.Bb - Manure management																				
	Total	Calves <1 year	Female young >2 years	Heifers >2 years	Fattening bulls 1-2 years	Mature male cattle >2 years	Lactating dairy cows	Suckler cows	Sows	Fattening pigs	Weaners 10-30 kg	Mature sheep	Sheep lambs <1 year	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deer
1990	0.072	0.008	0.006	0.006	0.005	0.003	0.033	0.007	0.001	0.001	0.0003	0.0001	0.00002	0.0000	0.0004	0.000005	0.00007	0.000001	NO	0.000115	0.000003
1991	0.069	0.008	0.006	0.006	0.006	0.003	0.030	0.007	0.001	0.001	0.0002	0.0001	0.00002	0.0000	0.0004	0.000005	0.00007	0.000001	NO	0.000106	0.000005
1992	0.065	0.007	0.006	0.006	0.005	0.003	0.027	0.007	0.001	0.001	0.0002	0.0001	0.00002	0.0000	0.0004	0.000004	0.00006	0.000001	NO	0.000094	0.000004
1993	0.065	0.007	0.006	0.006	0.006	0.003	0.027	0.008	0.001	0.001	0.0002	0.0001	0.00002	0.0000	0.0004	0.000005	0.00007	0.000001	NO	0.000073	0.000004
1994	0.063	0.008	0.006	0.005	0.006	0.002	0.026	0.008	0.001	0.001	0.0002	0.0001	0.00002	0.0000	0.0004	0.000004	0.00007	0.000001	NO	0.000066	0.000006
1995	0.065	0.007	0.006	0.005	0.006	0.003	0.026	0.008	0.001	0.001	0.0002	0.0001	0.00002	0.0000	0.0005	0.000004	0.00006	0.000001	NO	0.000064	0.000006
1996	0.066	0.008	0.006	0.006	0.006	0.003	0.026	0.009	0.001	0.001	0.0003	0.0001	0.00002	0.0000	0.0005	0.000005	0.00007	0.000001	NO	0.000053	0.000004
1997	0.064	0.007	0.006	0.005	0.007	0.003	0.025	0.008	0.001	0.001	0.0002	0.0001	0.00002	0.0000	0.0005	0.000009	0.00006	0.000001	NO	0.000062	0.000005
1998	0.063	0.007	0.005	0.005	0.007	0.003	0.024	0.008	0.001	0.002	0.0003	0.0001	0.00002	0.0000	0.0005	0.000010	0.00006	0.000001	NO	0.000056	0.000009
1999	0.060	0.007	0.005	0.005	0.006	0.002	0.023	0.008	0.001	0.002	0.0003	0.0001	0.00002	0.0000	0.0006	0.000006	0.00006	0.000001	NO	0.000051	0.000010
2000	0.059	0.007	0.005	0.005	0.006	0.002	0.022	0.008	0.001	0.002	0.0003	0.0001	0.00002	0.0000	0.0006	0.000007	0.00007	0.000001	NO	0.000063	0.000012
2001	0.059	0.007	0.005	0.005	0.006	0.002	0.022	0.009	0.001	0.002	0.0003	0.0001	0.00002	0.0000	0.0006	0.000008	0.00008	0.000001	NO	0.000054	0.000011
2002	0.057	0.007	0.005	0.005	0.006	0.002	0.021	0.008	0.001	0.002	0.0003	0.0001	0.00002	0.0001	0.0006	0.000008	0.00008	0.000001	NO	0.000058	0.000010
2003	0.056	0.006	0.005	0.004	0.006	0.002	0.021	0.008	0.001	0.002	0.0003	0.0001	0.00002	0.0001	0.0007	0.000007	0.00008	0.000001	0.0000012	0.000053	0.000007
2004	0.057	0.006	0.005	0.004	0.005	0.002	0.022	0.008	0.001	0.002	0.0002	0.0001	0.00002	0.0002	0.0008	0.000006	0.00008	0.000001	0.0000017	0.000051	0.000009
2005	0.057	0.006	0.005	0.004	0.006	0.002	0.021	0.009	0.001	0.002	0.0003	0.0001	0.00003	0.0002	0.0008	0.000010	0.00008	0.000001	0.0000013	0.000052	0.000008
2006	0.056	0.006	0.005	0.004	0.005	0.002	0.021	0.009	0.001	0.002	0.0002	0.0001	0.00002	0.0002	0.0008	0.000009	0.00008	0.000001	0.0000010	0.000053	0.000008
2007	0.059	0.007	0.005	0.004	0.006	0.001	0.022	0.009	0.001	0.002	0.0002	0.0001	0.00002	0.0002	0.0008	0.000008	0.00008	0.000000	0.0000011	0.000040	0.000006
2008	0.060	0.007	0.005	0.004	0.006	0.002	0.021	0.011	0.001	0.002	0.0002	0.0001	0.00002	0.0003	0.0008	0.000004	0.00009	0.000000	0.0000013	0.000035	0.000011
2009	0.060	0.007	0.005	0.004	0.006	0.002	0.021	0.011	0.001	0.002	0.0002	0.0001	0.00002	0.0003	0.0009	0.000008	0.00010	0.000000	0.0000014	0.000036	0.000011
2010	0.062	0.007	0.005	0.004	0.006	0.002	0.021	0.012	0.001	0.002	0.0003	0.0001	0.00002	0.0004	0.0008	0.000008	0.00009	0.000000	0.0000012	0.000031	0.000010
2011	0.060	0.007	0.005	0.004	0.005	0.002	0.021	0.011	0.001	0.002	0.0003	0.0001	0.00002	0.0005	0.0008	0.000008	0.00011	0.000000	0.0000020	0.000027	0.000013
2012	0.058	0.007	0.005	0.003	0.005	0.001	0.021	0.011	0.000	0.002	0.0003	0.0001	0.00002	0.0005	0.0009	0.000008	0.00012	0.000001	0.0000013	0.000032	0.000012
2013	0.059	0.007	0.005	0.004	0.006	0.002	0.022	0.010	0.000	0.002	0.0002	0.0001	0.00002	0.0005	0.0008	0.000007	0.00012	0.000001	0.0000021	0.000032	0.000008
2014	0.061	0.008	0.005	0.004	0.006	0.002	0.022	0.010	0.000	0.002	0.0002	0.0001	0.00002	0.0004	0.0008	0.000007	0.00013	0.000001	0.0000011	0.000030	0.000008
2015	0.062	0.008	0.005	0.005	0.005	0.002	0.023	0.010	0.000	0.002	0.0003	0.0001	0.00002	0.0005	0.0007	0.000009	0.00012	0.000001	0.0000016	0.000029	0.000007
2016	0.063	0.008	0.005	0.004	0.005	0.002	0.025	0.009	0.000	0.002	0.0002	0.0001	0.00002	0.0005	0.0007	0.000009	0.00012	0.000001	0.0000015	0.000027	0.000005
2017	0.064	0.007	0.005	0.004	0.005	0.002	0.026	0.009	0.000	0.003	0.0003	0.0001	0.00002	0.0005	0.0007	0.000010	0.00013	0.000001	0.0000012	0.000023	0.000004
2018	0.063	0.007	0.005	0.005	0.004	0.002	0.027	0.009	0.000	0.002	0.0003	0.0001	0.00002	0.0005	0.0007	0.000010	0.00013	0.000000	0.0000013	0.000026	0.000005
2019	0.062	0.007	0.005	0.004	0.004	0.002	0.027	0.009	0.000	0.002	0.0003	0.0001	0.00002	0.0005	0.0007	0.000010	0.00014	0.000000	0.0000015	0.000025	0.000002
Trend 1990 -2019	-14%	-13%	-25%	-32%	-28%	-46%	-17%	33%	-50%	56%	4%	38%	1%	4471%	92%	91%	92%	-73%	NA	-79%	-46%
Trend 2018 -2019	-2%	3%	-5%	-11%	-11%	-2%	1%	0%	-14%	-9%	4%	1%	0%	-5%	1%	-3%	9%	-22%	15%	-4%	-67%

Source: SER.

Notes:

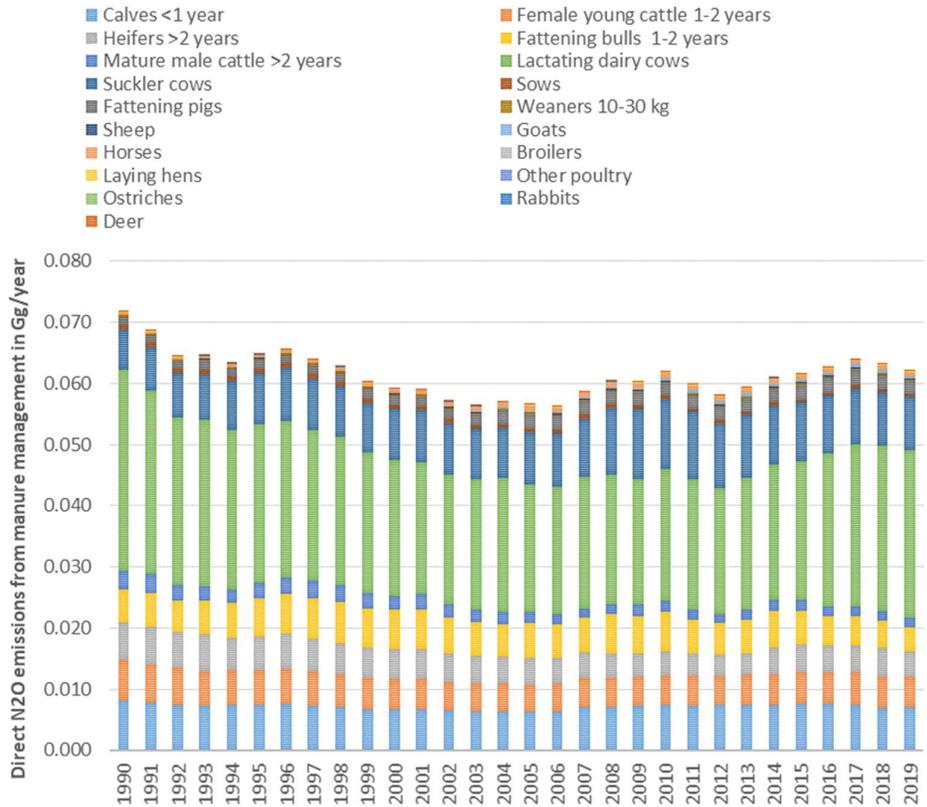
- Mules and asses are include with horses
- N₂O emissions by livestock category excluding emissions from pasture.

Figure 5-8 – CH₄ emissions from manure management (Gg/year) per animal category: 1990 - 2019



Source: SER.

Figure 5-9 – N₂O emissions from manure management (Gg/year) per animal category: 1990 - 2019



Source: SER.

Table 5-22 – N₂O emission trends for IPCC Category 3B – Manure Management: 1990-2019 (Gg)

3 - Agriculture N ₂ O emissions (Gg)						
Year	3Bb - Manure management					
	Total	Aerobic lagoon	Liquid	Solid	Pature	Digester
1990	0.072	NO	0.015	0.056	IE	NO
1991	0.069	NO	0.019	0.050	IE	NO
1992	0.065	NO	0.019	0.046	IE	NO
1993	0.065	NO	0.019	0.045	IE	NO
1994	0.063	NO	0.020	0.044	IE	NO
1995	0.065	NO	0.021	0.044	IE	NO
1996	0.066	NO	0.021	0.045	IE	NO
1997	0.064	NO	0.021	0.043	IE	NO
1998	0.063	NO	0.021	0.041	IE	NO
1999	0.060	NO	0.024	0.036	IE	NO
2000	0.059	NO	0.023	0.036	IE	NO
2001	0.059	NO	0.023	0.036	IE	NO
2002	0.057	NO	0.022	0.035	IE	NO
2003	0.056	NO	0.022	0.035	IE	NO
2004	0.057	NO	0.022	0.035	IE	NO
2005	0.057	NO	0.021	0.035	IE	NO
2006	0.056	NO	0.021	0.035	IE	NO
2007	0.059	NO	0.021	0.037	IE	NO
2008	0.060	NO	0.021	0.039	IE	NO
2009	0.060	NO	0.021	0.040	IE	NO
2010	0.062	NO	0.021	0.041	IE	NO
2011	0.060	NO	0.020	0.040	IE	NO
2012	0.058	NO	0.020	0.038	IE	NO
2013	0.059	NO	0.020	0.039	IE	NO
2014	0.061	NO	0.021	0.040	IE	NO
2015	0.062	NO	0.021	0.040	IE	NO
2016	0.063	NO	0.022	0.041	IE	NO
2017	0.064	NO	0.023	0.041	IE	NO
2018	0.063	NO	0.023	0.040	IE	NO
2019	0.062	NO	0.022	0.040	IE	NO
Trend 1990 -2019	-14%	NO	44%	-29%	IE	NO
Trend 2018 -2019	-2%	NO	-2%	-1%	IE	NO

Source: SER.

Notes: N₂O emissions from pasture are excluded from the total N₂O emissions in IPCC Category 3B since they have to be accounted for in IPCC Sub-category 3D2 – Emissions from PRP Manure.

Table 5-23 – CH₄ & N₂O emission trends for IPCC Category 3B – Manure Management and indirect atmospheric N₂O emissions: 1990-2019

3 - Agriculture				
GHG emissions by source & sink category (Gg CO ₂ eq)				
Year	Total	3B - Manure management		
		CH ₄	N ₂ O - direct emissions	Indirect atmospheric N ₂ O emissions
1990	78.5	47.7	21.4	9.33
1991	82.8	53.0	20.5	9.23
1992	81.0	53.0	19.2	8.81
1993	82.6	54.5	19.2	8.88
1994	82.5	54.9	18.9	8.75
1995	86.0	57.7	19.3	9.02
1996	86.9	58.2	19.6	9.13
1997	87.0	59.0	19.1	9.00
1998	87.8	60.1	18.7	8.92
1999	92.2	65.3	18.0	8.85
2000	89.9	63.6	17.7	8.68
2001	89.4	63.2	17.6	8.63
2002	86.6	61.2	17.0	8.35
2003	83.9	58.9	16.8	8.24
2004	83.9	58.5	17.0	8.38
2005	83.6	58.4	16.9	8.31
2006	81.3	56.3	16.8	8.20
2007	83.0	57.0	17.5	8.49
2008	83.7	57.1	18.0	8.67
2009	83.0	56.5	18.0	8.61
2010	83.5	56.3	18.4	8.76
2011	81.9	55.5	17.9	8.53
2012	80.1	54.4	17.3	8.30
2013	81.8	55.7	17.7	8.43
2014	84.6	57.8	18.2	8.67
2015	87.5	60.4	18.4	8.79
2016	89.4	61.8	18.7	8.94
2017	91.5	63.3	19.1	9.18
2018	90.7	62.8	18.8	9.06
2019	89.5	62.1	18.5	8.86
Trend 1990 -2019	14%	30%	-13.5%	-5%
Trend 2018 -2019	-1%	-1%	-1.6%	-2%

Source: SER.

Note: CH₄ emissions were converted in CO₂-eq. by multiplying the emissions by 25 and N₂O emissions were converted in CO₂-eq. by multiplying the emissions by 298.

5.4.3 Methodological issues

Table 5-24 gives an overview of the status, the methods and emission factors (EF) used for the IPCC Source Category 3.B.

Table 5-24 –Overview of IPCC Source Category 3.B: Status, methods and EF used

GHG source & sink category	Description	CH ₄			N ₂ O		
		Status	Method	EF	Status	Method ^e	EF
3.B.1 opt. C	Calves < 1 year	x	T2	CS	x	T2	D
3.B.1	Female young cattle 1-2 years	x	T2	CS	x	T2	D
3.B.1	Heifers > 2 years	x	T2	CS	x	T2	D
3.B.1	Fattening bulls 1-2 years	x	T2	CS	x	T2	D
3.B.1	Mature male cattle >2 years	x	T2	CS	x	T2	D
3.B.1	Lactating dairy cows	x	T2	CS	x	T2	D
3.B.1	Suckler cows	x	T2	CS	x	T2	D
3.B.2	Mature sheep	x	T2	CS	x	T2	D
3.B.2	Sheep lamb < 1 year	x	T2	CS	x	T2	D
3.B.3	Sows	x	T2	CS	x	T2	D
3.B.3	Fattening pigs >30 kg	x	T2	CS	x	T2	D
3.B.3	Weaners (10-30 kg)	x	T2	CS	x	T2	D
3.B.4	Horses ^a	x	T2	CS	x	T2	D
3.B.4	Goats ^b	x	T2	CS	x	T2	D
3.B.4	Poultry ^c	x	T2	CS	x	T2	D
3.B.4	Ostrich	x	T2	CS	x	T2	D
3.B.4	Rabbits ^d	x	T2	CS	x	T2	D
3.B.4	Deer	x	T1	D	x	T2	D
3.B.5	Indirect N ₂ O emissions	NA			x	T2	D

Notes: An “x” indicates that emissions from this sub-category have been estimated.

- Including also ponys, mules and asses. Ponys, mules and asses are pet animals, as are also the majority of the horses (i.e. riding horses).
- Goats are split in 2 sub-categories: i) mature goats and ii) goat kid for the calculations, but reported in the CRF as one category.
- Poultry, excluding ostriches are split in 3 sub-categories: i) broilers; ii) laying hens; iii) other poultry for the calculations.
- Rabbits are split in 2 sub-categories: i) female breeding animals and ii) other rabbits for the calculations but reported in the CRF as one category.

Used abbreviations: CS = country-specific value EF; D = IPCC default EF; NA = not applicable; T1 = IPCC Tier 1; T2 = IPCC Tier 2.

5.4.3.1 Activity data

Livestock numbers and manure management systems (MMS) are the two main types of activity data for estimating methane emissions. Livestock numbers were presented in section 5.2.2.1 and MMS for the different animal categories in section 5.2.3.

For direct N₂O emissions, livestock numbers and N.ex per head/place per year are the two main types of activity data. Livestock numbers were presented in section 5.2.2.1 and N.ex. in kg/head, respectively kg/place were discussed in detail in section 5.2.5.

Livestock numbers and N.ex per head/place are the activity data used for estimating NH₃-N emissions (kg NH₃-N/year and kg NO) and NO_x-N emissions (kg NO_x-N /year, expressed as nitrogen monoxide) for all defined livestock categories *i* within NFR Category 3B (Manure management). Volatilisation of N from manure management in forms of NH₃ and NO_x are the activity data used to estimate the indirect N₂O emissions from manure management, and are summarized in Table 5-25. Those emissions were estimated following the N-flow model described in section 5.2.6. More details are provided in the Informative Inventory Report (IIR, 2021) in section 5.3.3.

Table 5-25 – Activity data - Volatilisation of N from manure management in forms of NH₃ and NO_x

3 - Agriculture		
Activity data - Volatilisation of N from manure management in forms of NH3 and NOx (NRF 3B) (kg NH3-N/year and kg NO-N/year)		
Year	NH3-N Emissions	NO-N Emissions
1990	1 962 517	29 790
1991	1 944 953	26 959
1992	1 856 716	24 816
1993	1 871 610	24 754
1994	1 844 428	23 909
1995	1 902 223	24 320
1996	1 924 321	24 742
1997	1 898 674	23 795
1998	1 881 013	22 947
1999	1 870 371	20 515
2000	1 832 529	20 255
2001	1 821 949	20 359
2002	1 763 257	19 565
2003	1 738 978	19 631
2004	1 768 717	20 013
2005	1 754 063	19 977
2006	1 731 964	20 101
2007	1 792 560	21 172
2008	1 830 002	22 269
2009	1 816 276	22 423
2010	1 846 817	23 311
2011	1 799 900	22 438
2012	1 750 664	21 709
2013	1 778 358	22 042
2014	1 828 114	22 577
2015	1 855 184	22 644
2016	1 887 156	22 798
2017	1 937 008	23 245
2018	1 912 275	22 899
2019	1 870 129	22 548
Trend 1990 -2019	-5%	-24%
Trend 2018 -2019	-2%	-2%

Source: (IIR, 2021)

5.4.3.2 Emission factors

5.4.3.2.1 Emission factors - manure management related methane emissions

Emission factors used for the calculation of manure management related methane emissions were estimated using an IPCC Tier 1 for deer and an IPCC Tier 2 for all other livestock categories and are detailed in the following sections.

Emission factors for deer

For the IPCC Tier 1 method, default emission factors (EF) for manure management related methane emissions in kg CH₄ per head per year were derived from Table 10.16 in the 2006 IPCC guidelines (IPCC 2006a), namely 0.22 kg for deer (=deer), and multiplied with annual livestock numbers to obtain annual emissions. For the assumed uncertainties, see Annex 3: B.

Emission factors for all other livestock categories

For all other livestock categories an IPCC Tier 2 approach was taken. Annual implied emission factors (IEF) for the calculation of manure management related methane emissions for livestock category *i*, expressed in kg CH₄/head/year, were estimated following equation 10.23 of the 2006 IPCC guidelines (IPCC 2006a)

$$IEF_{CH_4} B_i = (VS_i * 365) * \left[B_{o(i)} * 0.67 * \sum_j \frac{MCF_j}{100} * MMS_{(i,j)} \right]$$

with:

VS_i	= Daily volatile solid excreted for livestock category <i>i</i> , kg dry matter per animal per day
365	= the basis for calculating annual VS production
$B_{o(i)}$	= maximum methane producing capacity for manure produced by livestock category <i>i</i> , m ³ CH ₄ kg ⁻¹ of VS excreted
0.67	= conversion factor of m ³ CH ₄ to kilograms CH ₄
MCF_j	= methane conversion factors for each manure management system, %
$MMS_{(i,j)}$	= fraction of livestock category <i>i</i> 's manure handled using manure management system <i>j</i> in the country

The used fraction of livestock category *i*'s manure handled using manure management system *j* were explained in more details in section 5.2.3, and are summarized in

Table 5-6 to Table 5-9.

The default values as provided in the 2006 IPCC guidelines (IPCC 2006a) were used for the methane conversion factors (MCFs) for sheep, goats, poultry, ostriches and rabbits. Having no country-specific data, but similar conditions, breeds and systems than Germany, the MCF for slurry was adapted to better fit local conditions of slurry storage (for details see section 5.2.4), by using the same values as in the German Inventory (Rösemann, et al., 2019), namely 10% for cattle slurry stored in open slurry tanks with a natural crust; 17% for cattle slurry stored either in covered slurry tanks or underneath a slatted floor. For swine, the used MCF was 25% for untreated slurry for all three types of storage, i.e. open slurry tanks without a natural crust, covered slurry tanks and slurry stored underneath a slatted floor (Rösemann, et al., 2019). All used MCFs are summarized in Table 5-26.

Table 5-26 – Used methane conversion factors (MCF) for the different manure management system for animal category *i*
3- Agriculture

Methan conversion factors (MCF) for the different manure management systems for animal category *i*

Animal category	Pasture	Liquid/Slurry	Solid	Digester
Dairy cattle	1% (IPCC 2006a) – Table 10A-4	10% for open tanks; 17% for covered tanks and underneath a slatted floor (Rösemann et al. 2019)	2% (IPCC 2006a) – Table 10A-4	10% (IPCC 2006a) – Table 10A-4
Non-dairy cattle	1% (IPCC 2006a) – Table 10A-5	10% for open tanks; 17% for covered tanks and underneath a slatted floor (Rösemann et al. 2019)	2 (IPCC 2006a) – Table 10A-5	10% (IPCC 2006a) – Table 10A-5
Swine (i.e. sows; fattening pigs & weaners)	NO	25% (Rösemann et al. 2019) for all three types of slurry storage (i.e. open tanks; covered tanks; underneath a slatted floor)	2% (IPCC 2006a) – Table 10A-8	10% (IPCC 2006a) – Table 10A-8
Sheep	1%(IPCC 2006a) – Table 10A-9	NO	1% (IPCC 2006a) – Table 10A-9	NO
Goats	1% (IPCC 2006a) – Table 10A-9	NO	1% (IPCC 2006a) – Table 10A-9	NO
Horses	1% (IPCC 2006a) – Table 10A-9	NO	1% (IPCC 2006a) – Table 10A-9	NO
Broilers	1.5% (IPCC 2006a) – Table 10A-9	NO	1.5% (IPCC 2006a) – Table 10A-9	NO
Laying hens	1.5% (IPCC 2006a) – Table 10A-9	NO	1.5% (IPCC 2006a) – Table 10A-9	NO
Other poultry	1.5% (IPCC 2006a) – Table 10A-9	NO	1.5% (IPCC 2006a) – Table 10A-9	NO

Ostriches	8% (IPCC 2006a) – Table 10A-9	NO	8% (IPCC 2006a) – Table 10A-9	NO
Rabbits	NO	NO	1% (IPCC 2006a) – Table 10A-9	NO

Note: NO=not occurring.

There were no country-specific B_o measurement values available. The 2006 IPCC guidelines (IPCC 2006a) default values were used for sheep, goats, horses, poultry, ostriches and rabbits, and summarized in Table 5-27. Having no country-specific data, but similar conditions, breeds and systems than Germany and the Netherlands, the B_o for swine was assumed to be 0.305 (i.e. average of Dutch and German B_o (Germany (0.30 (Rösemann, et al., 2019)) and NL: 0.31 (Lagerwerf, et al., 2019)), and the B_o for cattle was assumed to be 0.225 (i.e. average of Dutch and German B_o (NL: 0.22 (Lagerwerf, et al., 2019)) and Germany (0.23 (Rösemann, et al., 2019)))).

Based on the 2006 IPCC guidelines (IPCC 2006a), the default values for VS_i for swine, goats, horses, rabbits, poultry and ostriches were used and are summarized in Table 5-27. For the different cattle and sheep categories VS_i was estimated following equation 10.24 of the 2006 IPCC guidelines (IPCC 2006a)

$$VS_i = \left[GE * \left(1 - \frac{DE\%}{100} \right) + (UE * GE) \right] * \left[\frac{(1 - ASH)}{18.45} \right]$$

with:

GE	= Gross energy intake, MJ per day (for the values used see Table 5-18)
DE%	= digestibility of the feed in percent (for the values used see Table 5-17)
(UE*GE)	= urinary energy expressed as a fraction of GE.
ASH	= the ash content of manure calculated as a fraction of the dry matter feed intake.
18.45	= conversion factor for dietary GE per kg of dry matter (MJ per kg).

Default values for UE and ash were used and are summarized in Table 5-27.

The so-obtained IEFs for manure management related methane emissions, expressed in kg CH_4 /head/year for the years 1990-2018 are summarized for livestock category i for the years 1990-2018 in Table 5-28. These IEFs were multiplied with annual livestock numbers to obtain annual emissions per livestock category, and summarized over all livestock categories to obtain total emissions per year. For the assumed uncertainties, see Annex 3: B.

For cattle and sheep, VS rates and manure management system usage data were country-specific, and default values of the 2006 IPCC guidelines were used for all other parameters.

Table 5-27 – Used values for volatile solids (VS_i), ash, urine energy (UE) and maximum methane producing capacity for manure produced by animal category *i* (B_{0(i)}).

3- Agriculture

Volatile solids (VS), ash, urine energy (UE) and maximum methane producing capacity (B₀) for manure produced by animal category *i*

Animal category	VS _i	ASH	UE	B ₀
Dairy cattle	Calculated	0.08 (IPCC 2006a) page 10.42	0.04 (IPCC 2006a) page 10.42	0.225 (Rösemann et al. 2019, Lagerwerf et al. 2019)
Non-dairy cattle	Calculated	0.08 (IPCC 2006a) page 10.42	0.04 (IPCC 2006a) page 10.42	0.225 (Rösemann et al. 2019, Lagerwerf et al. 2019)
Sows	0.46 (IPCC 2006a) – Table 10A-8	-	-	0.305 (Rösemann et al. 2019, Lagerwerf et al. 2019)
Fattening pigs	0.3 (IPCC 2006a) – Table 10A-7	-	-	0.305 (Rösemann et al. 2019, Lagerwerf et al. 2019)
Weaners	0.3 (IPCC 2006a) – Table 10A-7	-	-	0.305 (Rösemann et al. 2019, Lagerwerf et al. 2019)
Sheep	Calculated	0.08 (IPCC 2006a) – Table 10A-9	0.04 (IPCC 2006a) page 10.42	0.19 (IPCC 2006a) – Table 10A-9
Goats	0.3 (IPCC 2006a) – Table 10A-9	0.08 (IPCC 2006a) – Table 10A-9	0.04 (IPCC 2006a) page 10.42	0.18 (IPCC 2006a) – Table 10A-9
Horses	2.13 (IPCC 2006a) – Table 10A-9	-	-	0.3 (IPCC 2006a) – Table 10A-9
Broilers	0.01 (IPCC 2006a) – Table 10A-9	-	-	0.36 (IPCC 2006a) – Table 10A-9
Laying hens	0.02 (IPCC 2006a) – Table 10A-9	-	-	0.39 (IPCC 2006a) – Table 10A-9
Other poultry	0.02 (IPCC 2006a) – Table 10A-9, ducks as proxy	-	-	0.36 (IPCC 2006a) – Table 10A-9
Ostriches	1.16 (IPCC 2006a) – Table 10A-9	-	-	0.25 (IPCC 2006a) – Table 10A-9
Rabbits	0.1 (IPCC 2006a) – Table 10A-9	-	-	0.32 (IPCC 2006a) – Table 10A-9

Table 5-28 – Implied emission factors (IEFs) for manure management related methane emissions, in kg CH₄/head/year for the years 1990-2019

3 - Agriculture																				
Implied emission factors (IEF) for manure management related methane emissions, in kg CH ₄ /head/year for animal category <i>i</i>																				
Year	Calves <1 year	Female young cattle 1-2 years	Heifers >2 years	Fattening bulls 1-2 years	Mature male cattle >2 years	Lactating dairy cows	Suckler cows	Sows	Fattening pigs > 30 kg	Weaners 10-30 kg	Mature sheep	Sheep lambs <1 year	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deer
1990	2.69	5.54	5.19	8.12	8.08	12.4	8.94	8.18	5.34	5.34	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
1991	3.10	6.41	6.00	9.25	9.20	14.5	10.34	8.18	5.34	5.34	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
1992	3.21	6.64	6.21	9.55	9.50	15.5	10.70	8.18	5.34	5.34	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
1993	3.24	6.71	6.28	9.65	9.60	16.0	10.82	8.18	5.34	5.34	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
1994	3.32	6.88	6.44	9.87	9.82	16.4	11.10	8.18	5.34	5.34	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
1995	3.38	6.99	6.54	10.01	9.96	17.0	11.28	8.18	5.34	5.34	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
1996	3.38	6.99	6.54	10.01	9.96	17.1	11.28	8.18	5.34	5.34	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
1997	3.46	7.16	6.70	10.24	10.18	17.7	11.55	8.18	5.34	5.34	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
1998	3.55	7.35	6.88	10.48	10.43	18.3	11.85	8.18	5.34	5.34	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
1999	3.87	8.03	7.51	11.37	11.31	20.3	12.95	8.18	5.34	5.34	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2000	3.83	7.96	7.44	11.28	11.22	20.5	12.82	8.07	5.30	5.30	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2001	3.78	7.85	7.34	11.14	11.09	20.6	12.64	7.97	5.26	5.26	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2002	3.75	7.79	7.29	11.08	11.02	20.8	12.55	7.86	5.22	5.22	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2003	3.65	7.59	7.10	10.82	10.77	20.6	12.21	7.75	5.18	5.18	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2004	3.59	7.46	6.98	10.66	10.60	20.6	12.00	7.64	5.14	5.14	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2005	3.36	7.50	7.02	10.68	10.63	20.9	11.06	7.53	5.10	5.10	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2006	3.13	7.54	7.06	10.70	10.65	21.3	10.13	7.43	5.06	5.06	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2007	2.90	7.59	7.10	10.72	10.67	21.4	9.19	7.32	5.02	5.02	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2008	2.67	7.63	7.14	10.75	10.69	21.9	8.25	7.21	4.98	4.98	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2009	2.44	7.67	7.18	10.77	10.71	22.1	7.32	7.10	4.94	4.94	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2010	2.21	7.71	7.22	10.79	10.74	22.6	6.38	6.99	4.90	4.90	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2011	2.27	7.64	7.15	11.14	11.08	22.9	6.31	6.99	4.90	4.90	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2012	2.27	7.59	7.10	10.91	10.85	23.1	6.24	6.99	4.90	4.90	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2013	2.27	7.59	7.10	10.91	10.85	22.8	6.17	6.99	4.90	4.90	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2014	2.27	7.59	7.10	10.91	10.85	23.8	6.10	6.99	4.90	4.90	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2015	2.27	7.59	7.10	10.91	10.85	24.9	6.03	6.99	4.90	4.90	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2016	2.27	7.59	7.10	10.91	10.85	25.1	5.96	6.99	4.90	4.90	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2017	2.27	7.59	7.10	10.91	10.85	25.1	5.96	6.99	4.90	4.90	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2018	2.27	7.59	7.10	10.91	10.85	25.8	5.96	6.99	4.90	4.90	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22
2019	2.27	7.59	7.10	10.91	10.85	26.0	5.96	6.99	4.90	4.90	0.18	0.10	0.13	1.56	0.01	0.03	0.03	5.67	0.08	0.22

Source: SER.

Note: Mules and asses were recorded together with horses.

5.4.3.2.2 Emission factors – direct N₂O emissions from manure management

The IPCC Tier 2 method has been applied to all animal categories when estimating the N₂O emissions related to manure management.

Direct N₂O emissions from manure management in the country ($N_2O_{D(mm)}$), expressed in kg N₂O per year was obtained by:

$$N_2O_{D(mm)} = N_2O - N_{D(mm)} * \left(\frac{44}{28}\right)$$

with:

$N_2O - N_{D(mm)}$ = direct N₂O-N emissions from manure management in the country, kg N₂O-N/year

44/28 = conversion of N₂O-N_(mm) emissions to N₂O_(mm) emissions.

Direct N₂O-N emissions from manure management in the country ($N_2O - N_{D(mm)}$), expressed as kg N₂O-N per year, were estimated following equation 10.25 of the 2006 IPCC guidelines (IPCC 2006a):

$$N_2O - N_{D(mm)} = \left[\sum_j \left[\sum_i (n_i * N.ex_{(i)} * MMS_{(ij)}) \right] * EF_{dN_2O(j)} \right]$$

with:

n_i = number of head/places of livestock category i

$N.ex_{(i)}$ = annual average N excretion per head/place of livestock category i , in kg N per head/place per year

$MMS_{(i,j)}$ = fraction of livestock category i 's manure handled using manure management system j in the country

$EF_{dN_2O(j)}$ = emission factor for direct N₂O emissions from manure management system j in the country, kg N₂O-N/kg N in manure management system j

Yearly nitrogen excretion ($N.ex_{(i)}$)/head, respectively per place for livestock category i , as described in section 5.2.5 were used. Livestock numbers were presented in section 5.2.2.1 and manure management system j for the different livestock categories were explained in more details in section 5.2.3 and are summarized in

Table 5-6 to Table 5-9.

Emission factors (EF) default values as provided in Table 10.21 of the 2006 IPCC guidelines (IPCC 2006a) for the different manure management systems, and the different slurry storage systems were used and are summarized in Table 5-29.

Table 5-29 – Default EFs for N₂O emissions per selected MMS and livestock categories (Source: (IPCC 2006a)– Table 10.21)

	MMS			
	Liquid System	Solid Storage	Pasture	Digester
Cattle	0.005 ^{a,b} 0.002 ^c	0.005	IE	0
Pigs	0.005 ^b 0.002 ^c 0 ^d	0.005	NO	0
Sheep	NO	0.005	IE	NO
Goats	NO	0.005	IE	NO
Horses	NO	0.005	IE	NO
Poultry	NO	0.001	NO	NO
Ostriches	NO	0.005	IE	NO
Rabbits	NO	0.005	NO	NO
Deer	NO	0.005	IE	NO

- a) Cattle slurry stored in an open tank with natural crust cover;
- b) Slurry stored in a covered slurry tank;
- c) Storage of slurry underneath a slatted floor;
- d) Swine slurry stored in an open slurry tank without natural crust cover (i.e. swine slurry).

Notes: Emissions related to pasture are accounted for under IPCC Category 3D- Agricultural Soils. Abbreviation used: IE = estimated elsewhere. NO=not occurring

5.4.3.2.3 Emission factors – indirect N₂O emissions from manure management

The indirect N₂O emissions due to volatilisation of N from manure management in forms of NH₃ and NO_x in the country, expressed as kg N₂O per year were estimated using an N-flow model (for more details see section 5.2.6 and a schematic representation of the N flows in Figure 5-6).

Indirect N₂O emissions due to volatilisation of N from manure management in the country ($N_2O_{G(mm)}$), expressed in kg N₂O per year was obtained by:

$$N_2O_{G(mm)} = N_2O - N_{G(mm)} * \left(\frac{44}{28}\right)$$

with:

$N_2O - N_{G(mm)}$ = indirect N₂O-N emissions due to volatilization of N from manure management in the country, kg N₂O-N per year

44/28 = conversion of N₂O-N_(mm) emissions to N₂O_(mm) emissions.

Indirect N₂O-N emissions due to volatilisation of N from manure management in the country ($N_2O - N_{G(mm)}$), expressed as kg N₂O-N per year, were estimated by multiplying the total emissions of NH₃ and NO_x from animal housing, manure management and NH₃ from manure storage by an emission factor.

$$N_2O - N_{G(mm)} = \{ [NH_3 - N \text{ emissions manure management} + NO_x - N \text{ emissions manure management}] * EF_{iN_2O-N} \}$$

with:

NH₃-N emissions manure management = NH₃-N emissions (kg NH₃-N/year) for all defined livestock categories *i* within NFR Category 3B (Manure management), see Table 5-25. For additional information see section 5.2.6 and the (IIR, 2021); Note: n_i= the number of animals in the *i*-th livestock category.

$$= \sum_i [\{ E_{build_sturry_NH3-N(i)} + E_{build_solid_NH3-N(i)} + E_{storage_sturry_NH3-N(i)} + E_{storage_solid_NH3-N(i)} \} * n_i]$$

NO_x-N emissions manure management = NO_x-N emissions (kg NO_x-N /year, expressed as nitrogen monoxide) for all defined livestock categories *i* within NFR Category 3B (Manure management), see Table 5-25. For additional information see section 5.2.6 and the (IIR, 2021); Note: n_i= the number of animals in the *i*-th livestock category.

$$= \sum_i [\{ E_{storage_sturry_NO-N(i)} + E_{storage_solid_NO-N(i)} \} * n_i]$$

EF_{iN₂O}-N manure management indirect = Nitrous oxide emission factor for indirect emission following atmospheric deposition of NH₃ and NO_x, here the default IPCC value from Table 11.3 of the 2006 IPCC guidelines (IPCC 2006a) was used, namely 0.01.

Leaching and/or uncontrolled surface runoff from manure management (including management of bio-digester) is, according to the EU Nitrate Directive (EU, 1991) forbidden on grounds of protection of inshore waters (EU, 1991). Hence, no indirect N₂O emissions from leaching and runoff was calculated for the manure management. This was done so for all years since 1990.

Indirect N₂O emissions as a consequence of spreading of manure are reported in Sector 3.D.

5.4.4 Category-specific recalculations including changes made in response to the review process

Revised manure management systems resulted in a slight increase of the methane emissions from manure management. Additional details are provided in Annex 3:A, and the recalculations are provided in Table A3-4 in Annex 3:A.

Revised manure management systems, the updated N.ex for suckler cows and the revised N-flow influenced the N₂O emissions from manure management, both direct and indirect.

A detailed description of the different changes is provided in Annex 3:A, and the recalculations are provided in Table A3-5 in Annex 3:A.

5.4.5 Category specific uncertainty

Uncertainty is model using Monte-Carlo technique. A detailed description of the assumed uncertainties for animal population numbers, N.ex, manure management systems and emission factors for manure management for methane emissions and N₂O emissions, both direct and indirect, are provided in Annex 3:B.

5.4.6 Category-specific QA/QC and verification

Consistency and completeness checks have been performed directly while building and calculating GHG emissions from the agriculture sector.

The plausibility of the estimates, as well as the calculation methods, were discussed and developed by the sector experts in the country.

5.4.7 Planned improvement

With additional data on manure management system collected during the 2020 agriculture census - additional changes will be made in future submissions, ones analysed. Further, with the publication of new IPCC guidelines and/or emissions factors will the necessary changes, where appropriated, be incorporated.

5.5 Rice Cultivation (IPCC Source Category 3.C)

This source category does not exist in Luxembourg

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5.6 Agricultural Soils (IPCC Source Category 3.D)

This section describes the estimation of nitrous oxide emissions linked to agricultural soils, whether these are direct or indirect emissions originating from crops or from spreading on soils. In 2019, this source category was responsible for 88% of agricultural nitrous oxide emissions and for 61.42% of the total nitrous oxide emissions estimated for Luxembourg. N₂O emissions linked to agricultural soils represented 29% of the total GHG emissions from the agriculture sector and represented 1.92% of the total GHG emissions in CO₂e (excluding LULUCF).

5.6.1 Key source

With 1.92% of the total GHG emissions in CO₂e, excluding LULUCF in 2019, nitrous oxide emissions from agricultural soils (IPCC Category 4D) is a key source, whether LULUCF is included or excluded. It has been a key source in both cases without interruption since 1990 (see Table 5-3 in section 5.1.2)

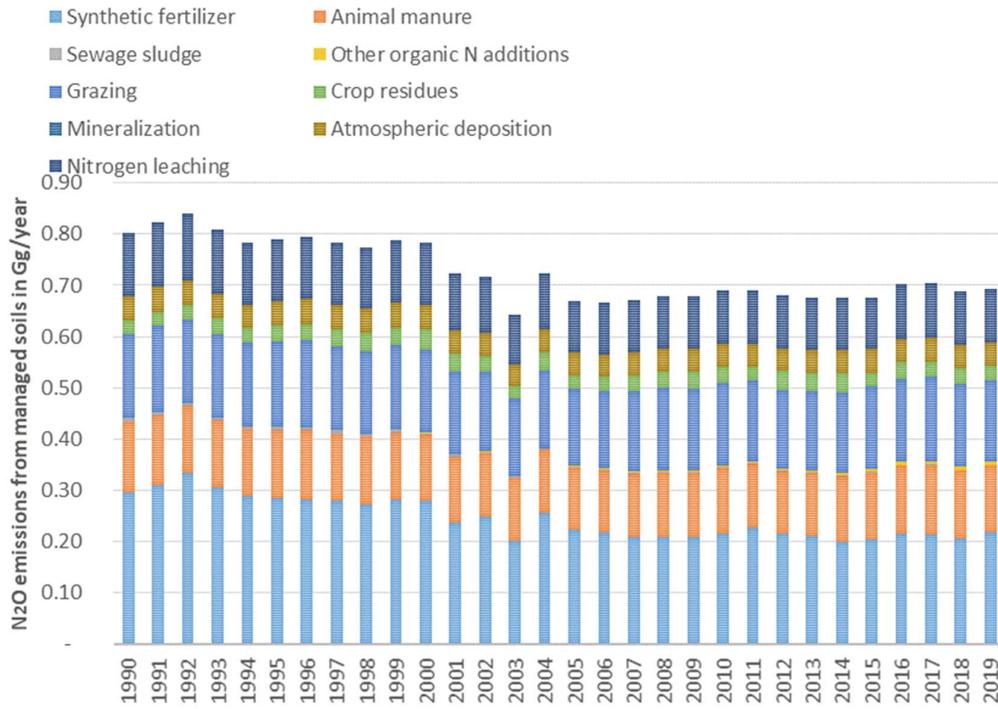
5.6.2 Source category description

The source category agricultural soils covers:

- direct N₂O soil emissions (IPCC Sub-category 3D1) resulting from manure application, including digestate originating from animal manure, grazing, application of mineral fertiliser, sewage sludge, other organic fertilizer (i.e. compost and digestate originating from energy crops and other waste) and crop residues.
- and indirect N₂O soil emissions (IPCC Sub-category 3D2) resulting from deposition of reactive nitrogen and via leaching and run-off.

Since 1990, agricultural soil N₂O related emissions declined by 13%, Table 5-30 and Figure 5-10. The largest decline was observed for sewage sludge (-93%), mineralisation (-88%) and synthetic fertilizer (-27%). N₂O emissions from crop residues varies over the years, as depending on growth conditions (i.e. precipitation and temperature). The most important category in absolute terms was synthetic fertilizer, which was in 2019 responsible for 31% of the direct N₂O emission from managed soils (Table 5-30 and Figure 5-10).

Figure 5-10 – N₂O emissions from managed soils (Gg/year): 1990 -2019



Source: SER

Table 5-30 – N₂O emission trends (Gg) for IPCC Category 3D – Agricultural Soils: 1990-2019

3 - Agriculture Sector												
N ₂ O emissions (Gg)												
Year	3 D - Agricultural soils (including LULUCF)											
	Total	Synthetic fertilizer	Animal manure	Sewage sludge	Other organic N additions*	Grazing	Crop residues	Mineralization	Organic soils	Other	Atmospheric deposition	Nitrogen leaching
1990	0.80	0.30	0.14	0.0058	NO	0.17	0.026	0.00021	NO	NO	0.046	0.12
1991	0.82	0.31	0.14	0.0058	NO	0.17	0.027	0.00021	NO	NO	0.048	0.13
1992	0.84	0.33	0.13	0.0059	NO	0.16	0.028	0.00021	NO	NO	0.048	0.13
1993	0.81	0.30	0.13	0.0061	NO	0.16	0.030	0.00021	NO	NO	0.047	0.12
1994	0.78	0.29	0.13	0.0064	NO	0.16	0.028	0.00021	NO	NO	0.047	0.12
1995	0.79	0.28	0.13	0.0064	NO	0.17	0.030	0.00021	NO	NO	0.048	0.12
1996	0.79	0.28	0.13	0.0055	NO	0.17	0.031	0.00021	NO	NO	0.048	0.12
1997	0.78	0.28	0.13	0.0058	NO	0.16	0.034	0.00021	NO	NO	0.048	0.12
1998	0.77	0.27	0.13	0.0058	NO	0.16	0.034	0.00021	NO	NO	0.047	0.12
1999	0.79	0.28	0.13	0.0058	NO	0.16	0.035	0.00021	NO	NO	0.049	0.12
2000	0.78	0.28	0.13	0.0030	0.0015	0.16	0.039	0.00020	NO	NO	0.048	0.12
2001	0.72	0.24	0.13	0.0028	0.0007	0.16	0.036	0.00019	NO	NO	0.046	0.11
2002	0.72	0.25	0.12	0.0030	0.0008	0.16	0.029	0.00019	NO	NO	0.045	0.11
2003	0.64	0.20	0.12	0.0023	0.0006	0.15	0.024	0.00018	NO	NO	0.043	0.10
2004	0.72	0.26	0.12	0.0019	0.0012	0.15	0.034	0.00017	NO	NO	0.045	0.11
2005	0.67	0.22	0.12	0.0025	0.0020	0.15	0.026	0.00016	NO	NO	0.044	0.10
2006	0.67	0.22	0.12	0.0022	0.0025	0.15	0.028	0.00016	NO	NO	0.044	0.10
2007	0.67	0.21	0.12	0.0026	0.0025	0.16	0.031	0.00015	NO	NO	0.045	0.10
2008	0.68	0.21	0.13	0.0025	0.0029	0.16	0.032	0.00014	NO	NO	0.046	0.10
2009	0.68	0.21	0.13	0.0016	0.0034	0.16	0.032	0.00013	NO	NO	0.045	0.10
2010	0.69	0.22	0.13	0.0016	0.0038	0.16	0.029	0.00012	NO	NO	0.047	0.10
2011	0.69	0.23	0.12	0.0022	0.0034	0.16	0.025	0.00011	NO	NO	0.046	0.10
2012	0.68	0.21	0.12	0.0026	0.0039	0.15	0.036	0.00010	NO	NO	0.045	0.10
2013	0.68	0.21	0.12	0.0021	0.0031	0.16	0.035	0.00009	NO	NO	0.044	0.10
2014	0.68	0.20	0.13	0.0019	0.0041	0.16	0.037	0.00008	NO	NO	0.045	0.10
2015	0.68	0.20	0.13	0.0023	0.0049	0.16	0.027	0.00007	NO	NO	0.045	0.10
2016	0.70	0.22	0.13	0.0012	0.0053	0.16	0.033	0.00006	NO	NO	0.046	0.11
2017	0.70	0.21	0.14	0.0012	0.0060	0.17	0.030	0.00005	NO	NO	0.047	0.11
2018	0.69	0.20	0.13	0.0007	0.0057	0.16	0.030	0.00004	NO	NO	0.046	0.10
2019	0.69	0.22	0.13	0.0004	0.0055	0.16	0.029	0.00003	NO	NO	0.046	0.10
Trend 1990 -2019	-13%	-27%	-4%	-93%		-4%	14%	-88%	NO	NO	-1%	-15%
Trend 2018 -2019	1%	6%	-2%	-42%	-4%	-2%	-3%	-29%	NO	NO	-1%	1%

Source: SER.

* Other organic N additions = compost & digestate originating from energy crops and waste.

5.6.3 Methodological issues

Table 5-31 gives an overview of the status, the methods and emission factors (EF) used for category 3.D – Agricultural Soils.

Table 5-31 – Overview of category 3.D: Status, methods and emission factors (EF) used.

GHG source & sink category	Description	N ₂ O		
		Status	Method	EF
3.D.1	<i>Direct soil emissions</i>			
	Synthetic fertilizers	x	T1	D
	Animal manure applied to soils, including digestate originating from animal manure	x	T2	D
	Sewage sludge	x	T1	D
	Compost and digestate originating from energy crops and other waste	x	T1	D
	Crop Residue	x	T1	D
	Urine and dung N deposited on pasture by grazing animals	x	T2	D
	Drainage/management of organic soils	NO	-	-
3.D.2	<i>Indirect soil emissions</i>			
	Atmospheric Deposition	x	T2	D
	Nitrogen Leaching & Run-off	x	T1	D

Note: An “x” indicates that emissions from this sub-category has been estimated.

Used abbreviations: D = IPCC default EF; IE= included elsewhere; NO=not occurring; T1 = IPCC Tier 1.

5.6.3.1 Activity data

Activity data used to estimate N₂O estimates for IPCC Category 3D are:

- Synthetic N fertilizer, see Table 5-32.
- Applied organic N fertiliser, including animal manure, sewage sludge and other organic N additions (i.e. compost and digestate originating from energy crops and other waste), see Table 5-32.
- Urine and dung N deposited on pasture by grazing animals, see Table 5-32.
- N in crop/forage residues, see Table 5-32.
- Mineralisation associated with loss of soil organic matter resulting from change of land use or management of mineral soils, see Table 5-32.
- Atmospheric depositions of nitrogen compounds that have evaporated in the form of NH₃ and NO_x from inorganic N fertilizer, the application of animal manure, grazing, sewage sludge and other organic N additions (i.e. compost and digestate originating from energy crops and other waste), see Table 5-36.

Table 5-32 – Activity data (kg N) for IPCC Category 3D: 1990-2019

3 - Agriculture											
Activity data - Annual amount of N inputs to soil (kg N/year) from different sources											
Year	Synthetic fertilizer	Animal manure	Sewage sludge	Other organic N	Grazing	Crop residues	Mineral-ization	Organic soils	Other	Atmospheric deposition	Nitrogen leaching
1990	18 895 444	8 739 795	371 985	NO	5 294 922	1 643 597	13 312	NO	NO	2 954 405	10 487 716
1991	19 688 595	8 711 146	372 205	NO	5 428 252	1 703 159	13 312	NO	NO	3 082 766	10 775 001
1992	21 245 368	8 292 154	376 491	NO	5 252 363	1 791 330	13 312	NO	NO	3 049 022	11 091 306
1993	19 381 205	8 332 831	391 126	NO	5 256 751	1 932 991	13 312	NO	NO	3 011 354	10 592 465
1994	18 399 940	8 238 717	409 055	NO	5 229 701	1 784 346	13 312	NO	NO	2 973 192	10 222 521
1995	18 054 158	8 469 785	406 178	NO	5 383 203	1 902 935	13 312	NO	NO	3 042 668	10 268 871
1996	17 992 452	8 565 956	352 796	NO	5 475 419	1 956 771	13 312	NO	NO	3 067 232	10 307 012
1997	17 718 714	8 428 455	369 747	NO	5 297 288	2 142 122	13 312	NO	NO	3 028 542	10 190 891
1998	17 375 970	8 358 791	370 828	NO	5 223 660	2 181 055	13 312	NO	NO	3 013 080	10 057 085
1999	17 917 875	8 363 647	368 839	NO	5 265 103	2 229 136	13 312	NO	NO	3 099 184	10 247 373
2000	17 730 456	8 200 569	193 515	93 077	5 233 733	2 501 279	12 838	NO	NO	3 044 420	10 189 640
2001	15 118 132	8 157 481	181 353	43 384	5 210 117	2 283 852	12 364	NO	NO	2 927 473	9 302 005
2002	15 761 472	7 899 847	191 920	52 353	5 046 585	1 846 480	11 890	NO	NO	2 868 393	9 243 164
2003	12 846 702	7 741 470	146 205	38 701	4 920 941	1 515 546	11 417	NO	NO	2 715 782	8 166 294
2004	16 293 626	7 814 547	121 081	75 067	4 920 683	2 190 137	10 943	NO	NO	2 841 490	9 427 825
2005	14 082 348	7 730 593	159 100	128 948	4 863 518	1 676 528	10 469	NO	NO	2 808 077	8 595 451
2006	13 900 105	7 638 046	139 750	160 019	4 850 040	1 771 669	9 995	NO	NO	2 787 572	8 540 887
2007	13 199 745	7 921 752	165 609	160 677	5 071 856	1 961 830	9 521	NO	NO	2 852 312	8 547 297
2008	13 198 210	8 064 289	156 780	181 850	5 162 384	2 054 186	8 861	NO	NO	2 898 157	8 647 968
2009	13 277 456	8 008 940	103 488	219 239	5 150 102	2 057 322	8 201	NO	NO	2 867 848	8 647 424
2010	13 700 295	8 152 651	103 729	244 117	5 233 218	1 876 481	7 540	NO	NO	2 959 885	8 795 409
2011	14 387 670	7 940 291	137 317	214 474	5 110 484	1 614 139	6 880	NO	NO	2 914 101	8 823 377
2012	13 643 864	7 729 741	165 135	248 435	4 973 818	2 317 347	6 219	NO	NO	2 835 714	8 725 368
2013	13 341 600	7 903 114	132 854	195 266	5 019 174	2 217 483	5 559	NO	NO	2 817 979	8 644 515
2014	12 677 997	8 129 367	122 577	262 820	5 141 581	2 385 921	4 899	NO	NO	2 863 417	8 617 549
2015	12 984 741	8 249 808	144 931	310 172	5 239 141	1 722 323	4 238	NO	NO	2 894 590	8 596 606
2016	13 700 554	8 434 138	77 569	336 741	5 272 680	2 091 599	3 578	NO	NO	2 906 753	8 975 058
2017	13 575 361	8 640 958	78 285	380 389	5 338 416	1 902 189	2 917	NO	NO	2 971 192	8 975 554
2018	13 037 517	8 535 938	46 674	363 272	5 260 173	1 921 389	2 257	NO	NO	2 937 836	8 750 166
2019	13 794 769	8 392 712	26 853	347 642	5 154 764	1 869 888	1 596	NO	NO	2 921 116	8 876 468

Sources: SER, MECDD, STATEC

* Other organic N additions = compost & digestate originating from energy crops and waste

5.6.3.1.1 Synthetic N fertilizer

Only nitrogenous fertilizers have been considered as synthetic N fertilizers since these are the ones generating nitrous oxide emissions.

Up to 1998 included, statistics were not recording fertilizer application, but fertilizer sales in Luxembourg. Therefore, for the years prior to 1999, the hypothesis that fertilizers consumption/application equals fertilizer sales (i.e. no stocks and stock changes) has been made. Thereafter, consumption data had been used. Synthetic N fertilizer, expressed in kg N, was based on data collected within the Luxembourgish “landwirtschaftliche Testbetriebsnetz (LTBN)”¹¹⁴, using a nutrient balance methodology (in German the so-called “Feld – Stall Bilanz”) (Weckbecker, 2018).

National utilisation was obtained by multiplying the weighted average kg N per ha used agriculture surface (STATEC, 2020) by the used agriculture surface (STATEC, 2020)

5.6.3.1.2 Applied organic N fertiliser

Applied organic N fertilizers comprise animal manure, including digestate originating from animal manure, sewage sludge and other organic N additions (i.e. compost and digestate originating from energy crops and other waste). The total annual amount of organic N fertilizer applied to soils other than by grazing animals (F_{on}), in kg N per year was calculated according to equation 11.3 in the 2006 IPCC guidelines (IPCC 2006b)

$$F_{ON} = F_{AM} + F_{SEW} + F_{COMP} + F_{DEC}$$

with:

F_{AM}	= annual amount of animal manure N applied to soils, kg N per year, see Table 5-32
F_{SEW}	= annual amount of total sewage N that is applied to soils, kg N per year, see Table 5-32
F_{COMP}	= annual amount of total compost N applied to soils, kg N per year see Table 5-32.
F_{DEC}	= annual amount of total digestate N originating from energy crops and other waste applied to soils, kg N per year see Table 5-32.

N in animal manure applied to soil was determined using a mass-flow approach based on the concept of a flow of total ammoniacal nitrogen (TAN) through the manure management, which was determined following the fifteen steps from the 2019 guidelines (EMEP, 2019), which were described in section 5.2.6 and schematically shown in Figure 5-6. Gross amounts are used throughout, i.e. emissions of various N substances from a given source are calculated using the same basic nitrogen amount. Both the N in animal manure stored on the farm and the N in digestate created by the anaerobic digestion of manure and returned from NRF 5.B.2 is taken into consideration. This corresponds to step 11 described in section 5.2.6.

$$F_{AM} = \left[\sum_i ([m_{applic_slurry_N(i)} + m_{applic_solid_N(i)}] * n_i) \right]$$

114 Luxembourg has the obligation to collect data from agriculture farms for the Farm Accountancy Data Network (FADN). For details on the FADN see <http://ec.europa.eu/agriculture/rica/>, for the Luxembourgish “landwirtschaftliche Testbetriebsnetz (LTBN)” see <https://agriculture.public.lu/de/betriebsfuhrung/buchfuhrung/testbetriebsnetz.html>. The LTBN is situated in the division «Division de la gestion, de la comptabilité et de l’entraide agricoles», at the SER. This division gets from about 840 farms farm accountancy data (<https://agriculture.public.lu/de/betriebsfuhrung/buchfuhrung.html>). Out of these farms, a representative sample of 450 farms are selected to form the sample size shared with FADN (<https://agriculture.public.lu/de/betriebsfuhrung/buchfuhrung/testbetriebsnetz.html>).

with:

$m_{\text{applic_slurry_N}(i)}$	the net amount of N applied to the field from liquid manure (expressed in kg N per year per head/place) for animal category i ;
$m_{\text{applic_solid_N}(i)}$	the net amount of N applied to the field from solid manure (expressed in kg N per year per head/place) for animal category i ;
n_i	the number of animals in livestock category i and shown in Table 5-5;

A detailed description can be found in the (IIR, 2021).

The annual amount of total sewage N applied to soils (in kg per year), was estimated based on published statistics w.r.t. to tonnage, N content and the destination, see Table 5-32.

Sewage sludge data used in the inventory were derived from:

- estimates for the total sewage sludge produced in the various wastewater treatment plant (WWTP) of the country. These estimates have been prepared by the MECDD-AEV (Environment Agency) with some corrections performed by the MECDD for the years 2000 to 2004;
- annual reports on sewage sludge that are regularly issued since 2003.¹¹⁵ These reports are based on a questionnaire sent to WWTPs with at least 2000 inhabitants-eq., hence not all the WWTPs are interrogated. The questionnaire requests, among other things, to indicate the destination and the use of the sludge, both in Luxembourg and abroad.
- a five-year trend estimate was used for 2019, as data collection was still on-going.

The annual amount of compost N applied to soils (in kg per year) was estimated based on published statistics w.r.t. to tonnage, N content and the destination, see Table 5-32.

Compost data used in the inventory were derived from:

- Recent compost statistics were obtained from annual reports.¹¹⁶
- Previously, data has been estimated by both the MDDI-DEV and the MDDI-AEV (Environment Agency) on the basis of annual reports and official statistics on wastewater treatment in Luxembourg.

The annual amount of digestate N originating from energy crops and other waste (in kg N/year), as returned from NRF 5.B.2, was the used N quantities for estimating N₂O emissions from soils, both direct and indirect N₂O emissions. The annual amount was derived, starting with activity data of the use of energy crops and other waste in biogas facilities from national statistics, and transferred into an N_{tot} flowing the 2019 EMEP guidelines (EMEP, 5.B.2 Biological treatment of waste - anaerobic Digestion Biogas, 2019) (IIR, 2021) schematically shown in Figure 5-6 and described in full detail in the IIR 2021 (IIR, 2021).

Activity data were derived:

- for energy crops and other waste for the years 2007-2019 from annual reports¹¹⁷;

¹¹⁵ See <https://data.public.lu/en/datasets/boues-depuration/>.

¹¹⁶ See https://data.public.lu/en/datasets/biodechets/#_.

¹¹⁷ See https://data.public.lu/en/datasets/biodechets/#_. Please note, that not all reports are online available.

- for other waste for the years 2002-2006 from the 2019 annual report (AEV, Anonymisierte tabellarische und grafische Zusammenfassung ausgewählter Daten der Jahresberichte 2019 der luxemburgischen Kofermentationsanlagen, 2020) (AEV, 2020);
- for energy crops for the years 2002-2006, however, no data was available, why activity data for energy crops were estimated, presuming the same proportion of energy crops and other waste as observed for the year 2007.

5.6.3.1.3 N in crop/forage residues

The annual amount of N in crop residues (above and below ground), including N-fixing crops and from forage/pasture renewal, returned to soils annually (F_{CR}), expressed in kg N per year is summarized in Table 5-32, and was estimated based on equation 11.6 of the 2006 IPCC Guidelines (IPCC 2006b)

$$F_{CR} = \sum_k \{Crop_k * Frac_{Renew(k)} * (Area_k * R_{AG(k)} * N_{AG(k)} * (1 - Frac_{Renew(k)}) + Area_k * R_{BG(k)} * N_{BG(k)})\}$$

with:

$Crop_k$	= harvested annual dry matter yield for crop k , kg dry matter per ha, with k = crop or forage type
$Area_k$	= total annual area harvested of crop k , ha per year
$Frac_{Renew(k)}$	= fraction of total area under crop k that is renewed annually, see Table 5-35
$R_{AG(k)}$	= ratio above ground residues dry-matter ($AG_{DM(k)}$) to harvested yield for crop k , kg dry matter, = $AG_{DM(k)} * 1000 / Crop_k$
$N_{AG(k)}$	= N content in above ground residues in kg N
$Frac_{Removed(k)}$	= fraction of above-ground residues of crop k removed annually for purposes as feed and bedding, see Table 5-35
$R_{BG(k)}$	= ratio below ground residues to harvest yield for crop k , kg dry matter, whereby $R_{BG(k)}$ was calculated by multiplying $R_{BG-BIO(k)}$ in Table 11.2 (IPCC 2006b) and summarized in see Table 5-35 by $R_{AG(k)}$
$N_{BG(k)}$	= N content in below ground residues in kg N (values taken from Table 11.2 (IPCC 2006b) and summarized in Table 5-35)

Note: The above equation was slightly adapted as burning of crop residues is forbidden by law in Luxembourg, and therefore assumed to not occur.

The cultivated crop area for 1990-2019 ($Area_k$) is summarized in Table 5-33, and the harvest yield for the different crop cultivated ($Crop_k$) is summarized in Table 5-34. Area data were based on both, published and unpublished data from the agriculture census (Sources: unpublished data: Fränk Steichen; personal communication, December 2019; SER – Statistiques agricoles, marchés agricoles et relations extérieures; Published data: (STATEC, 2020)). Official statistics were consulted for the harvest yield data (STATEC, 2020) , whereby cash crops were mainly extracted from unpublished LTBN data and forage yields were based on measurements conducted by ASTA in different experimental fields through the country (for example for pasture <http://www.grengland.lu/grunland-ticker>).

With the exception of clover, grass-clover and pasture and meadows were all crops annually renewed (see Table 5-35). Clover and grass-clover leys were renewed every 3 years, similar to Germany (Haenel H.-D. , et al., 2018). Whereas permanent grassland (i.e. pasture and meadows) is forbidden to plough (GDR, 30 juillet 2015).

The above ground residues dry-matter ($AG_{DM(k)}$) used to determine the $R_{AG(k)}$, was calculated according to the formula provided in Table 11.2 (IPCC 2006b), namely:

$$AG_{DM(k)} = (Crop_k/1000) * slope + intercept$$

Whereby using the information provided for slope and intercept in Table 11.2 (IPCC 2006b) and summarized in Table 5-35.

Straw from wheat and other cereals would be annually completely removed from the field and used as bedding material. Maize for silage, is a whole plant silage, and accordingly also here would be the whole plant removed from the field during the harvest. Fodder beet, clover, grass-clover, pasture and meadows were used as forage plants, whereby the whole plant would be used, see Table 5-35.

Values used for $N_{AG(k)}$, $R_{BG-BIO(k)}$ and $N_{BG(k)}$ were taken from Table 11.2 (IPCC 2006b) and are summarized in see Table 5-35 .

Grains such as wheat, barley and triticale, but also rapeseed were the major cash crops cultivated in Luxembourg. Grass, cover-grass and maize for silage (whole plant) are and were the main forage crops grown in Luxembourg, see Figure 5-2 (STATEC, 2020) . In particularly the cultivated area for wheat and maize for silage increased over the years, whereas barley and oat decreased. This change was partly driven by improved plant breeds and an increased proportion of maize in the feed rations of dairy cows and fattening bulls.

Variations in precipitation (see Figure 2-9) and in air temperature (see Figure 2-5 and Figure 2-6) resulted in large fluctuations of the harvest crops between years, and hence impacted also the crop residues.

Table 5-33 – Cash crop plants, fodder plants, pasture and total agricultural area (ha): 1990-2019

3 - Agriculture															
Activity data - Agriculture surface area, cash crop plants, fodder plants and pasture (in ha)															
Year	agricultural area	winter wheat	spring wheat	rye and mix-	barley	oat	triticale	rape	potatoes	pulses	grain maize	maize for silage & bio	fodder beet	clover, grass-	pasture and
1990	126 298	7 647	978	1 255	15 682	5 146	2 272	1 951	826	537	NO	7 473	231	11 573	68 827
1991	125 469	7 334	621	1 147	14 755	4 499	2 670	2 595	859	591	NO	7 844	246	11 862	68 531
1992	125 742	7 574	574	1 107	13 658	4 104	2 717	1 520	946	761	NO	8 676	280	12 749	69 192
1993	127 215	7 706	662	923	13 746	3 819	2 665	1 686	834	835	NO	7 951	248	14 428	68 186
1994	126 765	8 361	668	1 097	13 564	3 524	2 423	1 665	784	614	NO	8 540	234	13 564	68 025
1995	126 865	8 917	418	1 094	12 681	2 790	2 874	1 954	802	474	NO	9 385	221	14 166	67 515
1996	125 348	9 360	432	927	12 836	2 595	3 032	2 443	797	404	NO	9 528	178	14 111	66 513
1997	125 629	9 299	443	973	12 584	2 517	3 095	2 250	842	421	457	10 024	165	16 075	64 965
1998	126 235	9 342	462	1 263	12 260	2 299	3 419	2 862	842	414	505	9 881	129	16 381	64 441
1999	126 494	6 629	1 168	1 234	12 798	2 456	2 756	4 069	840	557	502	10 491	106	16 238	64 377
2000	127 009	10 590	381	1 331	10 538	1 909	3 635	3 245	829	431	255	10 799	77	15 281	65 277
2001	127 257	9 065	760	1 315	11 622	1 725	3 066	3 084	734	693	476	11 241	61	15 171	65 114
2002	127 520	11 552	466	1 466	9 585	1 963	4 010	3 492	672	667	326	11 016	51	14 436	65 042
2003	127 574	10 738	449	1 142	10 355	2 163	3 724	3 674	623	601	337	11 621	43	14 539	64 828
2004	127 593	11 380	340	1 427	8 882	1 907	3 578	4 190	635	507	350	12 284	43	14 663	65 068
2005	127 789	11 296	630	1 309	9 938	1 696	3 411	4 061	608	467	215	12 100	51	12 288	67 504
2006	127 641	12 257	408	1 411	9 512	1 502	3 470	4 782	594	372	288	11 566	37	11 860	67 659
2007	129 791	12 246	340	1 431	9 226	1 443	3 546	5 394	628	367	281	11 985	39	12 480	68 290
2008	129 141	14 179	418	1 557	9 674	1 252	3 608	5 208	604	222	379	12 192	30	12 039	67 172
2009	129 726	13 369	472	1 343	9 370	1 383	4 055	4 629	604	305	409	13 261	32	12 221	67 367
2010	130 479	13 668	342	1 150	8 261	1 136	4 780	4 715	615	336	375	13 435	27	12 818	67 593
2011	130 797	13 367	511	1 206	7 940	1 123	4 340	4 674	635	268	300	13 690	32	13 653	67 638
2012	131 191	13 055	462	1 328	7 142	919	4 736	4 596	639	166	196	14 131	59	14 567	67 292
2013	130 800	13 740	511	1 148	7 740	1 130	4 561	4 496	593	282	243	13 996	75	13 493	66 897
2014	130 701	11 506	1 159	1 235	8 318	1 178	4 787	4 146	607	378	216	14 745	102	13 790	66 827
2015	131 159	13 698	796	1 141	7 714	1 194	4 604	3 975	570	588	141	14 448	137	13 089	66 923
2016	130 357	13 373	435	1 319	6 901	1 094	4 609	3 508	615	682	125	14 938	154	13 501	67 115
2017	131 163	13 696	488	1 243	6 594	1 309	4 520	3 267	622	621	108	15 194	111	13 647	67 413
2018	131 559	12 633	351	1 353	6 004	1 238	4 669	3 393	627	409	61	15 876	77	14 658	67 705
2019	131 592	13 143	315	1 415	6 064	1 402	4 911	2 883	601	407	143	15 781	79	14 208	67 884

* The area for clover & grass-clover was obtained by subtracting: i) the area for maize silage/bio-digester; and ii) the area for fodder beets from the total arable forage area.

Source: (STATEC, 2020) and SER (unpublished data; SER – Statistiques agricoles, marchés agricole et relations extérieures).

Table 5-34 – Crop harvest (kg/ha): 1990-2019

3 - Agriculture														
Activity data - Crop harvest (kg/ha)														
Year	winter wheat	spring wheat	rye and mix-	barley	oat	triticale	rape	potatoes	pulses	grain maize	maize for silage & bio	fodder beet ^{a,b}	Clover, grass-clover leys,	Pasture and meadows ^{a,d}
1990	5 186	3 941	3 604	4 439	3 645	4 612	2 741	27 800	2 533	NO	14 056	12 030	8 534	5 165
1991	5 630	4 849	4 477	4 980	4 330	4 990	2 562	22 700	3 092	NO	14 056	12 030	8 534	3 920
1992	5 720	4 880	4 031	5 153	4 200	4 946	1 520	28 400	2 870	NO	14 056	12 030	8 534	5 322
1993	5 870	4 985	3 617	4 951	4 480	5 220	2 669	30 760	2 610	NO	14 056	12 030	8 534	5 623
1994	5 130	3 519	3 316	4 415	3 510	4 804	2 160	22 779	2 990	NO	14 056	12 030	8 534	5 079
1995	5 715	4 269	3 534	4 954	4 355	5 077	2 614	28 500	2 911	NO	14 056	12 030	8 534	5 880
1996	6 644	5 129	4 588	5 645	5 117	5 980	3 124	25 400	4 745	NO	14 056	12 030	8 534	5 708
1997	5 904	4 688	4 460	5 454	5 263	4 994	3 496	27 100	3 636	5 000	14 056	12 030	8 534	6 957
1998	6 125	4 680	4 972	5 158	5 086	6 323	3 210	26 500	3 430	8 500	14 056	12 030	8 534	7 767
1999	6 001	5 178	5 113	5 452	4 986	6 282	3 334	30 600	4 141	6 200	14 056	12 030	8 534	5 959
2000	5 599	4 968	4 535	5 080	4 828	5 459	2 580	33 605	2 866	8 000	12 060	11 000	11 460	9 800
2001	5 563	4 730	5 301	4 609	4 521	5 429	2 847	31 022	3 285	9 099	14 050	11 000	9 970	8 530
2002	5 978	5 669	6 403	5 406	5 206	5 747	3 586	29 913	3 486	7 100	13 400	12 650	7 440	6 360
2003	6 178	5 129	5 786	5 343	5 278	5 369	3 412	29 425	3 571	5 649	15 400	12 000	5 020	4 290
2004	6 843	6 199	6 875	5 941	4 959	6 453	3 944	35 010	3 407	10 332	15 368	13 500	8 780	7 510
2005	6 070	5 021	5 677	5 318	4 561	5 433	3 621	31 784	3 184	9 576	15 980	13 770	6 940	5 940
2006	5 982	5 590	5 303	5 263	4 429	5 669	3 398	27 664	3 184	6 520	13 900	12 000	8 410	7 190
2007	5 622	4 762	5 420	4 838	3 905	4 983	3 393	31 828	2 247	7 540	17 110	12 500	8 890	7 600
2008	6 707	5 136	6 316	5 422	4 985	5 966	3 154	36 022	3 462	9 141	15 930	12 100	9 590	8 200
2009	6 575	6 369	5 970	5 806	5 200	6 268	3 917	33 185	3 954	9 289	16 340	10 375	9 120	7 800
2010	5 981	5 062	5 283	5 206	4 214	5 339	3 371	31 739	2 892	8 316	13 480	8 583	8 300	7 100
2011	5 578	4 451	4 529	4 843	3 595	5 138	3 332	30 991	2 328	7 787	12 790	7 610	6 300	5 383
2012	5 906	4 524	4 798	5 306	5 168	4 946	3 337	32 254	2 765	8 255	14 060	11 038	10 200	8 730
2013	6 402	6 062	5 376	5 489	4 898	5 645	3 394	29 594	3 303	8 930	13 460	10 528	10 220	8 739
2014	6 303	4 674	5 917	5 526	4 647	6 282	3 788	31 244	2 773	7 743	15 830	10 528	10 610	9 053
2015	6 324	5 567	5 772	5 754	4 923	5 946	3 482	22 750	2 662	6 578	12 350	8 376	7 200	6 154
2016	5 107	4 066	4 277	4 927	4 834	4 956	3 112	30 447	1 913	6 697	12 680	24 003	9 520	8 130
2017	5 501	4 979	4 588	5 300	4 522	5 242	3 464	34 237	2 593	8 597	16 750	8 231	7 640	6 520
2018	6 075	4 749	4 932	5 773	5 636	5 726	3 227	25 841	3 762	6 225	12 710	8 727	7 900	6 743
2019	6 030	5 000	5 372	5 830	5 000	5 750	3 391	25 503	2 889	5 669	11 810	9 000	8 000	6 832

Notes: a) In kg/ha dry matter; b) No data were available on the harvest of silage maize, fodder beets, clover and grass-clover for the years 1990-1999. The average as observed for the years 2000-2004 was taken; c) No data were available on the harvest maize used to feed the bio-digester for the years 1990-2001. The same harvest as for maize for silage was taken; d) No data was available on the harvest of pasture and meadows for the year 1990. The average as observed for the years 1991-1995 was taken. Sources: (STATEC, 2020)

Table 5-35 – Parameters values used for $Frac_{RENEW(k)}$, $Frac_{REMOVE(k)}$, $N_{AG(k)}$, $N_{BG(k)}$, $R_{BIO(k)}$, $Dry\ matter_{(k)}$, the slope and the intercept of $AG_{DM(k)}$

	$Frac_{RENEW}$	$Frac_{REMOVE}$	N_{AG}	N_{BG}	R_{BIO}	Dry matter (%)	Slope of AG_{DM}	Intercept of AG_{DM}
Winter wheat	1	1	0.006	0.009	0.23	0.89	1.61	0.4
Spring wheat	1	1	0.006	0.009	0.28	0.89	1.29	0.75
Rye and mix-cereals	1	1	0.006 ^a	0.009 ^a	0.22 ^a	0.88	1.09 ^a	0.88 ^a
Barley	1	1	0.007	0.014	0.25	0.89	0.98	0.59
Oat	1	1	0.007	0.008	0.22	0.89	0.91	0.89
Triticale	1	1	0.006 ^a	0.009 ^a	0.22 ^a	0.88	1.09 ^a	0.88 ^a
Rape	1	0	0.006 ^a	0.009 ^a	0.22 ^a	0.91	1.09 ^{a,b}	0.88 ^{a,b}
Potatoes	1	0	0.019	0.014	0.2	0.22	0.1	1.06
Pulses	1	0	0.008	0.008	0.19	0.91	1.13	0.85
Grain maize	1	0	0.006	0.007	0.22	0.87	1.03	0.61
Maize for silage	1	1	0.006 ^b	0.007 ^b	0.22 ^b	-	1.03 ^b	0.61 ^b
Fodder beet	1	1	0.19 ^c	0.014 ^c	0.2 ^c	-	0.1 ^c	1.06 ^c
Clover, grass-clover & similar	0.33 ^b	1	0.015 ^d	0.012 ^d	0.8 ^d	-	0.3 ^d	0 ^d
Pasture and meadows	NO ^e	1	0.015	0.012	0.8	-	0.3	0

Note: a) Used values applicable to “all grain”; b) Similar to (Haenel H.-D. , et al., 2018) ; c) used values for tubers; d) used values for Non-N-fixing forages as the clover area is only marginal. D) It is forbidden by law to plough permanent grassland, therefore assumed to no occur.

5.6.3.1.4 Urine and dung N deposited on pasture by grazing animals

The annual amount of urine and dung N deposited on pasture by grazing animals (F_{PRP}), expressed in kg N per year is summarized in Table 5-32, and was determined using a mass-flow approach based on the concept of a flow of total ammoniacal nitrogen (TAN) through the manure management, which was determined following the fifteen steps from the 2019 guidelines (EMEP, 2019), which were described in section 5.2.6 and schematically shown in Figure 5-6. The annual amount of urine and dung N deposited on pasture by grazing animals is described in step 4 in section 5.2.6.

$$F_{PRP} = \left[\sum_i ([m_{grazing_N(i)}] * n_i) \right]$$

with:

$m_{grazing_N(i)}$ the amount of the annual N excreted during grazing, expressed in kg N per year per head/place for animal category i ; $m_{grazing_N(i)}$ corresponds to step 4 described in section 5.2.6

n_i the number of animals in livestock category i and shown in Table 5-5;

5.6.3.1.5 Mineralisation associated with loss of soil organic matter from land use changes

The annual release of direct N_2O emissions due to the conversion of land to cropland is summarized in Table 5-32. The methodology is described in section 6.3.4.2.3.

5.6.3.1.6 Atmospheric depositions of nitrogen compounds

Atmospheric depositions of nitrogen compounds that have evaporated in the form of NH_3 and NO_x from inorganic N fertilizer, the application of animal manure, including digestate originating from animal manure, grazing, sewage sludge, compost and digestate originating from energy crops and other waste, see Table 5-36. The methodology used to determine the NH_3 -N and NO_x -N emissions is described in the (IIR, 2021).

Table 5-36 – Activity data: atmospheric depositions of nitrogen compounds that have evaporated in the form of NH₃ and NO_x from inorganic N fertilizer, the application of animal manure, including digestate originating from animal manure, grazing, sewage sludge, compost and digestate originating from energy crops and other waste.

3 - Agriculture										
Activity data - atmospheric depositions of nitrogen compounds that have evaporated in the form of NH ₃ and NO _x (NRF 3D)										
Year	kg NH ₃ -N/ year	kg NO-N/ year								
1990	252 416	352 715	1 802 913	163 143	39 824	6 944	-	-	237 612	98 839
1991	252 416	367 520	1 900 672	162 608	39 848	6 948	-	-	240 831	101 327
1992	263 011	396 580	1 836 719	154 787	40 307	7 028	-	-	231 750	98 044
1993	283 807	361 782	1 855 849	155 546	41 873	7 301	-	-	231 972	98 126
1994	258 905	343 466	1 850 050	153 789	43 793	7 636	-	-	231 042	97 621
1995	245 797	337 011	1 918 111	158 103	43 485	7 582	-	-	236 713	100 486
1996	241 177	335 859	1 944 732	159 898	37 770	6 586	-	-	239 827	102 208
1997	240 353	330 749	1 925 565	157 331	39 585	6 902	-	-	232 831	98 883
1998	236 696	324 351	1 926 241	156 031	39 700	6 922	-	-	230 209	97 508
1999	232 118	334 467	1 991 276	156 121	39 487	6 885	-	-	233 308	98 282
2000	239 357	330 969	1 961 036	153 077	20 717	3 612	6 132	1 737	232 589	97 696
2001	236 853	282 205	1 936 734	152 273	19 415	3 385	2 858	810	230 580	97 256
2002	201 956	294 214	1 868 461	147 464	20 547	3 583	4 032	977	224 363	94 203
2003	210 550	239 805	1 822 191	144 507	15 653	2 729	5 621	722	221 082	91 858
2004	171 613	304 148	1 828 299	145 872	12 963	2 260	14 056	1 401	222 979	91 853
2005	217 659	262 870	1 789 468	144 304	17 033	2 970	18 304	2 407	221 568	90 786
2006	258 366	259 469	1 769 398	142 577	14 961	2 609	29 384	2 987	220 631	90 534
2007	255 022	246 395	1 838 567	147 873	17 730	3 091	29 022	2 999	229 787	94 675
2008	242 173	246 367	1 873 584	150 533	16 785	2 927	32 867	3 395	233 192	96 365
2009	242 145	247 846	1 837 355	149 500	11 079	1 932	43 978	4 092	232 331	96 135
2010	243 599	255 739	1 872 315	152 183	11 105	1 936	47 231	4 557	236 620	97 687
2011	280 512	268 570	1 812 843	148 219	14 701	2 563	44 682	4 004	231 428	95 396
2012	291 696	254 685	1 759 656	144 288	17 679	3 083	58 553	4 637	226 412	92 845
2013	273 875	249 043	1 770 588	147 525	14 223	2 480	44 377	3 645	227 280	93 691
2014	265 127	236 656	1 816 207	151 748	13 123	2 288	61 131	4 906	231 989	95 976
2015	249 393	242 382	1 828 766	153 996	15 516	2 705	70 908	5 790	235 363	97 797
2016	241 367	255 744	1 826 148	157 437	8 304	1 448	75 214	6 286	237 912	98 423
2017	239 837	253 407	1 873 829	161 298	8 381	1 461	83 743	7 101	242 436	99 650
2018	239 885	253 407	1 873 829	161 298	8 381	1 461	83 743	7 101	242 436	99 650
2019	254 643	243 367	1 848 509	159 338	4 997	871	81 168	6 781	239 972	98 190

*Other organic fertilizer = compost and digestate originating from energy crops and other waste.

Source: (IIR, 2021)

5.6.3.2 Emission factors

5.6.3.2.1 Emission factors – direct N₂O emissions from managed soil

The direct N₂O emissions from managed soil (N_2O_{Direct}), expressed as kg N₂O per year were estimated using an IPCC Tier 1 approach, whereby following equation 11.1 of the 2006 IPCC guidelines (IPCC 2006b):

$$N_2O_{Direct} = [N_2O_{N\ inputs} + N_2O_{PRP}]$$

Whereby

$$N_2O_{N\ inputs} = [(F_{SN} + F_{ON} + F_{CR} + F_{SOM}) * EF_1] * \left(\frac{44}{28}\right)$$

with:

$N_2O_{N\ inputs}$	= annual direct N ₂ O emissions from N inputs to managed soils, kg N ₂ O per year
F_{SN}	= annual amount of synthetic fertilizer N applied to soils, kg N per year, see Table 5-32
F_{ON}	= annual amount of organic N applied to soils from animal manure including digestate originating from animal manure; sewage sludge; compost and digestate originating from energy crops and other waste; kg N per year, see Table 5-32 and for the calculations see also section 5.6.3.1.2
F_{CR}	= annual amount of N in crop residues, including N-fixing crops and from forage/pasture renewal, returned to soils, kg N per year, see Table 5-32 and for the calculations see also section 5.6.3.1.3
F_{SOM}	= annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N per year, see Table 5-32
EF_1	= emission factor for N ₂ O inputs, kg N ₂ O-N. For the emissions calculations the default value provided in Table 11.1 in the 2006 IPCC guidelines (IPCC 2006b), namely 0.01 was used.
44/28	= conversion of N ₂ O-N _(mm) emissions to N ₂ O _(mm) emissions.

And further

$$N_2O_{PRP} = [(F_{PRP,CPP} * EF_{3PRP,CPP}) + (F_{PRP,SO} * EF_{3PRP,SO})] * \left(\frac{44}{28}\right)$$

with:

N_2O_{PRP}	= annual direct N ₂ O emissions from urine and dung inputs to grazed soils, kg N ₂ O per year
F_{PRP}	= annual amount of urine and dung deposited by grazing animals on pasture, kg N per year, see Table 5-32 and for the calculations see also section 5.6.3.1.4. Note, the subscripts CPP and SO refer to cattle, poultry and pigs, and sheep and other animals, respectively
$EF_{3,PRP}$	= emission factor for N ₂ O emissions from urine and dung N deposited on pasture by grazing animals, kg N ₂ O-N. For the emissions calculations the default values provided in Table 11.1 in the 2006 IPCC guidelines (IPCC 2006b), namely 0.02 was used for cattle, pigs and poultry ($EF_{3,PRP,CPP}$), and 0.01 for sheep and other animals ($EF_{3,PRP,SO}$).
44/28	= conversion of N ₂ O-N _(mm) emissions to N ₂ O _(mm) emissions.

Direct N₂O emissions from managed organic soils are not occurring, and where therefore not considered in the above equation.

5.6.3.2.2 Emission factors – indirect N₂O emissions from managed soil

The indirect N₂O emissions from managed soils consist of a) N₂O emissions from atmospheric deposition of N volatilised from managed soils and b) N₂O emissions from leaching and runoff.

The indirect N₂O emissions occurring after atmospheric depositions of nitrogen compounds that have evaporated in the form of NH₃ and NO_x from inorganic N fertilizer, the application of animal manure, grazing, sewage sludge, compost and digestate originating from energy crops and other waste (all attributed to agricultural soils) were calculated using the following formula:

indirect soil N₂O emissions

$$= \{ [E_{NH_3-N} + E_{NO-N}]_{fert} + [E_{NH_3-N} + E_{NO-N}]_{SAM} + [E_{NH_3-N} + E_{NO-N}]_{SSS} + [E_{NH_3-N} + E_{NO-N}]_{Comp} + [E_{NH_3-N} + E_{NO-N}]_{DEC} + [E_{NH_3-N} + E_{NO-N}]_{graz} \} * EF_{N_2O-N \text{ indirect soil}} * \left(\frac{44}{28}\right)$$

Where:

- Indirect N₂O emissions resulting from the deposition of NH₃ and NO_x emitted from agricultural soils, in Gg/year
- $[E_{NH_3-N} + E_{NO-N}]_{fert}$: NH₃-N and NO-N emissions from mineral fertilizer, in Gg/year, see .
- $[E_{NH_3-N} + E_{NO-N}]_{SAM}$: NH₃-N and NO-N emissions from spreading of animal manure, in Gg/year.
- $[E_{NH_3-N} + E_{NO-N}]_{SSS}$: NH₃-N and NO-N emissions from spreading of sewage sludge, in Gg/year.
- $[E_{NH_3-N} + E_{NO-N}]_{Comp}$: NH₃-N and NO-N emissions from spreading of compost, in Gg/year.
- $[E_{NH_3-N} + E_{NO-N}]_{DEC}$: NH₃-N and NO-N emissions from spreading of digestate originating from energy crops and other waste, in Gg/year.
- $[E_{NH_3-N} + E_{NO-N}]_{graz}$: NH₃-N and NO-N emissions from grazing, Gg/year.
- $EF_{N_2O-N \text{ indirect soil}}$: Default IPCC N₂O-N emission factor for indirect emissions from deposition (i.e. (0.01 (IPCC 2006b)), expressed in kg N₂O-N/kg N
- 44/28 : Conversion factor from kg N₂O-N to kg N₂O

And consequently the fraction of synthetic fertilizer N ($Frac_{GASF}$) that volatilizes as NH₃ and NO_x, was calculated by using the following formula:

$$Frac_{GASF} = \frac{[E_{NH_3-N} + E_{NO-N}]_{fert}}{F_{SN}}$$

Where:

- F_{SN} : annual amount of synthetic fertilizer N applied to soil, in Gg/year

Also is the fraction of applied organic N fertilizer materials and of urine and dung N deposited by grazing animals ($Frac_{GASM}$) that volatiles as NH₃ and NO_x, calculated by using the following formula:

$$Frac_{GASM} = \frac{[E_{NH_3-N} + E_{NO-N}]_{SAM} + [E_{NH_3-N} + E_{NO-N}]_{SSS} + [E_{NH_3-N} + E_{NO-N}]_{Comp} + [E_{NH_3-N} + E_{NO-N}]_{DEC} + [E_{NH_3-N} + E_{NO-N}]_{graz}}{(F_{ON} + F_{PRP})}$$

Where:

- F_{ON} : annual amount of managed animal manure, including digestate originating from animal manure, of sewage sludge, of compost and of digestate originating from energy crops and other waste, all organic N additions applied to soils, in Gg/year
- F_{PRP} : annual amount of urine and dung N deposited by grazing animals on pasture, in Gg/year

For nitrogen from synthetic fertilizers, from organic fertilizers, from urine and dung deposited by grazing animals, from crop residues and from mineralization that were lost through leaching and run-off, N₂O emissions had been estimated using equation 11.10 – IPCC 2006 GLs:

$$N_2O_L = \{[(F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) * Frac_{LEACH}] * EF_5\} * \left(\frac{44}{28}\right)$$

with:

F _{SN}	= annual amount of synthetic fertilizer N applied to soils, kg N per year, see Table 5-32
F _{ON}	= annual amount of animal manure, including digestate originating from animal manure, sewage sludge, compost and digestate originating from energy crops and other waste, all organic N additions applied to soils, kg per year, see Table 5-32 and for the calculations see also section 5.6.3.1.2
F _{PRP}	= annual amount of urine and dung deposited by grazing animals on pasture, kg N per year, see Table 5-32
F _{CR}	= annual amount of N in crop residues, including N-fixing crops and from forage/pasture renewal, returned to soils, kg N per year, see Table 5-32.
F _{SOM}	= annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N per year, see Table 5-32
Frac _{LEACH}	= fraction of synthetic fertiliser N that volatilises as NH ₃ and NO _x , kg N volatilised. The default value from Table 11.3 from the 2006 IPCC guidelines (IPCC 2006b), i.e. 0.3 was used.
EF ₅	= emission factor for N ₂ O emissions from atmospheric deposition of N on soils and water surfaces, kg N ₂ O-N. For the emissions calculations the default values provided in Table 11.3 in the 2006 IPCC guidelines (IPCC 2006b), namely 0.0075 was used.
44/28	= conversion of N ₂ O-N _(mm) emissions to N ₂ O _(mm) emissions.

5.6.4 Category-specific recalculations including changes made in response to the review process

- The adapted manure management system, the revised assumption w.r.t. natural crust of cattle slurry stored in open tanks, the updated N_{ex} for suckler cows and the revised N-flows for the manure management affecting the quantities of animal manure applied to soil, as well as the urine and dung deposited by grazing animals.
- The quantities of animal manure applied to soil was further impacted by the error correction in Step 7; the fact that in step 11 the digestate created by the anaerobic digestion of manure, which is returned from 5.B.2, added and hence impacting the N in animal manure applied to soil. Furthermore, the annual amount of animal manure N applied to soils (kg N per year) were revised as erroneously the mass returned to soil was used rather than the mass applied to soil. All factors that impact the direct and indirect N₂O emissions from soil.
- Digestate originating from energy crops and other waste was added as an additional source of organic N additions to soil in this year inventories, impacting the different N emissions, and hence direct and indirect N₂O emissions.

- The NH₃ emissions originating from synthetic N-fertilizer, were derived using a Tier 2 methodology (used to be Tier 1) with consequently lower NH₃ emissions, and hence also lower indirect N₂O emissions occurring after atmospheric depositions of nitrogen compounds from this source:
- The NH₃-N EF emissions for slurry application with trailing shoe were revised, and impacting indirect N₂O emissions.
- The provisional activity data for sewage sludge for the year 2018 were replaced by published data.

Full details are provided in Annex 3:A, including the recalculations itself.

5.6.5 Category specific uncertainty

A detailed description of the assumed uncertainties for activity data such as crop data, crop harvest, synthetic fertilizer, sludge sewage, animal manure, compost and digestate originated from energy crops and other waste for the used emission factors is provided in Annex 3:B.

5.6.6 Category-specific QA/QC and verification

Consistency and completeness checks have been performed directly while building and calculating GHG emissions from the agriculture sector.

The plausibility of the estimates, as well as the calculation methods, were discussed and developed by the sector experts in the country.

5.6.7 Planned improvement

An update of the manure management system using data collected in the 2020 agriculture census is planned for the following submissions.

The data availability on energy crops in the earlier years is rather scarce, and used quantities are probably an underestimation. Alternative data sources will be investigated.

Furthermore, in the next submission the EF for grazing will be update to the 2019 EMEP/EEA guidelines.

As the area cultivated by Luxemburgish farmers, i.e. the area derived from the agriculture census, is - in particularly in recent years – overestimating the agriculture area in Luxemburg (in 2018, 7% of the land cultivated by Luxemburgish farmers were situated in neighbouring countries, in total 8651 ha, versus only 342 ha land that was situated in Luxemburg and cultivated by neighbouring farmers (Jean-Paul Didier; SER – Division des paiements directs)), alternative data sources are currently investigated, and adaptations are planned for the submission 2022.

Further, with the publication of new IPCC guidelines and/or emissions factors will the necessary changes, where appropriated, be incorporated.

5.7 Prescribed Burning of Savannahs (IPCC Source Category 3.E)

This source category does not exist in Luxembourg.

5.8 Field Burning of Agricultural Residues (IPCC Source Category 3.F)

Article 14, indent 2 of the Law of August, 11 1982 concerning the protection of nature and natural resources (Climat & Environnement, 1982), later abrogated by (Climat & Environnement, 2004) (Climat & Environnement, 2018) forbids clearing and burning (in French “essartement”) of fields, meadows, grasslands, roadsides, forests between the 1st of March and the 30th of September. According to this law, the clearing and burning of agricultural residues (such as straw) is not strictly forbidden. However, for economic reasons (residues can be used as litter, as feeding stuff for animals or can be sold), field burning is not practiced in Luxembourg and, therefore, emission estimates have been recorded as not occurring (notation key NO) in the inventory.

5.9 Emissions from Liming (IPCC source Category 3G)

This section describes the estimation of carbon dioxide emissions resulting from liming in agricultural soils. Liming is used to reduce soil acidity and improve plant growth in managed systems, particularly agricultural lands and managed forests. In 2019, this source category was responsible for 1.5% of the total GHG emissions from the agriculture sector and represented 0.10% of the total GHG emissions in CO₂eq (excluding LULUCF).

5.9.1 Source category description

This category consists of emissions resulting from the agricultural use of dolomite and limestone.

Thomas slag as fertilizer was commonly used in Luxembourg until the eighties/ninties, but with the closing of blast furnaces and the re-structuration of the iron industry in Luxembourg, local Thomas slag got scarce, and farmers had to looked for other types of liming fertilizers. Hence the use of lime has significantly increased over time, see Table 5-37. Note that in 2016 there is a small drop in the use of lime. This drop was related to the weather conditions, hampering the application of lime.

In previous year more than 95% of the applied lime was dolomite (Turmes 2018). For simplification reason it was therefore assumed that 100% of the lime would be dolomite and the application of limestone would be zero, hence the notification of “NO” in the CRF table. However, in 2018, a larger quantity of limestone was sold, why since 2018 both dolomite and limestone are considered separately.

Table 5-37 - CO₂ emission trends for IPCC Category 3G – Liming: 1990-2019 (Gg)

3 - Agriculture Sector CO ₂ emissions (Gg)			
Year	3G - Liming		
	total	lime	Dolomite
1990	0.26	NO	0.26
1991	0.46	NO	0.46
1992	0.66	NO	0.66
1993	1.02	NO	1.02
1994	1.49	NO	1.49
1995	1.22	NO	1.22
1996	1.07	NO	1.07
1997	1.59	NO	1.59
1998	2.19	NO	2.19
1999	1.22	NO	1.22
2000	2.04	NO	2.04
2001	2.48	NO	2.48
2002	3.15	NO	3.15
2003	3.05	NO	3.05
2004	2.62	NO	2.62
2005	4.23	NO	4.23
2006	3.30	NO	3.30
2007	3.34	NO	3.34
2008	3.10	NO	3.10
2009	4.41	NO	4.41
2010	3.81	NO	3.81
2011	5.29	NO	5.29
2012	5.48	NO	5.48
2013	6.29	NO	6.29
2014	6.95	NO	6.95
2015	7.36	NO	7.36
2016	6.99	NO	6.99
2017	8.80	NO	8.80
2018	10.31	0.66	10.31
2019	10.38	0.55	9.83
Trend 1990 -2019	3960%		3745%
Trend 2018 -2019	1%	-17%	-5%

Sources: SER.

5.9.2 Methodological issues

Tier 1 method has been used to estimate the emissions resulting from liming.

5.9.2.1 Activity data

Activity data for this emission sources are data on lime usage, limestone and dolomite. Table 5-38 shows the activity data used for the emission estimations.

According to Turmes (2018), director of Versis S.A. Luxemburg, more than 95% of the lime used in Luxemburg used to be dolomite. A fact that was confirmed by the data collected by the Luxemburg partner within the LTBN (Karl Weckbecker, Service d'Economie Rurale, Luxemburg; personal communication; October 2018). For simplification reason it was therefore assumed that up to 2017 100% would be dolomite. However, in 2018, a larger quantity of limestone was sold, why since 2018 both dolomite and limestone are considered separately.

There was up to 2012 one main seller for lime in Luxemburg. Since then there are two major lime sellers in Luxemburg (Turmes 2018, (Hess, November 2019), (Palzkill K., November 2019). In 2013 these two main sellers were responsible for approximately 100% of all lime selling's in Luxemburg, but their market share has decreased since then to roughly 80% in 2018 and in-2019 (Hess, November 2019), (Palzkill K., November 2019).

Selling statistics, collected by Marc Weyland, Administration des Services Techniques de l'Agriculture (ASTA), Luxemburg, were available from 1993-2013. Having no data for the years 1990-1992, a trend estimation was conducted based on the 1993-2003 data. For the years 2014-2019 own investigations at the Service d'Economie Rurale took place (Turmes 2018, (Hess, November 2019) Palzkill 2019). For the years 2013-2019, selling numbers collected from the two main suppliers were extrapolated to cover the whole country, assuming a linear decrease of their market share between 2013 (100% market share) up to 2018 (80% market share).

Table 5-38 shows the activity data used for the emission estimations.

Table 5-38 - Activity data (t) for IPCC Category 3G Liming: 1990-2019

3 - Agriculture		
Activity data - 3G Liming (in tonnes/year)		
Year	Lime	Dolomite
1990	NO	536
1991	NO	959
1992	NO	1 381
1993	NO	2 150
1994	NO	3 120
1995	NO	2 550
1996	NO	2 250
1997	NO	3 330
1998	NO	4 595
1999	NO	2 560
2000	NO	4 290
2001	NO	5 200
2002	NO	6 600
2003	NO	6 400
2004	NO	5 500
2005	NO	8 880
2006	NO	6 930
2007	NO	7 000
2008	NO	6 500
2009	NO	9 260
2010	NO	8 000
2011	NO	11 100
2012	NO	11 500
2013	NO	13 200
2014	NO	14 583
2015	NO	15 435
2016	NO	14 659
2017	NO	18 452
2018	1 500	21 625
2019	1 250	20 625

Sources: 1990-1992: Trend estimations; 1993-2013: ASTA (Marc Weyland); 2014-2017: (Turmes 2018) ; 2018-2019 (Hess, November 2019), Palzkill 2019).

5.9.2.2 Emission factors

An IPCC Tier 1 method was used for estimating CO₂ emissions from liming.

CO₂ emissions from liming in tonnes per year were calculated according to equation 11.12 see equation (IPCC 2006b):

$$CO_2 \text{ Emissions} = [(M_{Dolomite} * EF_{Dolomite}) + (M_{Limestone} * EF_{Limestone})] * \left(\frac{44}{12}\right)$$

with,

$M_{Dolomite}$ = the annual amount of dolomite (in tonnes per year).

$EF_{Dolomite}$ = emission factor, the 2006 IPCC default emissions factor for dolomite ($EF_{Dolomite}$), i.e. 0.13 (IPCC 2006b) was used.

$M_{Limestone}$ = the annual amount of limestone (in tonnes per year).

$EF_{Limestone}$ = emission factor, the 2006 IPCC default emissions factor for limestone ($EF_{Limestone}$), i.e. 0.12 (IPCC 2006b) was used.

44/12 = conversion of CO₂-C emissions to CO₂ emissions.

Note, limestone was assumed not to occur in Luxembourg for the years 1990-2017.

5.9.3 Category-specific recalculations including changes made in response to the review process

The 2018 liming data were updated; full details are provided in Annex 3:A, including the recalculations itself.

5.9.4 Category specific uncertainty

A detailed description of the assumed uncertainties for activity data and for the used emission factors is provided in Annex 3:B.

5.9.5 Category-specific QA/QC and verification

Consistency and completeness checks have been performed directly while building and calculating GHG emissions from the agriculture sector.

The plausibility of the estimates, as well as the calculation methods, were discussed and developed by the sector experts in the country.

5.9.6 Planned improvement

With the publication of new IPCC guidelines and/or emissions factors will the necessary changes, where appropriated, be incorporated.

5.10 Emissions from urea application (IPCC Source Category 3H)

This section describes the estimation of carbon dioxide emissions resulting from urea application in agricultural soils. The use of urea as a synthetic N fertilizer was never a common practice in Luxembourg. In 2019, this source category was responsible for <0.00001% of the total GHG emissions from the agriculture sector.

5.10.1 Source category description

This category consists of emissions resulting from the urea application in agricultural managed soils; CO₂ emissions. The use of urea as a synthetic N fertilizer was never a common practice in Luxembourg. Now-a-days just a handvoll of farmers were using urea; and often just for certain crops, respectively treatments use urea as synthetic N fertilizer, see Table 5-39.

Table 5-39 - CO₂ emission trends and activity data for IPCC Category 3H – Urea application: 1990-2019 (Gg)

3 - Agriculture Sector CO ₂ emissions (Gg) and Activity data (tonnes utilized urea/year)		
Year	3H - Urea application	
	CO ₂ Emissions	Utilized urea (tonnes/year)
1990	0.0000	-
1991	0.0000	-
1992	0.0000	-
1993	0.0000	-
1994	0.0000	-
1995	0.0000	-
1996	0.0000	-
1997	0.0000	-
1998	0.0000	-
1999	0.0000	-
2000	0.0000	-
2001	0.0000	-
2002	0.0000	-
2003	0.0000	-
2004	0.0000	-
2005	0.0004	590.37
2006	0.0004	582.73
2007	0.0004	553.37
2008	0.0004	553.30
2009	0.0004	556.62
2010	0.0004	524.93
2011	0.0004	499.36
2012	0.0003	424.32
2013	0.0003	366.79
2014	0.0002	302.81
2015	0.0002	263.29
2016	0.0002	228.38
2017	0.0001	177.32
2018	0.0001	123.26
2019	0.0001	80.66
Trend 1990 -2019		
Trend 2018 -2019	-35%	-35%

Sources: SER.

5.10.2 Methodological issues

Tier 1 method has been used to estimate the emissions from the urea application.

5.10.2.1 Activity data

Activity data for this emission sources are data on the utilization of urea. Table 5-39 shows the activity data used for the emission estimations.

The national utilisation of kg N used on agriculture surface (see section 5.6.3.1.1) was the basis for the estimation of the national utilisation of urea. In a first step was the national utilisation of kg N obtained by multiplying the weighted average kg N per ha used agriculture surface (STATEC, 2020b) by the used agriculture surface (STATEC, 2020). In a second step were the estimated utilized N redistributed over the different fertilizer in questions, including urea and CAN. The allocation of fertiliser types was based on the consumption of the farmers within the Luxembourgish “landwirtschaftliche Testbetriebsnetz” (LTBN). Since 2000 nearly every year, price statistics had been published on the used fertiliser types, presuming that at least 8 farmers had used them, and that total consumption was minimum 10,000 kg, if solid fertilizer, respectively 25 hl, if liquid fertilizer. Together with the price, was also the quantities published on which prices had been based (i.e. the quantities used by LTBN farmers). (Brücher & Jacqué, Preisstatistik, 2010) (Brücher & Jacqué, Preisstatistik, 2011) (Brücher & Jacqué, Preisstatistik, 2012) (Conter, Preisstatistik 2000, 2001) (Conter, 2002) (Conter, 2003) (Conter, 2004) (Conter, 2005) (Conter, 2006) (Conter, 2007) (Hermes C., Preisstatistik 2007, 2008) (Hermes C., 2009) (Majerus, Preisstatistik 2016, 2017) (Majerus, 2018; Majerus, 2019) There were no data for the years 1990-1999. But according to field experts¹¹⁸ was the distribution of the used synthetic N-fertilizer similar to the one observed for the years 2000-2004, why assuming the same distribution for the years 1990-1999 as observed in 2000-2004. Given that prices are driving annual sales, multiannual sales data were considered to be more appropriate for the allocation of fertilizer type. The years chosen were 2000-2004, 2005-2009, 2010-2012 and 2016-2018. No information was available for the years 2013-2015, why using as proxy for the years 2013 and 2014 the 2010-2012 multiannual sales data and for the year 2015, the 2016-2018 multiannual sales data. For the year 2019, information from all LTBN farmers were used, and the allocation was derived directly from the LTBN database (Karl Weckbecker and Paul Jacqué, SER, Division de la gestion, de la comptabilité et de l'entraide agricoles, personal communication 24-11-2020). But given that urea utilisation is rather seldom in Luxembourg, and therefore showed only up in the period 2005-2009, and again in the 2019, an interpolation was made for the years 2010-2018 presuming a linear decrease from 1.9% in 2005-2009 to 0.3% in 2019. This correction was applied on the costs of the allocation of CAN, the major synthetic N-fertilizer used in Luxembourg. The amount of N was scaled to the total N use of inorganic fertiliser in Luxembourg. The quantities of utilized urea in kg, were derived by dividing the so-obtained national utilisation of kg N originating from urea by 46%, i.e. the assumed percentage of N per kg N-fertilizer. (<https://de.eurochemagro.com/produkte/stickstoff-einzel-duenger/harnstoff/>) and are summarized in Table 5-39.

¹¹⁸ Karl Weckbecker and Paul Jacqué, SER, Division de la gestion, de la comptabilité et de l'entraide agricoles; Simone Marx; ASTA, Service de pédologie; personal communications; July 2020

5.10.2.2 Emission factors

An IPCC Tier 1 method was used for estimating CO₂ emissions from the urea application.

CO₂ emissions from urea utilization in tonnes per year were calculated according to equation 11.13 see equation (IPCC 2006b):

$$CO_2 \text{ Emissions} = [(M_{Urea} * EF_{Urea})] * \left(\frac{44}{12}\right)$$

with,

M_{Urea} = the annual amount of urea fertilisation (in tonnes fertilizer per year).

EF_{Urea} = emission factor, the 2006 IPCC default emissions factor for urea (EF_{Urea}), i.e. 0.2 (IPCC 2006b) was used.

44/12 = conversion of CO₂-C emissions to CO₂ emissions.

5.10.3 Category-specific recalculations including changes made in response to the review process

No recalculations, as the first time considered in the inventory.

5.10.4 Category specific uncertainty

A detailed description of the assumed uncertainties for activity data and for the used emission factors is provided in Annex 3:B.

5.10.5 Category-specific QA/QC and verification

Consistency and completeness checks have been performed directly while building and calculating GHG emissions from the agriculture sector.

The plausibility of the estimates, as well as the calculation methods, were discussed and developed by the sector experts in the country.

5.10.6 Planned improvement

With the publication of new IPCC guidelines and/or emissions factors will the necessary changes, where appropriated, be incorporated.

5.11 Other carbon containing fertilizer (IPCC Source Category 3I)

This section describes the estimation of carbon dioxide emissions resulting from the application of carbon-containing fertilizers on agricultural soils. Calcium ammonium nitrate (CAN) is the most common synthetic N fertilizer used in Luxembourg. In 2019, this source category was responsible for 0.6% of the total GHG emissions from the agriculture sector and represented 0.04% of the total GHG emissions in CO₂eq (excluding LULUCF)..

5.11.1 Source category description

This category consists of emissions resulting from the use of carbon-containing fertilizer on agricultural managed soils.

Synthetic N fertilizer, and hence also the use of CAN, is showing a decreasing trend over the years, see Table 5-40.

Table 5-40 - CO₂ emission trends and activity data for IPCC Category 3H – Carbon-containing fertilizer: 1990-2019 (Gg)

3 - Agriculture Sector CO ₂ emissions (Gg) and Activity data (tonnes CaCO ₃ /year)		
Year	3I - Carbon-containing fertilizer	
	CO ₂ Emissions	Calcium ammonium nitrate (tonnes CaCO ₃ / year)
1990	6.04	13 722
1991	6.29	14 298
1992	6.79	15 428
1993	6.19	14 075
1994	5.88	13 362
1995	5.77	13 111
1996	5.75	13 066
1997	5.66	12 867
1998	5.55	12 619
1999	5.73	13 012
2000	5.67	12 876
2001	4.83	10 979
2002	5.04	11 446
2003	4.10	9 329
2004	5.21	11 833
2005	4.27	9 709
2006	4.22	9 584
2007	4.00	9 101
2008	4.00	9 100
2009	4.03	9 154
2010	4.01	9 104
2011	4.22	9 580
2012	4.01	9 103
2013	3.92	8 919
2014	3.74	8 492
2015	3.89	8 842
2016	4.17	9 483
2017	4.13	9 384
2018	3.85	8 747
2019	4.17	9 476
Trend 1990-2019		
Trend 2018-2019	8%	8%

Source: SER

5.11.2 Methodological issues

Tier 1 method has been used to estimate the emissions resulting from liming.

5.11.2.1 Activity data

The national utilisation of kg N used on agriculture surface (see section 5.6.3.1.1) was the basis for the estimation of the national utilisation of calcium ammonium nitrate (CAN). In a first step was the national utilisation of kg N obtained by multiplying the weighted average kg N per ha used agriculture surface (STATEC, 2020b) by the used agriculture surface (STATEC, 2020). In a second step were the estimated utilized N redistributed over the different fertilizer in questions, including CAN. The allocation of fertiliser types was based on the consumption of the farmers within the Luxemburgish "landwirtschaftliche Testbestriebsnetz" (LTBN). Since 2000 nearly every year, price statistics had been published on the used fertiliser types, presuming that at least 8 farmers had used them, and that total consumption was minimum 10,000 kg, if solid fertilizer, respectively 25 hl, if liquid fertilizer. Together with the price, was also the quantities published on which prices had been based (i.e. the quantities used by LTBN farmers). (Brücher & Jacqué, Preisstatistik, 2010) (Brücher & Jacqué, Preisstatistik, 2011) (Brücher & Jacqué, Preisstatistik, 2012) (Conter, Preisstatistik 2000, 2001) (Conter, 2002) (Conter, 2003) (Conter, 2004) (Conter, 2005) (Conter, 2006) (Conter, 2007) (Hermes C., Preisstatistik 2007, 2008) (Hermes C., 2009) (Majerus, Preisstatistik 2016, 2017) (Majerus, 2018; Majerus, 2019) There were no data for the years 1990-1999. But according to field experts¹¹⁹ was the distribution of the used synthetic N-fertilizer similar to the one observed for the years 2000-2004, why assuming the same distribution for the years 1990-1999 as observed in 2000-2004. Given that prices are driving annual sales, multiannual sales data were considered to be more appropriate for the allocation of fertilizer type. The years chosen were 2000-2004, 2005-2009, 2010-2012 and 2016-2018. No information was available for the years 2013-2015, why using as proxy for the years 2013 and 2014 the 2010-2012 multiannual sales data and for the year 2015, the 2016-2018 multiannual sales data. For the year 2019, information from all LTBN farmers were used, and the allocation was derived directly from the LTBN database (Karl Weckbecker and Paul Jacqué, SER, Division de la gestion, de la comptabilité et de l'entraide agricoles, personal communication 24-11-2020). But given that urea utilisation is rather seldom in Luxembourg, and therefore showed only up in the period 2005-2009, and again in the 2019, an interpolation was made for the years 2010-2018 presuming a linear decrease from 1.9% in 2005-2009 to 0.3% in 2019. This correction was applied on the costs of the allocation of CAN, the major synthetic N-fertilizer used in Luxembourg. The amount of N was scaled to the total N use of inorganic fertiliser in Luxembourg.

The quantities of utilized CAN in kg CaCO₃ were derived by dividing the national utilisation of kg N originating from CAN first by 27%, i.e. the percentage of N per kg N-fertilizer, (https://de.eurochemagro.com/uploads/PDS_27N-weiss_KAS_5572_ANT_Deutschland.pdf#zoom=FitV) and in a second step by 21.48%. The majority of applied CAN has a content of 12% CaO, (https://de.eurochemagro.com/uploads/PDS_27N-weiss_KAS_5572_ANT_Deutschland.pdf#zoom=FitV) which is equivalent to 21.48 % CaCO₃. Due to a lack of data, it was assumed that 100% of the carbon in CAN is presented as CaCO₃. Table 5-40 shows the quantities of utilized CAN in tonnes CaCO₃.

¹¹⁹ Karl Weckbecker and Paul Jacqué, SER, Division de la gestion, de la comptabilité et de l'entraide agricoles; Simone Marx; ASTA, Service de pédologie; personal communications; July 2020

5.11.2.2 Emission factors

An IPCC Tier 1 method was used for estimating CO₂ emissions from carbon-containing fertilizer, i.e. CAN.

CO₂ emissions from the quantities of utilized CAN in tonnes CaCO₃, per year were calculated according to equation 11.12 see equation (IPCC 2006b):

$$CO_2 \text{ Emissions} = [(M_{CAN_CaCO_3} * EF_{Limestone})] * \left(\frac{44}{12}\right)$$

with,

$M_{CAN_CaCO_3}$ = the annual amount of utilized CAN (in tonnes CaCO₃ per year).

$EF_{Limestone}$ = emission factor, the 2006 IPCC default emissions factor for limestone ($EF_{Limestone}$), i.e. 0.12 (IPCC 2006b) was used.

44/12 = conversion of CO₂-C emissions to CO₂ emissions.

Note: The current estimations might be an overestimation, as due to a lack of data, it is unclear if 100% of the carbon in CAN is presented as CaCO₃.

5.11.3 Category-specific recalculations including changes made in response to the review process

No recalculations, as the first time considered in the inventory.

5.11.4 Category specific uncertainty

A detailed description of the assumed uncertainties for activity data and for the used emission factors is provided in Annex 3:B.

5.11.5 Category-specific QA/QC and verification

Consistency and completeness checks have been performed directly while building and calculating GHG emissions from the agriculture sector.

The plausibility of the estimates, as well as the calculation methods, were discussed and developed by the sector experts in the country.

5.11.6 Planned improvement

Looking for additional information/data source allowing to eventually confirm, respectively to revise, if not applicable, the assumption that 100% of CAN would be presented as CaCO₃.

With the publication of new IPCC guidelines and/or emissions factors will the necessary changes, where appropriated, be incorporated.

5.12 Others (IPCC Source Category 3J)

This source categorie are not used in Luxembourg's GHG inventory.

5.13 Uncertainty assessment

Uncertainty assessment for GHG emissions from agriculture is calculated using Monte Carlo techniques. The model is built in MS Excel using the add-in software Palisade @Risk 7.5. A probability distribution is chosen for most parameters to manage uncertainty, whereby using mostly either a Pert-distribution or a uniform distribution, depending on which distribution fits best. A detailed description of the assumed uncertainties for the different activity data and for the used emission factors is provided in Annex 3:B.

A value is drawn from such distributions iteratively using Latin Hypercube sampling with 10,000 iterations. The 95% uncertainty interval (95% UI), corresponding to the 2.5th and 97.5th percentiles of the results' distribution is computed to define the uncertainty for the agriculture sector as a whole, and for the separate CRF categories.

6 Land Use, Land-Use Change and Forestry (CRF sector 4)

Chapter 6 includes information on and description of methodologies used for estimating GHG emissions as well as references to activity data and emission factors reported under CRF Sector 4 – Land Use, Land-use Change and Forestry – *i.e.* LULUCF – for the period 1990 to 2019.

6.1 Sector Overview

In 2019, *Land Use, Land Use Change and Forestry* was a net sink in Luxembourg (

Table 6-1). Net removals from the LULUCF sector amounted to 312.39 Gg CO₂e. Since 1990, net emissions have decreased by -468.22% per cent (the sector was a source of net emissions in 1990 (84.84 Gg CO₂e) and a source of net removals in 2019). The key driver for the fall in emissions is the ongoing increase in net removals in forest land remaining forest land following the recovery from the major disturbance events in the early 1990s. Within the sectors, forest land and grassland resulted in net removals (-376.43 Gg CO₂e and -39.76 Gg CO₂e, respectively). All other categories resulted in net emissions: the largest source of emissions was from settlements (56.91 Gg CO₂e), followed by cropland (34.85 Gg CO₂e), wetlands (3.61 Gg CO₂e) and other land (0.10 Gg CO₂e).

Table 6-1 - Emissions and Removals from CRF category 4 - LULUCF

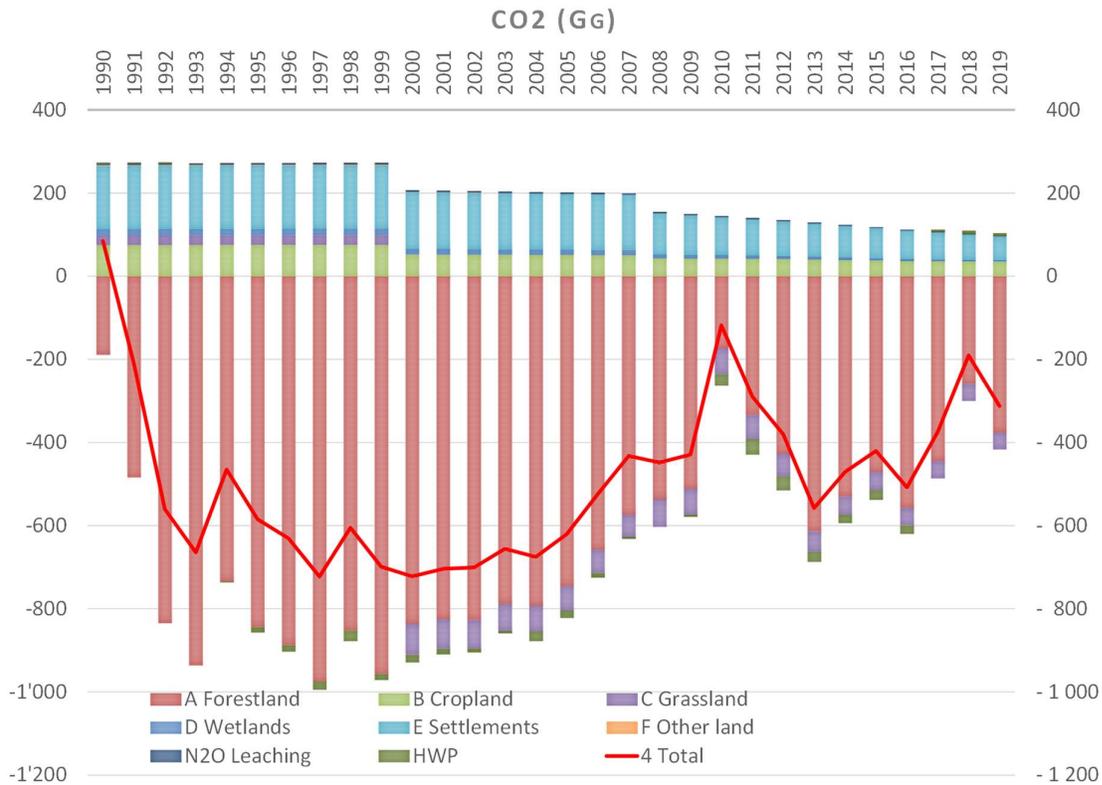
4 - Land Use, Land Use Change & Forestry									
Greenhouse gas emissions/removals (Gg CO₂ e)									
Year	4 Total	A Forestland	B Cropland	C Grassland	D Wetlands	E Settlements	F Other land	N₂O Leaching	HWP
1990	84.84	-188.74	75.03	22.52	15.90	152.40	1.70	3.92	2.11
1991	-210.46	-484.05	75.06	22.61	15.90	152.43	1.70	3.92	1.97
1992	-560.70	-834.68	75.08	22.71	15.91	152.46	1.70	3.92	2.21
1993	-664.50	-935.97	75.11	22.80	15.91	152.49	1.70	3.92	-0.45
1994	-464.70	-734.54	75.13	22.89	15.91	152.52	1.70	3.92	-2.23
1995	-584.58	-844.37	75.16	22.99	15.91	152.55	1.70	3.92	-12.44
1996	-630.55	-887.46	75.18	23.08	15.92	152.58	1.70	3.92	-15.46
1997	-722.39	-975.62	75.21	23.17	15.92	152.61	1.70	3.92	-19.29
1998	-605.17	-852.57	75.24	23.26	15.92	152.64	1.70	3.92	-25.27
1999	-699.02	-956.68	75.26	23.35	15.93	152.67	1.70	3.92	-15.17
2000	-722.13	-836.22	52.02	-74.27	13.71	136.19	0.98	3.86	-18.40
2001	-704.15	-824.74	51.84	-71.21	13.59	135.56	0.94	3.80	-13.92
2002	-700.78	-827.16	51.66	-68.15	13.47	134.92	0.90	3.74	-10.16
2003	-655.60	-788.09	51.49	-65.10	13.35	134.28	0.86	3.68	-6.08
2004	-675.41	-792.85	51.31	-62.04	13.23	133.64	0.83	3.63	-23.16
2005	-620.65	-745.58	51.13	-58.98	13.11	133.01	0.79	3.57	-17.69
2006	-524.51	-658.30	50.96	-55.92	12.99	132.37	0.75	3.51	-10.86
2007	-432.36	-574.18	50.78	-52.87	12.87	131.73	0.71	3.45	-4.86
2008	-448.01	-536.53	42.86	-66.38	9.78	97.94	0.60	3.32	0.42
2009	-429.10	-511.35	42.34	-62.50	9.22	94.39	0.55	3.19	-4.94
2010	-118.08	-173.35	42.38	-62.62	8.65	90.23	0.51	3.07	-26.95
2011	-289.53	-333.76	41.75	-58.69	8.09	86.53	0.46	2.94	-36.85
2012	-380.31	-426.98	41.40	-53.70	7.53	82.83	0.42	2.81	-34.62
2013	-557.83	-613.54	40.10	-49.37	6.97	79.12	0.37	2.68	-24.16
2014	-470.84	-529.50	38.88	-44.07	6.41	75.42	0.33	2.54	-20.84
2015	-420.10	-470.49	37.72	-43.79	5.85	71.72	0.28	2.39	-23.78
2016	-507.87	-557.50	36.30	-41.66	5.29	68.02	0.24	2.25	-20.81
2017	-374.74	-444.82	36.19	-41.87	4.73	64.31	0.19	2.12	4.41
2018	-190.42	-259.27	35.52	-40.79	4.17	60.61	0.15	1.98	7.21
2019	-312.39	-376.43	34.85	-39.72	3.61	56.91	0.10	1.85	6.44
Trend 1990-2019	-468.22%	99.45%	-53.56%	-276.36%	-77.30%	-62.66%	-93.86%	-52.76%	205.33%
Trend 2018-2019	64.05%	45.19%	-1.89%	-2.64%	-13.43%	-6.11%	-30.02%	-6.70%	-10.76%

6.1.1 Emission Trends

In 2019, removals from category forest land corresponded to 2.99% of total GHG in Luxembourg (incl. LULUCF). The net removals have increased from the base year to 2019, mainly due to the fact that in 1990 forestland was less of a carbon sink due to the heavy windfall during the winter 1990/1991, but also due to an increase of the carbon stock in forest land in the years after (Figure 6-1).

The net carbon stock changes in forest biomass (sector 4.A.1) have a major impact on the overall results in sector 4. These changes vary considerable between single years mainly due to fluctuating harvest rates. The harvest rates in their turn are influenced by timber demand and prices, insect infestation or wind throws.

Figure 6-1 - Emissions and Removals from CRF category 4 - LULUCF



6.1.2 Key categories

The methodology and results of the key category analysis are presented in Chapter 1. Table 6-2 presents the key categories of category 4 - LULUCF.

Table 6-2 - Key categories of category 4 - LULUCF

4 - Land Use, Land-Use Change and Forestry						
Key sources						
IPCC Category	Category Name	GHG	LA excl. LULUCF	LA incl. LULUCF	TA excl. LULUCF	TA incl. LULUCF
4A1	Forest Land remaining Forest Land	CO ₂	NA	90-09, 11-19	NA	X
4A2	Land Converted to Forest Land	CO ₂	NA	90-17	NA	X
4B2	Land Converted to Crop Land	CO ₂	NA	95-99	NA	
4C2	Land Converted to Grassland	CO ₂ , N ₂ O	NA	00-03, 08-10	NA	
4E2	Land Converted to Settlements	CO ₂ , N ₂ O	NA	90-19	NA	X

Source: Environment Agency

Notes: LA = Level Assessment (Tier 1) including respectively excluding LULUCF
TA = Trend Assessment 2019 (Tier 1) including respectively excluding LULUCF

6.1.3 Methodology

The territory of Luxembourg has an area of 2 586 km². In 1990, 90.5% of that area was covered by agriculturally used areas and forests, 8.6% were covered by buildings and roads. The remaining areas were covered by water and other land (0.8%). In 2019, the respective areas were 89.4%, 10.0% and 0.6%. Thus, Luxembourg has some 96 203 ha of forests, some 134 904 ha of agriculturally used land, and some 26 207 ha covered by buildings and roads. Rivers, lakes, wetlands and other lands cover a surface of some 1 232 ha.

Meteorologically, Luxembourg is situated in an area with temperate maritime climate, with an annual average temperature of 9.8°C in Luxembourg-city (Statec, Average yearly temperature of Luxembourg - Table A2100, 2019) (year 2019), approximately.

6.1.3.1 Information on approaches used for representing land areas and on land use databases used for the inventory preparation

Before deciding which activity data would be used, an inventory of the available activity data sources for Luxembourg was made. Until 2009, the only datasets available in Luxembourg for different time periods and covering all the land uses in the whole country was the CORINE Land cover database. It is available for the reference year 1989 and has been updated in 2000 and 2007. Land-use and land-use change areas of submissions until 2009 were estimated on the basis of the CORINE Landcover database.

The base data used since submission 2010 under the UNFCCC as well as under the Kyoto Protocol is the so-called OBS map data "Occupation Biophysique du Sol". This is a detailed land use / land cover map in digital format covering the entire territory of Luxembourg. Three versions of the OBS map data set exist. The first OBS data set, the OBS89, was collected in the field over several years and published in 1989 by the Environment Ministry. The second data set for the year 1999, the OBS99, was collected based on aerial colour infra-red ortho-photos and some field surveying, the third set, covering the year 2007, is the OBS07, which is an update of the OBS99 using very high resolution satellite images (1m pixel size) of the US commercial Earth observation satellite IKONOS. The

latest dataset on land use in Luxembourg, covering the year 2012, is the LU12, which is based on satellite images from the RapidEye (RE) space segment, which is composed of five sun-synchronous Earth observation satellites providing large area, multi-spectral images with frequent revisits in high resolution (5m).

6.1.3.2 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories (e.g. land use and land-use change matrix)

The land use classification system used is in accordance with the 2006 IPCC Good Practice Guidance on LULUCF. The categories are defined as presented in Table 6-3.

The OBS categories – that are different for OBS89 and OBS99/07 – have been assigned to the LULUCF categories, as defined in Table 6-3, according to the following matching tables: Table 6-4 for OB89 to LULUCF and Table 6-5 for OBS99/07 to LULUCF.

Table 6-3 – LULUCF Nomenclature

Land Use Class	Definition
ForestLand	All forest and wooded land with: <ul style="list-style-type: none"> • Minimum land area: 0.05 ha • tree crown cover \geq 10 % • tree height \geq 5 m. <p>In the geodata set, Forest land has been sub-divided into the forest types as defined below.</p>
Conifers:	Including all forest land with > 10 % crown cover and on which more than 75 percent of the tree crown cover consists of coniferous species.
Deciduous:	Including all forest land with > 10 % crown cover and on which more than 75 percent of the tree crown cover consists of broadleaved species
Mixed (coniferous and deciduous):	with > 10 % crown cover and less than 75 % crown cover of one class.
Annual Cropland	Includes agro-forestry systems where tree cover falls below the level used in the forest categories (IPCC GPG definition) with the following specifications: land on which different crops are grown in a yearly changed rhythm including artificial meadows (not permanent) including land temporarily set aside
Permanent Cropland	Includes agro-forestry systems where tree cover falls below the level used in the forest categories (IPCC GPG definition) with the following specifications: land on which different crops are grown in a permanent manner, <i>i.e.</i> not changing in a yearly rhythm
Grassland	All grassland that is not considered as cropland including systems with vegetation or tree cover below the density used in the forest category. This includes all grassland from wild lands, recreational areas as well as agricultural systems. (IPCC GPG definition).
Settlements	All developed land, including transportation and any size of human settlement unless already included under other categories.(IPCC GPG definition)
Wetland	Land that is covered or saturated by water for all or part of the year (<i>e.g.</i> peat land) and that does not fall into other categories.
Water	Land that is covered by water for all the year and that does not fall into other categories. This includes reservoirs. (IPCC GPG definition)
Other land	This category includes bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.

Table 6-4 –OBS89 - LULUCF matching table

OBS89 Nomenclature (Part 1/3)						
Acronym	Code	Original in French	translated into German	LULUCF_v7	Forest Types_v7	Forest Areas_v7
P	31	forets	Wald			Forest Area
Pe	312	forets de coniferes	Nadelwald	Coniferous Forest	Coniferous Forest	Forest Area
Pm	3121	epiceas, sapins	Fichte, Tannen	Coniferous Forest	Coniferous Forest	Forest Area
Pr	3122	pins, mezeles	Kiefern, Lärchen	Coniferous Forest	Coniferous Forest	Forest Area
	3123	autres resineux	Other Land Nadelbaeume	Coniferous Forest	Coniferous Forest	Forest Area
F/Q	311	forets de feuillus	Laubwald	Deciduous Forest	Deciduous Forest	Forest Area
Qb	3111	forets acidophiles	Saure Wälder	Deciduous Forest	Deciduous Forest	Forest Area
Fs	31111	chenaie acidophile tres pauvre	artenarmer saurer Eichenwald	Deciduous Forest	Deciduous Forest	Forest Area
Qs	31112	hetraie et chenaie-hetraie acidophile	saurer Buchen und Eichen-Buchenwald	Deciduous Forest	Deciduous Forest	Forest Area
Fl	31113	chenaie acidophile	saurer Eichenwald	Deciduous Forest	Deciduous Forest	Forest Area
Ql	31114	hetraie a luzule blanche	Buchen mit weissen Luzernen	Deciduous Forest	Deciduous Forest	Forest Area
FF	31115	chenaie a luzule blanche	Eichenwald mit Luzernen	Deciduous Forest	Deciduous Forest	Forest Area
	31116	hetraie a grande fetuque	Buchenwald mit hohen Graesern	Deciduous Forest	Deciduous Forest	Forest Area
			besondere trockenheitsliebende Eichenart auf Schiefer und Sandstein	Deciduous Forest	Deciduous Forest	Forest Area
Qx	31117	chenaie a charmes xerophile sur schistes et gres	Sandstein	Deciduous Forest	Deciduous Forest	Forest Area
F/Q	3112	forets neutroclines a mull	Wälder auf neutralen Bodenverhältnissen	Deciduous Forest	Deciduous Forest	Forest Area
Fm	31121	hetraie a melique et asperule	Buchenwald mit irgendeinem bestimmten Unterwuchs	Deciduous Forest	Deciduous Forest	Forest Area
Qa	31122	chenaie a charmes humide	besondere Eichenart auf feuchten Standorten	Deciduous Forest	Deciduous Forest	Forest Area
Qm	31123	chenaie-charmaie a melique et asperule	besondere Eichenart mit irgendeinem Unterwuchs	Deciduous Forest	Deciduous Forest	Forest Area
F/Q	3113	forets basidines	Wälder auf basischen Bodenverhältnissen	Deciduous Forest	Deciduous Forest	Forest Area
FK	31131	hetraie calcicole	Buchenwald auf kalkhaltigem Substrat	Deciduous Forest	Deciduous Forest	Forest Area
Qk	31132	chenaie a charmes xerophile	trockenheitsliebende besondere Eichenart	Deciduous Forest	Deciduous Forest	Forest Area
R	3114	forets ruderales	Schuttwälder	Deciduous Forest	Deciduous Forest	Forest Area
Ru	31141	ormais ruderales	Ulmenwald in Aufschuettungen	Deciduous Forest	Deciduous Forest	Forest Area
P	3115	plantation de feuillus	Laubwald Anpflanzung	Deciduous Forest	Deciduous Forest	Forest Area
Ps	31151	peuplerie en site sec	Pappelwald in trockenen Gebieten	Deciduous Forest	Deciduous Forest	Forest Area
Ph	31152	peuplerie en site humide	Pappelwald in feuchten Gebieten	Deciduous Forest	Deciduous Forest	Forest Area
PF	31153	plantation d'autres essences feuillus	Anpflanzungen Other Landr Laubbäume	Deciduous Forest	Deciduous Forest	Forest Area
E	3116	forets de ravins	Schluchtwälder	Deciduous Forest	Deciduous Forest	Forest Area
Ek	31161	foret de ravin sur substrat calcaire	Schluchtwald auf kalkhaltigem Substrat	Deciduous Forest	Deciduous Forest	Forest Area
Es	31162	foret de ravin sur substrat siliceux	Schluchtwald auf silikatischem Substrat	Deciduous Forest	Deciduous Forest	Forest Area
V	3117	forets alluviaux sur sols mineraux	Auewald auf mineralischem Boden	Deciduous Forest	Deciduous Forest	Forest Area
Va	31171	ormais-frenaie alluviale	Ulmen-Eschenwald in Flusssedimenten	Deciduous Forest	Deciduous Forest	Forest Area
Vb	31172	aulnaie-frenaie alluviale mesotrophe	Erlen-Eschenwälder in Flusssedimenten	Deciduous Forest	Deciduous Forest	Forest Area
Vn	31173	aulnaie alluviale nitrophile	Erlenwälder in nitratreichen Flusssedimenten	Deciduous Forest	Deciduous Forest	Forest Area
Vc	31174	aulnaie-frenaie des sources et ruisseaux	Erlen-Eschenwälder in Quellgebieten und an Rinnsalen	Deciduous Forest	Deciduous Forest	Forest Area
V	3118	forets marecegeuses a sedimentation organique	Moorbruchwälder	Deciduous Forest	Deciduous Forest	Forest Area
Vm	31181	aulnaie mesotrophe a laiches	Erlenwälder mit Seggen	Deciduous Forest	Deciduous Forest	Forest Area
Vx	31182	boulaie marcegeuse	sumpfiger Birkenwald	Deciduous Forest	Deciduous Forest	Forest Area
S	323	vegetations sclerophylles	Holzartiges Gebüsch	Deciduous Forest	Deciduous Forest	Forest Area
	324	forets et vegetation arbustive en mutation	Wald und Gehölz im Übergang	Deciduous Forest	Deciduous Forest	Forest Area
	3241	fourres en sites secs	Wälder auf trockenen Standorten	Deciduous Forest	Deciduous Forest	Forest Area
Sp	32411	fourre d'epineux	dorniges Dickicht	Deciduous Forest	Deciduous Forest	Forest Area
Sk	32412	fourre calcaire	Dickicht auf kalkhaltigem Untergrund	Deciduous Forest	Deciduous Forest	Forest Area
Sx	32413	fourre de buis	Buchsbaumdickicht	Deciduous Forest	Deciduous Forest	Forest Area
Se	32414	vegetation des coupes forestiere	Vegetation der Waldrodungsflächen	Deciduous Forest	Deciduous Forest	Forest Area - no trees
Sz	32415	recrus divers	verschiedene Pionierpflanzen nach Rodung	Deciduous Forest	Deciduous Forest	Forest Area - no trees
	3242	fourres en sites humides	Wälder auf feuchten Standorten	Deciduous Forest	Deciduous Forest	Forest Area
So	32421	saualaie humide sur sol tourbeux ou acide	Weidenbäume auf einem feuchten, torfigen oder sauren Boden	Deciduous Forest	Deciduous Forest	Forest Area
Sf	32422	saualaie humide mesotrophe ou eutrophe	Weidenbäume auf einem feuchten, mittelmaessig oder gut mit Nährstoffen versorgten Boden	Deciduous Forest	Deciduous Forest	Forest Area
P	313	forets melanges	Mischwald	Mixed Forest	Mixed Forest	Forest Area
Pl	3131	par pied ou par bouquet	truppenweise Mischung (uebernomen aus 1999)	Mixed Forest	Mixed Forest	Forest Area
Pp	3132	par parcelle	Mischung in Parzellen	Mixed Forest	Mixed Forest	Forest Area
H	23	prairies	Wiesen	Grassland	Non-Forest Area	Non-Forest Area
	231	prairies permanentes	Dauerwiesen	Grassland	Non-Forest Area	Non-Forest Area
	2311	prairies semi-naturelles, humides et non-amendees	Halbnatürliche Wiesen	Grassland	Non-Forest Area	Non-Forest Area
Hc	23111	prairie humide peu ou non fertilisee	Feuchtwiese kaum oder nicht geduegt	Grassland	Non-Forest Area	Non-Forest Area
Hj	23112	prairie humide peu ou non fertilisee a joncs	Feuchtwiese kaum oder nicht geduegt mit Binsen	Grassland	Non-Forest Area	Non-Forest Area
Hf	23113	prairie humide a reine des pres	Feuchtwiese mit einem krautigen Rosaceengewachs	Grassland	Non-Forest Area	Non-Forest Area
Hm	23114	prairie humide non fertilisee a molinie	ungeduegte Feuchtwiese mit bestimmtem Suessgrasgewachs	Grassland	Non-Forest Area	Non-Forest Area
Hmo	231141	type oligotrophe	wenig Nährstoffe	Grassland	Non-Forest Area	Non-Forest Area
Hmm	231142	type mesotrophe	mittelmaessig Nährstoffe	Grassland	Non-Forest Area	Non-Forest Area
Hme	231143	type eutrophe	viel Nährstoffe	Grassland	Non-Forest Area	Non-Forest Area
Hu	2312	prairies mesophiles ameliores	mesophile Weidewiese	Grassland	Non-Forest Area	Non-Forest Area
Hua	23121	prairie mesophile de fauche	mesophile Mahdwiese	Grassland	Non-Forest Area	Non-Forest Area
Hup	23122	prairie mesophile de fauche atypique	untypische mesophile Mahdwiese	Grassland	Non-Forest Area	Non-Forest Area
Hpb	23123	pature a ray grass et trefle blanc	Futterpflanzen in breiten Streifen und Klee	Grassland	Non-Forest Area	Non-Forest Area
Hx	23124	prairie a flore tres pauvre	Wiesen mit geringer Biodiversitaet	Grassland	Non-Forest Area	Non-Forest Area
Hr	23125	prairie mesophile abandonnee a flore ruderales	aufgegebene mesophile Wiese mit Ruderalvegetation	Grassland	Non-Forest Area	Non-Forest Area
	32	milieux a vegetation arbustive et/ou herbacee	Gehölze und Buschwerk	Grassland	Non-Forest Area	Non-Forest Area
H	321	pelouses et paturages naturels	Naturnahe Weideflächen	Grassland	Non-Forest Area	Non-Forest Area
Ha	3211	pelouses silicicole a agrostis	Silikatrasen mit irgendeiner Viehfutterpflanze	Grassland	Non-Forest Area	Non-Forest Area
Hn	3212	pelouse silicicole a nard	Silikatrasen mit irgendeiner aromatischen Krautpflanze	Grassland	Non-Forest Area	Non-Forest Area
Hk	3213	pelouse calcaire	Kalkrasen	Grassland	Non-Forest Area	Non-Forest Area
Hkm	32131	sur marne	auf Mergel	Grassland	Non-Forest Area	Non-Forest Area
Hkx	32132	sur sol pierreux	auf steinreichem Boden	Grassland	Non-Forest Area	Non-Forest Area
Hks	32133	sur sol sableux	auf sandreichem Boden	Grassland	Non-Forest Area	Non-Forest Area
Hg	3214	pelouse pionniere des carrieres	Pionierassen in Steinbruechen	Grassland	Non-Forest Area	Non-Forest Area
Hz	3215	pelouse sur sol intoxique	Rasen auf giftigem (vielleicht schwermetallbelasteten) Gelaende	Grassland	Non-Forest Area	Non-Forest Area
C	322	landes et broussailles	Heide und Buschwerk	Grassland	Non-Forest Area	Non-Forest Area
Cg	3221	lande seche a callune	trockene Heide mit irgendeinem speziellen Heidekrautgewachs	Grassland	Non-Forest Area	Non-Forest Area
			Heidekrautgewachse mit Strauch mit widerstaendigen,			
Cj	3222	lande a callune genevrier	stacheligen Blaettern, der Beeren ausbildet	Grassland	Non-Forest Area	Non-Forest Area
Cd	3223	lande a callune degradee	degradierte Heide mit speziellem Heidekrautgewachs	Grassland	Non-Forest Area	Non-Forest Area
Cdm	32231	a dominance de molinie	mit Dominanz irgendeines Suessgrasgewachs	Grassland	Non-Forest Area	Non-Forest Area
Cdc	32232	a dominance de canche flexueuse	mit Dominanz einer flexiblen biegsamen Futterpflanze	Grassland	Non-Forest Area	Non-Forest Area
Cdf	32233	a dominance de fougere aigle	mit Dominanz eines bestimmten Farns	Grassland	Non-Forest Area	Non-Forest Area
Cv	3224	lande seche a myrtille	trockene Heide mit Heidelbeere	Grassland	Non-Forest Area	Non-Forest Area
Ct	3225	lande tourbeuse a myrtille	Torfheide mit Heidelbeere	Grassland	Non-Forest Area	Non-Forest Area
Cs	3226	lande a genets	Heide mit Ginster	Grassland	Non-Forest Area	Non-Forest Area

OBS89 Nomenclature (Part 2/3)

Acronym	Code	Original in French	translated into German	LULUCF_v7	Forest Types_v7	Forest Areas v7
B	21	terres arables	Ackerland	Cropland annual	Non-Forest Area	Non-Forest Area
Ba	211	terres arables hors perimetre d'irrigation	Ackerland, nicht bewässert	Cropland annual	Non-Forest Area	Non-Forest Area
Bp	2111	culture annuelle	jaehrlche Kulturen	Cropland annual	Non-Forest Area	Non-Forest Area
B	22	pepiniere	Baumschule	Cropland permanent	Non-Forest Area	Non-Forest Area
Bv	221	cultures permanentes	Dauerkulturen	Cropland permanent	Non-Forest Area	Non-Forest Area
Bvn	2211	vignobles	Weinberge	Cropland permanent	Non-Forest Area	Non-Forest Area
Bvt	2212	vignobles en pentes	Weinberge in Steillagen	Cropland permanent	Non-Forest Area	Non-Forest Area
Bve	2213	vignobles en terrasses	Weinberge in Terrassen	Cropland permanent	Non-Forest Area	Non-Forest Area
Bve	2213	vignobles en plaine	Weinberge in ebenen Gebieten	Cropland permanent	Non-Forest Area	Non-Forest Area
Be	222	verges et petits fruits	Streuobst und kleine/niedrigwachsende Fruechte	Cropland permanent	Non-Forest Area	Non-Forest Area
Beh	2221	verges, hautes tiges	Streuobst mit hohen Staemmen	Cropland permanent	Non-Forest Area	Non-Forest Area
Beb	2222	verges, basses tiges	Streuobst mit niedrigen Staemmen	Cropland permanent	Non-Forest Area	Non-Forest Area
U	11	zones urbanisees	Städtisches Gebiet	Settlements	Non-Forest Area	Non-Forest Area
Uh	111	tissu urbain continu	Zusammenhängendes Stadtgebiet	Settlements	Non-Forest Area	Non-Forest Area
Uhh	1111	zone urbaine dense	dicht besiedeltes Gebiet	Settlements	Non-Forest Area	Non-Forest Area
Uhh	11111	batiments hauts	mit hohen Gebauden	Settlements	Non-Forest Area	Non-Forest Area
Uhb	11112	batiments bas	mit niedrigen Gebauden	Settlements	Non-Forest Area	Non-Forest Area
Uhb	112	tissu urbain discontinu	Unzusammenhängendes Stadtgebiet	Settlements	Non-Forest Area	Non-Forest Area
Uf	1121	zone semi-urbaine	semirurbaner Raum	Settlements	Non-Forest Area	Non-Forest Area
Ufv	11211	avec vegetation importante	mit bedeutenden Vegetationsanteilen	Settlements	Non-Forest Area	Non-Forest Area
Ufs	11212	sans vegetation importante	ohne bedeutende Vegetationsanteile	Settlements	Non-Forest Area	Non-Forest Area
Ul	1122	extension de l'habitat le long des routes	Siedlungen entlang von Strassen	Settlements	Non-Forest Area	Non-Forest Area
Ue	1123	espace urbain ouvert sans verdure importante	unbebauter staedischer Raum ohne bedeutende Vegetation	Settlements	Non-Forest Area	Non-Forest Area
Uea	11231	places	Plaetze	Settlements	Non-Forest Area	Non-Forest Area
Uep	11232	parkings	Parkplaetze	Settlements	Non-Forest Area	Non-Forest Area
Uef	11233	friche urbaine	Siedlungsbrache	Settlements	Non-Forest Area	Non-Forest Area
Ur	1124	zone d'habitat rural	laendlicher Siedlungsraum	Settlements	Non-Forest Area	Non-Forest Area
I/T	12	zones industrielles, commerciales et reseaux de communication	Industrie- und Handelsflächen sowie Transportgelände	Settlements	Non-Forest Area	Non-Forest Area
I/T	121	zones industrielles, commerciales et socio-culturelles	Flächen genutzt von Industrie, Handel und Kultur	Settlements	Non-Forest Area	Non-Forest Area
I/T	1211	industries et commerce	Industrie- und Handelsflächen	Settlements	Non-Forest Area	Non-Forest Area
I/T	12111	industrie lourde	Schwerindustrie	Settlements	Non-Forest Area	Non-Forest Area
Il	12112	zoning industriel (+ domaine militaire)	Industriegebiet (+ militaerische Nutzung)	Settlements	Non-Forest Area	Non-Forest Area
Im	12113	zone d'activites multiples	Zone zahlreicher Nutzungen	Settlements	Non-Forest Area	Non-Forest Area
Is	12114	infrastructure agricole, horticole	Gartenbau- und Landwirtschaftsinfrastruktur	Settlements	Non-Forest Area	Non-Forest Area
Is	1212	installations socio-culturelles	Flächen für Freizeit- und Kulturnutzung	Settlements	Non-Forest Area	Non-Forest Area
Iu	12121	campus universitaire/ecole	Universitaetscampus und Schulhof	Settlements	Non-Forest Area	Non-Forest Area
If	12122	expositions et foires	Ausstellungen und Messen	Settlements	Non-Forest Area	Non-Forest Area
Ih	12123	hopitaux	Krankenhaeuser	Settlements	Non-Forest Area	Non-Forest Area
Ic	12124	centre culturel et/ou sportif	Zentrum fuer Kultur und Sport	Settlements	Non-Forest Area	Non-Forest Area
It	1213	installations specialisees	Sonderflächen	Settlements	Non-Forest Area	Non-Forest Area
It	12131	distribution haute tension	Stromversorgung	Settlements	Non-Forest Area	Non-Forest Area
Ik	12132	installation d'assainissement des eaux usees	Klaeranlage	Settlements	Non-Forest Area	Non-Forest Area
Ir	12133	stockage d'hydrocarbures ou gaz	Gas- oder Kohlenwasserstofftanks	Settlements	Non-Forest Area	Non-Forest Area
Ir	122	reseau routier, ferroviaire et espaces associes	Schienewegenetz und zugehörige Flächen	Settlements	Non-Forest Area	Non-Forest Area
Ir	1221	routes	Strassennetz	Settlements	Non-Forest Area	Non-Forest Area
Ta	12211	autoroutes	Autobahnen	Settlements	Non-Forest Area	Non-Forest Area
Tn	12212	route nationale	Bundesstrasse	Settlements	Non-Forest Area	Non-Forest Area
Tr	12213	chemin repris	Weg zur Entnahme	Settlements	Non-Forest Area	Non-Forest Area
Tc	12214	route communale	Landstrasse	Settlements	Non-Forest Area	Non-Forest Area
Te	12215	chemin d'exploitation	Betriebsstrassen ?	Settlements	Non-Forest Area	Non-Forest Area
Ts	12216	aires et surfaces carrossables	befahrbare Oberflaechen und Plaetze	Settlements	Non-Forest Area	Non-Forest Area
Ts	1222	chemins de fer	schienewegenetz	Settlements	Non-Forest Area	Non-Forest Area
Tg	12221	gare importante	wichtiger Bahnhof	Settlements	Non-Forest Area	Non-Forest Area
Tt	12222	tirage	Zug	Settlements	Non-Forest Area	Non-Forest Area
Tv	12223	voies ferrees	Schiennetz	Settlements	Non-Forest Area	Non-Forest Area
Ip	123	zones portuaires	Hafengebiete	Settlements	Non-Forest Area	Non-Forest Area
Ipi	1231	installation portuaire industrielle	Industriehafen	Settlements	Non-Forest Area	Non-Forest Area
Ipp	1232	zone portuaire de plaisance	Yachthafen	Settlements	Non-Forest Area	Non-Forest Area
Ia	124	aeroports	Flughafen	Settlements	Non-Forest Area	Non-Forest Area
Iah	1241	terminal, hangar	Terminals, Hangar	Settlements	Non-Forest Area	Non-Forest Area
Iaa	1242	piste et taxiways	Landebahnen	Settlements	Non-Forest Area	Non-Forest Area
K	13	mines, decharges et chantiers	Minen, Schutthalden und Baustellen	Settlements	Non-Forest Area	Non-Forest Area
Ks	131	extraction de materiaux (en activite)	Abbauflächen	Settlements	Non-Forest Area	Non-Forest Area
Ks	1311	carriere (sable, pierres ...)	Steinbruch	Settlements	Non-Forest Area	Non-Forest Area
Kg	1312	graviere	Kiesgrube	Settlements	Non-Forest Area	Non-Forest Area
Km	1313	mines a ciel ouvert (minerais)	Tagebau	Settlements	Non-Forest Area	Non-Forest Area
Km	132	decharges et friches	Brachflächen	Settlements	Non-Forest Area	Non-Forest Area
Ko	1321	depotoir	Muelldeponie	Settlements	Non-Forest Area	Non-Forest Area
Ki	1322	crassier et friche industrielle	Halde und industrielle Brache	Settlements	Non-Forest Area	Non-Forest Area
Ky	1323	friche hors zone urbaine et industrielle	Brachen ausserhalb besiedelter und industrieller Gebiete	Settlements	Non-Forest Area	Non-Forest Area
Ky	133	chantiers	Baustellen	Settlements	Non-Forest Area	Non-Forest Area
Kc	1331	chantier en cours	aktuelle Baustellen	Settlements	Non-Forest Area	Non-Forest Area
Ku	1332	surface rudérale ou remblais	Aufschüttungen	Settlements	Non-Forest Area	Non-Forest Area
N	14	espaces verts artificialises, non agricoles	Grünflächen, nicht landwirtschaftlich genutzt	Settlements	Non-Forest Area	Non-Forest Area
N	141	espaces verts urbains	städtische Grünflächen	Settlements	Non-Forest Area	Non-Forest Area
Nc	1411	cimetiere	Friedhof	Settlements	Non-Forest Area	Non-Forest Area
Nv	1412	zone vertes, parcs	Gruenanlagen, Parks	Settlements	Non-Forest Area	Non-Forest Area
Nb	1413	route borde d'espace vert important	Strasse mit bedeutenden Gruenstreifen	Settlements	Non-Forest Area	Non-Forest Area
Np	1414	parking avec verdure important	Parkplatz mit bedeutender Vegetation	Settlements	Non-Forest Area	Non-Forest Area
Nj	142	equipements sportifs et de loisir	Sport- und Freizeitanlagen	Settlements	Non-Forest Area	Non-Forest Area
Nj	1421	plaine de sport et/ou de jeux	Sport- oder Spielplatz	Settlements	Non-Forest Area	Non-Forest Area
Nr	1422	zone recreative	Erholungsgebiet	Settlements	Non-Forest Area	Non-Forest Area
Ns	1423	amenagement particulier	besondere Einrichtung	Settlements	Non-Forest Area	Non-Forest Area
Ng	1424	cite jardiniere	Kleingartenanlagen	Settlements	Non-Forest Area	Non-Forest Area

OBS89 Nomenclature (Part 3/3)

Acronym	Code	Original in French	translated into German	LULUCF_v7	Forest Types_v7	Forest Areas v7
M	41	zones humides interieures	Feuchtfleichen im Binnenland	Wetland	Non-Forest Area	Non-Forest Area
	411	marais interieurs	Sumpfgelbiete	Wetland	Non-Forest Area	Non-Forest Area
Mr	4111	roseliere	Schilf	Wetland	Non-Forest Area	Non-Forest Area
Mrp	41111	a baldingere	mit Rohrglanzgras (aehnlich Schilfrohr)	Wetland	Non-Forest Area	Non-Forest Area
Mrg	41112	a glycerie	wasserliebendes Suessgras mit langen Blaettern	Wetland	Non-Forest Area	Non-Forest Area
Mrs	41113	a jonc des chaisiers	wasserliebendes Kraut mit langem Stengel	Wetland	Non-Forest Area	Non-Forest Area
Mrt	41114	a massette	mit schmalblattrigem Rohrkolben	Wetland	Non-Forest Area	Non-Forest Area
Mrm	41115	melangee	gemischt	Wetland	Non-Forest Area	Non-Forest Area
Mrr	41116	a roseaux	Schilf	Wetland	Non-Forest Area	Non-Forest Area
Mc	4112	magnocaricaie	Feuchtgebietsvegetation	Wetland	Non-Forest Area	Non-Forest Area
Ms	4113	bas-marais acide	saures Niedermoor	Wetland	Non-Forest Area	Non-Forest Area
Ma	4114	bas-marais alcalin	basisches Niedermoor	Wetland	Non-Forest Area	Non-Forest Area
Mb	4115	bas-marais alcalin ruderalise	basisches Niedermoor (ruderal)	Wetland	Non-Forest Area	Non-Forest Area
	33	espaces ouverts sans ou avec peu de vegetation	Offene Flaechen mit wenig oder keiner Vegetation	Other Land	Non-Forest Area	Non-Forest Area
	332	roches nues	Offener Fels	Other Land	Non-Forest Area	Non-Forest Area
G	3321	carriere abandonnee	aufgegebenen Steinbruch	Other Land	Non-Forest Area	Non-Forest Area
A	51	eaux continentales	Wasserlaechen im Binnenland	Water	Non-Forest Area	Non-Forest Area
	511	cours et voies d'eaux	Wasserlaefue und -strassen	Water	Non-Forest Area	Non-Forest Area
An	5111	cours d'eau naturels	natuerliche Wasserlaefue	Water	Non-Forest Area	Non-Forest Area
Ac	5112	voies d'eau artificielles	kuenstliche Wasserlaefue	Water	Non-Forest Area	Non-Forest Area
	512	plans d'eau	Wasserlaechen (Seen, Teiche etc.)	Water	Non-Forest Area	Non-Forest Area
Al	5121	plan d'eau naturel	natuerliche Wasserflaechen	Water	Non-Forest Area	Non-Forest Area
Alh	51211	plus ou moins sale	mehr oder weniger salzhaltig	Water	Non-Forest Area	Non-Forest Area
Alo	51212	oligotrophe	wenig Naehrstoffe	Water	Non-Forest Area	Non-Forest Area
Alm	51213	mesotrophe	mittelmassig Naehrstoffe	Water	Non-Forest Area	Non-Forest Area
Ale	51214	eutrophe	viel Naehrstoffe	Water	Non-Forest Area	Non-Forest Area
Aa	5122	plan d'eau artificiel	kuenstliche Wasserflaechen	Water	Non-Forest Area	Non-Forest Area
Aah	51221	plus ou moins sale	mehr oder weniger salzhaltig	Water	Non-Forest Area	Non-Forest Area
Aao	51222	oligotrophe	wenig Naehrstoffe	Water	Non-Forest Area	Non-Forest Area
Aam	51223	mesotrophe	mittelmassig Naehrstoffe	Water	Non-Forest Area	Non-Forest Area
Aae	51224	eutrophe	viel Naehrstoffe	Water	Non-Forest Area	Non-Forest Area
Ab	5123	bras mort	Altarm	Water	Non-Forest Area	Non-Forest Area
?	5124	petit plan d'eau, mardelle	Teich	Water	Non-Forest Area	Non-Forest Area
Ar	5125	bassin, reservoir, etc. ...	Becken, Reservoir	Water	Non-Forest Area	Non-Forest Area
Aro	51251	oligotrophe	wenig Naehrstoffe	Water	Non-Forest Area	Non-Forest Area
Arm	51252	mesotrophe	mittelmassig Naehrstoffe	Water	Non-Forest Area	Non-Forest Area
Are	51253	eutrophe	viel Naehrstoffe	Water	Non-Forest Area	Non-Forest Area
Arz	51254	sans valeur biologique	ohne biologischen Wert	Water	Non-Forest Area	Non-Forest Area

Table 6-5 – OBS99/07 - LULUCF matching table

OBS99/07 Nomenclature							
German Acronym	French Acronym	Code	Original in French	translated into German	LULUCF_v7	Forest Types_v7	Forest Areas v7
WLE	FFC	3.1.1.1	Laubwald, Eiche	Forêt feuillue à dominance de chêne	Deciduous Forest	Deciduous Forest	Forest
WLB	FFH	3.1.1.2	Laubwald, Buche	Forêt feuillue à dominance de hêtre	Deciduous Forest	Deciduous Forest	Forest
WLS	FFD	3.1.1.3	Laubwald, sonstige Laubbaumarten	Forêt feuillue divers	Deciduous Forest	Deciduous Forest	Forest
WLM	FFM	3.1.1.4	Laubwald, gemischt, Eiche, Buche	Forêt feuillue mélangee de chênes et de hêtres	Deciduous Forest	Deciduous Forest	Forest
WLN	FTC	3.1.1.5	Eichen-Niederwald	Taillis de chêne	Deciduous Forest	Deciduous Forest	Forest
WLO	FFP	3.1.1.6.1	Laubwald, Pappel-Monokulturen	Peupleraie et autres monocultures feuillues	Deciduous Forest	Deciduous Forest	Forest
SBT	BPS	3.2.4.1	Buschwerk, Vorwälder trockener Standorte	Buissons, prebois sur sols secs	Deciduous Forest	Deciduous Forest	Forest
SBM	BPF	3.2.4.2	Buschwerk, Vorwälder mittlerer Standorte	Buissons, prebois sur sols frais	Deciduous Forest	Deciduous Forest	Forest
SBF	BPH	3.2.4.3	Buschwerk, Vorwälder feuchter Standorte	Buissons, prebois sur sols humides	Deciduous Forest	Deciduous Forest	Forest
SBG	BPE	3.2.4.4	Blockschutt- und Geröllwälder	Forêts, prebois sur éboulis	Deciduous Forest	Deciduous Forest	Forest
SBP	BPA	3.2.4.5	Gehölzplantzungen	Plantations cubustives	Deciduous Forest	Deciduous Forest	Forest
WNF	FRE	3.1.2.1	Nadelwald, Fichte/Douglasie/Tanne	Forêt résineuse (épicéas, douglas, sapins)	Coniferous Forest	Coniferous, Spruce/Douglas Fir	Forest
WNK	FRP	3.1.2.2	Nadelwald, Kiefer/Lärche	Forêt résineuse (pins, mélèzes et autres résineux)	Coniferous Forest	Coniferous Pine/Larch	Forest
WNM	FRM	3.1.2.3	Nadelwald, gemischt	Forêt résineuse mélangee	Coniferous Forest	Coniferous mixed	Forest
WMT	FMP	3.1.3.1	Mischwald (Laub/Nadel), truppweise Mischung	Forêt mélangee (feuillus/résineux) par pied, par bouquet	Mixed forest	Mixed forest	Forest
WMF	FMM	3.1.3.2	Mischwald (Laub/Nadel), fließende Mischung	Forêt mélangee (feuillus/résineux), mélange intime	Mixed forest	Mixed forest	Forest
WAU	FCD	3.1.3.3	Aufrostungen, Landungen, Dickungen (Baumart nicht erkennbar)	Culture forestière d'essences non définies	Mixed forest	Mixed forest	Forest
WSF	FSD	3.1.3.4	Sonstige Forest Landflächen (Schlagflur, Windbruch)	Autres surfaces forestières (coupes rases, chablis)	Mixed forest	Mixed forest	Forest
LA	RAA	2.1.1.1	Acker	Terres agricoles, cultures annuelles	Cropland annual	Non-Forest	Non-Forest
LBG	RAH	2.1.1.2	Baumschule, Gartenbau	Pépinières, horticulture, arbres de Noël	Cropland permanent	Non-Forest	Non-Forest
LWT	RVT	2.2.1.1	Weinbau, Terrasse	Vignoble en terrasse	Cropland permanent	Non-Forest	Non-Forest
LWS	RVA	2.2.1.2	Weinbau, sonstige	Autres vignobles	Cropland permanent	Non-Forest	Non-Forest
LSH	RHT	2.2.2.1	Streubst, Hochstamm	Verger à hautes tiges	Cropland permanent	Non-Forest	Non-Forest
LSN	RBT	2.2.2.2	Obst, Niederstamm	Verger à basses tiges	Cropland permanent	Non-Forest	Non-Forest
LF	RPR	2.3.1.1	Feuchtrüdenland	Prairie humide	Grassland	Non-Forest	Non-Forest
LMG	RPM	2.3.1.2	Mesophiles Grünland	Prairie mésophile	Grassland	Non-Forest	Non-Forest
KSI	PSI	3.2.1.1	Silicatrockenrasen	Pelouse silicicole	Grassland	Non-Forest	Non-Forest
KKA	PCA	3.2.1.2	Kalkmagerrasen	Pelouse calcaire	Grassland	Non-Forest	Non-Forest
KFE	PSR	3.2.1.3	Fels- und Schotterrasen, Pionierfluren	Pelouses pionnières (sur substrat rocheux ou graveleux)	Grassland	Non-Forest	Non-Forest
KHE	PLR	3.2.2	Heiden, Rohbodenstandorte	Landes, sols nus	Grassland	Non-Forest	Non-Forest
KRM	PFR	3.2.3.1	Ruderalstandorte, Staudenfluren mittlerer bis trock	Surfaces rudéralisées et friches sur sols secs à frais	Grassland	Non-Forest	Non-Forest
KRF	PFH	3.2.3.2	Ruderalstandorte, Staudenfluren feuchter Standorte	Surfaces rudéralisées et friches sur sols humides	Grassland	Non-Forest	Non-Forest
BSC	UAD	1.1.1	Siedlungsgebiet, Verdichtungsgrad >80%, City	Tissu urbain dense (degré de l'imperméabilisation des sols >80%)	Settlements	Non-Forest	Non-Forest
BSM	UAA	1.1.2.1.1	Siedlungsgebiet mit Verdichtungsgrad von 50-80%	Zone semi-urbaine, degré de l'imperméabilisation des sols 50-80%	Settlements	Non-Forest	Non-Forest
BSO	UAS	1.1.2.1.2	Siedlungsgebiet Verdichtungsgrad 30-50%	Zone semi-urbaine, degré de l'imperméabilisation des sols 30-50%	Settlements	Non-Forest	Non-Forest
BSB	UAL	1.1.2.2	Siedlungsbaender entlang von Strassen	Urbanisation longiligne, Bandes urbanisées le long des routes	Settlements	Non-Forest	Non-Forest
BSP	UAP	1.1.2.3.1	Oeffentliche Plaetze	Place	Settlements	Non-Forest	Non-Forest
BSR	UAF	1.1.2.3.2	Siedlungsbrachen ohne/geringe Vegetation	Friche urbaine, Espace urbain ouvert sans verdure importante	Settlements	Non-Forest	Non-Forest
BSE	UAH	1.1.2.4	Einzelhaeuser, Hoefe etc. ausserhalb Bebauung	Habitat disseminé en zone rurale, hameau	Settlements	Non-Forest	Non-Forest
BII	UIL	1.2.1.1.1	Industrie	Industrie lourde	Settlements	Non-Forest	Non-Forest
BIG	UIA	1.2.1.1.2	Gewerbe, Militaer, Dienstleistung	Zone d'activités économiques, terrain militaire	Settlements	Non-Forest	Non-Forest
BIO	UPS	1.2.1.2	Oeffentliche Bebauung	Bâtiments et installations à destination socio-culturelle	Settlements	Non-Forest	Non-Forest
BIS	UPE	1.2.1.3.1	Sondergebiete, Stromversorgung	Installations de distribution électrique	Settlements	Non-Forest	Non-Forest
BIW	UPU	1.2.1.3.2	Sondergebiete, Wasserversorgung	Installation de traitement des eaux usées	Settlements	Non-Forest	Non-Forest
BIA	UPH	1.2.1.3.3	Sondergebiete, Gasversorgung gewerbliche Landwirtschaft	Installations de stockage d'hydrocarbures et de gaz	Settlements	Non-Forest	Non-Forest
BIL	UAC	1.2.1.4	(Stallanlagen, Gewaechshaeuser)	Constructions agricoles et horticoles, étables, serres	Settlements	Non-Forest	Non-Forest
BVS	UTR	1.2.2.1.1	bedeutende Strassen (>20m)	Routes importantes (>20m), voies rapides	Settlements	Non-Forest	Non-Forest
BVP	UTS	1.2.2.1.2	Parkplatz	Zones de stationnement	Settlements	Non-Forest	Non-Forest
BVB	UTF	1.2.2.2	Bahnanlage	Infrastructure ferroviaire, gare	Settlements	Non-Forest	Non-Forest
BVH	UTP	1.2.3	Hafengebiete	Zone portuaire	Settlements	Non-Forest	Non-Forest
BVT	UTA	1.2.4.1	Flughafen, Gebaeude, Terminal	Aéroport; terminal, hangar	Settlements	Non-Forest	Non-Forest
BVL	UTT	1.2.4.2	Flughafen, Landebahn	Aéroport; piste et taxiways	Settlements	Non-Forest	Non-Forest
BAF	UEM	1.3.1	Abfallaecher, Tagebau	Zone d'extraction de matériaux	Settlements	Non-Forest	Non-Forest
BAA	UER	1.3.2.1	Aufschuttung, Deponie	Remblais et décharges	Settlements	Non-Forest	Non-Forest
BAH	UEC	1.3.2.2	Halden	Crassier	Settlements	Non-Forest	Non-Forest
BAB	UEF	1.3.2.3	Brachen industrieller Gebiete	Friche industrielle	Settlements	Non-Forest	Non-Forest
BAU	UEH	1.3.2.4	Baustellen	Chantier	Settlements	Non-Forest	Non-Forest
BGF	UVC	1.4.1.1	Friedhoefe	Cimetière	Settlements	Non-Forest	Non-Forest
BGG	UVV	1.4.1.2	Gruenanlagen, Parks	Zones de verdure, parcs	Settlements	Non-Forest	Non-Forest
BGS	UVS	1.4.2.1	Sport-, Spiel-, Camping-, Golfplaetze	Terrain de sport, espace récréatif, camping, golf etc.	Settlements	Non-Forest	Non-Forest
BGK	UVJ	1.4.2.2	Kleingartenanlagen	Cité jardinière	Settlements	Non-Forest	Non-Forest
FRO	ROS	4.1.1.1	Roehrichte	Roselière	Wetland	Non-Forest	Non-Forest
FGS	MAG	4.1.1.2	Grossseggenrieder	Magnocaritaie	Wetland	Non-Forest	Non-Forest
FKS	MBA	4.1.1.3	Kleinsseggenrieder	Bas marais	Wetland	Non-Forest	Non-Forest
OFF	RNU	3.3.2	Offene Felsflaechen	Roche nue	Other Land	Non-Forest	Non-Forest
OFK	RNU	3.3.2	Offene Felsflaechen < 1500m2	Roche nue < 1500m2	Other Land	Non-Forest	Non-Forest
OBS	REN	3.3.2.1	Offene Blockschutt- und Schotterflaechen	Eboulis et graviers non colonisés	Other Land	Non-Forest	Non-Forest
GFN	ECN	5.1.1.1.1	Fließgewaesser natuerlicher Entstehung, naturnah	Cours d'eau naturel	Water	Non-Forest	Non-Forest
GFF	ECA	5.1.1.1.2	Fließgewaesser natuerlicher Entstehung, naturnah	Cours d'eau artificialise	Water	Non-Forest	Non-Forest
GFK	EEA	5.1.1.2	Fließgewaesser kuenstlicher Entstehung	Cours d'eau artificiels	Water	Non-Forest	Non-Forest
GSN	EPN	5.1.2.1	Stilgewaesser natuerlicher Entstehung	Plans d'eau anthropogène proche de l'état naturel	Water	Non-Forest	Non-Forest
GSK	EPA	5.1.2.2	Stilgewaesser kuenstlicher Entstehung	Plan d'eau artificiel	Water	Non-Forest	Non-Forest
GAA	EBM	5.1.2.3	Altarme, Altwasser	Bras mort	Water	Non-Forest	Non-Forest
GMD	EMA	5.1.2.4	"Mardelle"	Mardelle	Water	Non-Forest	Non-Forest
GBB	BRE	5.1.2.5.1	Becken, Reservoir von biol. Interesse	Becken, réservoir ayant un intérêt écologique	Water	Non-Forest	Non-Forest
GBO	BRS	5.1.2.5.2	Becken, Reservoir ohne biol. Wert	Bassin, réservoir à ciel ouvert sans intérêt écologique	Water	Non-Forest	Non-Forest

6.1.3.3 Methodology used to develop the land transition matrix

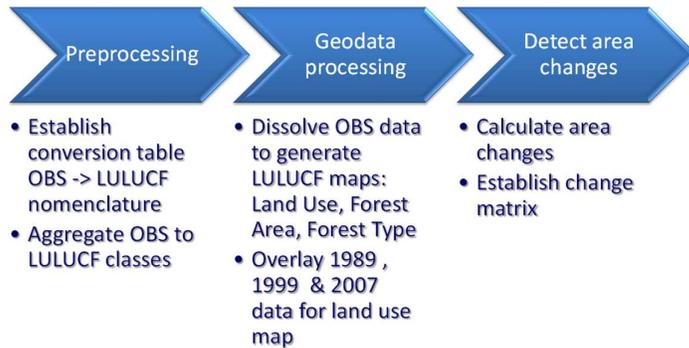
The generation of the LULUCF maps is based on the OBS and RE data. Data processing of OBS89, OBS99 and OBS07 follows the same processing scheme.

The original OBS categories for the years 1989, 1999 and 2007 were assigned to the relevant classes of the LULUCF nomenclatures. The correspondence of OBS89 respectively OBS99/07 classification to the LULUCF nomenclature has been established in close collaboration with the relevant administrations and experts. The conversion tables from OBS89-99-07 to LULUCF are presented in the above section. For RE data, the areas were directly assigned to the corresponding land use classes of the LULUCF nomenclature

After aggregation of the class assignments according to the LULUCF nomenclature (for OBS data), the next step in geo data processing (using Geographic Information System software "ArcGIS") is to dissolve the polygons to the respective classes, *i.e.* all neighbouring polygons belonging to the same LULUCF class were aggregated to one single polygon. This process results in land use maps, *i.e.* LU89, LU99, LU07 and LU12.

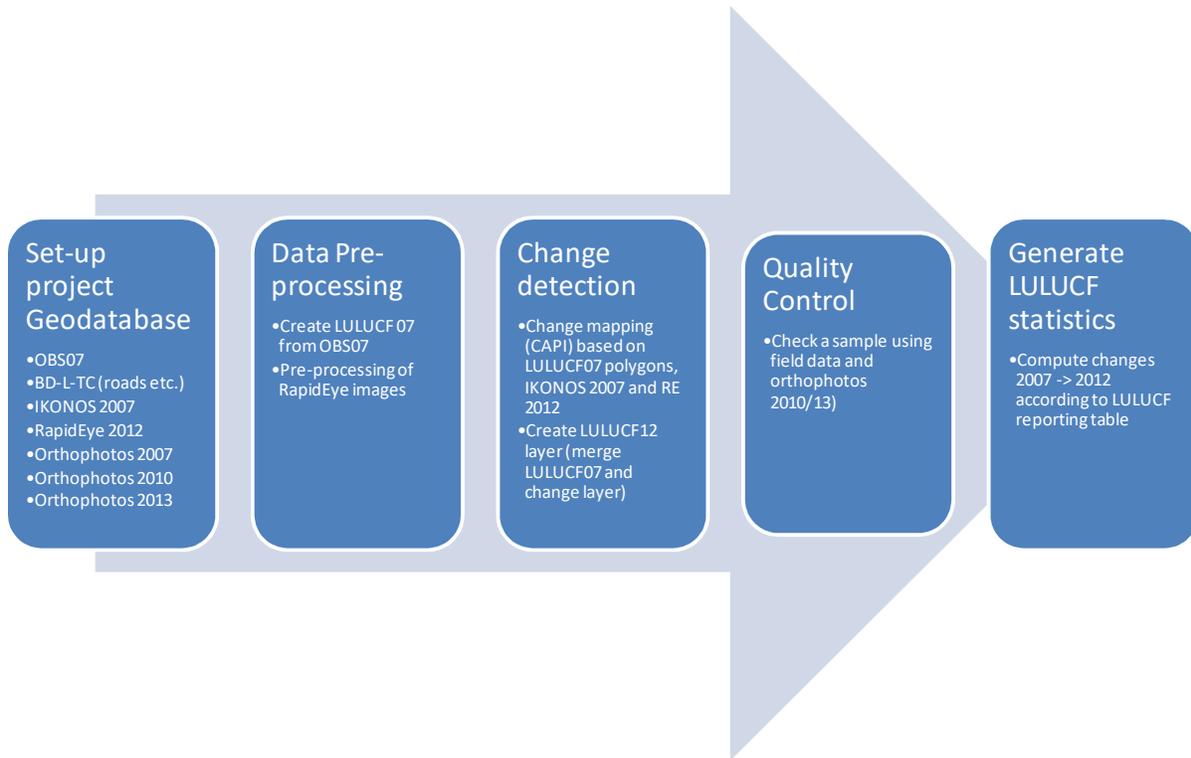
In order to preserve the detail in the data for the generation of the area statistics, no generalisation was performed before the change detection. Change detection of Land Use / Forest types between the selected reference years 1989, 1999 and 2007 has been carried out by overlay (intersect) of the Land Use maps LU89, LU99 and the LU07 data sets. Figure 6-2 shows the processing steps.

Figure 6-2 – Processing chain for the creation of LULUCF maps



For the change detection between the reference years 2007 and 2012, the overlay (intersect) of land use maps LU07 and LU12 has been carried out using the following processing steps. (Figure 6-3)

Figure 6-3– Processing chain for the creation of LU12 and change detection between LU07 and LU12



The resulting maps of the intersection show the differences in land use and the changes from which land use class to which other one. The total area as computed from the GIS data sets differs slightly from the official area of the Luxembourg territory. This is simply due to resolution /scale and data processing inaccuracies in the data sets. Therefore, the areas derived from the geodata have been put in relation to the official area of Luxembourg (258 600 ha). It means that all areas resulting from the geodata processing are proportional to the official territory of Luxembourg that is 2 586 km². From this data the change statistics are derived and illustrated in the change matrix.

6.1.3.4 Surface statistics according to LULUCF categories

Table 6-6 – Land use change matrix (1989-1999) surfaces (ha) according to LULUCF categories (raw data)

LULUCF 1999 (raw data ha)	1989											Totals 1999
	settlements	cropland	permanent crops	grassland	deciduous forest	coniferous forest	mixed forest	forest without trees	other land	wetland	water	
settlements	17	1 107.7	480.6	2 747.8	619.1	238.3	27.7		55.0	14.7	67.4	23 195
cropland	289.3	36	172.8	9 315.0	358.5	229.3	4.7		5.7	9.1	14.1	46 653
permanent crops	363.1	219.0	3 170.1	758.6	120.6	29.2	2.4		2.3	0.4	1.9	4 668
grassland	2 267.8	17	1 568.7	62	1 697.3	956.2	36.8		188.3	143.9	140.6	87 257
deciduous forest	1 176.3	580.1	407.6	2 260.6	49	3 438.1	371.2		571.7	51.9	108.5	58 587
coniferous forest	90.4	218.7	37.0	578.6	2 866.5	18	129.8		18.8	3.9	12.5	22 622
mixed forest	155.4	198.2	32.2	467.8	7 581.7	5 802.6	165.9		21.1	4.5	6.1	14 435
forest without trees												0
other land	10.7	0.2	0.0	0.9	11.3	3.6	0.5		30.3	0.0	0.8	58
wetland	4.3	6.5	0.7	95.5	12.1	10.9	0.3		0.0	65.0	11.3	207
Water	55.9	11.7	1.1	54.6	44.3	10.7	2.1		0.3	3.2	733.4	917
Totals 1989	22 250	56 289	5 871	78 845	62 933	29 384	741		893	297	1 097	258 600

Table 6-6 is a change matrix showing the land use changes that have occurred between 1989 and 1999 according to the OBS maps of 1989 and 1999. Grey marked cells are the land uses that have not changed and remained within their category. Highlighted in red are the land uses changes between cropland and grassland. Both OBS maps were partially based on aerial colour infra-red and ortho-photos. Those types of photos do not allow differentiating between permanent changes from grassland to cropland and a temporary grass cover on a crop rotation. In Luxembourg, and especially in the northern part of Luxembourg (Oesling), a crop rotation including temporary grass is largely used by the farmers. An alternative way to estimate the LUC between cropland and grassland was found, using administrative data of the Ministry of Agriculture coming from the administration of the “aid scheme for the maintenance of the landscape and the natural environment and for encouraging an agriculture respecting the environment”, an agro-environmental aid scheme administered by the “Service d’Economie Rurale”, an administration of the Ministry of Agriculture. As a land use change from permanent grassland to cropland is not allowed within this aid scheme, except in special circumstances and after a special authorization and as this aid scheme is largely taken up by the farmers, it was possible to estimate the annual LUC grassland to cropland (269 ha). Similarly the permanent change from cropland to grassland was also estimated at 269 ha. Thus, the LUC areas grassland to cropland respectively cropland to grassland going beyond 269 ha according to OBS are allocated to the category “cropland remaining cropland”. Hence the change matrix was modified as followed with the changed values highlighted in green:

Table 6-7 – Modified Land use change matrix (1989-1999)

LULUCF 1999 (modified data ha)		1989										Totals 1999
		settlements	Cropland	permanent crops	grassland	deciduous forest	coniferous forest	mixed forest	forest without trees	other land	wetland	
settlements	17	1 107.7	480.6	2 747.8	619.1	238.3	27.7		55.0	14.7	67.4	23 195
cropland	289.3	57	172.8	2 690.0	358.5	229.3	4.7		5.7	9.1	14.1	61 655
permanent crops	363.1	219.0	3 170.1	758.6	120.6	29.2	2.4		2.3	0.4	1.9	4 668
grassland	2 267.8	2 690.0	1 568.7	62	1 697.3	956.2	36.8		188.3	143.9	140.6	72 255
deciduous forest	1 176.3	580.1	407.6	2 260.6	49	3 438.1	371.2		571.7	51.9	108.5	58 587
coniferous forest	90.4	218.7	37.0	578.6	2 866.5	18	129.8		18.8	3.9	12.5	22 622
mixed forest	155.4	198.2	32.2	467.8	7 581.7	5 802.6	165.9		21.1	4.5	6.1	14 435
forest without trees												0
other land	10.7	0.2	0.0	0.9	11.3	3.6	0.5		30.3	0.0	0.8	58
wetland	4.3	6.5	0.7	95.5	12.1	10.9	0.3		0.0	65.0	11.3	207
Water	55.9	11.7	1.1	54.6	44.3	10.7	2.1		0.3	3.2	733.4	917
Totals 1989	22 250	62 914	5 871	72 220	62 933	29 384	741	0	893	297	1 097	258 600

It is important to highlight two points:

- Changing the values in the change matrix unfortunately leads to certain inconsistencies when comparing the change matrix 1989/1999 with the change matrix 1999/2007. This becomes clear when comparing the total grassland and total cropland areas generated for the year 1999 (see comparison with Table 6-7).
- It is also possible that a cropland under rotation was covered in grass in 1989 and 1999 during satellite or ortho-photo imagery and was subsequently put in the category grassland. There is however no immediate possibility to change the data in the short term. The category grassland can thus be slightly overestimated in comparison to the cropland category.

The change matrix showing the land use changes between 1999 and 2007 was established in a similar way to the change matrix between 1989 and 1999 and is shown here below (Table 6-8):

Table 6-8 – Land use change matrix (1999-2007) surfaces (ha) according to LULUCF categories (raw data)

		1999										Totals 2007	
LULUCF 2007 (raw data ha)	Settlements	cropland	permanent crops	grassland	deciduous forest	coniferous forest	mixed forest	forest without trees	other land	wetland	water		
	2007	settlements	21	430.7	149.2	1 798.1	378.2	55.5	62.2	0.0	1.2	2.0	16.3
cropland		108.1	42	39.8	14	31.3	17.9	37.2	0.0	0.0	2.1	0.2	57 366
permanent crops		94.4	92.3	4 245.6	414.3	32.5	3.9	22.6	0.0	0.0	0.0	0.2	4 906
grassland		812.7	3 084.8	177.8	69	216.8	91.1	107.7	0.0	0.5	12.1	20.7	74 379
deciduous forest		289.7	61.5	42.2	475.0	55	139.5	179.7	0.0	0.9	1.4	9.3	56 519
coniferous forest		48.3	10.4	1.1	64.0	108.4	20	157.1	0.0	0.2	0.1	0.3	20 419
mixed forest		70.7	36.5	4.2	295.8	2 377.9	1 399.5	13	0.0	1.9	0.9	1.1	17 797
forest without trees		0.0	0.0	0.0	0.0	0.0	0.0	0.0	1 303.9	0.0	0.0	0.0	1 304
other land		0.5	0.1	0.0	0.5	1.3	0.1	0.0	0.0	53.5	0.0	0.0	56
wetland		0.5	1.7	0.2	21.8	4.6	1.2	0.7	0.0	0.0	186.6	1.1	218
water		30.2	13.6	0.8	75.5	23.1	0.9	2.2	0.0	0.0	1.6	867.6	1 016
Totals 1999	23 182	46 655	4 661	87 206	58 494	21 739	14 178	1 304	58	207	917	258 600	

Table 6-9 shows the modified change matrix between the year 1999 and 2007. Here as well land uses changes between cropland and grassland have been set to a fixed value of 269 ha per year and remaining land use change areas have been added to the category cropland remaining cropland.

Table 6-9 – Modified land use change matrix (1999-2007) surfaces (ha)

		1999										Totals 2007	
LULUCF 1999 (modified data ha)	settlements	cropland	permanent crops	grassland	deciduous forest	coniferous forest	mixed forest	forest without trees	other land	wetland	water		
	2007	Settlements	21	430.7	149.2	1 798.1	378.2	55.5	62.2	0.0	1.2	2.0	16.3
Cropland		108.1	55	39.8	2 152.0	31.3	17.9	37.2	0.0	0.0	2.1	0.2	58
permanent crops		94.4	92.3	4 245.6	414.3	32.5	3.9	22.6	0.0	0.0	0.0	0.2	4 905.9
Grassland		812.7	2 152.0	177.8	69	216.8	91.1	107.7	0.0	0.5	12.1	20.7	73
deciduous forest		289.7	61.5	42.2	475.0	55	139.5	179.7	0.0	0.9	1.4	9.3	56
coniferous forest		48.3	10.4	1.1	64.0	108.4	20	157.1	0.0	0.2	0.1	0.3	20
mixed forest		70.7	36.5	4.2	295.8	2 377.9	1 399.5	13	0.0	1.9	0.9	1.1	17
forest without trees		0.0	0.0	0.0	0.0	0.0	0.0	0.0	1 303.9	0.0	0.0	0.0	1 303.9
other land		0.5	0.1	0.0	0.5	1.3	0.1	0.0	0.0	53.5	0.0	0.0	56.1
Wetland		0.5	1.7	0.2	21.8	4.6	1.2	0.7	0.0	0.0	186.6	1.1	218.4
Water		30.2	13.6	0.8	75.5	23.1	0.9	2.2	0.0	0.0	1.6	867.6	1 015.5
Totals 1999	23 182	58 709	4 661	75 151	58 494	21 739	14 178	1 304	58	207	917	258 600	

As already mentioned above, changing the data between cropland and grassland leads to the fact that both change matrixes (Table 6-7 & Table 6-9) will give different results for the total area of grassland as well as cropland.

Table 6-10 – Land use change matrix (2007-2012) surfaces (ha) according to LULUCF categories (raw data)

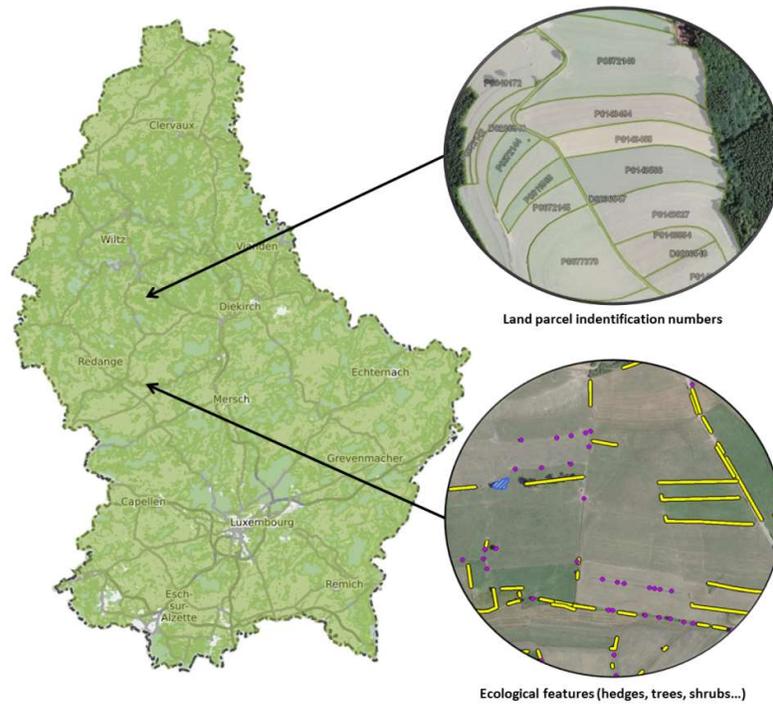
		2007										Totals 2012	
LULUCF 2007 (raw data ha)		settlements	cropland	permanent crops	grassland	deciduous forest	coniferous forest	mixed forest	forest without trees	other land	wetland		water
2012	settlements	24	140.1	23.7	450.3	44.4	5.1	19.9	1.3	0.0	0.0	3.5	25 281
	cropland	0.7	57	0.7	300.9	1.4	14.4	0.6	13.1	0.0	0.0	0.0	57 422
	permanent crops	6.2	0.0	4 867.4	0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	4 874
	grassland	10.7	102.4	1.6	73	8.5	75.0	9.9	0.5	0.0	0.0	0.4	73 627
	deciduous forest	0.3	5.3	0.1	88.6	56	0.1	0.0	22.3	0.0	0.5	0.1	56 471
	coniferous forest	2.6	3.7	0.6	9.9	0.1	19	0.0	4.6	0.0	0.0	0.0	19 258
	mixed forest	1.7	1.8	8.7	70.5	0.5	0.2	17	195.1	0.0	0.5	0.0	17 999
	forest without trees	3.2	22.2	3.2	39.7	109.8	1 087.9	46.3	1 066.1	1.3	0.0	0.0	2 380
	other land	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	54.8	0.0	0.0	55
	wetland	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	217.3	0.7	218
	water	1.5	0.5	0.0	0.6	0.6	0.0	0.0	0.9	0.0	0.1	1 010.8	1 015
	Totals 2007		24 6209	57 366	4 906	74 379	56 519	20 419	17 797	1 304	56	218	1 016

Table 6-10 is the change matrix for the year 2007 to 2012. For the preparation of this project multi-temporal RapidEye images have been acquired in March, April and in August 2012. Multi-temporal imagery analysis means that the interpretation is based on at least 2 images over the area of interest at different points in time, best in accordance with the vegetation period and the harvesting time. This allows a better distinction between cropland (i.e. arable land that is ploughed: bare in spring and after harvest) and grassland (permanent grass vegetation). As a result the land use change between cropland and grassland were so small that there is no need to amend the data for this change matrix.

Using satellite imagery at two different moments of the year is however not necessarily sufficient to distinguish between a cropland that has a grass cover as part of its rotation and grassland. The grass cover during a rotation stays in general for about 2 years on a field and will give the same satellite image during spring as during autumn.

Nevertheless the data will not be used as Luxembourg is operating a detailed LPIS (Land Parcel Identification System since 2009). The LPIS is being used for registration of reference parcels considered eligible for direct payments of CAP subsidies to farmers. Information contained in the LPIS includes parcel area and boundaries, crop description and land owner or herd number. Its role is to identify and quantify the land eligible for payments.

Figure 6-4 – Land Parcel Identification System (LPIS) in Luxembourg



A year on year analysis can be difficult as the data is not stable over time (e.g. changes in boundaries, intermittent recording when parcels are not subject to payment claims, changes in ownership). The data is spatially explicit and offers the opportunity to analyse gross land-use changes between crops (mainly grassland to cropland and vice versa).

The main advantage of using LPIS information (especially for areas with grass cover) is that it allows circumventing the problems between Land Cover vs Land Use data. The data from the OBS represents land cover rather than land use. Hence a cropland with an intermediate grass cover is perceived as grassland whereas the same parcel is clearly labelled as cropland under the LPIS system.

The disadvantage of the LPIS system is that it includes only those areas eligible for CAP payments, which means that +/- 4.000 ha are not included (predominantly perennial cropland but also a lot of grassland along highways and roads for example). Total cropland and grassland areas obtained via a detailed land use/land cover map of Luxembourg in combination with satellite imagery and aerial photography are hence still more relevant.

The following procedures were taken in order to utilise the data:

- The database was reduced to a utilisable **subset**: The database was reduced to those fields that maintained the same identification number between 2009 and 2017 and to those that had a surface >0.1 ha. This led to a reduction of the sample of +/- 30,000 entries. A further reduction has been undertaken to filter out those entries where no crop was declared in any of the years between 2009 and 2017. This led to a reduction of a further 4,600 entries. The chosen subset represents 87,557 ha compared to approximately 126,000 ha in the total database.
- Land use change between grassland and cropland were only considered if they occurred only once between 2009 and 2017. Multiple land use changes are generally considered to be crop rotation on cropland.
- The land use changes between cropland and grassland were expressed in %. In order to determine absolute land use changes those % were applied to the sum of grassland and cropland as determined by the OBS maps in 2012 (131,049 ha).
- As the data for 2018 was not available at the time of this submission the change value for 2018 and 2019 as assumed to be identical to 2017.

Table 6-11 – Land use changes between grassland and cropland extrapolated from LPIS database

	2010	2011	2012	2013	2014	2015	2016	2017
cropland -> grassland (LPIS)	0.46%	0.31%	0.16%	0.13%	0.04%	0.39%	0.42%	0.62%
grassland ->cropland (LPIS)	0.27%	0.23%	0.24%	0.17%	0.14%	0.13%	0.11%	0.19%
cropland -> grassland (ha)	597.0	408.9	205.3	170.2	51.4	507.8	548.8	811.0
grassland ->cropland (ha)	349.4	302.6	308.2	218.0	182.6	170.8	140.4	252.6

Table 6-12 – Modified land use change matrix (2007-2012) surfaces (ha)

		2007										Totals 2012	
LULUCF 2007 (raw data ha)		settlements	cropland	permanent crops	Grassland	deciduous forest	coniferous forest	mixed forest	forest without trees	other land	wetland		water
2012	settlements	24	140.1	23.7	450.3	44.4	5.1	19.9	1.3	0.0	0.0	3.5	25 281
	cropland	0.7	55	0.7	1498.2	1.4	14.4	0.6	13.1	0.0	0.0	0.0	57 097
	permanent crops	6.2	0.0	4 867.4	0.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	4 874
	grassland	10.7	1 749.3	1.6	72	8.5	75.0	9.9	0.5	0.0	0.0	0.4	73 952
	deciduous forest	0.3	5.3	0.1	88.6	56	0.1	0.0	22.3	0.0	0.5	0.1	56 471
	coniferous forest	2.6	3.7	0.6	9.9	0.1	19	0.0	4.6	0.0	0.0	0.0	19 258
	mixed forest	1.7	1.8	8.7	70.5	0.5	0.2	17	195.1	0.0	0.5	0.0	17 999
	forest without trees	3.2	22.2	3.2	39.7	109.8	1 087.9	46.3	1 066.1	1.3	0.0	0.0	2 380
	other land	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	54.8	0.0	0.0	55
	wetland	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	217.3	0.7	218
	water	1.5	0.5	0.0	0.6	0.6	0.0	0.0	0.9	0.0	0.1	1 010.8	1 015
	Totals 2007	24 6209	57 366	4 906	74 379	56 519	20 419	17 797	1 304	56	218	1 016	258 600

Table 6-13 – Land Cover surfaces (ha) according to LULUCF categories

4 - Land Use, Land Use Change & Forestry							
Land cover surfaces (ha)							
Year	A Forestland	B Cropland	C Grassland	D Wetlands	E Settlements	F Other land	Note
1971	88'404	73'216	72'156	1'878	20'549	2'397	linear interpolation (from land use changes measured between 89 and 99)
1972	88'663	72'970	72'160	1'851	20'643	2'313	
1973	88'921	72'724	72'163	1'824	20'738	2'230	
1974	89'180	72'478	72'167	1'797	20'832	2'146	
1975	89'438	72'231	72'170	1'770	20'927	2'063	
1976	89'697	71'985	72'174	1'743	21'021	1'979	
1977	89'956	71'739	72'177	1'716	21'116	1'896	
1978	90'214	71'493	72'181	1'690	21'210	1'812	
1979	90'473	71'247	72'184	1'663	21'305	1'729	
1980	90'731	71'000	72'188	1'636	21'400	1'645	
1981	90'990	70'754	72'191	1'609	21'494	1'562	
1982	91'249	70'508	72'195	1'582	21'589	1'478	
1983	91'507	70'262	72'198	1'555	21'683	1'395	
1984	91'766	70'016	72'202	1'528	21'778	1'311	
1985	92'024	69'769	72'206	1'501	21'872	1'228	
1986	92'283	69'523	72'209	1'474	21'967	1'144	
1987	92'542	69'277	72'213	1'447	22'061	1'060	
1988	92'800	69'031	72'216	1'420	22'156	977	
1989	93'059	68'785	72'220	1'393	22'250	893	OBS89
1990	93'317	68'538	72'223	1'366	22'345	810	linear interpolation
1991	93'576	68'292	72'227	1'339	22'439	726	
1992	93'835	68'046	72'230	1'312	22'534	643	
1993	94'093	67'800	72'234	1'286	22'628	559	
1994	94'352	67'554	72'237	1'259	22'723	476	
1995	94'610	67'307	72'241	1'232	22'817	392	
1996	94'869	67'061	72'244	1'205	22'912	309	
1997	95'128	66'815	72'248	1'178	23'006	225	
1998	95'386	66'569	72'251	1'151	23'101	142	
1999	95'645	66'323	72'255	1'124	23'195	58	
2000	95'694	65'933	72'404	1'138	23'373	58	linear interpolation
2001	95'743	65'543	72'553	1'151	23'552	58	
2002	95'793	65'154	72'702	1'165	23'730	57	
2003	95'842	64'764	72'850	1'179	23'908	57	
2004	95'891	64'374	72'999	1'193	24'086	57	
2005	95'941	63'984	73'148	1'206	24'264	57	
2006	95'990	63'595	73'297	1'220	24'442	56	
2007	96'039	63'205	73'446	1'234	24'620	56	OBS07
2008	96'053	62'933	73'572	1'234	24'752	56	linear interpolation
2009	96'067	62'662	73'698	1'234	24'884	56	
2010	96'080	62'390	73'824	1'233	25'017	56	
2011	96'094	62'118	73'950	1'233	25'149	55	
2012	96'107	61'847	74'076	1'233	25'281	55	
2013	96'121	61'860	73'918	1'233	25'414	55	linear extrapolation
2014	96'135	61'956	73'676	1'233	25'546	55	
2015	96'148	61'584	73'902	1'233	25'678	55	
2016	96'162	61'141	74'200	1'233	25'810	54	
2017	96'175	60'547	74'648	1'232	25'943	54	
2018	96'189	59'954	75'095	1'232	26'075	54	
2019	96'203	59'361	75'543	1'232	26'207	54	
Trend 1990-2019	3.09%	-13.39%	4.60%	-9.83%	17.29%	-93.35%	NA
Trend 2013-2019	0.08%	-4.04%	2.20%	-0.08%	3.12%	-2.02%	NA
Trend 2007-2012	0.07%	-2.15%	0.86%	-0.06%	2.69%	-1.65%	NA
Share in 1990	36.09%	26.50%	27.93%	0.53%	8.64%	0.31%	NA
Share in 2019	37.20%	22.95%	29.21%	0.48%	10.13%	0.02%	NA

Table 6-13 represents the land cover surfaces in ha for the different LULUCF categories, for the period from 1989 to 2018.

The LU maps (based on OBS89, OBS99, OBS07 and RE12) are highlighted in yellow. The years in between have been estimated by linear interpolation.

6.1.4 Completeness

Table 6-14 provides an overview of the IPCC categories included under CRF Sector 4 and provides information on the status of emission estimates of all subcategories.

Table 6-14 – Status of emission estimates for category 4 – LULUCF

GHG source & sink category	Description	Status		
		Net CO ₂	CH ₄	N ₂ O
4A1	forest land remaining forest land	X	NO	NO
4A2	land converted to forest land	X	NO	NO
4B1	cropland remaining cropland	X	NO	IE*,X
4B2	land converted to cropland	X	NO	X
4C1	grassland remaining grassland	IE**, X**	NO	NO
4C2	land converted to grassland	X	NO	X
4D1	wetlands remaining wetlands	NE,NO	NO	NO
4D2	land converted to wetlands	X	NO	X
4E1	settlements remaining settlements	NE	NE	NE
4E2	land converted to settlements	X	NE	X
4F1	other land remaining other land			
4F2	land converted to other land	X	NO	X
4G	Other (Harvested wood products)	IO	NO	NO

Note: a **X** indicates that emissions from this sub-category have been estimated, the grey shaded cells are those also shaded in the CRF tables.

(*) CO₂ emissions from cropland remaining cropland due to land use change from perennial to annual cropland are included in agriculture

(**) CO₂ emissions from lime application on grassland are included in agriculture.

(**) emissions and removals from grassland remaining grassland have been estimated but they equal to zero, hence NO is being used in the CRF tables.

6.2 Forest Land (4A)

Luxembourg has some 96 203 ha of forests, covering about 37% of the country's area. The population is well situated with an average forest area of approximately 0.16 ha per person.

6.2.1 Category description

With regard to forest land, the annual net CO₂ emissions/removals of the reported period 1990-2019 range from -189 Gg CO₂ (removal) to -976 Gg CO₂ (removal). The most important sub-category is forest land remaining forest land (5.A.1), whereas land use changes to forests (5.A.2) and from forests (5.B.2 to 5.F.2) have only minor influence on the net CO₂ balance.

For the reported period 1990 to 2019, the total annual net CO₂ removals (biomass and soil) from land use changes to forest range from about -305.46 Gg CO₂ to -41.65 Gg CO₂ (Table 6-15).

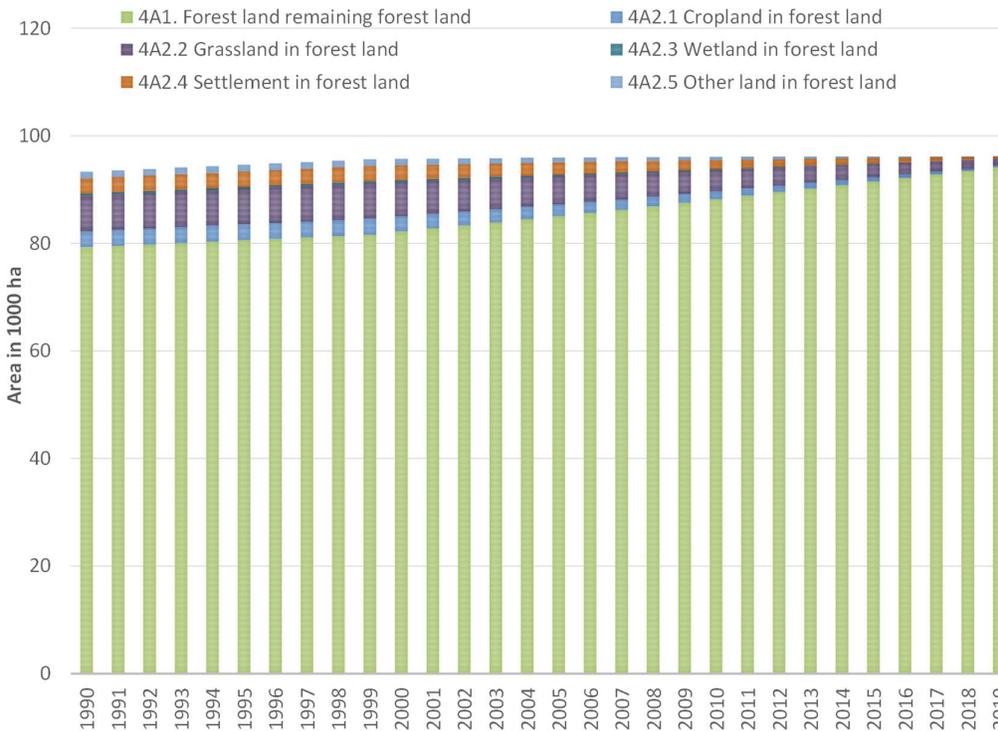
Table 6-15 – CO₂ removals/emissions from category 4A – Forest Land from 1990-2019

Greenhouse gas emissions/removals (Gg CO ₂ e)								
Year	4A Total Forest Land	4A1 FL remaining FL	4A2 Land -> FL	4A2.1 Cropland -> FL	4A2.2 Grassland -> FL	4A2.3 Wetland -> FL	4A2.4 Settlement -> FL	4A2.4 Other land -> FL
1990	- 188.74	114.57	- 303.30	- 60.60	- 107.45	- 13.50	-77.68	-44.07
1991	- 484.05	- 180.51	- 303.55	- 60.65	- 107.57	- 13.50	-77.73	-44.09
1992	- 834.68	- 530.89	- 303.79	- 60.70	- 107.68	- 13.51	-77.78	-44.11
1993	- 935.97	- 631.95	- 304.03	- 60.75	- 107.80	- 13.52	-77.83	-44.14
1994	- 734.54	- 430.27	- 304.27	- 60.80	- 107.91	- 13.52	-77.87	-44.16
1995	- 844.37	- 539.86	- 304.51	- 60.85	- 108.02	- 13.53	-77.92	-44.18
1996	- 887.46	- 582.72	- 304.75	- 60.90	- 108.14	- 13.54	-77.97	-44.20
1997	- 975.62	- 670.64	- 304.98	- 60.95	- 108.25	- 13.54	-78.02	-44.22
1998	- 852.57	- 547.35	- 305.22	- 61.00	- 108.36	- 13.55	-78.07	-44.24
1999	- 956.68	- 651.22	- 305.46	- 61.05	- 108.47	- 13.55	-78.12	-44.26
2000	- 836.22	- 533.40	- 302.81	- 60.89	- 109.87	- 12.94	-77.04	-42.08
2001	- 824.74	- 533.86	- 290.88	- 58.15	- 105.99	- 12.33	-74.50	-39.90
2002	- 827.16	- 548.24	- 278.92	- 55.42	- 102.11	- 11.71	-71.97	-37.72
2003	- 788.09	- 521.14	- 266.95	- 52.67	- 98.22	- 11.10	-69.43	-35.53
2004	- 792.85	- 537.89	- 254.96	- 49.93	- 94.32	- 10.48	-66.89	-33.34
2005	- 745.58	- 502.63	- 242.95	- 47.18	- 90.41	- 9.87	-64.34	-31.15
2006	- 658.30	- 427.37	- 230.93	- 44.42	- 86.50	- 9.25	-61.80	-28.96
2007	- 574.18	- 355.30	- 218.89	- 41.66	- 82.58	- 8.63	-59.25	-26.76
2008	- 536.53	- 330.05	- 206.48	- 38.88	- 79.00	- 7.97	-56.07	-24.56
2009	- 511.35	- 319.75	- 191.60	- 35.89	- 73.95	- 7.30	-52.11	-22.36
2010	- 173.35	3.35	- 176.70	- 32.89	- 68.89	- 6.63	-48.14	-20.16
2011	- 333.76	- 171.97	- 161.79	- 29.89	- 63.83	- 5.96	-44.17	-17.95
2012	- 426.98	- 280.12	- 146.86	- 26.88	- 58.76	- 5.29	-40.19	-15.74
2013	- 613.54	- 481.64	- 131.90	- 23.87	- 53.68	- 4.62	-36.21	-13.53
2014	- 529.50	- 412.58	- 116.92	- 20.85	- 48.59	- 3.94	-32.22	-11.32
2015	- 470.49	- 368.57	- 101.92	- 17.83	- 43.49	- 3.27	-28.23	-9.10
2016	- 557.50	- 470.61	- 86.89	- 14.80	- 38.37	- 2.60	-24.23	-6.89
2017	- 444.82	- 372.99	- 71.84	- 11.77	- 33.25	- 1.92	-20.22	-4.67
2018	- 259.27	- 202.51	- 56.76	- 8.73	- 28.12	- 1.25	-16.22	-2.44
2019	- 376.43	- 334.77	- 41.65	- 5.69	- 22.97	- 0.57	-12.20	-0.22
Trend 1990-2019	99.45%	-392.20%	-86.27%	-90.61%	-78.62%	-95.76%	-84.29%	-99.50%
Trend 2019-2019	45.19%	65.31%	-26.61%	-34.84%	-18.31%	-54.13%	-24.75%	-91.01%

The net carbon stock changes in forest biomass (sub-category 4.A.1) have a major impact on the overall results in sector 4. These changes vary considerably between single years. The reason is that the figures for annual harvest of forest biomass and to a lesser extent forest area differ significantly year by year. The annual harvest will be analysed in chapter 6.2.4.1.1 (page 521) is influenced by timber demand and prices as well as salvage logging after windfalls. The influence of those factors on the annual variations in the CO₂ net removals of this sector will be explained in the same chapter.

The variation within the time trend for LUCs to forest land is mainly due to the change of LUC areas and its composition of previous land use types across the time series. Figure 6-5 gives an overview of the LUCs to and from forests from 1970 and 1990 on, respectively. LUC areas are in the LUC subcategory for a transition period of 20 years starting 20 years before 1990.

Figure 6-5 – Trend of forest land and LUC to forest land (20 year conversion period) from 1990-2019



6.2.2 Information on approaches used for representing land areas and on land-use databases used for the inventory approach

In Luxembourg statistical data about forests are established and updated by the Nature and Forest Administration (Administration de la Nature et des Forêts (ANF)) of the Ministry of sustainable Development and Infrastructures. The forest inventory is partly based on aerial photography and partially based on territorial measurements (field-work).

The forest area comprises all territories as described in Table 6-16 and in accordance to the definition provided by FAO 2000.

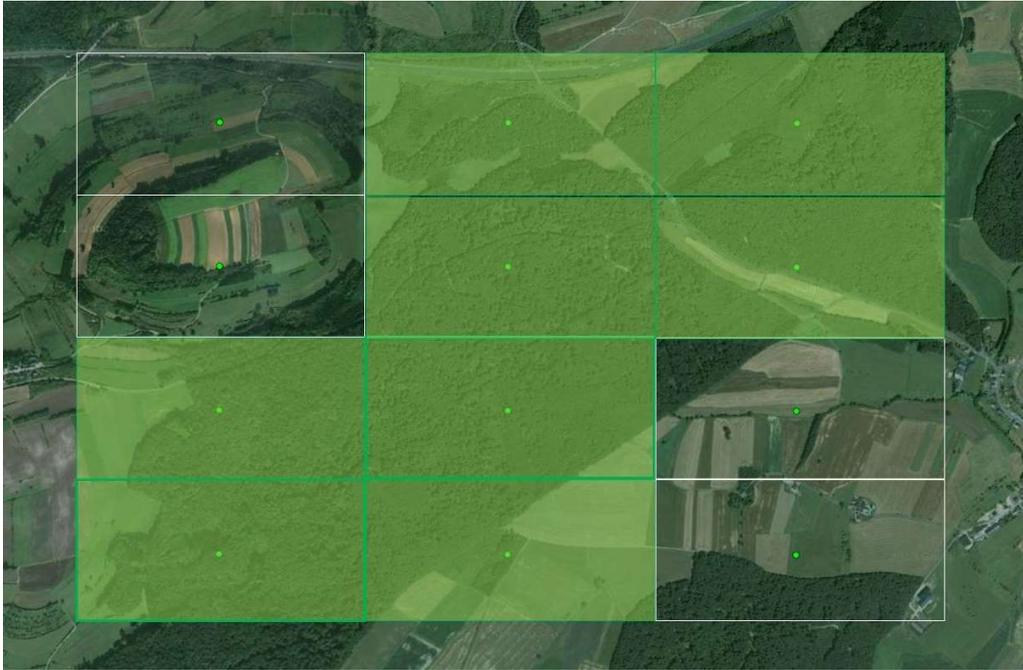
Table 6-16 - Definition of forest as applied during forest inventory

Total forest area	Forest	Land with tree crown cover (or equivalent stocking level) of more than 10 % and area of more than 0.50 ha. The trees should be able to reach a minimum height of 5 m at maturity in situ. Young natural stands and all plantations established (0.1 – 0.5 ha) for forestry purposes which have yet to reach a crown density of 10 % or tree height of 5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention or natural causes but which are expected to revert to forest.
	Grove	Group or cluster of trees with an area of 0.05 – 0.50 ha with a crown density of 10 % and where tree height potentially reached 5 m at adult stage.
	Other wooded land	Land either with a crown cover (or equivalent stocking level) of 5-10 percent of trees able to reach a height of 5 m at maturity in situ; or a crown cover (or equivalent stocking level) of more than 10 percent of trees not able to reach a height of 5 m at maturity in situ (e.g. dwarf or stunted trees); or with shrub or bush cover of more than 10 percent.
	Other land in forest areas	Area without tree cover which are enclosed, partially enclosed, or even attached to one side to a forest area and which have a surface area > 0.5 ha (pond, clearing, fallow land...)

The total forest area estimated during the second forest inventory (NFI 2 2010) for the year 2010 is 92 150 ha and is subdivided in the following types of forests:

- hardwood forests: 58 050 ha: 63 %
- coniferous forest (spruce, pin, douglas *etc.*) 27 250 ha: 30 %
- other forested (shrubs, forest roads, quarries, clear cuttings, *etc.*) 6 850 ha: 7 %

Figure 6-6 – Example of calculation method of forest area according to forest inventory



The forest inventory is a periodic survey of permanent forest sample plots based on a randomised systematic grid sample design. Each grid has a dimension of 1 000 m * 500 m and this grid density equates to 5 200 points nationally, each representing 50 ha. If a point on the grid is considered as being a forest (use of aerial photography) the equivalent of 50 ha are added to the forest area. In the image shown here above the forest area is estimated at 400 ha (8 points).

Figure 6-7 – Calculation method of forest area according to LUC method

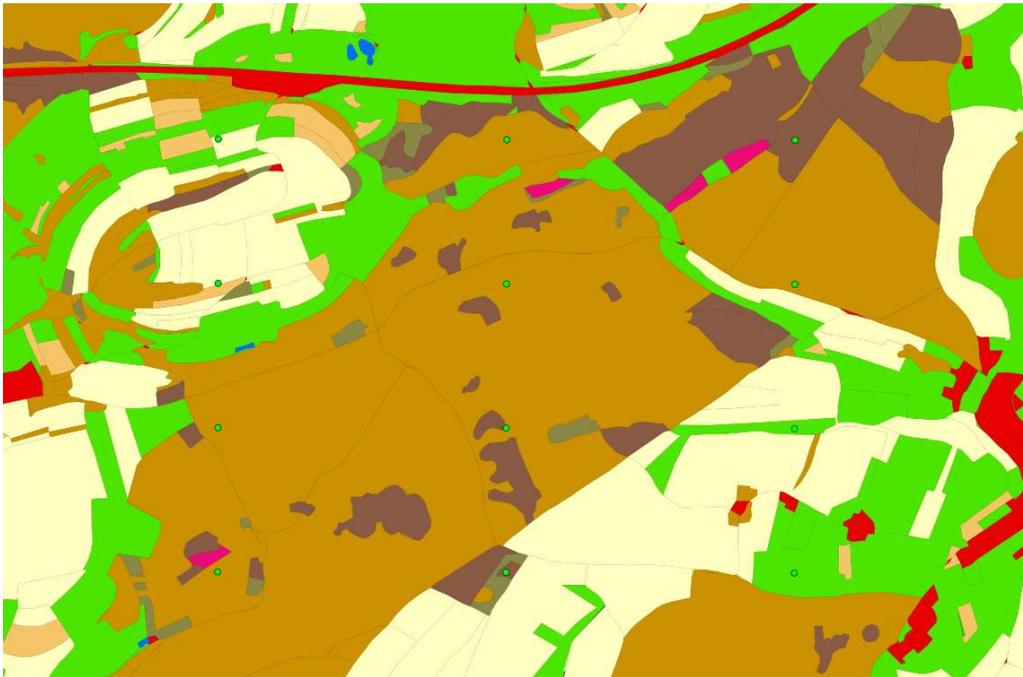


Figure 6-7 shows the same portion of land as Figure 6-6 but with the LUC method applied and based on occupational soil maps and satellite as well as aerial photography. The increased level of detail of the LUC method can be appreciated by comparing both figures.

It is important to highlight that both, the occupational soil maps, as well as the NFI, provide data on distribution of deciduous and coniferous forests. The assumption, at this point, is taken that the data of type of forest is more reliable from the forest inventory and hence the total forest areas of the occupational soil maps have been aggregated and redistributed to coniferous forests and deciduous forest according to the percentages of those types of forests from the NFI. The occupational soil maps do however provide data on land use changes from and to, either coniferous, deciduous and mixed forests. This information can however not be used for consistency reasons as the emission factors of biomass growth, harvest data, carbon stock etc are all based on the NFI. Instead the assumption is taken that land use changes to and from the different forest types are randomly distributed and reflect the species distribution of the NFI.

6.2.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

The LU89, LU99, LU07 and LU12 land use maps are the main data providers for the greenhouse gas reporting of IPCC category forestland. The National Forest Inventory (NFI) of Luxembourg is the main data provider for the development of carbon stock factors. Consequently and for reason of consistency, the applied forest definition for the reporting follows the definition used within the NFI and the OBS maps. The selected parameters are:

Land Use Class	Definition
ForestLand	All forest and wooded land according to the FAO TBRA2000 definition: <ul style="list-style-type: none"> • Minimum land area: 0.05 ha • tree crown cover \geq 10 % • tree height \geq 5 m. In the geodata set, Forest land has been sub-divided into the forest types as defined below.
Conifers:	Including all forest land with > 10 % crown cover and on which more than 75 percent of the tree crown cover consists of coniferous species.
Deciduous:	Including all forest land with > 10 % crown cover and on which more than 75 percent of the tree crown cover consists of broadleaved species
Mixed (coniferous and deciduous):	with > 10 % crown cover and less than 75 % crown cover of one class.

Permanently unstocked basal areas that are directly connected with forest in terms of space and forestry enterprise and contribute directly to its management (such as forest hauling systems, wood storage places, forest glades, forest roads) also represent forests. Areas which are used in short rotation with a rotation period of up to thirty years as well as forest arboretums, forest seed orchards, Christmas tree plantations and plantations of woody plants for the purpose of obtaining fruits such as walnut or sweet chestnut do not account as forests but represent cropland. Rows of trees (except shelter belts for wind protection) and areas with woody plants in a park structure are not forest land.

6.2.4 Methodological issues

6.2.4.1 Forest Land remaining Forest Land (4A1)

6.2.4.1.1 Change of carbon stock in living biomass

For the changes in living biomass, the IPCC Guidelines 2006 Tier 2 approach (biomass gain-loss method) was used with country-specific estimated activity data and emission/removal factors extracted from the national forest inventory.

The calculation of gains in living biomass is mainly based on the results from the two forest inventories carried out in 2000 as well as in 2010. The data extracted from the combination of those two inventories allowed defining country specific values for above- and below-ground biomass growth, wood removal, dead wood as well as country-specific biomass conversion and expansion factors.

The methodology employed to estimate those country-specific values is described by (Alderweireld, 2015). The calculation of biomass volume stock is based on new research (compared to the calculation method described in the official forest inventory publication) and hence the method will be briefly described here below:

The merchantable volume of wood (for standing trees as well as for dead wood) is estimated with the equations of (Dagnelies, Palm, & Rondeux, 2013) which have been defined for 12 tree species. Those equations give the volume of wood from the main trunk and main branches up to a diameter of 7 cm.

The above-ground biomass is calculated with the following formula:

$$G_{W(ag)} = V \cdot BEF_{ag} \cdot WBD$$

where :

$G_{W(ag)}$ = average above-ground biomass (excluding leaves) for a specific woody vegetation type (tonnes d.m. ha⁻¹)

V = volume of merchantable wood calculated according to (Dagnelies, Palm, & Rondeux, 2013) (m³ ha⁻¹)

BEF_{ag} = biomass expansion factor for above-ground biomass (Deleuze, et al., 2014)

WBD = wood biomass density (tonnes d.m./m³) (Wagenführ & Schreiber, 1985)

The BEF values were calculated from the work of (Deleuze, et al., 2014), which provides a formula to calculate total above ground biomass depending on height and diameter. The work of (Deleuze, et al., 2014) is based on the work of (Vallet, Dhôte, Le Moguédec, Ravart, & Pignard, 2006).

The volume is calculated with the following formula (Dagnelies, Palm, & Rondeux, 2013) (m³ ha⁻¹):

$$V = 0.496 \frac{(h_{tot} \cdot c_{130})^2}{4\pi \left(1 - \frac{1.3}{h_{tot}}\right)}$$

where :

V = volume of merchantable wood calculated

h_{tot} = tree height

c_{130} = tree circumference at 130 cm height

The below-ground biomass is calculated with the following formula:

$$G_{W(bg)} = V \cdot BEF_{bg} \cdot WBD$$

where :

$G_{W(bg)}$ = average below-ground biomass (excluding leaves) for a specific woody vegetation type (tonnes d.m. ha⁻¹)

V = volume of merchantable wood calculated according to (Dagnelies, Palm, & Rondeux, 2013) (m³ ha⁻¹)

BEF_{bg} = biomass expansion factor for below-ground biomass (Vande Walle, et al., 2005)

WBD = wood biomass density (tonnes d.m./m³) (Wagenführ & Schreiber, 1985)

CF = carbon fraction of dry matter, tonne C (tonne d.m.)⁻¹

With:

$$BEF_{bg} = BEF_{ag} \cdot R$$

where :

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. (Vande Walle, et al., 2005)

BEF_{ag} = biomass expansion factor for above-ground biomass

The IPCC 2006 guidelines only use a biomass expansion factor and a below-ground to above-ground ratio. The study referenced here above introduces a new variable in order to determine below-ground biomass directly from volume of merchantable wood. Essentially the calculations are the same as the one under the IPCC guidelines 2006 but are more suitable to the methods employed by the NFI.

In order to estimate the gain in biomass due to biomass growth for *5A1 - Forest Land Remaining Forest Land*, country specific biomass increment factors have been generated by comparing the biomass increase between the two inventories on the same trees. This methodology has also allowed calculating growth factors for different age categories as can be seen on Figure 6-8. The age categories between 80 and 160 years (mainly for coniferous forests) are however not based on enough samples so that they cannot be seen as statistically reliable. The same applies to the age category 61-80 for deciduous trees which are also underrepresented.

The carbon content used in the calculations is the default value: 0,47 CF = carbon fraction of dry matter, tonnes C (tonne d. m.)⁻¹.

Figure 6-8 – Country-specific biomass growth by forest type and by age (source: NFI)

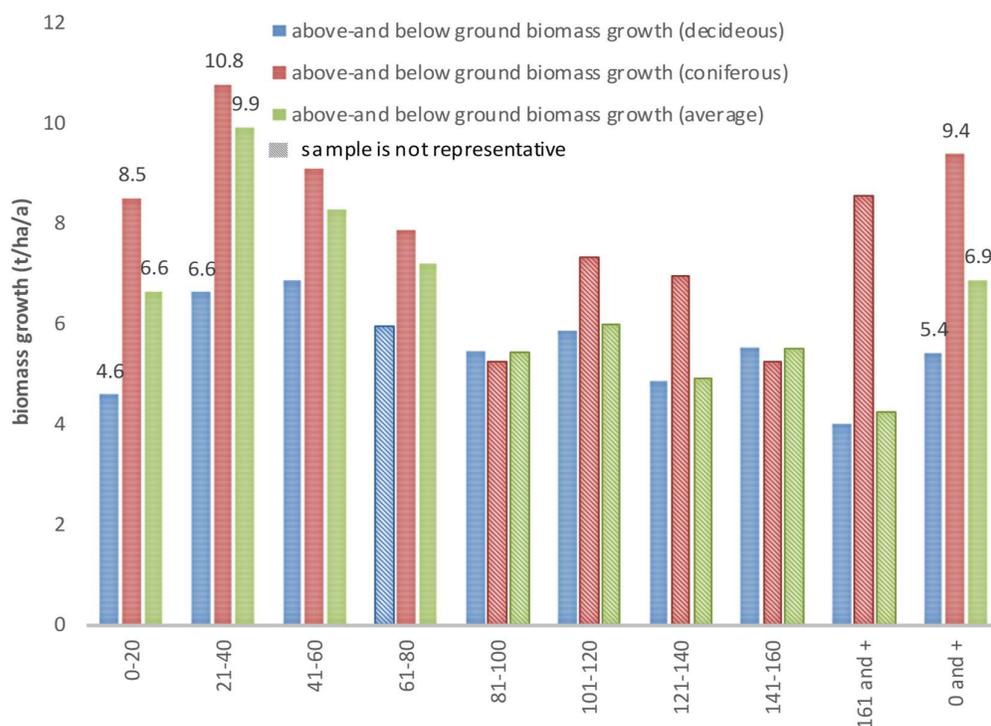


Table 6-17 – Country-specific values for above- and below ground biomass increment factors (tonnes d.m. ha⁻¹ yr⁻¹)

		above-ground biomass growth	below-ground biomass growth
deciduous	all ages	4.4	1.0
	age 0-20	3.8	0.8
	age 21-40	5.4	1.2
coniferous	all ages	7.8	1.5
	age 0-20	7.1	1.4
	age 21-40	9.0	1.8
average	all ages	5.7	1.2
	age 0-20	5.5	1.1
	age 21-40	8.3	1.6

The growth factors used for the purpose of the inventory are summarised in Table 6-17.

The age category 0-20 includes mainly areas that were clearfelled and to a lesser extent areas which have been afforested. Growth rates for afforested areas have not been separately determined as only 50 sample points have been identified as afforestation, the date of conversion is not known (2001 or 2009) and the previous land use is unknown (no distinction between grassland and cropland).

Table 6-18 – country-specific biomass conversion factor and ratio of below-ground to above-ground biomass used for the calculation of wood removal

	BCEFR	R
Deciduous forests	0.74	0.22
Coniferous forests	0.55	0.20
average	0.68	0.21

In order to estimate the carbon loss due to drain of living biomass (wood and fuelwood removal) stemwood drain data has to be converted in biomass. The data from the forest inventory (Alderweireld, 2015) has been used to define country specific biomass conversion and expansion factors by taking into account the number and type of trees found in coniferous forests as well as deciduous forest.

Data on wood harvest is derived from the statistics of the ANF (Administration de la Nature et des Forêts) as well as from the data extracted from the two consecutive forest inventories. The statistical data collected by the ANF is limited to the wood harvest of public forest and does not include wood harvest of private forests. Furthermore, ANF harvest statistics do not include biomass drain due to mortality (fallen dead trees remaining at site), but the drain according to the forest inventories includes this stemwood loss. In the previous submissions the wood harvest from private forests was simply estimated by using the same harvest rates as public forests and extrapolating it to the forest area of public forests (often with a simple 50/50 ratio). With the completion of the second forest inventory the following data has however become available:

- a) Stemwood drain from public deciduous forests: 4.8 m³/ha/a
- b) Stemwood drain from private deciduous forests: 3.3 m³/ha/a
- c) Stemwood drain from public coniferous forests: 8.7 m³/ha/a
- d) Stemwood drain from private coniferous forests: 8.7 m³/ha/a
- e) Proportion of public deciduous, public coniferous, private deciduous and private coniferous forests for the years 2000 and 2010
- f) Average annual stemwood drain measured during NFI between 2000 and 2010: 472 866 m³/a (amended to take into account the higher forest area estimated by the LUC methodology)

Figure 6-9 – Stemwood drain from public forests and estimated stemwood drain from private forests

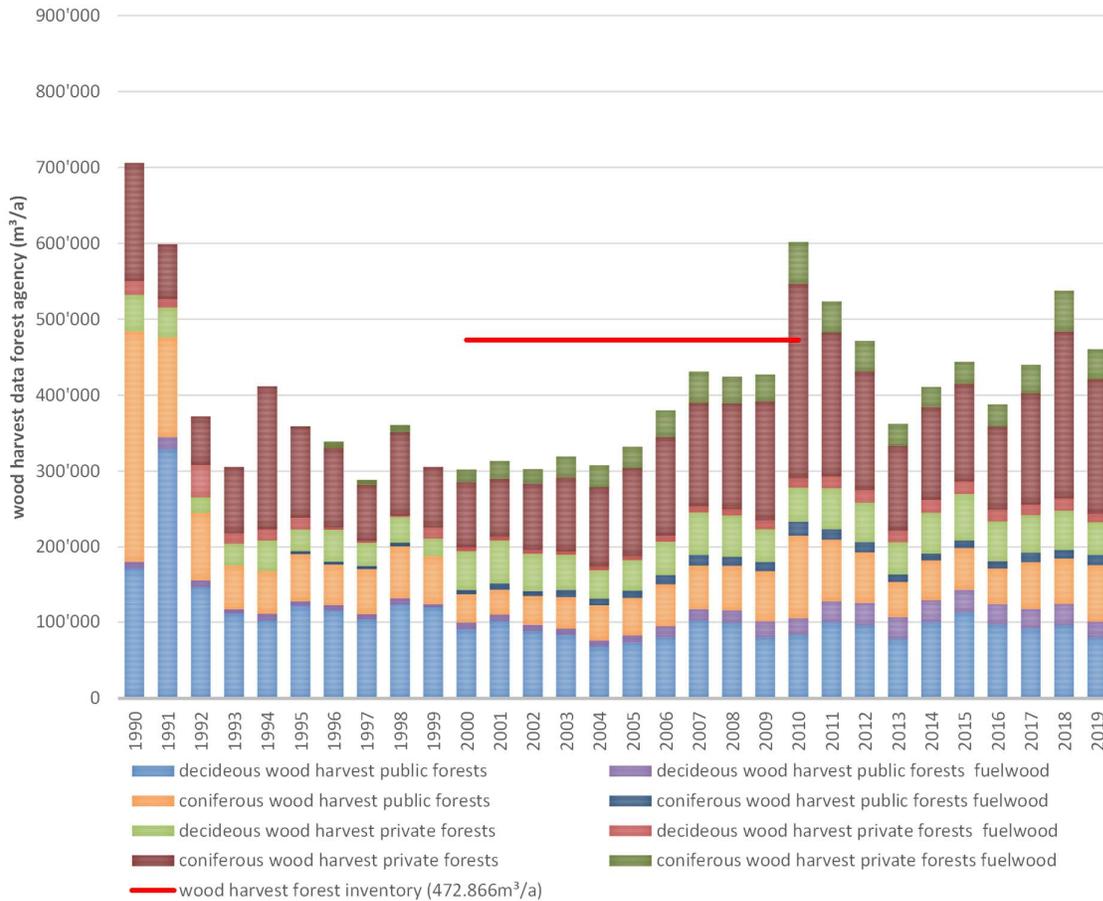
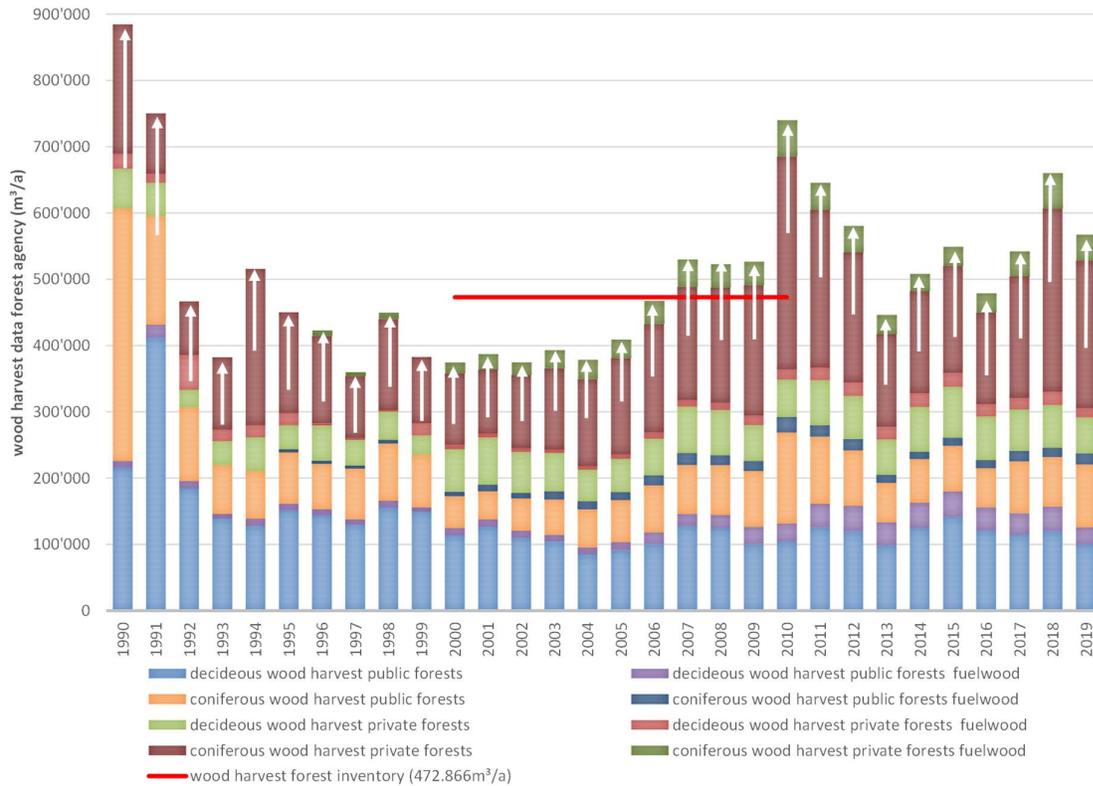


Figure 6-9 shows the yearly wood drain from public forests (yellow bars) as collected by the ANF. The green bars show the estimated wood drain from private forests estimated with the specific ratios of wood drain and forest distribution as collected during the forest inventory. The peaks 1990 and 1991 and the subsequent fall in wood drain can be explained through the salvage logging after the windstorm of 1990. The peak in 2010 has been traced back to the change of forest practice in one northern commune and also because of salvage logging after the windstorm Xinthia. Considering that this increase was mainly happening in coniferous wood (see red line) the estimated wood harvest of private forests was strongly affected as the area of private coniferous forest is twice as high as public coniferous forests and the average harvest rate out of coniferous forests is very high (8.7 m³/h/a).

The black dotted line shows the total average wood drain as estimated from the forest inventory. Compared to the average wood drain compiled with the methods described here above it is possible to see that the average wood drain between 2000 and 2010 is lower (377 000 m³/a) than the average measured during the forest inventory (472 866 m³/a). The difference is substantial (20 %) but can easily be explained (wood loss during harvest, wood (> 7cm in diameter) remaining as dead wood in forest, different time periods for data collection, estimation of wood harvest from public forests). Hence the whole time series of wood harvest data (1990-2018) was amended (+20%) to match the wood harvest rate of the forest inventory. The reasons to align the data collected from the ANF to the one from the forest inventory are the following:

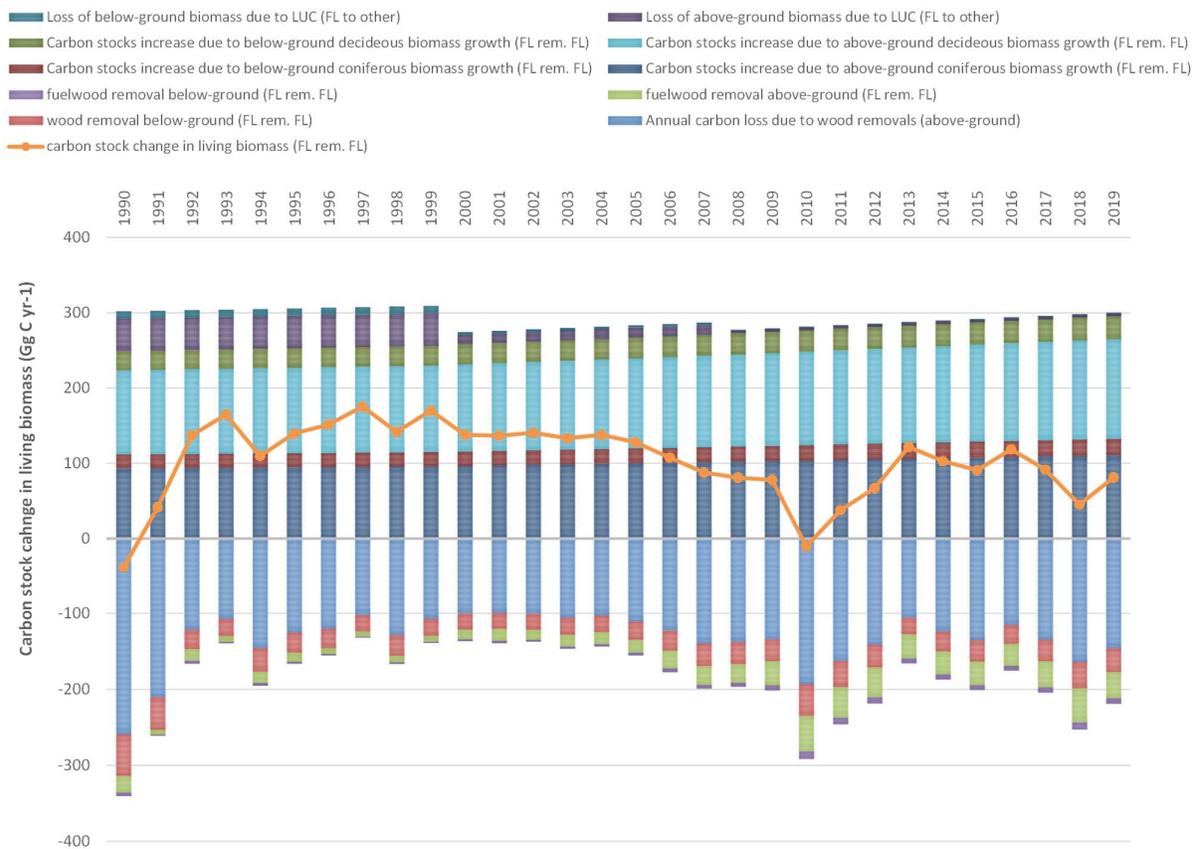
- The data collected from the inventory is more reliable as it is based on a more systematic approach
- The calculation of the total biomass removed is based on country specific biomass expansion and conversion factors (described here above) that are based on the assumption that all wood >7 cm in diameter is removed. Forest practices in public forest limit wood removal to wood with a diameter > 10 cm.

Figure 6-10 – amended time series of wood harvest (alignment with average wood harvest from forest inventory)



It is also important to note that the data on wood harvest shown in Figure 6-10 also includes the biomass removed during conversion of forestland in other land use. According to IPCC Guidelines 2006, Chapter 4.2.1.3, the definition of wood removals and fuelwood removals state clearly that “wood removal from Forest Land Remaining Forest Land and wood removal coming from Forest Land conversion to other uses should be separated”. In order to avoid double counting, the data of carbon loss due to biomass loss from forest land conversion to other land use (from chapters 6.3.4.2.1, 6.4.4.2, 6.5.4.2, 6.6.4.2, 6.7.4.2) has been subtracted from the carbon loss due to wood removal. In Figure 6-11 it is shown as a carbon gain in order to make it visible within the chart.

Figure 6-11 – change of carbon stock living biomass (forestland remaining forestland)



The practice of harvesting tree parts was practiced in the past in order to collect bark which was used in the leather tanning industry. Tree bark has since long been replaced by chemical products and most of these forests have since developed in regular woodlands. Nevertheless, as described in 11.4.3.2.4.4, the harvest from this practice is included in the NFI. As all harvest is however amended with the data of the forest inventory any harvest will be included in the reported data. With regards to natural disturbances it is assumed that during previous disturbances all stemwood was removed as part of salvage logging. Tree bark leather tanning industry

6.2.4.1.2 Change of carbon stock in soil

For the changes in soil carbon stock the IPCC GPG 2006 Tier 1 approach was used assuming that no changes in the soil carbon stock occur.

6.2.4.1.3 Change of carbon stock in dead wood

In the 2019 GHGI the results of the dead wood calculations from the FRL have been used. This means that the evolution of the carbon stock in dead wood is the same in GHGI and the FRL.

Data on dead wood stocks is available at two points in time (NFI 1 – year 2000 and NFI 2 – year 2010). Dead wood with a diameter greater than 7 cm and older than 3 years (unlikely to be harvested) was considered. In order to estimate the biomass for dead wood the biomass expansion factor were not applied which means that small branches of dead wood are not considered. Even though the degree of decomposition influences the quantity of biomass it is not considered in this study as no data on decomposition was collected.

Over the last years the forest agency has pursued an active policy to increase the dead wood in public forest. This has led to an increase in dead wood in the forest as can be seen in Table 6-19.

The following calculation estimates an evolution of the dead carbon stock by considering dynamic age-related characteristics. For the calculation a carbon pool variation module is used to estimate the evolution of this carbon pool. Carbon stock change factors (CSCF) were established according to the same stratification as applied for the calculation of harvest rate. CSCF factors were established according to forest type, ownership and age classes. The stratification according to age class allows taking into account the age class evolution.

Table 6-19 – values for dead wood by inventory year (tonnes d.m. ha⁻¹)

	2000	2010
Dead wood on floor	6.3	7.0
Dead wood standing	3.8	5.0

Table 6-20 – dead wood calculation parameters for coniferous forests under public ownership

age class	NFI 2000 (td.m. ha-1)	NFI 2010 (td.m. ha-1)	CSCF (td.m. ha-1yr-1)
0-20	2.5	6.1	0.36
21-40	10.1	10.3	0.02
41-60	11.3	14.6	0.33
61-80	19.6	12.9	-0.67
80+	0.4	13.1	1.26

Table 6-21 – dead wood calculation parameters for coniferous forests under private ownership

age class	NFI 2000 (td.m. ha-1)	NFI 2010 (td.m. ha-1)	CSCF (td.m. ha-1yr-1)
0-20	5.9	7.5	0.16
21-40	11.0	16.0	0.50
41-60	18.8	14.8	-0.40
61-80	12.8	15.0	0.22
80+	3.9	6.3	0.24

Table 6-22 – dead wood calculation parameters for deciduous forests under private ownership

age class	NFI 2000 (td.m. ha-1)	NFI 2010 (td.m. ha-1)	CSCF (td.m. ha-1yr-1)
0-20	5.7	6.2	0.05
21-40	7.0	9.9	0.30
41-60	13.0	11.0	-0.20
61-80	11.8	13.2	0.14
80+	1.4	3.0	0.15

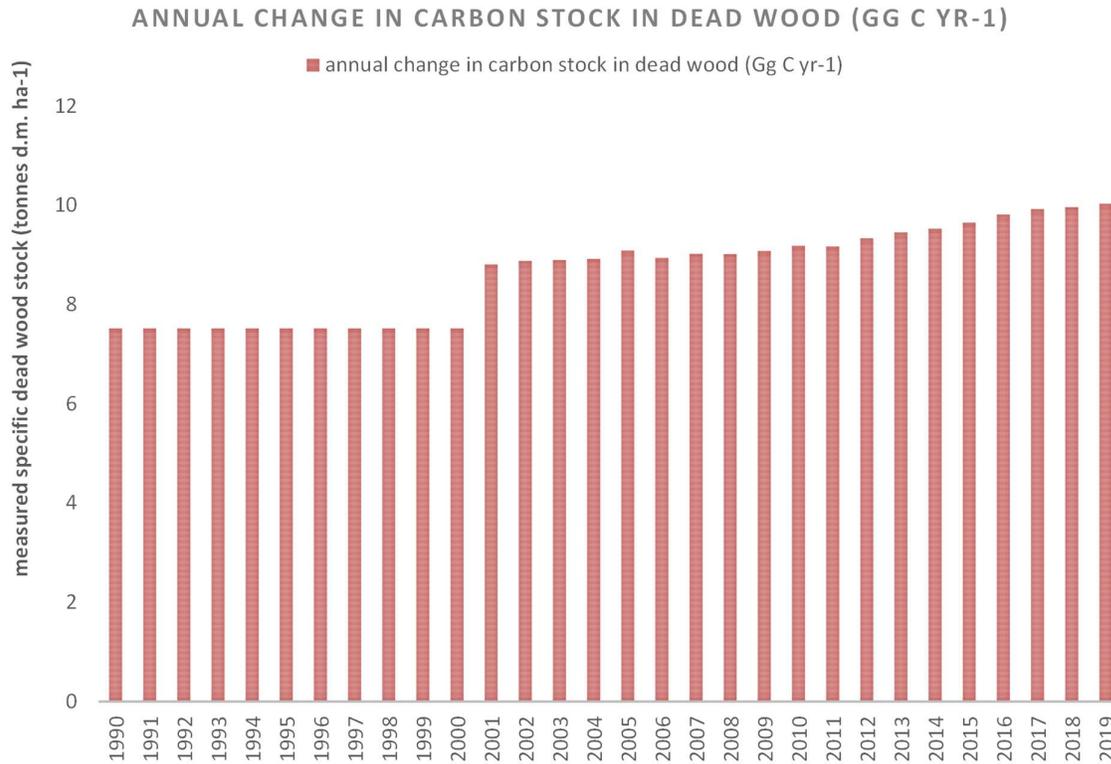
Table 6-23 – dead wood calculation parameters for coniferous forests under private ownership

age class	NFI 2000 (td.m. ha-1)	NFI 2010 (td.m. ha-1)	CSCF (td.m. ha-1yr-1)
0-20	2.6	4.0	0.14
21-40	10.2	17.2	0.71
41-60	21.8	21.6	-0.02
61-80	10.6	10.6	0.00
80+	21.5	40.6	1.91

In order to project the dead wood stock the projected forest areas for each stratum were calculated

using the age-structure module. Those projected areas were then multiplied by the respective CSCFs for each stratum calculated here above.

Figure 6-12 – change of carbon stock in dead wood



A continuous increase can be observed in the years after 2000 due to an increase of the area of forestland remaining forestland. It is important to highlight the importance of carrying out a third forest inventory in order to measure the dead wood stock before 2025. If this is not the case than any real increase of dead wood will not be accounted for in the GHGI.

6.2.4.1.4 Change of carbon stock in litter

For the changes in carbon stock in litter the IPCC GPG Tier 1 approach was used assuming that no changes in the litter carbon stock occur. Unfortunately no data on litter C stock changes has so far been collected in Luxembourg so that this hypothesis could not be verified.

6.2.4.2 Land Use Changes to Forest Land (4A2)

6.2.4.2.1 Change of carbon stock in living biomass of land converted to forest land

The method follows the Tier 2 IPCC GPG approach with default transition periods of 20 years for LUC and country specific data for biomass increase factors. It is assumed that no wood removal occurs in forest less than 20 years old.

For the calculation of annual change in carbon stocks of living biomass of land converted to forestland the IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$\text{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{ (B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO_OTHERS_i} \} \cdot CF$$

where :

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (The biomass increment factor for 4.A.2.1 - *Land converted to Forestland* is described under § 1.2.4.1. The first age class (0-20) values (Table 6-17) for the annual increment are being used: above-ground biomass growth of 5.5 tonnes d.m. ha⁻¹ yr⁻¹ and below-ground biomass growth 1.1 tonnes d.m. ha⁻¹ yr⁻¹.)

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha⁻¹ (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha⁻¹ (value for carbon stock of woody biomass before conversion depending on land use: see Table 6-24 as well as Table 6-25).

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr⁻¹ (default value = 0).

$\Delta A_{TO_OTHERS(i)}$ = area of land use converted to another land-use category in a certain year, ha yr⁻¹.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)⁻¹.

i = type of land use converted to another land-use category

Table 6-24 – Biomass stock for different land use categories (tonnes C ha⁻¹)

	Pool	value	Reference
Cropland annual	below-ground	5.0	Table 5.9 IPCC GPG (LULUCF 2006)
Cropland perennial	above-ground	6.4	See below
Forestland	above-ground	98.4	NFI
Forestland	below-ground	21.3	NFI
Grassland	above- and below-ground	6.3	Table 6.4 IPCC GPG (LULUCF 2006)
Wetlands	N/A	0.0	Tier 1
Settlements	above-ground	4.3	section 1.6.4.2
Other land	N/A	0.0	Tier 1

Table 6-20 summarises the biomass stock factors for the different land use categories that are being lost during land use change to forestland. The biomass decrease factor for 4.A.2.1 – *Annual cropland converted to Forestland* is 5.0 t C/ha and derives from Table 5.9 of the IPCC GPG (LULUCF 2006, Tier 1 default value). The biomass decrease factor for 4.A.2.2 - *Grassland converted to Forestland* is 6.3 t C/ha and derives from Table 6.4 of the IPCC GPG (LULUCF 2006, Tier 1 default value of 13.5 tonnes d.m ha⁻¹). As the distinction between below-and above-ground biomass at this level is not always very clear and in order to simplify the calculations all the biomass stock factors are being considered as above-ground. For wetland and other land the default value for biomass stock is set to 0.

According to the data from ASTA (Administration des Services Techniques de l'Agriculture) vineyards constitute 93 % of the perennial cropland in Luxembourg and it seems justified to calculate a country-specific biomass stock factor for perennial cropland (as was recommended during audit (FCC/ARR/2014/LUX)).

Table 6-25 – Biomass decrease factors for perennial cropland (tonnes C ha⁻¹)

	% of perennial cropland	Value	Reference
Vineyards	94	2.64 (2,09 (ag)+ 0.55 bg)	NIR Germany/Switzerland
orchards	6	63.00	IPCC GPG Table 5.1
Perennial cropland (average)	100	6.41	/

The biomass stock factor for perennial cropland used in Luxembourg is a weighted average of vineyards specific values used by neighbouring countries (Germany – NIR 2014: 1.66 Mg C ha⁻¹ (above ground biomass (1.22 Mg C ha⁻¹) and below ground biomass (0.44 Mg C ha⁻¹) and Switzerland – NIR 2015: 3.61 Mg C ha⁻¹ (above ground biomass (2.96 Mg C ha⁻¹) and below ground biomass (0.65 Mg C ha⁻¹)) and the default IPCC GPG value used typically for orchards (63.0 Mg C ha⁻¹). Germany, Switzerland and Luxembourg are all part of Europe's continental region with similar climatic conditions. Furthermore Germany and Switzerland have similar wine industry focussed on white wine production and are hence suitable indicators for biomass stock factors for vineyards in Luxembourg.

6.2.4.2.2 Change of carbon stock in soil of land converted to forest land

In October 2014, ASTA presented two new studies on the carbon content and stocks of different soil types in Luxembourg ("Mapping Topsoil Organic Carbon Content in the Grand-Duchy of Luxembourg" and "Mapping Topsoil Organic Carbon Stocks in the Grand-Duchy of Luxembourg"). While the first study provides detailed information on the carbon content in soils of Luxembourg (covering 90% of the territory and per land use type), the second study assesses the amount of carbon stored in soils of a given area by taking into account the soil density, soil depth (0-30 cm), and the proportion of fine earth to the total soil mass.

Table 6-26 – Carbon soil stocks per land use and soil type (t C/ha) in Luxembourg

Soil type	Total (ha)	Carbon soil stocks per land use and soil type (t C/ha)						
		Cropland (Annual Cropland)	Grassland	Forestland	Vineyard (Perennial cropland)	wetland	settlement	other land
Oesling	70'942	91.5	89.2	132.2	71.0	0.0	43.2	0.0
Buntsandstein	10'495	66.7	82.8	112.1	73.5	0.0	43.2	0.0
Dolomies du Muschelkalk	11'562	85.5	112.1	117.0	77.9	0.0	43.2	0.0
Calcaires du Bajocien	2'916	75.2	122.0	111.5	77.7	0.0	43.2	0.0
Grès de Luxembourg	25'060	50.7	83.3	80.6	76.2	0.0	43.2	0.0
Dépôts limoneux sur Grès	22'382	58.6	99.4	95.7	75.1	0.0	43.2	0.0
Argiles du Lias inf. et moyen	27'673	69.8	121.6	95.2	75.7	0.0	43.2	0.0
Argiles lourdes du Keuper	21'966	67.7	121.3	102.6	76.0	0.0	43.2	0.0
Argiles lourdes des schistes bitumineux	6'677	88.2	145.7	104.8	NA	0.0	43.2	0.0
Autres	12'824	80.7	110.8	126.6	74.9	0.0	43.2	0.0

According to GPG the use of country-specific values for carbon content changes during land-use change will be based “on paired-plot comparisons representing converted and unconverted lands”, “where all factors other than land-use history are as similar as possible” (p.3.130). As the soil carbon stock is provided per land use and per soil type the soil carbon it was agreed during the audit of 2014 that stock changes should be computed for each land-use transition within a given soil type. This would be in accordance with the GPG: soil type indeed is an acceptable proxy for “all factors other than land-use history” as further covariates cannot be included in the analysis.

One method of using those country specific values would be to attribute the relevant soil-type-specific IEF to each soil-type specific land use change observed, based on the geographic coordinates of the observed land-use change. This would, however, be very time-consuming and not feasible with the dataset as it is available at the moment. Considering that the land use changes are homogeneously distributed throughout Luxembourg, the alternative method was chosen to compute a weighted average of soil-type-specific IEFs, where the soil carbon stock changes for each land-use transition within a given soil type is weighted by its area in Luxembourg:

$$IEF(LUC_j) = \frac{\sum_i IEF(LUC_j)_{st,i} \cdot A_{st,i}}{\sum_i A_{st,i}}$$

IEF(LUC_j) = average yearly emission factor for carbon stock change in soil from land use change j (eg forestland in cropland)

IEF(LUC)_{st,i} = yearly emission factor for carbon stock change in soil from land use change j for a soil type i

A_{st,i} = area of soil type i

with:

$$IEF(LUC_j)_{st,i} = \frac{SOC(LU_a)_{st,i} - SOC(LU_b)_{st,i}}{\text{transition}_{\text{period}}}$$

IEF(LUC)_{st,i} = yearly emission factor for carbon stock change in soil from land use change j (eg CL->GL) for a soil type i

SOC(LU_{a,b})_{st,i} = soil organic content by land use type a or b and soil type i

transition_{period} = period where the change in carbon stock change is achieved (typically 20 years)

Numerical example first step: calculating the IEF for each land use transition in each soil type (example of Oesling)

$$IEF_{CL \rightarrow GL, Oesling} = \frac{SOC_{CL, Oesling} - SOC_{GL, Oesling}}{\text{transition}_{\text{period}}} = \frac{91.5 - 89.2}{20} = 0.115 \text{ tC} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$$

Second step: calculating the national average IEF for each land-use transition (this simplicity makes sense as Luxembourg justifies that D and AR is roughly equally distributed over its territory)

$$IEF_{CL \rightarrow GL, \text{national}} = \frac{IEF_{CL \rightarrow GL, Oesling} \times \text{area}_{Oesling} + IEF_{CL \rightarrow GL, Buntsandstein} \times \text{area}_{Buntsandstein} + \dots}{\text{area}_{Oesling} + \text{area}_{Buntsandstein} + \dots}$$

The calculation of all land use changes results in the following matrix:

Table 6-27 – land use change matrix for soil carbon emission factors (t C/ha*y)

from \ to	Forest land	Annual Cropland	Perennial Cropland	Grassland	Wetland	Settlement	Other land
Forest land	0	-1.784	-1.237	-0.476	-5.554	-3.393	-5.554
Annual Cropland	1.784	0	0.462	1.308	-3.770	-1.609	-3.770
Perennial Cropland	1.237	-0.462	0	1.517	-3.778	-1.616	-3.778
Grassland	0.476	-1.308	-1.517	0	-5.079	-2.917	-5.079
Wetland	5.554	3.770	3.778	5.079	0	2.162	0.000
Settlement	3.393	1.609	1.616	2.917	-2.162	0	-2.162
Other land	5.554	3.770	3.778	5.079	0.000	2.162	0

And thus the following increment factors were used for estimating the change of carbon stock in soil of land converted to forest land:

- annual cropland converted to forestland: +1.784 t C/ha*y
- perennial cropland converted to forestland: +1.237 t C/ha*y
- grassland converted to forestland: +0.476 t C/ha*y
- wetland converted to forestland: +5.554 t C/ha*y
- settlements converted to forestland: +3.393 t C/ha*y
- other land converted to forestland: +5.554 t C/ha*y

6.2.4.2.3 Change of carbon stock in dead wood and litter

In order to estimate the increase in dead wood stock the assumption was taken (Tier 1 of IPCC GPG (LULUCF 2006 – Volume 4) that “carbon in dead wood and litter pools in non-forest land are zero, and that carbon in dead organic matter pools increases linearly to the value of mature forests over a specified time period (default = 20 years)”.

The EF used for dead wood stock are those described in Figure 6-12 and for litter the default values (Table 2.2, IPCC GPG 2006, Chapter 2) of 16 tonnes C/ha for deciduous and 26 tonnes C/ha for coniferous forests were chosen.

6.3 Cropland (4.B)

6.3.1 Category description

In category *4.B Cropland*, the estimation of emissions from cropland remaining cropland, land converted to cropland and liming is carried out. The calculations were made for the individual years from 1990 to 2019. Some management practices (*e.g.* slash and burn, *etc.*) and organic soils do not occur and are prohibited in Luxembourg.

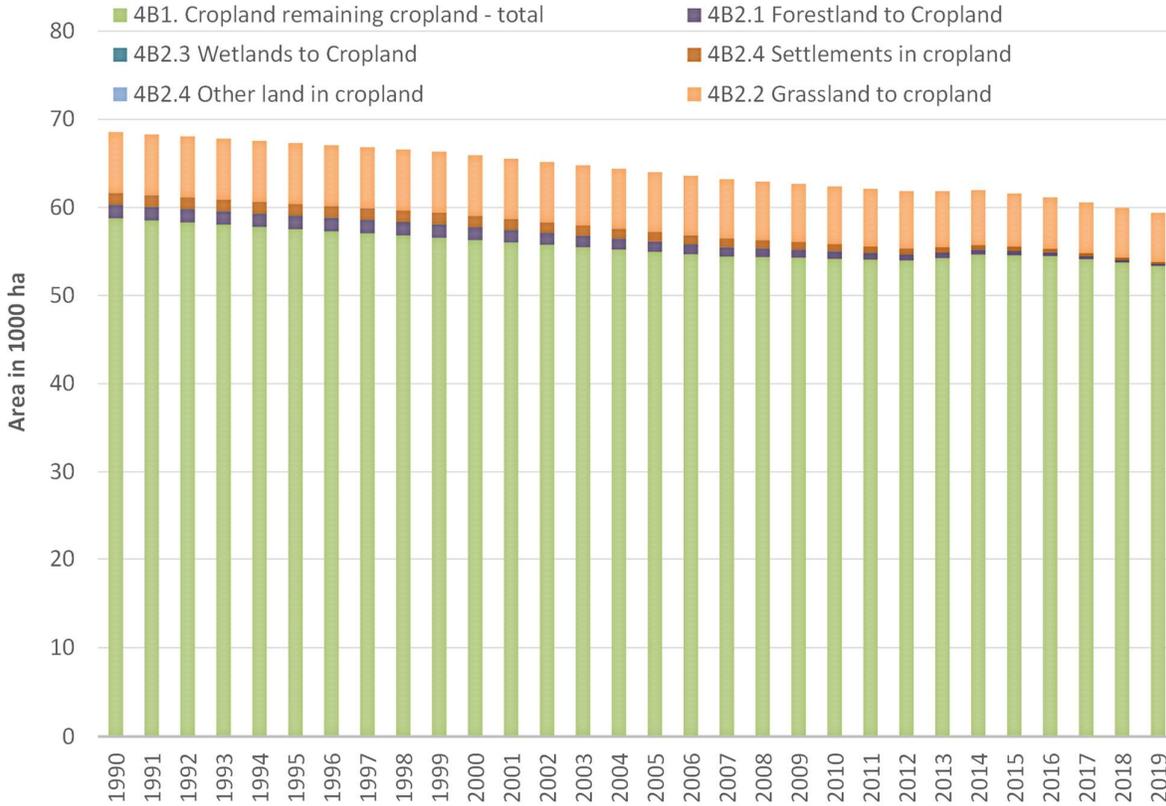
Emissions/Removals were estimated for the sub-categories and related sources/sinks as shown in Table 6-28.

Table 6-28 – Sources (or sinks) considered for cropland management.

Category/source or sink
4B Cropland - total
4B1 Cropland remaining cropland
- carbon stock change in living biomass of perennial cropland and LUC between annual and perennial cropland
4B2 Land converted to cropland
4B2.1 Forest land converted to cropland
- carbon stock change in living biomass and dead wood of annual/perennial cropland
4B2.2 Grassland converted to cropland
- carbon stock change in living biomass of annual/perennial cropland
- carbon stock change due to changes in organic matter input to cropland soils
4B2.3 Wetland converted to cropland
4B2.4 Settlement converted to cropland
4B2.5 Other land converted to cropland

In 2018, 60 547 ha of Luxembourg were arable land including annual and permanent crops. The land use changes are derived from land transition matrix. In 2018, the land use change area to cropland was 260 ha. The land use changes for a 20 year conversion period are shown in Figure 6-13.

Figure 6-13 – Trend of cropland and LUC to cropland (20 year conversion period) from 1990-2019



The annual emissions from 1990-2019 range between 75.26 Gg CO₂ equivalent and 34.84 Gg CO₂ equivalent respectively (Table 6-29). The source is mainly caused by soil C stock changes of land use change areas, particularly by grassland converted to cropland.

Table 6-29 – CO₂ removals/emissions from category 4B – Cropland for 1990-2019

Greenhouse gas emissions/removals (Gg CO ₂ e)									
Year	4B Total Cropland (excluding leaching)	4B1 CL remaining CL	4B2.1 FL -> CL	4B2.2 GL -> CL	4B2.3 WL -> CL	4B2.4 Settlement -> CL	4B2.5 OL -> CL	N ₂ O (in CO ₂ eq)	N ₂ O leaching (in CO ₂ eq)
1990	75.03	-1.28	44.31	36.15	-0.75	-7.78	-0.24	4.62	1.04
1991	75.06	-1.28	44.33	36.15	-0.75	-7.78	-0.24	4.62	1.04
1992	75.08	-1.28	44.36	36.15	-0.75	-7.78	-0.24	4.62	1.04
1993	75.11	-1.28	44.38	36.15	-0.75	-7.78	-0.24	4.62	1.04
1994	75.13	-1.28	44.41	36.15	-0.75	-7.78	-0.24	4.62	1.04
1995	75.16	-1.28	44.44	36.15	-0.75	-7.78	-0.24	4.62	1.04
1996	75.18	-1.28	44.46	36.15	-0.75	-7.78	-0.24	4.62	1.04
1997	75.21	-1.28	44.49	36.15	-0.75	-7.78	-0.24	4.62	1.04
1998	75.24	-1.28	44.51	36.15	-0.75	-7.78	-0.24	4.62	1.04
1999	75.26	-1.28	44.54	36.15	-0.75	-7.78	-0.24	4.62	1.04
2000	52.02	3.42	17.32	35.48	-0.68	-7.87	-0.22	4.57	1.03
2001	51.84	3.26	17.18	35.36	-0.65	-7.62	-0.20	4.51	1.02
2002	51.66	3.09	17.03	35.25	-0.62	-7.36	-0.19	4.46	1.00
2003	51.49	2.93	16.89	35.13	-0.59	-7.11	-0.18	4.41	0.99
2004	51.31	2.76	16.75	35.02	-0.56	-6.85	-0.17	4.36	0.98
2005	51.13	2.60	16.61	34.90	-0.53	-6.60	-0.16	4.31	0.97
2006	50.96	2.43	16.47	34.79	-0.50	-6.34	-0.15	4.25	0.96
2007	50.78	2.27	16.32	34.67	-0.47	-6.09	-0.14	4.20	0.95
2008	42.86	2.89	9.11	33.11	-0.42	-5.82	-0.12	4.11	0.93
2009	42.34	2.71	8.77	32.75	-0.39	-5.41	-0.11	4.02	0.91
2010	42.38	2.53	8.18	33.17	-0.35	-5.01	-0.10	3.98	0.89
2011	41.75	2.35	7.77	32.73	-0.32	-4.60	-0.09	3.90	0.88
2012	41.40	2.17	7.37	32.59	-0.28	-4.20	-0.08	3.83	0.86
2013	40.10	1.99	6.97	31.53	-0.25	-3.79	-0.07	3.72	0.84
2014	38.88	1.81	6.56	30.58	-0.21	-3.39	-0.06	3.59	0.81
2015	37.72	1.63	6.16	29.69	-0.18	-2.98	-0.05	3.45	0.78
2016	36.30	1.45	5.76	28.56	-0.14	-2.58	-0.03	3.29	0.74
2017	36.19	1.27	5.35	28.67	-0.11	-2.17	-0.02	3.19	0.72
2018	35.52	1.09	4.95	28.23	-0.07	-1.77	-0.01	3.10	0.70
2019	34.85	0.91	4.55	27.79	-0.03	-1.36	0.00	3.00	0.67
Trend 1990-2019	-53.56%	-170.69%	-89.74%	-23.13%	-95.39%	-82.49%	-100.00%	-35.07%	-35.07%
Trend 2018-2019	-1.89%	-16.58%	-8.15%	-1.56%	-50.54%	-22.92%	-100.00%	-3.16%	-3.16%

6.3.2 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

As described in section 6.1.3.4, an exception to the use of the OBS land use maps was made for LUC areas between cropland and grassland. The LUC areas grassland to cropland respectively cropland to grassland going beyond 269 ha according to OBS were allocated to the category “cropland remaining cropland” for the years 1990-2009. For the years following 2009 data extracted from the LPIS was used to determine land use changes between grassland and cropland.

6.3.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

The LU89, LU99, LU07 and LU12 land use maps are the main data providers for the greenhouse gas reporting of IPCC category cropland, with the exception that for LUC between cropland and grassland, the land transitions matrix needed to be adapted due to special national circumstances as explained in the previous section and in section 6.1.3.3. The selected parameters defining annual and perennial cropland are:

Land Use Class	Definition
Annual Cropland	Includes agro-forestry systems where tree cover falls below the level used in the forest categories (IPCC GPG definition) with the following specifications: land on which different crops are grown in a yearly changed rhythm including artificial meadows (not permanent) including land temporarily set aside
Permanent Cropland	Includes agro-forestry systems where tree cover falls below the level used in the forest categories (IPCC GPG definition) with the following specifications: land on which different crops are grown in a permanent manner, <i>i.e.</i> not changing in a yearly rhythm

6.3.4 Methodological issues

6.3.4.1 Cropland remaining Cropland (4B1)

6.3.4.1.1 Change of carbon stock of annual cropland

a) Changes of carbon stock in biomass of annual cropland remaining annual cropland:

As the biomass of annual crops is harvested every year, there is no change in carbon stock in biomass.

b) Changes of carbon stock in biomass of perennial cropland converted to annual cropland:

For the calculation of annual change in carbon stocks of living biomass of land converted to cropland the IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$\text{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{ (B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO_OTHERS_i} \} \cdot CF$$

where :

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for annual crops carbon accumulation rate is 5 t C ha⁻¹yr⁻¹).

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha⁻¹ (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha⁻¹ (value for carbon stock of woody biomass before conversion is 6.4 t C ha⁻¹ see section 6.2.4.2.1 and Table 6-24 as well as Table 6-25).

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr⁻¹ (default value = 0).

$\Delta T_{TO_OTHERS(i)}$ = area of land use i converted to another land-use category in a certain year, ha yr⁻¹.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)⁻¹.

i = type of land use converted to another land-use category

c) Changes of carbon stock in organic soils:

Organic soils cannot be found in Luxemburg.

d) Changes of carbon stock in mineral soils of annual cropland remaining annual cropland:

Emissions/removals were calculated using country specific values for the soil organic carbon content. The mean organic carbon content of soil per ha in the layer of 0-30 cm depth was determined for the different land uses (annual cropland, perennial cropland, grassland,

forest) by using the values of the soil database of ASTA (Administration des Services Techniques de l'Agriculture, Division des Laboratoires de Contrôle et d'Essais, Service de Pédologie).

According to expert judgment (EJ_4_01), there were no significant changes in relative stock change factors (tillage factor FMG; land use factor FLU; input factor FI) during the observation period 1990 to 2018 and these factors are set by default equal to 1. Thus there was no change in carbon stocks in annual cropland soils due to management.

e) Changes of carbon stock in mineral soils of perennial cropland converted to annual cropland:

According to the methodology described in Annex 3:, annual change in carbon stock of mineral soils = IEF(LUC_j) * conversion area, where :

$$IEF(LUC_{perennial\ cropland \rightarrow annual\ cropland}) = -0.462\ t\ C/ha\ *yr$$

IEF(LUC_j) = average yearly emission factor for carbon stock change in soil from land use change

6.3.4.1.2 Change of carbon stock of perennial cropland

a) Changes of carbon stock in biomass of perennial cropland remaining perennial cropland:

According to Tier 1 GPG (2006) for perennial cultures, a steady increase in biomass in the first 30 years is assumed. 3.33% of these cultures are removed and cause emissions. For older cultures the annual increase in biomass is assumed to be equal to the losses by harvesting. For calculating the carbon stock change of living biomass on perennial cropland the following formula was used:

$$Annual\ change\ in\ carbon\ stock\ in\ biomass = (area\ of\ perennial\ cropland * carbon\ accumulation\ rate) - (area\ of\ perennial\ cropland\ before\ 30\ years * 0.033 * biomass\ carbon\ stock\ at\ harvest)$$

where:

For the carbon accumulation rate the value of 0.21 t C ha⁻¹yr⁻¹ was used (stock at harvest - see below - divided by 30 years rotation cycle).

For the above ground biomass carbon stock at harvest the value of 6.4 t C ha⁻¹yr⁻¹ (see Table 6-25) was used.

b) Changes of carbon stock in biomass of annual cropland converted to perennial cropland:

For the calculation of annual change in carbon stocks of living biomass of land converted to cropland the IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$Annual\ change\ in\ carbon\ stock\ in\ biomass = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{ (B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO_OTHERS_i} \} \cdot CF$$

where :

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for perennial crops carbon accumulation rate is 0.21 t C ha⁻¹yr⁻¹ - see Table 6-24, Table 6-20 as well as Table 6-25 = accumulation of 6.4 tC/ha over 30 years).

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha⁻¹ (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha⁻¹ (value for carbon stock of biomass before conversion is 5 t C ha⁻¹ see section 6.2.4.2.1 and Table 6-24).

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr⁻¹ (default value = 0).

$\Delta T_{TO_OTHERS(i)}$ = area of land use I converted to another land-use category in a certain year, ha yr⁻¹.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)⁻¹.

i = type of land use converted to another land-use category

c) Changes of carbon stock in mineral soils of annual cropland converted to perennial cropland :

According to the methodology described in 1.2.4.2.2, annual change in carbon stock of mineral soils = IEF(LUC_j) * conversion area, where :

$$IEF(LUC_{annual\ cropland \rightarrow\ perennial\ cropland}) = +0.462\ t\ C/ha\ *yr$$

IEF(LUC_j) = average yearly emission factor for carbon stock change in soil from land use change

6.3.4.2 Land Use Changes to Cropland (4B2)

6.3.4.2.1 Change of carbon stock of land converted to annual cropland

The method follows the IPCC GPG with a transition period of 20 years for LUC areas and related estimates for the increases and decreases of biomass and soil C stocks. Growth rates for annual crops (annual cropland, grassland) are accounted only once in the year of LUC, while growth rates for perennial crops (perennial cropland, forest land) are accounted for the whole period of transition. In line with the IPCC GPG, a linear soil C stock change due to the LUCs between the average soil C stocks across 20 years was estimated.

a) Changes of carbon stock in biomass of land converted to annual cropland:

For the calculation of annual change in carbon stocks of living biomass of land converted to cropland the IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$\text{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{ (B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO_OTHERS_i} \} \cdot CF$$

where :

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for annual crops carbon accumulation rate is 5 t C ha⁻¹yr⁻¹).

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha⁻¹ (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha⁻¹ (value for carbon stock before conversion is 6.4 t C ha⁻¹ for perennial cropland, a dynamic value of 110.7 t C ha⁻¹ (previous 2000) and 128.7 t C ha⁻¹ (after 2010) for forestland with linear interpolation between 2000 and 2010, 6.3 t C ha⁻¹ for grassland, 4.3 t C ha⁻¹ for settlements and 0.0 t C ha⁻¹ for wetland and other land - see section 6.2.4.2.1 and Table 6-24.

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr⁻¹ (default value = 0).

$\Delta T_{TO_OTHERS(i)}$ = area of land use I converted to another land-use category in a certain year, ha yr⁻¹.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)⁻¹.

b) Changes of carbon stock in dead wood and litter of land converted to cropland:

For the calculation of annual change in carbon stocks of dead wood and litter of land converted to cropland equation 2.23 from the GPG 2006 is used:

$$\Delta D_{DOM} = \frac{(C_n - C_o) \cdot A_{on}}{T_{on}}$$

where :

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter (tonnes C yr⁻¹)

C_o = dead wood/litter stock, under the old land-use category, tonnes C ha⁻¹ (value dead wood in forest is a dynamic value ranging from 3,78 – 6.56 t C/ha*yr (as calculated in the NFAP for the FRL (AEV, www.emwelt.lu, 2019)) & default value for litter in forest = 19,2 t C/ha*yr (weighted average between default values of Table 2.2 of GPG 2006).

C_n = dead wood/litter stock, under the new land-use category, tonnes C ha⁻¹ (default value = 0 for all land-use categories but forest)

A_{on} = area undergoing conversion from old to new land-use category, ha

T_{on} = time period of the transition from old to new land-use category, yr. The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses.

d) Changes of carbon stock in mineral soils of land converted to annual cropland:

According to the methodology described in Annex 3:, annual change in carbon stock of mineral soils = IEF(LUC_j) * conversion area,

where :

$$IEF(LUC_{forestland \rightarrow annual\ cropland}) = -1.237 \text{ t C/ ha *yr}$$

$$IEF(LUC_{grassland \rightarrow annual\ cropland}) = -1.308 \text{ t C/ ha *yr}$$

$$IEF(LUC_{wetland \rightarrow annual\ cropland}) = +3.770 \text{ t C/ ha *yr}$$

$$IEF(LUC_{settlements \rightarrow annual\ cropland}) = +1.609 \text{ t C/ ha *yr}$$

$$IEF(LUC_{other\ land \rightarrow annual\ cropland}) = +3.770 \text{ t C/ ha *yr}$$

IEF(LUC_j) = average yearly emission factor for carbon stock change in soil from land use change j (eg forestland in cropland)

6.3.4.2.2 Change of carbon stock of land converted to perennial cropland

The method follows the IPCC GPG with a transition period of 20 years for LUC areas and related estimates for the increases and decreases of biomass and soil C stocks. Growth rates for annual crops (annual cropland, grassland) are accounted only once in the year of LUC, while growth rates for perennial crops (perennial cropland, forest land) are accounted for the whole period of transition. In line with the IPCC GPG, a linear soil C stock change due to the LUCs between the average soil C stocks across 20 years was estimated.

a) Changes of carbon stock in biomass land converted to perennial cropland:

For the calculation of annual change in carbon stocks of living biomass of grassland converted to perennial cropland the IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$\text{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO_OTHERS_i}\} \cdot CF$$

where :

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for perennial crops carbon accumulation rate is 0.21 t C ha⁻¹yr⁻¹).

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha⁻¹ (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha^{-1} (value for carbon stock before conversion is 5.0 t C ha^{-1} for annual cropland, 119.7 t C ha^{-1} for forestland, 6.3 t C ha^{-1} for grassland, 4.3 t C ha^{-1} for settlements and 0.0 t C ha^{-1} for wetland and other land - see section 6.2.4.2.1 and Table 6-24).

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr^{-1} (default value = 0).

$\Delta T_{TO_OTHERS(i)}$ = area of land use i converted to another land-use category in a certain year, $ha\ yr^{-1}$.

CF = carbon fraction of dry matter, tonne C (tonne d.m.) $^{-1}$.

i = type of land use converted to another land-use category

b) Changes of carbon stock in dead wood and litter of land converted to cropland:

For the calculation of annual change in carbon stocks of dead wood and litter of land converted to cropland equation 2.23 from the GPG 2006 is used:

$$\Delta D_{DOM} = \frac{(C_n - C_o) \cdot A_{on}}{T_{on}}$$

where :

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter (tonnes C yr^{-1})

dead wood/litter stock, under the old land-use category, tonnes C ha^{-1} (value dead wood in forest is a dynamic value ranging from 3,78 – 6.56 t C/ $ha \cdot yr$ (as calculated in the NFAP for the FRL (AEV, www.emwelt.lu, 2019)) & default value for litter in forest = 19,2 t C/ $ha \cdot yr$ (weighted average between default values of Table 2.2 of GPG 2006).

C_n = dead wood/litter stock, under the new land-use category, tonnes C ha^{-1} (default value = 0 for all land-use categories but forest)

A_{on} = area undergoing conversion from old to new land-use category, ha

T_{on} = time period of the transition from old to new land-use category, yr . The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses.

c) Changes of carbon stock in mineral soils of land converted to perennial cropland:

According to the methodology described in Annex 3:, annual change in carbon stock of mineral soils = IEF(LUC _{j}) * conversion area,

where :

$$IEF(LUC_{forestland \rightarrow perennial\ cropland}) = -1.237\ t\ C/ha \cdot yr$$

$$IEF(LUC_{grassland \rightarrow perennial\ cropland}) = -1.517\ t\ C/ha \cdot yr$$

$$IEF(LUC_{wetland \rightarrow perennial\ cropland}) = +5.079\ t\ C/ha \cdot yr$$

$$IEF(LUC_{settlements \rightarrow perennial\ cropland}) = +2.917\ t\ C/ha \cdot yr$$

$$IEF(LUC_{other\ land \rightarrow perennial\ cropland}) = +5.079\ t\ C/ha \cdot yr$$

IEF(LUC _{j}) = average yearly emission factor for carbon stock change in soil from land use change j (eg forestland in cropland)

6.3.4.2.3 N₂O emissions in soils of land converted to cropland

The annual release of direct N₂O emissions due to the conversion of land to cropland was calculated with IPCC default value (Tier 1) using equation 11.2 and 11.8 of the IPCC GPG (2006):

$$N_2O_{Direct} - N = F_{SOM} \cdot EF_1$$

$$F_{SOM} = \sum_{LU} \left[\left(\Delta C_{Mineral, LUC} \cdot \frac{1}{R} \right) \cdot 1000 \right]$$

where:

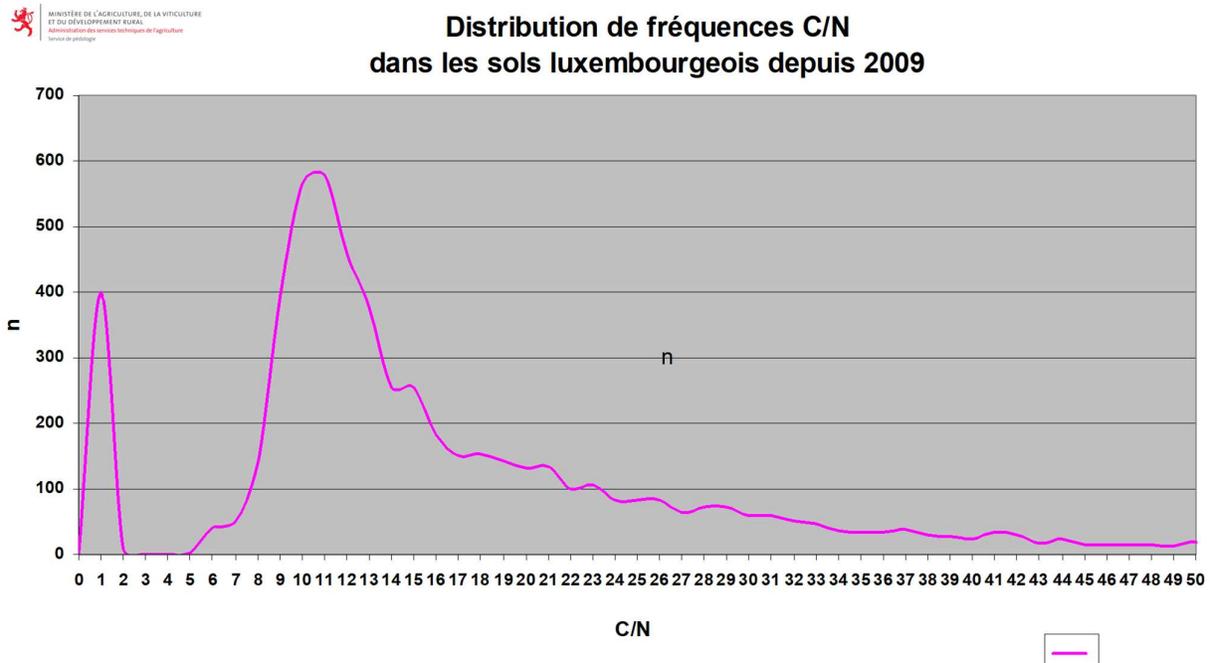
EF₁=emission factor for N mineralised as a result of loss of soil carbon (default value = 0.01)

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

ΔC_{Mineral,LU} = average annual loss of soil carbon for each land-use type (LU), tonnes C

R = C/N ratio = ratio by mass of C to N in the soil organic matter = 12. The country-specific C/N was derived from soil analysis done in 2009 (ARR 2011, §107), where C and N content was determined. The distribution curve of C/N ratio (as shown in Figure 6-14) shows a mean C/N ratio of approximately 12. Nevertheless it is important to highlight that the C/N ratio on mineral soils does not have the same significance compared to organic soils in forests. This is due the presence of nitrogen in the form of ammonium fixed in clay minerals. In this case the C/N ratio is however used to determine the potential of mineralisation of nitrogen contained in the organic matter. Separate soil analysis of C/N fraction does not exist for the different soil uses (forestland, grassland etc). According to expert judgement (EJ_4_02) (ASTA) the best available value at this moment in time remains 12.

Figure 6-14 - Frequency distribution of C/N ratio in Luxembourg's soils since 2009



Source: ASTA

The annual release of indirect N₂O emissions due to the conversion of land to cropland was calculated with IPCC default value (Tier 1) using equation 11.10 of the IPCC GPG (2006):

$$N_2O_{(L)} - N = F_{SOM} \cdot \text{Frac}_{LE} \cdot EF_5$$

where:

N₂O_(L)-N=annual amount of N₂O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kgN₂O-Nyr⁻¹

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

EF₅=emission factor for N₂O emissions from N leaching result of loss of soil carbon (default value = 0.0075)

$Frac_{LEACH-(H)}$ =fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kgN (kg of N additions)⁻¹ (default value = 0.30)

6.4 Grassland (4.C)

6.4.1 Category description

In this category emissions/removals from grassland management (grassland remaining grassland and land converted to grassland) are considered.

Some management practices (*e.g.* slash and burn *etc.*) and organic soils do not occur in Luxembourg. Dead wood and litter are considered in forestland converted to grass land areas but not for the remaining land categories converted to grassland.

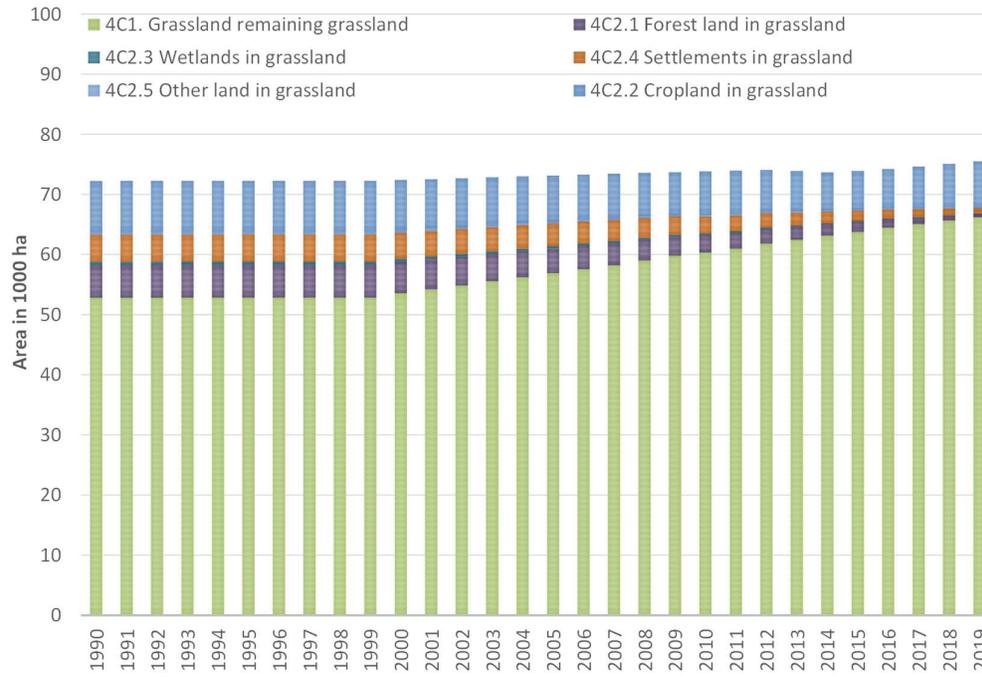
Emissions/Removals were estimated for the following IPCC sub-categories and their related sources/sinks (Table 6-30).

Table 6-30 – Sources (or sinks) considered for grassland management.

Category/source or sink
4C Grassland – total
4C1 Grassland remaining grassland
- carbon stock change due to changes in organic matter input to grassland soils
4C2 Land converted to grassland
4C2.1 Forest land converted to grassland
4C2.2 Cropland converted to grassland
- carbon stock change in living biomass of grassland
- carbon stock change due to changes in organic matter input (harvest residues) to grassland soils
4C2.3 Wetland converted to grassland
4C2.4 Settlement converted to grassland
4C2.5 Other land converted to grassland

In 2019, 75 543 ha of Luxembourg were grassland (Figure 6-15). Total grassland includes one cut meadows; two and more cut meadows, cultivated pastures, litter meadows, rough pastures and pastures and abandoned grassland.

Figure 6-15 – Trend of grassland and LUC to grassland (20 year conversion period) from 1990-2019



The annual emissions of grassland in Luxembourg amounted to 22.52 Gg CO₂ in 1990 and – 74.27 Gg CO₂ in 2020 (Table 6-31, Table 6-27). The source is mainly caused by soil C stock changes in land use change areas, particularly by forestland converted to grassland.

Table 6-31 – CO₂ removals/emissions for category 4C – Grassland for 1990-2019

4C - Grassland									
Greenhouse gas emissions/removals (Gg CO ₂ e)									
Year	4B Total Grassland (excluding leaching)	4C1 GL remaining GL	4C2.1 FL -> GL	4C2.2 CL -> GL	4C2.3 WL -> GL	4C2.4 Settlement -> GL	4C2.5 OL -> GL	N ₂ O (in CO ₂ eq)	N ₂ O leaching (in CO ₂ eq)
1990	22.52	NO	134.97	-44.56	-11.26	-50.18	-7.45	1.00	0.22
1991	22.61	NO	135.06	-44.56	-11.26	-50.18	-7.45	1.00	0.22
1992	22.71	NO	135.16	-44.56	-11.26	-50.18	-7.45	1.00	0.22
1993	22.80	NO	135.25	-44.56	-11.26	-50.18	-7.45	1.00	0.22
1994	22.89	NO	135.34	-44.56	-11.26	-50.18	-7.45	1.00	0.22
1995	22.99	NO	135.44	-44.56	-11.26	-50.18	-7.45	1.00	0.22
1996	23.08	NO	135.53	-44.56	-11.26	-50.18	-7.45	1.00	0.22
1997	23.17	NO	135.62	-44.56	-11.26	-50.18	-7.45	1.00	0.22
1998	23.26	NO	135.71	-44.56	-11.26	-50.18	-7.45	1.00	0.22
1999	23.35	NO	135.80	-44.56	-11.26	-50.18	-7.45	1.00	0.22
2000	-74.27	NO	33.44	-43.84	-10.24	-47.92	-6.67	0.96	0.22
2001	-71.21	NO	33.64	-43.09	-9.79	-46.58	-6.32	0.92	0.21
2002	-68.15	NO	33.85	-42.34	-9.33	-45.24	-5.97	0.88	0.20
2003	-65.10	NO	34.06	-41.59	-8.88	-43.90	-5.62	0.84	0.19
2004	-62.04	NO	34.26	-40.84	-8.43	-42.56	-5.27	0.80	0.18
2005	-58.98	NO	34.47	-40.09	-7.97	-41.22	-4.92	0.76	0.17
2006	-55.92	NO	34.67	-39.34	-7.52	-39.89	-4.57	0.72	0.16
2007	-52.87	NO	34.88	-38.59	-7.06	-38.55	-4.22	0.68	0.15
2008	-66.38	NO	16.44	-37.73	-6.44	-35.41	-3.87	0.63	0.14
2009	-62.50	NO	16.21	-36.86	-5.91	-33.01	-3.52	0.58	0.13
2010	-62.62	NO	15.18	-39.18	-5.39	-30.61	-3.17	0.54	0.12
2011	-58.69	NO	14.75	-38.05	-4.86	-28.20	-2.81	0.49	0.11
2012	-53.70	NO	14.32	-35.87	-4.33	-25.80	-2.46	0.44	0.10
2013	-49.37	NO	13.89	-34.35	-3.80	-23.40	-2.11	0.40	0.09
2014	-44.07	NO	13.46	-31.85	-3.27	-21.00	-1.76	0.35	0.08
2015	-43.79	NO	13.03	-34.38	-2.74	-18.59	-1.41	0.30	0.07
2016	-41.66	NO	12.60	-35.05	-2.21	-16.19	-1.06	0.26	0.06
2017	-41.87	NO	12.17	-38.07	-1.69	-13.79	-0.71	0.21	0.05
2018	-40.79	NO	11.75	-39.80	-1.16	-11.39	-0.36	0.17	0.04
2019	-39.72	NO	11.32	-41.53	-0.63	-8.98	-0.01	0.12	0.03
Trend 1990-2019	-276.36%	NA	-91.62%	-6.79%	-94.42%	-82.10%	-99.87%	-88.09%	-88.09%
Trend 2018-2019	-2.64%	NA	-3.65%	4.34%	-45.67%	-21.10%	-97.39%	-28.08%	-28.08%

6.4.2 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

For a detailed description of the development of the land transition matrix, please refer to section 6.1.3.3.

In exception to the use of the OBS land use maps has been made for LUC areas between cropland and grassland. The LUC areas grassland to cropland respectively cropland to grassland going beyond 269 ha (or LPIS data after 2009) according to OBS were allocated to the category “cropland remaining cropland”.

6.4.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

The LU89, LU99, LU07 and LU12 land use maps are the main data providers for the greenhouse gas reporting of IPCC category grassland, with the selected parameters defining grassland:

Land Use Class	Definition
Grassland	All grassland that is not considered as cropland including systems with vegetation or tree cover below the density used in the forest category. This includes all grassland from wild lands, recreational areas as well as agricultural systems. (IPCC GPG definition).

6.4.4 Methodological issues

6.4.4.1 Grassland remaining Grassland (4C1)

6.4.4.1.1 Carbon stock change of grassland

a) Changes in carbon stock in biomass of grassland remaining grassland:

As the biomass of grassland is harvested every year, there is no long term carbon storage in biomass of grassland remaining grassland.

b) Changes in carbon stock in mineral soils of grassland remaining grassland:

As for cropland, according to expert judgment, there was no change in relative stock change factors (tillage factor FMG; land use factor FLU; input factor FI) during the observation period 1990 to 2019 and these factors are set by default equal to 1. Thus, there was no change in carbon stocks in grassland soils due to management.

Consequently, there are neither emissions nor removals in IPCC Sub-category 5C1 - *Grassland remaining Grassland*, due to the fact that the biomass of grassland remaining grassland is harvested every year, and that there is no change in carbon stocks in grassland soils due to management (expert judgement EJ_4_03).

6.4.4.2 Land Use Changes to Grassland (4C2)

The method follows the IPCC GPG with a transition period of 20 years for LUC areas and related estimates for the increases and decreases of biomass and soil C stocks. Growth rates for annual crops (annual cropland, grassland) are accounted only once in the year of LUC, while growth rates for perennial crops (perennial cropland, forest land) are accounted for the whole period of transition. In line with the IPCC GPG, a linear soil C stock change due to the LUCs between the average soil C stocks across 20 years was estimated.

a) Changes in carbon stock in biomass of land converted to grassland:

For the calculation of annual change in carbon stocks of living biomass of land converted to grassland the IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$\text{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO_OTHERS_i}\} \cdot CF$$

where:

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for grassland carbon accumulation rate is 6.3 t C ha⁻¹yr⁻¹).

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha⁻¹ (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha⁻¹ (value for carbon stock before conversion is 6.4 t C ha⁻¹ for perennial cropland, a dynamic value of 110.7 t C ha⁻¹ (previous 2000) and 128.7 t C ha⁻¹ (after 2010) for forestland with linear interpolation between 2000 and 2010, 5.0 t C ha⁻¹ for annual cropland, 4.3 t C ha⁻¹ for settlements and 0.0 t C ha⁻¹ for wetland and other land- see section 6.2.4.2.1 and Table 6-24).

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr⁻¹ (default value = 0).

$\Delta T_{TO_OTHERS(i)}$ = area of land use i converted to another land-use category in a certain year, ha yr⁻¹.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)⁻¹.

i = type of land use converted to another land-use category

b) Changes of carbon stock in dead wood and litter of land converted to grassland:

For the calculation of annual change in carbon stocks of dead wood and litter of land converted to grassland equation 2.23 from the GPG 2006 is used:

$$\Delta D_{DOM} = \frac{(C_n - C_o) \cdot A_{on}}{T_{on}}$$

where :

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter (tonnes C yr⁻¹)

dead wood/litter stock, under the old land-use category, tonnes C ha⁻¹ (value dead wood in forest is a dynamic value ranging from 3,78 – 6.56 t C/ha*yr (as calculated in the NFAP for the FRL (AEV, www.emwelt.lu, 2019)) & default value for litter in forest = 19,2 t C/ha*yr (weighted average between default values of Table 2.2 of GPG 2006).

C_n = dead wood/litter stock, under the new land-use category, tonnes C ha⁻¹ (default value = 0 for all land-use categories but forest)

A_{on} = area undergoing conversion from old to new land-use category, ha

T_{on} = time period of the transition from old to new land-use category, yr. The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses

c) Changes in carbon stock in mineral soil of land converted to grassland:

According to the methodology described in Annex 3:, annual change in carbon stock of mineral soils = IEF(LUC_j) * conversion area,

where:

$$IEF(LUC_{forestland \rightarrow grassland}) = -0.476 \text{ t C/ ha *yr}$$

$$IEF(LUC_{annual cropland \rightarrow grassland}) = +1.308 \text{ t C/ ha *yr}$$

$$IEF(LUC_{perennial cropland \rightarrow grassland}) = +1.517 \text{ t C/ ha *yr}$$

$$IEF(LUC_{wetland \rightarrow grassland}) = +5.079 \text{ t C/ ha *yr}$$

$$IEF(LUC_{settlements \rightarrow grassland}) = +2.917 \text{ t C/ ha *yr}$$

$$IEF(LUC_{other land \rightarrow grassland}) = +5.079 \text{ t C/ ha *yr}$$

IEF(LUCj) = average yearly emission factor for carbon stock change in soil from land use change

6.4.4.2.1 N₂O emissions in soils of land converted to grassland

The annual release of direct N₂O emissions due to the conversion of land to grassland was calculated with IPCC default value (Tier 1) using equation 11.2 and 11.8 of the IPCC GPG (2006):

$$N_2O_{Direct} - N = F_{SOM} \cdot EF_1$$

$$F_{SOM} = \sum_{LU} \left[\left(\Delta C_{Mineral, LUC} \cdot \frac{1}{R} \right) \cdot 1000 \right]$$

where:

EF₁=emission factor for N mineralised as a result of loss of soil carbon (default value = 0.01)

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

ΔC_{Mineral, LU} = average annual loss of soil carbon for each land-use type (LU), tonnes C

R = C/N ratio = ratio by mass of C to N in the soil organic matter = 12.

The annual release of indirect N₂O emissions due to the conversion of land to cropland was calculated with IPCC default value (Tier 1) using equation 11.10 of the IPCC GPG (2006):

$$N_2O_{(L)} - N = F_{SOM} \cdot \text{Frac}_{LEACH-(H)} \cdot EF_5$$

where:

N₂O_(L)-N=annual amount of N₂O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kgN₂O-Nyr⁻¹

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

EF₅=emission factor for N₂O emissions from N leaching result of loss of soil carbon (default value = 0.0075)

Frac_{LEACH-(H)}=fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kgN (kg of N additions)⁻¹ (default value = 0.30)

6.5 Wetlands (4.D)

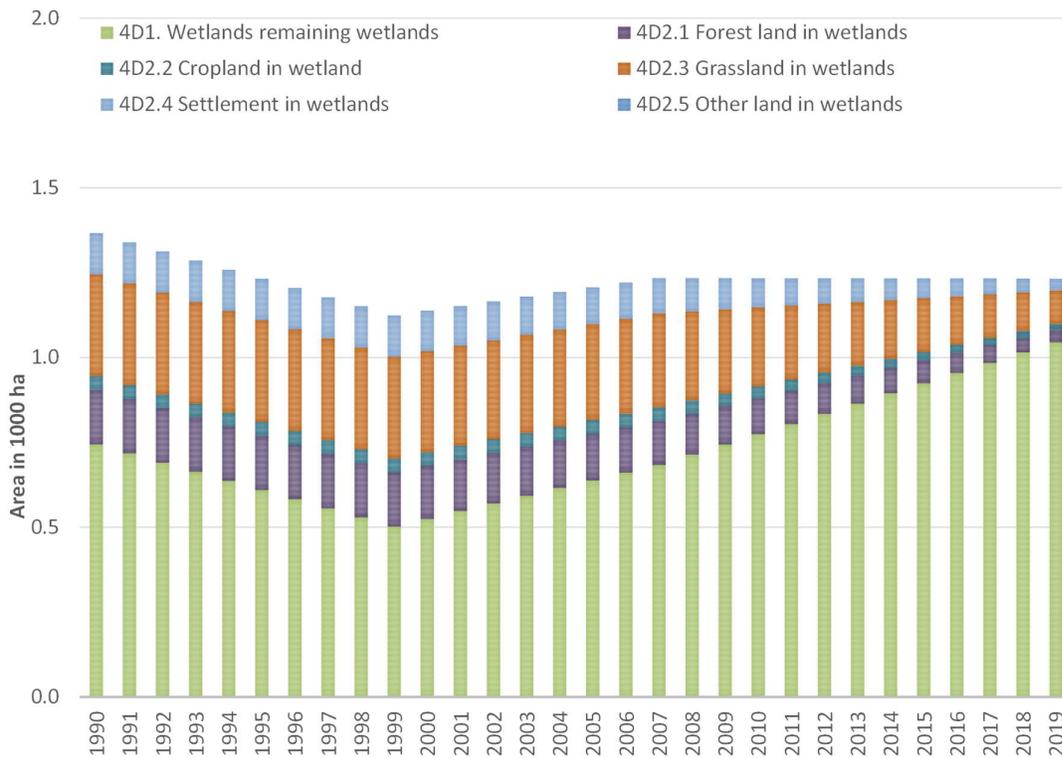
6.5.1 Category description

In this category emissions/removals from land converted to wetland are considered.

Due to the lack of information, it is assumed that the C stock in biomass, dead organic matter and soil of surface waters is zero.

In 2018, 1 232 ha of Luxembourg were wetland (Figure 6-16). Total wetland includes any areas covered by water (rivers, lakes, *etc.*) or saturated by water (marshes, mires, *etc.*). There is no peat land, hence no organic soils in wetlands in Luxembourg.

Figure 6-16 – Trend of wetland and LUC to wetland (20 year conversion period) from 1990-2019



The annual emissions from wetland in Luxembourg amounted to 15.9 Gg CO₂ in 1990 and 3.61 Gg CO₂ in 2019 (Table 6-32, Figure 6-28). The source is mainly caused by soil C stock changes in land use change areas, particularly by forestland and grassland converted to wetland.

Table 6-32 – CO₂ removals/emissions for category 4D – Wetland for 1990-2019

4D - Wetland									
Greenhouse gas emissions/removals (Gg CO ₂ e)									
Year	4D Total Wetland (excluding leaching)	4D1 WL remaining WL	4D2.1 FL -> WL	4D2.2 CL -> WL	4D2.3 GL -> WL	4D2.4 Settlements -> WL	4D2.5 OL -> WL	N ₂ O (in CO ₂ eq)	N ₂ O leaching (in CO ₂ eq)
1990	15.90	NE	7.22	0.59	5.94	1.05	0.00	1.10	0.25
1991	15.90	NE	7.22	0.59	5.94	1.05	0.00	1.10	0.25
1992	15.91	NE	7.22	0.59	5.94	1.05	0.00	1.10	0.25
1993	15.91	NE	7.23	0.59	5.94	1.05	0.00	1.10	0.25
1994	15.91	NE	7.23	0.59	5.94	1.05	0.00	1.10	0.25
1995	15.91	NE	7.23	0.59	5.94	1.05	0.00	1.10	0.25
1996	15.92	NE	7.23	0.59	5.94	1.05	0.00	1.10	0.25
1997	15.92	NE	7.24	0.59	5.94	1.05	0.00	1.10	0.25
1998	15.92	NE	7.24	0.59	5.94	1.05	0.00	1.10	0.25
1999	15.93	NE	7.24	0.59	5.94	1.05	0.00	1.10	0.25
2000	13.71	NE	5.21	0.59	5.82	1.00	0.00	1.09	0.24
2001	13.59	NE	5.18	0.59	5.77	0.98	0.00	1.07	0.24
2002	13.47	NE	5.14	0.59	5.71	0.96	0.00	1.06	0.24
2003	13.35	NE	5.11	0.59	5.66	0.95	0.00	1.04	0.23
2004	13.23	NE	5.08	0.59	5.61	0.93	0.00	1.02	0.23
2005	13.11	NE	5.04	0.59	5.55	0.91	0.00	1.01	0.23
2006	12.99	NE	5.01	0.60	5.50	0.89	0.00	0.99	0.22
2007	12.87	NE	4.97	0.60	5.45	0.88	0.00	0.98	0.22
2008	9.78	NE	2.65	0.53	4.89	0.78	0.00	0.92	0.21
2009	9.22	NE	2.50	0.51	4.61	0.73	0.00	0.87	0.20
2010	8.65	NE	2.33	0.48	4.34	0.68	0.00	0.81	0.18
2011	8.09	NE	2.17	0.45	4.06	0.64	0.00	0.76	0.17
2012	7.53	NE	2.02	0.43	3.78	0.59	0.00	0.71	0.16
2013	6.97	NE	1.86	0.40	3.51	0.55	0.00	0.65	0.15
2014	6.41	NE	1.70	0.38	3.23	0.50	0.00	0.60	0.13
2015	5.85	NE	1.54	0.35	2.95	0.46	0.00	0.55	0.12
2016	5.29	NE	1.39	0.32	2.67	0.41	0.00	0.49	0.11
2017	4.73	NE	1.23	0.30	2.40	0.37	0.00	0.44	0.10
2018	4.17	NE	1.07	0.27	2.12	0.32	0.00	0.38	0.09
2019	3.61	NE	0.92	0.25	1.84	0.28	0.00	0.33	0.07
Trend 1990-2019	-77.30%	NA	-87.32%	-58.51%	-68.97%	-73.67%	NA	-70.15%	-70.15%
Trend 2018-2019	-13.43%	NA	-14.68%	-9.64%	-13.08%	-14.09%	NA	-14.05%	-14.05%

6.5.2 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

For a detailed description of the development of the land transition matrix, please refer to section 6.1.3.3.

6.5.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

The LU89, LU99, LU07 and LU12 land use maps are the main data providers for the greenhouse gas reporting of IPCC category wetland.

The selected parameters defining wetland are:

Land Use Class	Definition
Wetland	Land that is covered or saturated by water for all or part of the year (<i>e.g.</i> peat land) and that does not fall into other categories.
Water	Land that is covered by water for all the year and that does not fall into other categories. This includes reservoirs. (IPCC GPG definition)

6.5.4 Methodological issues

6.5.4.1 Wetlands remaining Wetlands (4D1)

Due to a lack of required data on carbon stock changes, this category has not yet been estimated. Thus, it is assumed that the C stock in biomass, dead organic matter and soil of surface waters is 0. However, it should be noted, that areas next to rivers or lakes which can be flooded, are considered as grassland, as these areas are most often being used as grazing land for animals.

6.5.4.2 Land Use Changes to Wetlands (4D2)

a) Changes in carbon stock in biomass of land converted to grassland:

For the calculation of the annual change in carbon stocks of living biomass in land converted to wetland the following equation IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$\text{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{ (B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO_OTHER_i} \} \cdot CF$$

where :

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for carbon accumulation rate is 0.0 t C ha⁻¹yr⁻¹).

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha⁻¹ (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha⁻¹ (value for carbon stock before conversion is 6.4 t C ha⁻¹ for perennial cropland, a dynamic value of 110.7 t C ha⁻¹ (previous 2000) and 128.7 t C ha⁻¹ (after 2010) for forestland with linear interpolation between 2000 and 2010, 6.3 t C ha⁻¹ for grassland, 4.3 t C ha⁻¹ for settlements, 5.0 t C ha⁻¹ for annual cropland and 0.0 t C ha⁻¹ other land - see section 6.2.4.2.1 and Table 6-24).

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr⁻¹ (default value = 0).

$\Delta T_{TO_OTHERS(i)}$ = area of land use I converted to another land-use category in a certain year, ha yr⁻¹.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)⁻¹.

b) Changes of carbon stock in dead wood and litter of land converted to wetland:

For the calculation of annual change in carbon stocks of dead wood and litter of land converted to wetland equation 2.23 from the GPG 2006 is used:

$$\Delta D_{DOM} = \frac{(C_n - C_o) \cdot A_{on}}{T_{on}}$$

where :

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter (tonnes C yr⁻¹)

dead wood/litter stock, under the old land-use category, tonnes C ha⁻¹ (value dead wood in forest is a dynamic value ranging from 3,78 – 6.56 t C/ha*yr (as calculated in the NFAP for the FRL (AEV, www.emwelt.lu, 2019)) & default value for litter in forest = 19,2 t C/ha*yr (weighted average between default values of Table 2.2 of GPG 2006).

C_n = dead wood/litter stock, under the new land-use category, tonnes C ha⁻¹ (default value = 0 for all land-use categories but forest)

A_{on} = area undergoing conversion from old to new land-use category, ha

T_{on} = time period of the transition from old to new land-use category, yr. The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses

c) Changes in carbon stocks in soil of land converted to wetland

According to the methodology described in Annex 3., annual change in carbon stock of mineral soils = IEF(LUC_j) * conversion area,

where :

$$IEF(LUC_{forestland \rightarrow wetland}) = - 5.554 \text{ t C/ ha *yr}$$

$$IEF(LUC_{perennial cropland \rightarrow wetland}) = - 3.778 \text{ t C/ ha *yr}$$

$$IEF(LUC_{annual cropland \rightarrow wetland}) = -3.770 \text{ t C/ ha *yr}$$

$$IEF(LUC_{grassland \rightarrow wetland}) = - 5.079 \text{ t C/ ha *yr}$$

$$IEF(LUC_{settlements \rightarrow wetland}) = - 2.917 \text{ t C/ ha *yr}$$

$$IEF(LUC_{other land \rightarrow wetland}) = 2.162 \text{ t C/ ha *yr}$$

IEF(LUC_j) = average yearly emission factor for carbon stock change in soil from land use change

6.5.4.2.1 N₂O emissions in soils of land converted to wetland

The annual release of direct N₂O emissions due to the conversion of land to wetland was calculated with IPCC default value (Tier 1) using equation 11.2 and 11.8 of the IPCC GPG (2006):

$$N_2O_{Direct} - N = F_{SOM} \cdot EF_1$$

$$F_{SOM} = \sum_{LU} \left[\left(\Delta C_{Mineral, LUC} \cdot \frac{1}{R} \right) \cdot 1000 \right]$$

where:

EF₁=emission factor for N mineralised as a result of loss of soil carbon (default value = 0.01)

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

ΔC_{Mineral, LU} = average annual loss of soil carbon for each land-use type (LU), tonnes C

R = C/N ratio = ratio by mass of C to N in the soil organic matter = 12.

The annual release of indirect N₂O emissions due to the conversion of land to cropland was calculated with IPCC default value (Tier 1) using equation 11.10 of the IPCC GPG (2006):

$$N_2O_{(L)} - N = F_{SOM} \cdot FraC_{LEACH-(H)} \cdot EF_5$$

where:

N₂O_(L)-N=annual amount of N₂O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kgN₂O-Nyr⁻¹

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

EF₅=emission factor for N₂O emissions from N leaching result of loss of soil carbon (default value = 0.0075)

FraC_{LEACH-(H)}=fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kgN (kg of N additions)⁻¹ (default value = 0.30)

6.6 Settlements (4.E)

6.6.1 Category description

In this category emissions/removals from land converted to settlements are considered.

In 2019, 26 207 ha of Luxembourg were settlements (Figure 6-17). The area in conversion status from “Land converted to Settlement” causes annual emission due to C stock changes of biomass and soils from 152.67 Gg CO₂ to 56.91 Gg CO₂ (Table 6-33).

Annual LUCs to settlement occur from the sub-categories "Forestland", "Cropland", "Grassland", "Wetland" and "Other land".

Figure 6-17 – Trend of settlement and LUC to settlement (20 year conversion period) from 1990-2019

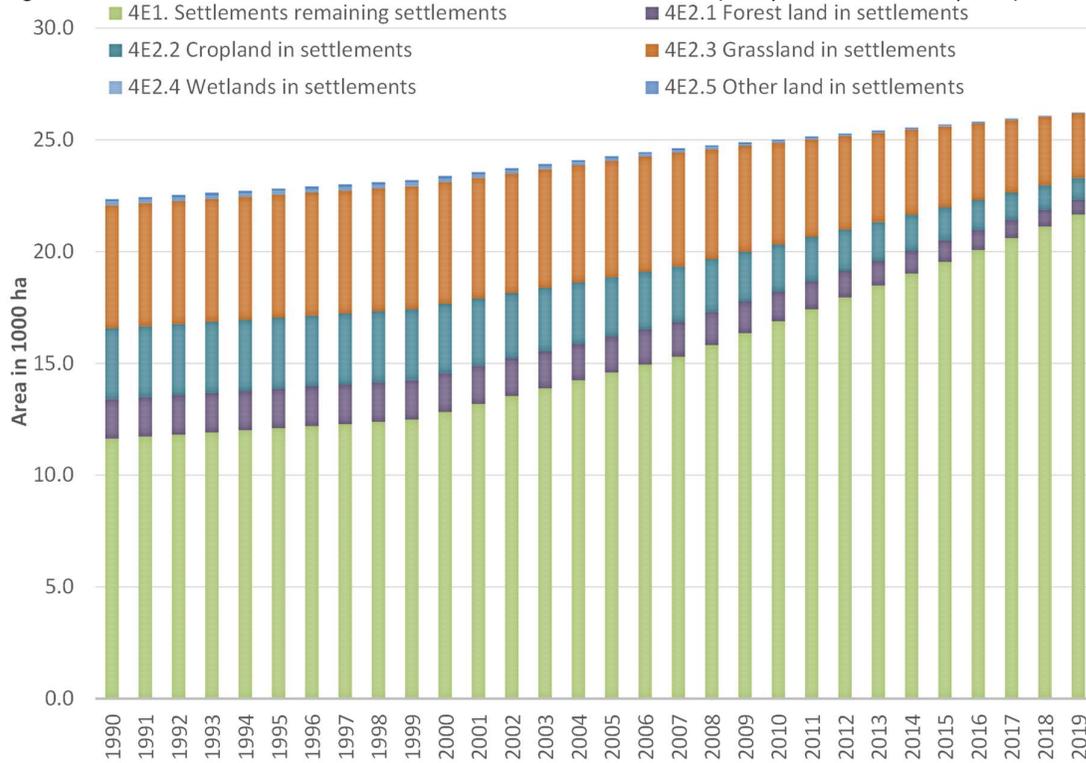


Table 6-33 – CO₂ removals/emissions for category 5E – Settlement from 1990-2019

4E - Settlement									
Greenhouse gas emissions/removals (Gg CO ₂ e)									
Year	4E Total Settlement (excluding leaching)	4E1 Settlement -> Settlement	4E2.1 FL -> Settlement	4E2.2 CL -> Settlement	4E2.3 GL -> Settlement	4E2.4 WL -> Settlement	4E2.5 OL -> Settlement	N ₂ O (in CO ₂ eq)	N ₂ O leaching (in CO ₂ eq)
1990	152.40	NE	64.00	19.40	60.80	-1.43	-0.96	10.60	2.38
1991	152.43	NE	64.03	19.40	60.80	-1.43	-0.96	10.60	2.38
1992	152.46	NE	64.06	19.40	60.80	-1.43	-0.96	10.60	2.38
1993	152.49	NE	64.09	19.40	60.80	-1.43	-0.96	10.60	2.38
1994	152.52	NE	64.12	19.40	60.80	-1.43	-0.96	10.60	2.38
1995	152.55	NE	64.15	19.40	60.80	-1.43	-0.96	10.60	2.38
1996	152.58	NE	64.18	19.40	60.80	-1.43	-0.96	10.60	2.38
1997	152.61	NE	64.21	19.40	60.80	-1.43	-0.96	10.60	2.38
1998	152.64	NE	64.24	19.40	60.80	-1.43	-0.96	10.60	2.38
1999	152.67	NE	64.27	19.40	60.80	-1.43	-0.96	10.60	2.38
2000	136.19	NE	51.01	17.61	59.37	-1.35	-0.89	10.45	2.35
2001	135.56	NE	51.39	17.15	58.86	-1.30	-0.84	10.30	2.32
2002	134.92	NE	51.78	16.68	58.35	-1.25	-0.80	10.16	2.29
2003	134.28	NE	52.16	16.22	57.85	-1.20	-0.75	10.01	2.25
2004	133.64	NE	52.54	15.76	57.34	-1.15	-0.71	9.86	2.22
2005	133.01	NE	52.92	15.30	56.83	-1.10	-0.66	9.72	2.19
2006	132.37	NE	53.30	14.84	56.33	-1.05	-0.62	9.57	2.15
2007	131.73	NE	53.69	14.38	55.82	-1.00	-0.57	9.43	2.12
2008	97.94	NE	25.82	13.09	51.45	-0.93	-0.52	9.04	2.03
2009	94.39	NE	25.09	12.41	49.58	-0.87	-0.48	8.65	1.95
2010	90.23	NE	23.76	11.74	47.70	-0.80	-0.43	8.26	1.86
2011	86.53	NE	22.88	11.07	45.83	-0.74	-0.38	7.87	1.77
2012	82.83	NE	22.00	10.39	43.96	-0.68	-0.34	7.49	1.68
2013	79.12	NE	21.12	9.72	42.09	-0.61	-0.29	7.10	1.60
2014	75.42	NE	20.25	9.04	40.21	-0.55	-0.24	6.71	1.51
2015	71.72	NE	19.37	8.37	38.34	-0.48	-0.20	6.32	1.42
2016	68.02	NE	18.49	7.69	36.47	-0.42	-0.15	5.93	1.34
2017	64.31	NE	17.61	7.02	34.60	-0.36	-0.10	5.55	1.25
2018	60.61	NE	16.73	6.35	32.72	-0.29	-0.06	5.16	1.16
2019	56.91	NE	15.86	5.67	30.85	-0.23	-0.01	4.77	1.07
Trend 1990-2019	-62.66%	NA	-75.22%	-70.76%	-49.26%	-83.97%	-98.92%	-54.99%	-54.99%
Trend 2018-2019	-6.11%	NA	-5.25%	-10.63%	-5.72%	-21.74%	-81.85%	-7.52%	-7.52%

6.6.2 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

For a detailed description of the development of the land transition matrix, please refer to section 6.1.3.3.

6.6.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

The LU89, LU99, LU07 and LU12 land use maps are the main data providers for the greenhouse gas reporting of IPCC category settlements. The selected parameters defining settlements are:

Land Use Class	Definition
Settlements	All developed land, including transportation and any size of human settlement unless already included under other categories.(IPCC GPG definition)

The settlement area in correspondence to the LULUCF category comprises the following subcategories:

- building land : sealed, partly sealed and unsealed area,
- parks and gardens,

- road, railway, track and excavation area,
- other, not further differentiated settlement area.

6.6.4 Methodological issues

6.6.4.1 Settlements remaining Settlements (4E1)

Due to a lack of data, this category has not been estimated.

6.6.4.2 Land Use Changes to Settlements (4E2)

a) Changes in carbon stock in biomass of land converted to settlements:

For the estimation of biomass stock and biomass growth in settlements, data from the municipality of Luxembourg was used. According to the magazine "EcoLogique n°1 2010" the municipality of Luxembourg has 18 500 trees in public unsealed areas which belong to the settlement category (*i.e.* are not forest or agricultural land). This amount was multiplied with annual growth rates of settlement trees as published in the IPCC GPG 2006 (Table 8.2). It was assumed that 75 % of these trees represent hardwood species for which according to this table 0.0100 t C/ha*y as annual growth rate per tree was taken. The other 25 % were assumed to be represented half-half by pine and spruce (0.0087 and 0.0092 t C/ha*y, respectively). The resulting annual growth rate was then divided by the related public unsealed area of Luxembourg city to get a per ha value. This resulted in an annual growth of trees at unsealed settlement areas of 0.25 t C/ha*y. For shrubs (each year 10 000 shrubs are planted at public areas of Luxembourg city) and annual plants, an annual growth rate of 0.125 and 3.2 t C/ha*y, respectively, at unsealed settlement areas was taken. Due to the lack of own data sources, these values were derived from the related estimates for Austria which are based on a study for the city of Vienna (Dörflinger, Hietz, Maier, Punz, & Fussenegger, 1995). From these values and the percentage of unsealed area per ha settlement (40 % - derived by the composition of the settlement area according to LU99 and LU07) the annual C stock growth rate of biomass per settlement area (sealed plus unsealed) was estimated: 0.15 t C/ha*y for perennial plants and 1.29 t C/ha*y for annual plants. These annual biomass growth rates were assumed to be a valid average for settlement areas in Luxembourg and were used for areas of LUCs to settlement and for the 20 years of transition period after LUC (perennial plants) or for the first year after LUC only (annual plants).

For the biomass losses at LUC areas from settlements to other land uses the same data origins were used. The average biomass C stock at these areas was estimated to represent an equivalent of 20 years of growth of the tree and shrub biomass with the annual growth rates above and one biomass of annual plants. This results in a total biomass stock of 4.34 t C/ha to be present per ha settlement area. The rationale, for the 20-year growth period (because at 20 years trees are comparatively small), is that settlement areas with an equal distribution of older and younger biomass stocks are converted. Therefore, from a range of settlement areas with biomass stocks representing 1 year to 40 years of growth that are converted, the biomass stock from this range of land-use change areas is the average one of 20 years.

The methodology and activity data are described in chapter 6.2.4. However, the perennial plants in the settlement areas are estimated with a continued annual growth during the whole LUC transition period of 20 years as described in chapter 6.6.4.2.

For the calculation of the annual change in carbon stocks of living biomass in land converted to settlements the following equation IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$\text{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO_OTHERS_i}\} \cdot CF$$

where:

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for perennial crops carbon accumulation rate is 0.15 t C ha⁻¹yr⁻¹ for perennial plants for a period of 20 years and 1.29 t C ha⁻¹yr⁻¹ for annual plants for a period of 1 year.

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha⁻¹ (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha⁻¹ (value for carbon stock before conversion is 6.4 t C ha⁻¹ for perennial cropland, a dynamic value of 110.7 t C ha⁻¹ (previous 2000) and 128.7 t C ha⁻¹ (after 2010) for forestland with linear interpolation between 2000 and 2010, 6.3 t C ha⁻¹ for grassland, 5.0 t C ha⁻¹ for annual cropland and 0.0 t C ha⁻¹ for wetland and 0.0 t C ha⁻¹ other land - see section 6.2.4.2.1 and Table 6-24.

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr⁻¹ (default value = 0).

$\Delta T_{TO_OTHERS(i)}$ = area of land use I converted to another land-use category in a certain year, ha yr⁻¹.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)⁻¹.

b) Changes of carbon stock in dead wood and litter of land converted to settlements:

For the calculation of annual change in carbon stocks of dead wood and litter of land converted to settlements equation 2.23 from the GPG 2006 is used:

$$\Delta D_{DOM} = \frac{(C_n - C_o) \cdot A_{on}}{T_{on}}$$

where :

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter (tonnes C yr⁻¹)

dead wood/litter stock, under the old land-use category, tonnes C ha⁻¹ (value dead wood in forest is a dynamic value ranging from 3,78 – 6.56 t C/ha*yr (as calculated in the NFAP for the FRL (AEV, www.emwelt.lu, 2019)) & default value for litter in forest = 19,2 t C/ha*yr (weighted average between default values of Table 2.2 of GPG 2006).

C_n = dead wood/litter stock, under the new land-use category, tonnes C ha⁻¹ (default value = 0 for all land-use categories but forest)

A_{on} = area undergoing conversion from old to new land-use category, ha

T_{on} = time period of the transition from old to new land-use category, yr. The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses

c) Changes in carbon stocks in soil of land converted to settlements

The following assumptions were taken to estimate the soil C stock in settlements. Sealed areas were assumed to have a soil C stock of 0 t C/ha. The unsealed settlement area (on average 40 % according to OBS99 and OBS07) was assumed to have the same soil C stock as grassland in Luxembourg (107 t C/ha). This resulted for total settlement in a soil C stock of 43 t C/ha which was used as initial soil C stock before LUC from settlement to other land uses or as final soil C stock after 20 years of transition after LUC to settlement.

According to the methodology described in Annex 3; annual change in carbon stock of mineral soils = IEF(LUC_j) * conversion area, where :

$$IEF(LUC_{forestland \rightarrow settlements}) = - 3.393 \text{ t C/ ha *yr}$$

$$IEF(LUC_{annual cropland \rightarrow settlements}) = - 1.609 \text{ t C/ ha *yr}$$

$$IEF(LUC_{perennial cropland \rightarrow settlements}) = - 1.616 \text{ t C/ ha *yr}$$

$$IEF(LUC_{grassland \rightarrow settlements}) = - 2.917 \text{ t C/ ha *yr}$$

$$IEF(LUC_{wetland \rightarrow settlements}) = + 2.162 \text{ t C/ ha *yr}$$

$$IEF(LUC_{other land \rightarrow settlements}) = + 2.162 \text{ t C/ ha *yr}$$

EF(LUC_j) = average yearly emission factor for carbon stock change in soil from land use change j

6.6.4.2.1 N₂O emissions in soils of land converted to settlements

The annual release of direct N₂O emissions due to the conversion of land to settlements was calculated with IPCC default value (Tier 1) using equation 11.2 and 11.8 of the IPCC GPG (2006):

$$N_2O_{Direct} - N = F_{SOM} \cdot EF_1$$

$$F_{SOM} = \sum_{LU} \left[\left(\Delta C_{Mineral, LUC} \cdot \frac{1}{R} \right) \cdot 1000 \right]$$

where:

EF₁=emission factor for N mineralised as a result of loss of soil carbon (default value = 0.01)

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

ΔC_{Mineral, LU} = average annual loss of soil carbon for each land-use type (LU), tonnes C

R = C/N ratio = ratio by mass of C to N in the soil organic matter = 12.

The annual release of indirect N₂O emissions due to the conversion of land to cropland was calculated with IPCC default value (Tier 1) using equation 11.10 of the IPCC GPG (2006):

$$N_2O_{(L)} - N = F_{SOM} \cdot \text{Frac}_{LEACH-(H)} \cdot EF_5$$

where:

N₂O_(L)-N=annual amount of N₂O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kgN₂O-Nyr⁻¹

F_{SOM}= the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

EF₅=emission factor for N₂O emissions from N leaching result of loss of soil carbon (default value = 0.0075)

Frac_{LEACH-(H)}=fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kgN (kg of N additions)⁻¹ (default value = 0.30)

6.7 Other Land (4.F)

6.7.1 Category description

In this category emissions/removals from land converted to other land are considered.

In 2018, 54 ha of Luxembourg were considered as other land Figure 6-18. The area in conversion status from “Land converted to Other Land” for a time period of 20 years ranges from 56 ha to 12 ha between the years 1990 and 2019, causing annual emission rates due to C stock changes of biomass and soils from 1.7 Gg CO₂ to 0.1 Gg CO₂ (Table 6-34).

Annual LUCs to other land occur in the sub-categories "Forestland", "Cropland", "Grassland", "Settlements" and "Wetland".

Figure 6-18—Trend of Other Land and LUC to Other Land (20 year conversion period) from 1990-2019

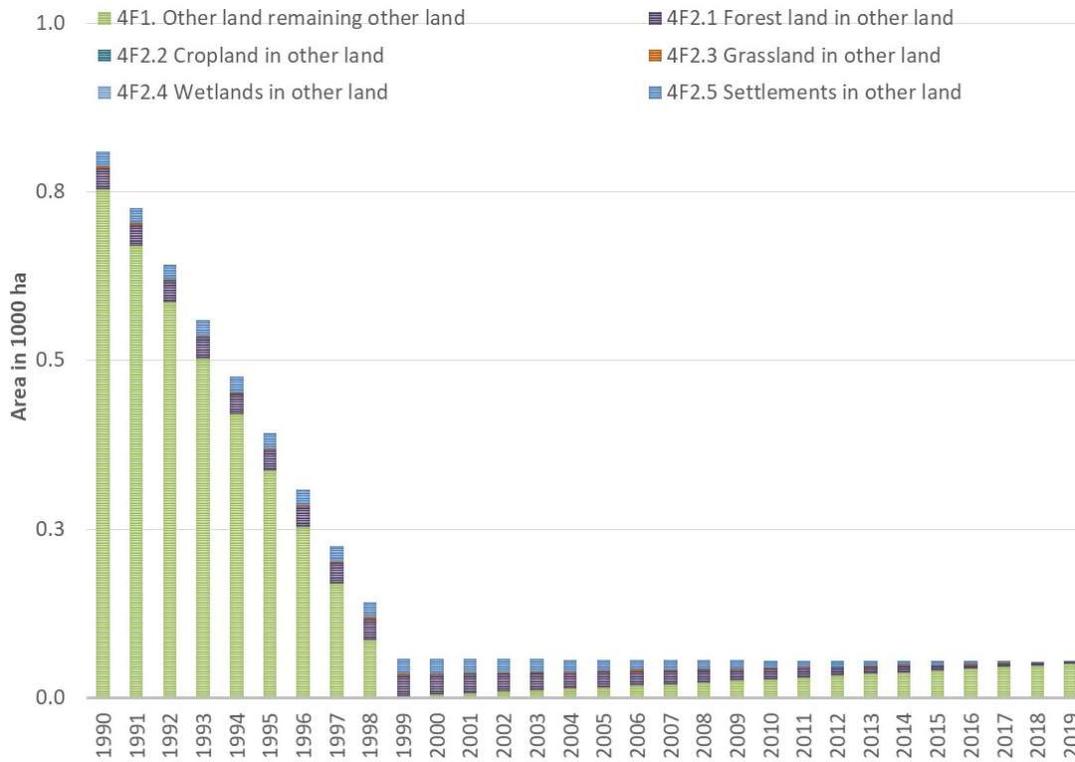


Table 6-34– CO₂ removals/emissions for category 4F – Other land from 1990-2018

4F - Other land									
Greenhouse gas emissions/removals (Gg CO ₂ e)									
Year	4F Total Other land (excluding leaching)	4F1 OL remaining OL	4F2.1 FL -> OL	4F2.2 CL -> OL	4F2.3 GL -> OL	4F2.4WL -> OL	4F2.5 Settlement -> OL	N ₂ O (in CO ₂ eq)	N ₂ O leaching (in CO ₂ eq)
1990	1.70	NE	1.38	0.01	0.04	0.00	0.19	0.09	0.02
1991	1.70	NE	1.38	0.01	0.04	0.00	0.19	0.09	0.02
1992	1.70	NE	1.38	0.01	0.04	0.00	0.19	0.09	0.02
1993	1.70	NE	1.38	0.01	0.04	0.00	0.19	0.09	0.02
1994	1.70	NE	1.38	0.01	0.04	0.00	0.19	0.09	0.02
1995	1.70	NE	1.38	0.01	0.04	0.00	0.19	0.09	0.02
1996	1.70	NE	1.38	0.01	0.04	0.00	0.19	0.09	0.02
1997	1.70	NE	1.38	0.01	0.04	0.00	0.19	0.09	0.02
1998	1.70	NE	1.38	0.01	0.04	0.00	0.19	0.09	0.02
1999	1.70	NE	1.39	0.01	0.04	0.00	0.19	0.09	0.02
2000	0.98	NE	0.69	0.01	0.03	0.00	0.16	0.09	0.02
2001	0.94	NE	0.66	0.01	0.03	0.00	0.15	0.08	0.02
2002	0.90	NE	0.64	0.01	0.03	0.00	0.15	0.08	0.02
2003	0.86	NE	0.61	0.01	0.03	0.00	0.14	0.07	0.02
2004	0.83	NE	0.59	0.01	0.03	0.00	0.13	0.07	0.02
2005	0.79	NE	0.56	0.01	0.03	0.00	0.12	0.07	0.01
2006	0.75	NE	0.54	0.01	0.03	0.00	0.11	0.06	0.01
2007	0.71	NE	0.51	0.01	0.03	0.00	0.11	0.06	0.01
2008	0.60	NE	0.41	0.01	0.03	0.00	0.10	0.05	0.01
2009	0.55	NE	0.38	0.01	0.03	0.00	0.09	0.05	0.01
2010	0.51	NE	0.35	0.00	0.02	0.00	0.08	0.05	0.01
2011	0.46	NE	0.32	0.00	0.02	0.00	0.07	0.04	0.01
2012	0.42	NE	0.29	0.00	0.02	0.00	0.06	0.04	0.01
2013	0.37	NE	0.26	0.00	0.02	0.00	0.05	0.03	0.01
2014	0.33	NE	0.23	0.00	0.02	0.00	0.05	0.03	0.01
2015	0.28	NE	0.20	0.00	0.02	0.00	0.04	0.02	0.01
2016	0.24	NE	0.17	0.00	0.01	0.00	0.03	0.02	0.00
2017	0.19	NE	0.14	0.00	0.01	0.00	0.02	0.02	0.00
2018	0.15	NE	0.11	0.00	0.01	0.00	0.01	0.01	0.00
2019	0.10	NE	0.08	0.00	0.01	0.00	0.00	0.01	0.00
Trend 1990-2019	-93.86%	NA	-93.98%	-75.88%	-75.59%	NA	-97.74%	-92.75%	-92.75%
Trend 2018-2019	-30.02%	NA	-26.49%	-16.25%	-16.16%	NA	-66.80%	-40.04%	-40.04%

6.7.2 Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

For a detailed description of the development of the land transition matrix, please refer to section 6.1.3.3.

6.7.3 Land-use definitions and the classification systems used and their correspondence to the LULUCF categories

The OBS89, OBS99 and OBS07 land use maps are the main data providers for the greenhouse gas reporting of IPCC category other land. The selected parameters defining other land are:

Land Use Class	Definition
Other land	This category includes bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.

The other land area in correspondence to the LULUCF category comprises the following subcategories:

- Rocks and screes

- Land with no vegetation,
- Abandoned quarries.

6.7.4 Methodological issues

6.7.4.1 Other Land remaining Other Land (4F1)

Due to a lack of required data on carbon stock changes, this category has not yet been estimated.

6.7.4.2 Land Use Changes to Other Land (4F2)

6.7.4.2.1 Biomass and soil

According to the land use assessment systems OBS89, OBS99 and OBS07, other land in Luxembourg is constituted by rocks, scree slopes and gravel areas. It is assumed that these areas have no C stock in biomass and soil, so 0 was used as previous or final C stock at areas of LUCs from or to other land, respectively.

For the calculation of the annual change in carbon stocks of living biomass in land converted to wetland the following equation IPCC GPG 2006 LULUCF Tier 1 method equation 2.15 and 2.16 was applied:

$$\text{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{ (B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO_OTHERS_i} \} \cdot CF$$

where :

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for perennial crops carbon accumulation rate is 0.0 t C ha⁻¹yr⁻¹).

$B_{AFTER(i)}$ = stocks on land type i immediately after conversion, tonnes d.m. ha⁻¹ (default value = 0).

$B_{BEFORE(i)}$ = stocks on land type i before conversion, tonnes d.m. ha⁻¹ (value for carbon stock before conversion is 6.4 t C ha⁻¹ for perennial cropland, a dynamic value of 110.7 t C ha⁻¹ (previous 2000) and 128.7 t C ha⁻¹ (after 2010) for forestland with linear interpolation between 2000 and 2010, 6.3 t C ha⁻¹ for grassland, 4.3 t C ha⁻¹ for settlements, 5.0 t C ha⁻¹ for annual cropland and 0.0 t C ha⁻¹ other land - see section 6.2.4.2.1 and Table 6-24).

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr⁻¹ (default value = 0).

$\Delta T_{TO_OTHERS(i)}$ = area of land use i converted to another land-use category in a certain year, ha yr⁻¹.

CF = carbon fraction of dry matter, tonne C (tonne d.m.)⁻¹.

b) Changes of carbon stock in dead wood and litter of land converted to other land:

For the calculation of annual change in carbon stocks of dead wood and litter of land converted to other land equation 2.23 from the GPG 2006 is used:

$$\Delta D_{DOM} = \frac{(C_n - C_o) \cdot A_{on}}{T_{on}}$$

where :

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter (tonnes C yr⁻¹)

dead wood/litter stock, under the old land-use category, tonnes C ha⁻¹ (value dead wood in forest is a dynamic value ranging from 3,78 – 6.56 t C/ha*yr (as calculated in the NFAP for the FRL (AEV, www.emwelt.lu, 2019)) & default value for litter in forest = 19,2 t C/ha*yr (weighted average between default values of Table 2.2 of GPG 2006).

C_n = dead wood/litter stock, under the new land-use category, tonnes C ha⁻¹ (default value = 0 for all land-use categories but forest)

A_{on} = area undergoing conversion from old to new land-use category, ha

T_{on} = time period of the transition from old to new land-use category, yr. The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses

c) Changes in carbon stocks in soil of land converted to other land

According to the methodology described in 0, annual change in carbon stock of mineral soils = $IEF(LUC_j)$ * conversion area, where :

$$IEF(LUC_{forestland \rightarrow other\ land}) = - 5.554 \text{ t C/ ha *yr}$$

$$IEF(LUC_{perennial\ cropland \rightarrow other\ land}) = - 3.778 \text{ t C/ ha *yr}$$

$$IEF(LUC_{annual\ cropland \rightarrow other\ land}) = -3.770 \text{ t C/ ha *yr}$$

$$IEF(LUC_{grassland \rightarrow other\ land}) = - 5.079 \text{ t C/ ha *yr}$$

$$IEF(LUC_{settlements \rightarrow other\ land}) = - 2.162 \text{ t C/ ha *yr}$$

$$IEF(LUC_{wetland \rightarrow other\ land}) = 0.0 \text{ t C/ ha *yr}$$

$IEF(LUC_j)$ = average yearly emission factor for carbon stock change in soil from land use change j

6.7.4.2.2 N₂O emissions in soils of land converted to other land

The annual release of direct N₂O emissions due to the conversion of land to other land was calculated with IPCC default value (Tier 1) using equation 11.2 and 11.8 of the IPCC GPG (2006):

$$N_2O_{Direct} - N = F_{SOM} \cdot EF_1$$

$$F_{SOM} = \sum_{LU} \left[\left(\Delta C_{Mineral,LU} \cdot \frac{1}{R} \right) \cdot 1000 \right]$$

where:

EF_1 =emission factor for N mineralised as a result of loss of soil carbon (default value = 0.01)

F_{SOM} = the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

$\Delta C_{Mineral,LU}$ = average annual loss of soil carbon for each land-use type (LU), tonnes C

R = C/N ratio = ratio by mass of C to N in the soil organic matter = 12.

The annual release of indirect N₂O emissions due to the conversion of land to cropland was calculated with IPCC default value (Tier 1) using equation 11.10 of the IPCC GPG (2006):

$$N_2O_{(L)} - N = F_{SOM} \cdot \text{Frac}_{LEACH-(H)} \cdot EF_5$$

where:

$N_2O_{(L)}-N$ =annual amount of N₂O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kgN₂O-Nyr⁻¹

F_{SOM} = the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

EF_5 =emission factor for N₂O emissions from N leaching result of loss of soil carbon (default value = 0.0075)

$\text{Frac}_{LEACH-(H)}$ =fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kgN (kg of N additions)⁻¹ (default value = 0.30)

6.8 Uncertainties and time-series consistency

6.8.1 Uncertainties in relation to the emission factors extracted from the NFI

In order to calculate the uncertainties within the forestland category a separate study was commissioned in order to estimate the errors related to the individual emission factors extracted from the NFI (Bauwens, 2015).

There are many sources of uncertainty in forest biomass estimates (section 3.1.5 of the volume1 of the 2006 IPCC guidelines) and many intermediate steps are necessary to estimate the individual parameters (biomass, biomass growth rate, biomass expansion factor etc) extracted from NFI data. An error is associated with each of these intermediate steps. The global uncertainty related to any other parameter combines all those individual uncertainties. Due to the nature of the NFI (sampling method) the “statistical random sampling error” is also part of the whole uncertainty assessment. The error related to the estimations is based on statistical formula relating the standard error of the mean and the t-student variable with a risk of 5 % as recommended by IPCC guidelines.

$$\widehat{SE}_x = \frac{\hat{\sigma}_x}{\sqrt{n}} = \frac{\sum(x - \bar{x})^2}{\sqrt{(n-1)n}}$$
$$Error (\%) = t_{1-\frac{\alpha}{2}} \cdot \frac{\widehat{SE}_x}{\bar{x}}$$

where:

\widehat{SE}_x , the estimated standard error of the variable x

$\hat{\sigma}_x$, the estimated standard-deviation of the variable x;

n the total number of sample;

\bar{x} the mean of the variable x;

t the t-student variable with a risk α .

In order to estimate carbon stock the NFI used species-specific values for biomass expansion factors, wood density and below-ground to above-ground biomass ratios (R). The biomass expansion factors are based on a detailed study by (Dagnelies, Palm, & Rondeux, 2013) and are estimated at $\pm 15\%$. It seems reasonable to assume that a specific calculated value a smaller error has than the default value of 29%, as found in TABLE 3A.1.10, for temperate coniferous and broadleaf. The below-ground to above-ground biomass ratios (R) are based on a study by (Vande Walle, et al., 2005) which itself is based on a comparison of values used across Europe. Hence the default error values of $\pm 93\%$ for coniferous wood (value R=0.2 [0.12-0.49]) and $\pm 56\%$ for deciduous wood (value R=0.24 [0.17-0.44]) were used. The values of wood density chosen for the NFI are based on (Wagenführ & Schreiber, 1985). Here as well the default value for uncertainty from IPCC guidelines was chosen. The latter one is estimated to be between 10-40% and hence the value was set at $\pm 25\%$. The uncertainty on the carbon factor is also based on the default value of $\pm 5.3\%$ (0.47 [0.44-0.49]). For litter the default emission factor and associated uncertainty were extracted from the IPCC guidelines (weighted average of deciduous 16 tC/ha⁻¹ (5 tC/ha⁻¹ - 31 tC/ha⁻¹) and coniferous 26 tC/ha⁻¹ (10 tC/ha⁻¹ - 48 tC/ha⁻¹).

Those calculations translated into the following errors for the individual emission factors:

Table 6-35 – Errors linked to emission NFI factors (t C/ha)

emission factor	Sample size	Stedv (sample)	value	error
Above ground biomass growth coniferous trees	415	0.21 t/ha/a	7.83 tC/ha ⁻¹	±30%
Above ground biomass growth deciduous trees	219	0.10 t/ha/a	4.40 tC/ha ⁻¹	±30%
Below ground biomass growth coniferous trees	415	0.04 t/ha/a	1.54 tC/ha ⁻¹	±97.3%
Below ground biomass growth deciduous trees	219	0.02 t/ha/a	1.01 tC/ha ⁻¹	±63.8%
Above ground biomass growth trees 0-20y	95	0.39 t/ha/a	5.53 tC/ha ⁻¹	±32.7%
Below ground biomass growth trees 0-20y	95	0.08 t/ha/a	1.12 tC/ha ⁻¹	±81.2%
Dead wood	1126	0.60 t/ha/a	11.96 tC/ha ⁻¹	±36.6%
Litter (default IPPC)			19.20 tC/ha ⁻¹	±77.2%
Biomass carbon stocks in forests (above-and below ground)	1576	3.94 t/ha/a	119.7 tC/ha ⁻¹	±80.3%

The data on wood harvest is based on data extracted from the NFI as well as from yearly data of wood sales from public forests. The error applied on those figures is the default value of ±20% (IPPC guideline page 4.19).

6.8.2 Uncertainties of activity data in relation to area (activity data)

The accuracy assessment was carried out for the land use maps that were developed in 2012 and was based on aerial photographs and LUCAS 2012 data/photographs, provided by Eurostat. The quality assessment consisted in controlling 2 200 randomly sampled points (200 per class) enabling to detect omission and commission errors of these points by another expert based on the reference information. This interpretation has been compared to the result of the change detection.

In addition LC/LU (Land Cover/Use changes) data of about 215 LUCAS (Land Use/Cover Area statistical Survey) points have been compared to LULUCF12 data, using the LC/LU information and the photographs taken during the LUCAS survey in 2012.

In total out of the 2 415 points controlled, 48 were wrongly classified meaning that an overall accuracy of 98.01 % was achieved.

This does however not take into account the error in relation to the underlying accuracy of the polygons of the LU2007 maps. The polygons of the 2007 layer were established with a MMU (Minimum Mapping Unit) of 1 500 m². Hence the overall error is determined by the accuracy assessment of 2012 (with regards to land use) as well as the minimum mapping unit used for establishing the land use maps in 2007.

The translation of the MMU in overall error is unfortunately not that simple. The individual categories (settlements, forests etc) occur in different cluster sizes, depending on their composition. This leads to disparate class accuracy. For example, forest areas are typically large and relatively heterogeneous; thus, one would expect that these areas would become more uniform due to the smoothing effect of the resampling filter. This uniformity could result in those areas having a higher accuracy.

Luxembourg is planning on commissioning the creation of a new OBS (land use map). As part of this contract a detailed uncertainty analysis will also be carried out. According to the IPPC guidelines (Chapter 4 page 4.20) the uncertainties in forest areas is approximately 3%. Considering the method described here above the overall uncertainty on areas determined with satellite imagery is most likely lower. It would however be extremely difficult to calculate the exact value and hence the decision was taken to use the default value for uncertainty of ±3%.

6.8.3 Uncertainties of emission factors from soil samples

According to the methodology described in section 0 carbon stock changes have been measured for the individual regions and soil covers in Luxembourg. The error computed here represents the standard deviation of the individual sample plots multiplied by two. This is in line with the first footnote of Table 2.3 (IPPC Guidelines – Chapter 2) where “a nominal error estimate of $\pm 90\%$ (expressed as 2x standard deviations as percent of the mean)” was provided for standard soil organic carbon stocks.

Table 6-36 – Carbon soil stocks and errors per land use and soil type (t C/ha) in Luxembourg

Soil type	Carbon soil stocks per land use and soil type (t C/ha) and error (%)			
	Cropland (Annual Cropland)	Grassland	Forestland	Vineyard (Perennial cropland)
Oesling	91.5 \pm 27%	89.2 \pm 13%	132.2 \pm 20%	71.0 \pm 0%
Buntsandstein	66.7 \pm 29%	82.8 \pm 26%	112.1 \pm 41%	73.5 \pm 0%
Dolomies du Muschelkalk	85.5 \pm 35%	112.1 \pm 28%	117.0 \pm 20%	77.9 \pm 0%
Calcaires du Bajocien	75.2 \pm 33%	122.0 \pm 16%	111.5 \pm 21%	77.7 \pm 0%
Grès de Luxembourgs	50.7 \pm 25%	83.3 \pm 31%	80.6 \pm 23%	76.2 \pm 0%
Dépôts limoneux sur Grès	58.6 \pm 36%	99.4 \pm 35%	95.7 \pm 25%	75.1 \pm 0%
Argiles du Lias inf. et moyen	69.8 \pm 35%	121.6 \pm 21%	95.2 \pm 21%	75.7 \pm 0%
Argiles lourdes du Keuper	67.7 \pm 40%	121.3 \pm 23%	102.6 \pm 22%	76.0 \pm 0%
Argiles lourdes des schistes bitumineux	88.2 \pm 46%	145.7 \pm 14%	104.8 \pm 17%	NA
Others	80.7 \pm 61%	110.8 \pm 28%	126.6 \pm 55%	74.9 \pm 0%
ALL	76.8 \pm 48%	107.4 \pm 37%	110.7 \pm 42%	73.5 \pm 4%

It is important to highlight that the error on the mean is very low because the amount of soil samples is very high. Hence the confidence interval on the mean value is also very narrow (the probability that the average value measured corresponds to the true average value is hence very high). If the total carbon content was calculated as a total figure for the whole country the error would also be very low. For the purpose of IPPC calculations the carbon soil contents are however used to determine carbon soil changes due to land use change at parcel level. This means that the variability of the samples has to be taken into account. Compared to the error of the mean the variability of the dataset is however very high. Because the variability has to be considered, when calculating carbon stock changes due to land use change, the overall error on carbon stock changes associated with land is very high. This error cannot be reduced by taking more soil samples. The only way to reduce the error would be to cross-reference the soil samples taken with the land use change maps in order to only consider those soil samples which were taken on those parcels where the land use change took place. This would however require an important computing effort and it is not guaranteed that the error would be reduced because even at parcel level the variability of results in soil carbon content can be very high.

Table 6-37 – Land use change matrix for soil carbon emission factors with errors (t C/ha*yr)

from \ to	Forest land	Annual Cropland	Perennial Cropland	Grassland	Wetland	Settlement	Other land
Forest land	0	-1.8 ±176%	-1.2 ±196%	-0.5 ±672%	-5. ±306%	-3.4 ±306%	-5.6 ±306%
Annual Cropland	1.8 ±176%	0	0.5 ±433%	1.3 ±221%	-3.8 ±306%	-1.6 ±306%	-3.8 ±306%
Perennial Cropland	1.2 ±196%	-0.5 ±433%	0	1.5 ±138%	-3.8 ±306%	-1.6 ±306%	-3.8 ±306%
Grassland	0.5 ±672%	-1.3 ±221%	-1.5 ±138%	0	-5.1 ±306%	-2.9 ±306%	-5.1 ±306%
Wetland	5.6 ±306%	3.8 ±306%	3.8 ±306%	5.1 ±306%	0	2.2 ±306%	0.000
Settlement	3.4 ±306%	1.6 ±306%	1.6 ±306%	2.9 ±306%	-2.2 ±306%	0	-2.2 ±306%
Other land	5.6 ±306%	3.8 ±306%	3.8 ±306%	5.1 ±306%	0.0 ±306%	2.2 ±306%	0 ± 27%

Table 6-37 indicates the errors of the emission factors used for calculation of soil carbon stock changes. The errors are calculated by taking into account the individual errors of carbon soil content categories as well as the variability. As the matrix is giving the difference between two levels of carbon soil contents the relative errors (in %) becomes very high. For the categories wetland, settlements, grassland and other land the average error of the remaining categories was chosen.

6.8.4 Uncertainties of emission factors from biomass carbon stocks

Table 6-38 – Errors linked to emission factors of biomass carbon stock (t C/ha)

emission factor	value	error	origin
biomass carbon stock for perennial cropland (see Table 6-25)	6,3 tC/ha ⁻¹¹	±75%	IPPC default value (Table 5.1)
biomass carbon stock for annual cropland	5,0 tC/ha ⁻¹	±75%	IPPC default value (Table 5.9)
biomass carbon stock for grassland	6,3 tC/ha ⁻¹	±75%	IPPC default value (Table 6.4)
biomass carbon stock for wetland	0,0 tC/ha ⁻¹	±0%	
biomass carbon stock for settlements	4,3 tC/ha ⁻¹	±75%	See comment here below
biomass carbon stock for other land	0,0 tC/ha ⁻¹	±0%	

The error for N₂O emissions is a combination of the error on the C/N ratio (±40%) and the error of the linked calculation of carbon emission. The biomass carbon stock for settlement is not known as it has been roughly estimated by analysing land use maps of settlement areas. For this reason it was assumed that the error is identical to the error proposed by IPPC default value for perennial cropland, annual cropland and grassland.

6.8.5 Overall uncertainty assessment

Compared to the other sectors the LULUCF sector is particular as it does not only cover CO₂ emission but also CO₂ removals. This means that the calculated uncertainties are best evaluated for emissions and removals separately in order to get a good understanding of the quality of the data collected.

Figure 6-19 – Errors in the LULUCF sector by land use categories and by removals and emissions

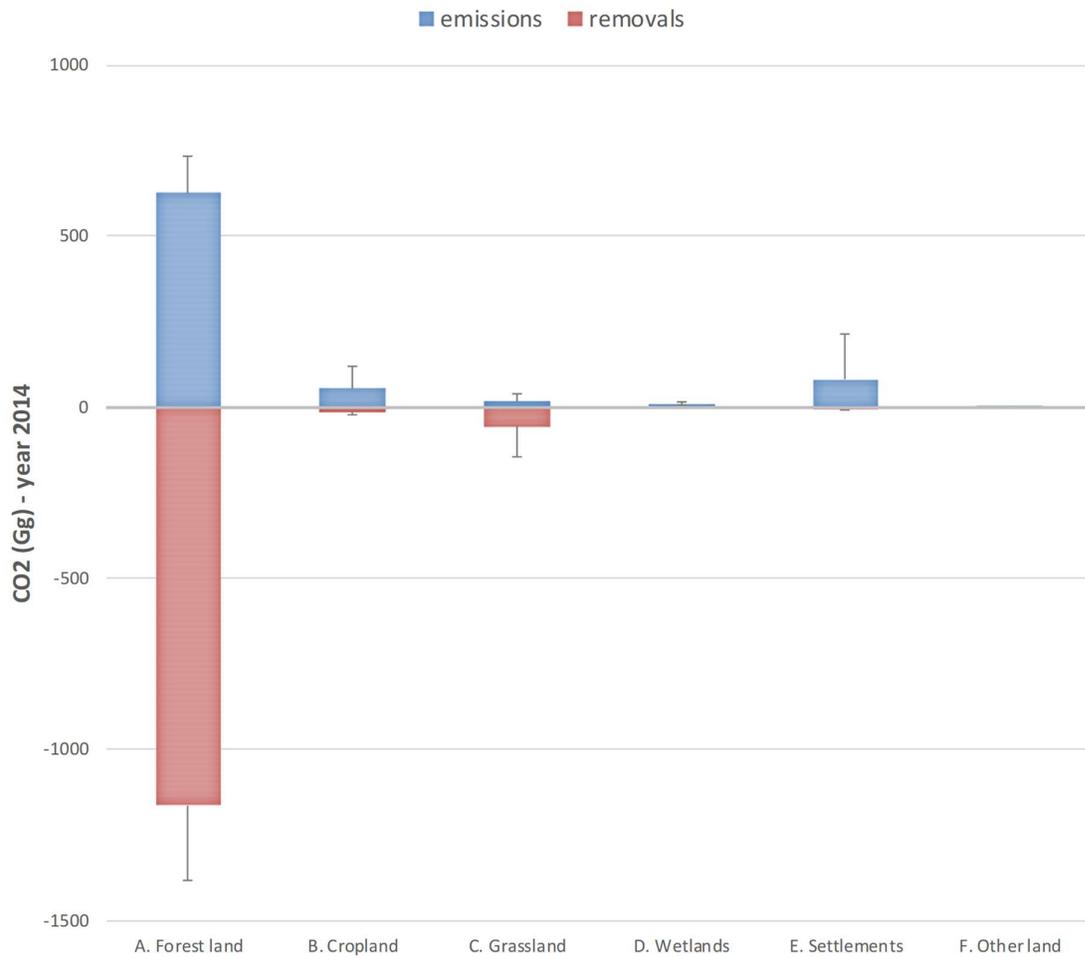
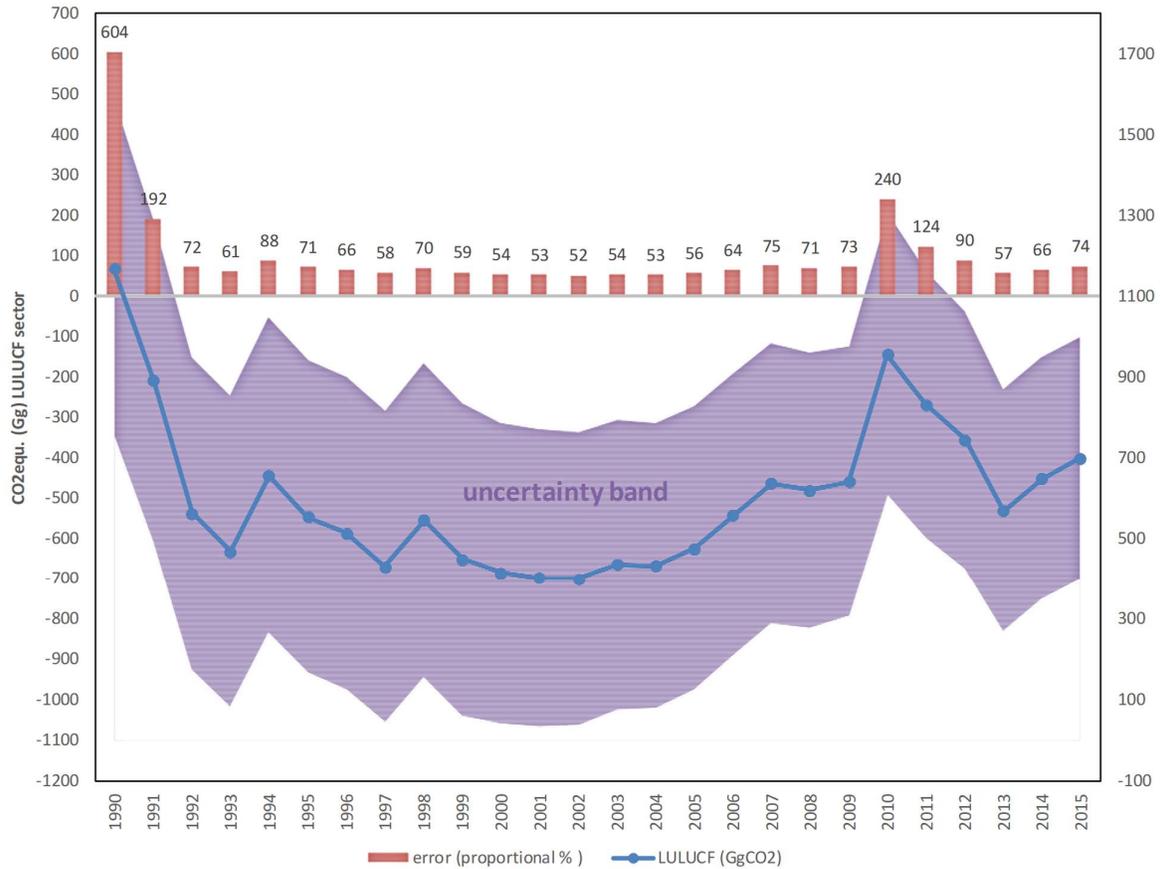


Figure 6-19 highlights how the overall LULUCF sector is mainly influenced by emissions and removals in the forest sector. The error on emissions and removals for the forest sector are $\pm 17\%$ and $\pm 19\%$. The other land use categories contribute a lot less to the overall emissions and removals of the LULUCF sector. The errors within those categories are proportionally also higher. The settlement categories is characterised by high emission due to soil carbon loss resulting from urbanisation. Considering that the errors associated to soil carbon change are very high the results of these categories are very high.

Figure 6-20 – Absolute and proportional error in relation to total emissions in LULUCF sector



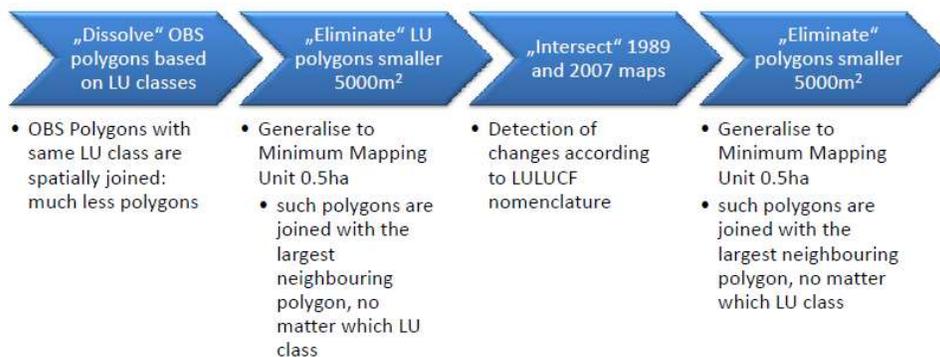
For the year 2015 the proportional error is 74 %. This value is however strongly dependant on the proportion of removals and emissions and tends towards infinity as the sum of removals and emissions tends to zero. This is very striking when comparing the year 1990 with any of the years between 1999 and 2006 in Figure 6-20. The absolute error is more or less constant but the proportional error is much higher for the year 1990 where the sum of emissions and removals was close to zero. In order to qualify the errors of the LULUCF sector it would be more useful to assess the error separately for the emissions and removals as it is done in Figure 6-19. The proportional error of the LULUCF sector can only be used to assess the error on the overall result but cannot be used to assess the quality of the underlying data.

6.8.6 Time series consistency

Within the LULUCF land use change matrixes are the most critical type of data when analysing time series consistency. Other emission factors have been used consistently for the entire time series. When, for example new emission factors from the second NFI were being introduced the entire time series was subsequently being updated in order to reflect those new emission factors (e.g. growth rates).

In OBS 89 the minimum mapping unit (MMU) was set to 1 500 m². In OBS99 the official MMU was 2 500 m² for surface features, respectively 1 500 m² for several objects of specific biologic interest. For the 2007 update the MMU was set to 500 m². For the 2012 update the same polygons of the 2007 OBS were kept and only land used changes were recorded with a minimum areas size of 1 500 m².

Figure 6-21 – Geodata processing methodology to guarantee time series consistency



In order to guarantee time series consistency when working with land use maps of different MMU the individual land use maps were modified in order to have the same MMU as shown on Figure 6-21. The resulting land use changes were also capped to polygons greater than 1 500 m².

The total area as computed from the GIS data sets differs slightly from the official area of the Luxembourg territory. This is simply due to resolution /scale and data processing inaccuracies in the data sets. Therefore, the areas derived from the geodata have been put in relation to the official area of Luxembourg (258 600 ha). It means that all areas resulting from the geodata processing are proportional to the official territory of Luxembourg that is 2 586 km².

6.9 Harvested Wood Products (4.G)

LU does unfortunately not have very reliable data on HWP and has in the past not provided estimates on this carbon pool. The lack of reliable data can be partly explained by the small size of the country with high import and export of wood products. LU has addressed certain issues regarding incomplete and inconsistent datasets by using a different range of conservative hypothesis and simplifications.

Emissions from the use and disposal of harvested wood products are estimated using the model described in (Hirashi, et al., 2014). The basis of this model is the first order decay function which simulates total stock volumes depending on the life expectancy of products. The life expectancy of HWP is described by using half-life values. The half-life is the number of years it takes for the quantity of carbon stored in a harvested wood products category to decrease to one half of its initial value. The evolution of stock volumes are calculated using the following equations:

$$C(i + 1) = e^{-k} \cdot C(i) + \left[\frac{1 - e^{-k}}{k} \right] \cdot Inflow(i) \quad \text{(Equation 6-1)}$$

$$\Delta C(i) = C(i + 1) - C(i) \quad \text{(Equation 6-2)}$$

where :

i = year

C(i) = the carbon stock in the particular HWP category at the beginning of the year i, (GgC)

k = decay constant of first order decay function for each HWP category given in units yr⁻¹ (k=ln(2)/HL, where HL is the half-life of the HWP pool in years)

Inflow(i) = the inflow to the particular HWP category during the year i (GgC/a)

ΔC(i) = carbon stock change of the HWP category during year i (GgC/a)

The evolution of stock volumes is carried for two different types of products: sawnwood (which has a half-life of 35 years) and wood-based panels (which have a half-life of 25 years).

LU chose to use the production approach which estimates the net change of the proportion of the HWP carbon pool that originates from wood harvested in LU. Hence, imported HWP is not be accounted for. The share of industrial roundwood for the domestic production of HWP originating from domestic forests is calculated for each year is calculated with the following equation (Hirashi, et al., 2014):

$$f_{IRW}(i) = \frac{IRW_P(i) - IRW_{EX}(i)}{IRW_P(i) + IRW_{IM}(i) - IRW_{EX}(i)} \quad \text{(Equation 6-3)}$$

6.9.1.1 Data available in the FAO database

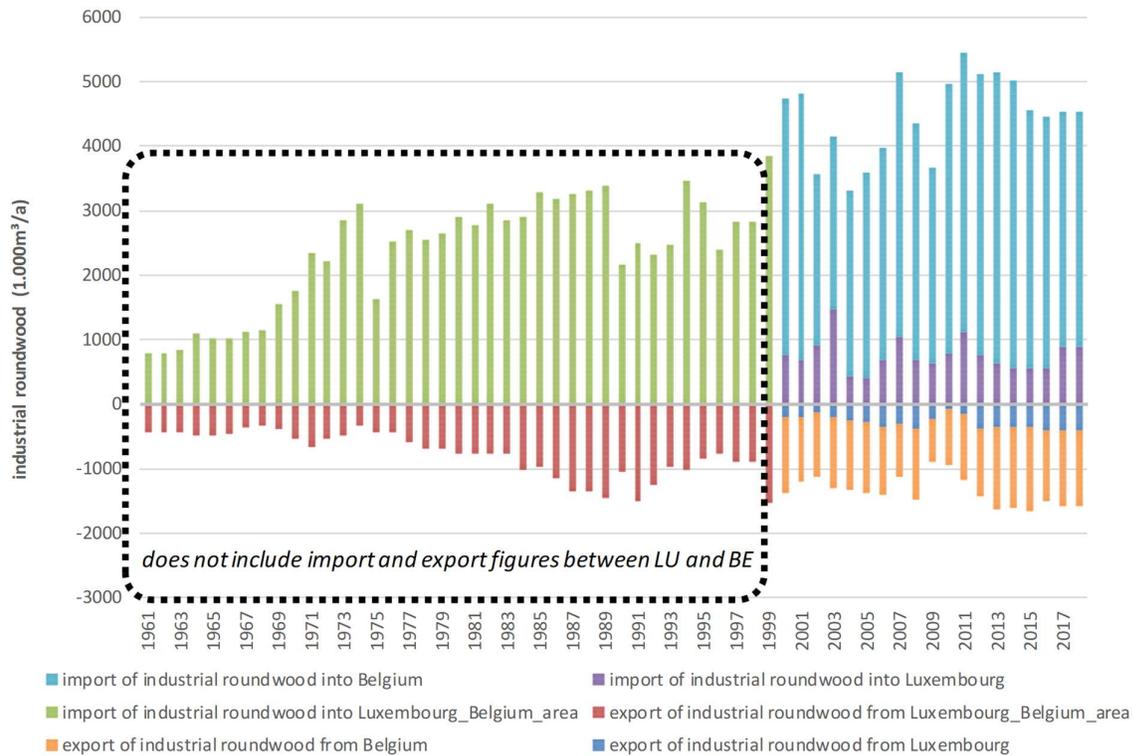
FAOSTAT-Forestry provides annual production and trade estimates for numerous forest products, primarily wood products such as roundwood, sawnwood, wood panels, pulp and paper. For most countries, historical data are available from 1961 onwards. These estimates are provided by countries through an annual survey conducted by FAO (JFSQ questionnaire). In cases where countries have not provided information through the questionnaire, FAO estimates annual production. The LU forest agency is responsible for submitting this questionnaire. For LU the JFSQ questionnaire is often prefilled with import and export data from Eurostat (comex). The

comex database does however only include import and export data but not production of HWP. The forest agency only submits data on production data on roundwood (industrial roundwood, sawlogs, and pulpwood). Production data on wood-based panels, sawnwood, wood pulp, paper etc have only submitted occasionally and were based on basic production capacity figures of individual factories rather than actual production figures.

6.9.1.2 Data available on production, imports and exports of industrial roundwood

In order to use the production approach, the share of industrial roundwood, originating from domestic forests, for the domestic production of HWP needs to be calculated. Furthermore, data for the main HWP categories need to date back, ideally, to 1960. For most countries data on HWP categories in the FAO database date back to 1960. For Luxembourg this is unfortunately not the case as all the data on HWP categories only date back to the year 2000. From 1961 until 2000 data is combined for Luxembourg and Belgium who are jointly considered as one region. Figure 6-22 is showing import and export of industrial roundwood retrieved from the FAO database for Luxembourg, Belgium and the Luxembourg-Belgium area.

Figure 6-22 import and export of industrial roundwood in Luxembourg and Belgium (source: FAO)



As Luxembourg and Belgium are considered as one region between 1961 and 2000, fluxes of roundwood between both countries are not available. This is visible in Figure 6-22 as there is a clear jump in combined export and import figures between both countries after 2000. Import and export figures between Luxembourg and Belgium are however considerable in relation to the total production of roundwood in LU. Luxembourg exports a high amount of beech wood to a paper mill in Belgium. This paper mill has been in operation since the seventies. On the other hand, Luxembourg has one of the biggest wood-panel producers in Europe. It is however estimated that only 10% of the wood, needed for the production, originates from Luxembourg. Hence it can be assumed that a vast majority of this wood is imported from Belgium. One reason for the high volume of wood import is that the production of wood-panels requires coniferous wood which is very abundant in Belgium.

Figure 6-23 amended import and export of industrial roundwood in Luxembourg and Belgium

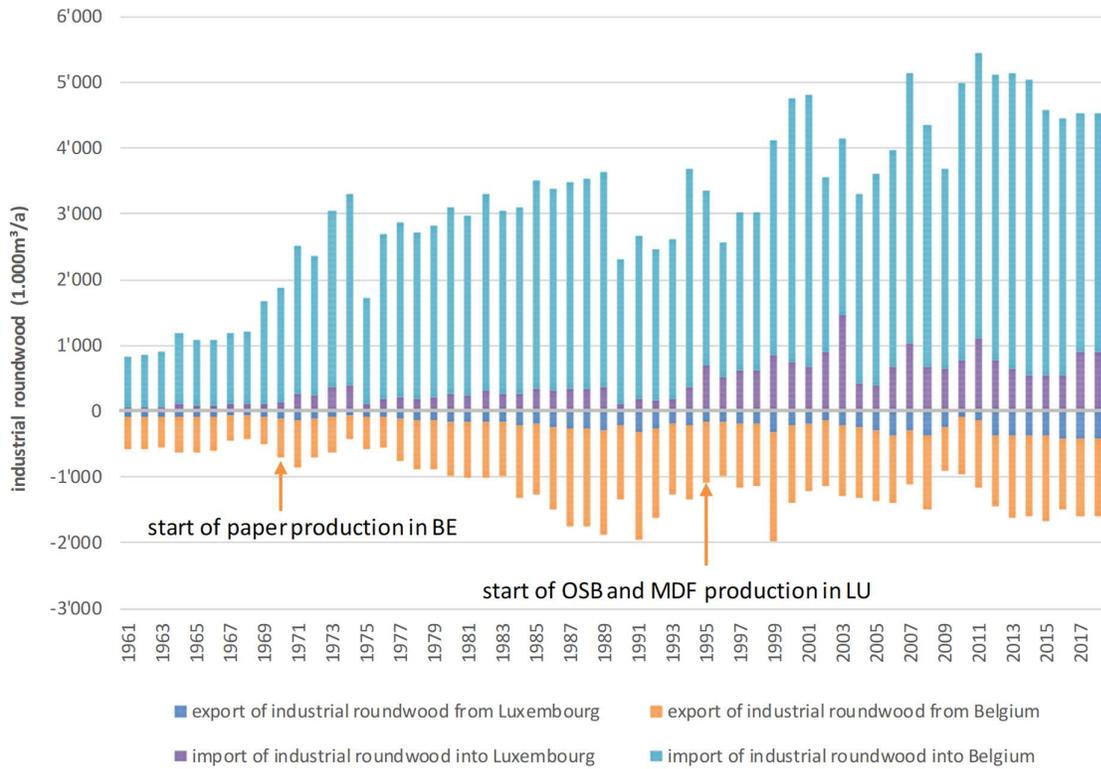
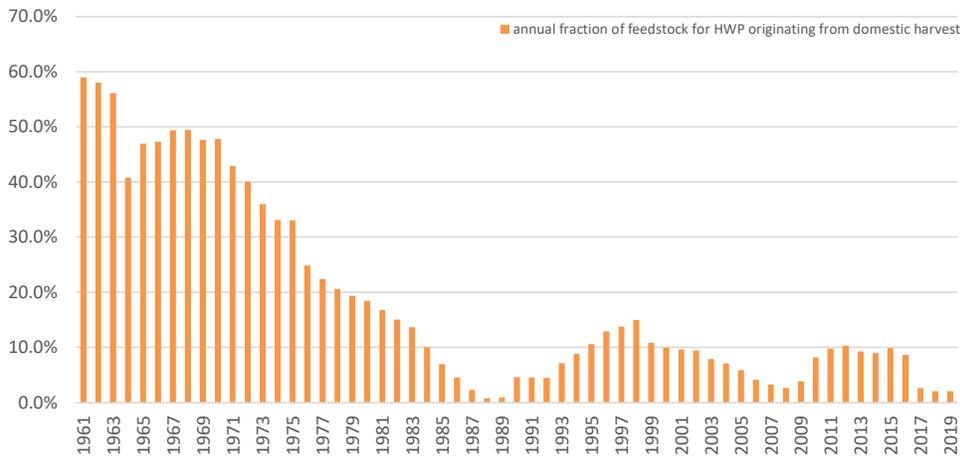


Figure 6-23 illustrates how the import and export of industrial roundwood was amended to take into account import and export figures between LU and BE:

- Increase of combined export of roundwood from Luxembourg and Belgium in order to take into account the export and import figures between those two countries. This was realised by comparing total import and export between 2000 and 1999
- A decrease of industrial roundwood into Luxembourg before the start of the wood-panel production in 1995.

The high annual fluctuations of roundwood import into Luxembourg is probably due to stock fluctuations of roundwood purchased by the HWP producers.

Figure 6-24 annual fraction of feedstock for HWP originating from domestic harvest



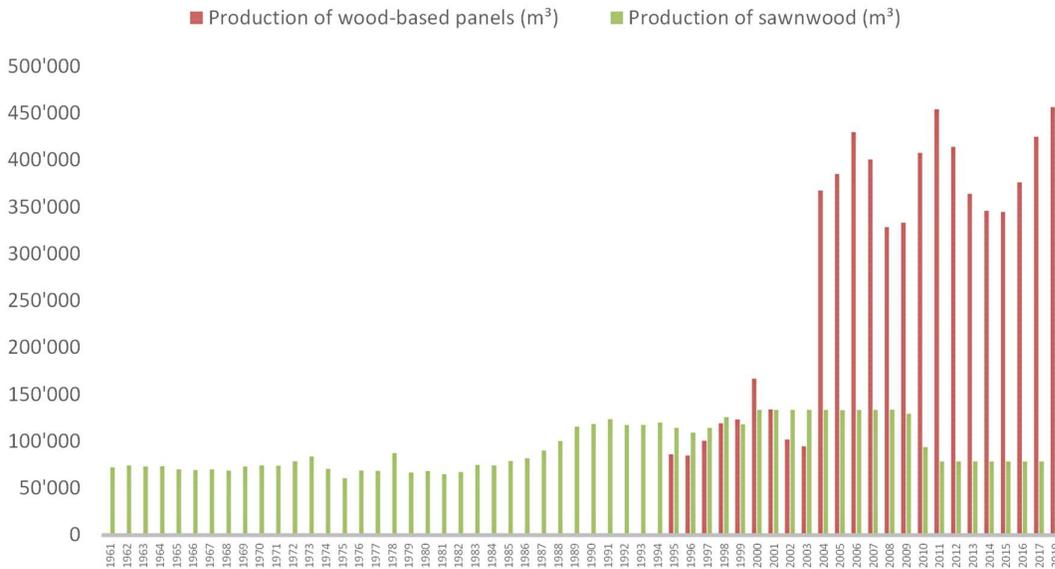
Import and export of industrial roundwood are very high and show strong yearly fluctuations. Those fluctuations can partly be explained by stock changes and bulk purchases by the wood processing industry. Unfortunately, yearly fluctuations of import and export can, on an annual basis, lead to inconsistent results. For this reason, a 10-year moving average (see Figure 6-22) was used in order to calculate the annual fraction of feedstock for HWP originating from domestic harvest (firw).

6.9.1.3 Production of wood-based panels and sawnwood

As mentioned in the previous chapters a major wood-panel (mainly OSB and MDF) producer is operating in LU. Unfortunately, no production data is collected in LU. Data on export of wood-based panels is however based on the comex database and are very reliable. Hence the assumption is taken that the production of wood-based panels is equal to the export of wood-based panels. This assumption seems justified as it is a conservative approach and the market for wood-based panels in LU is small compared to the production.

For the production of sawnwood and wood-based panels before 2000 the combined production between LU and BE was split onto both countries by considering the production ratio of both countries for the period between 2000 and 2005 (5-year average). As the production of wood-based panels only started in 1995 the calculation for wood-based panels was considered to be zero before that year.

Figure 6-25 production of wood-based panels and sawnwood in Luxembourg

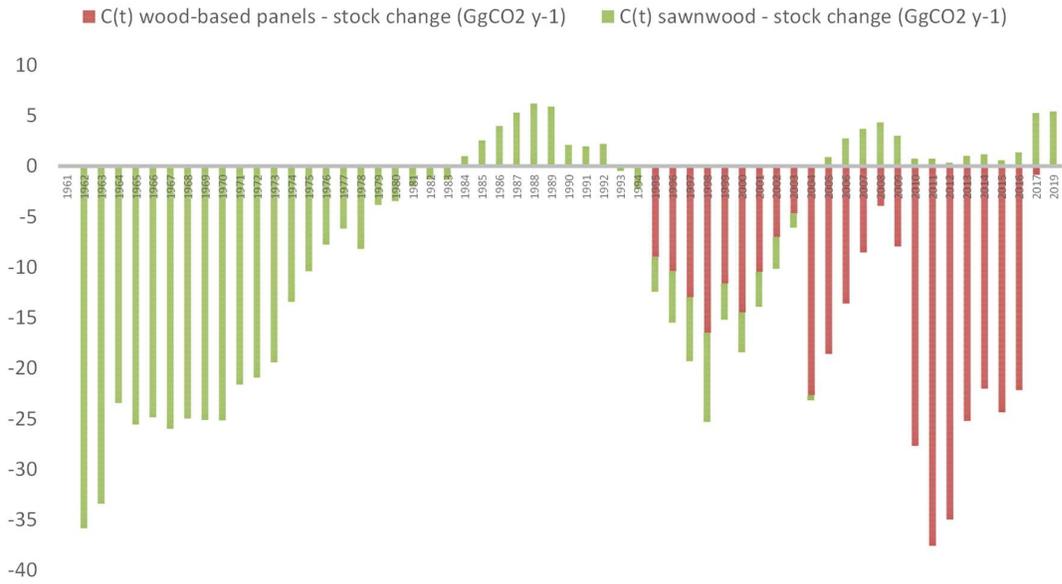


6.9.1.4 Data available on production, imports and exports of pulpwood

There is no production of paper and paperboard in Luxembourg using pulpwood originating from LU forests.

6.9.1.5 Calculated emissions and removals in the HWP pool.

Figure 6-26 carbon emission and removals in HWP



By 1985 the balance for sawnwood in terms of inflow and outflow has been reached. For wood-panels the production only started in 1995 and hence a balance has not yet been reached.

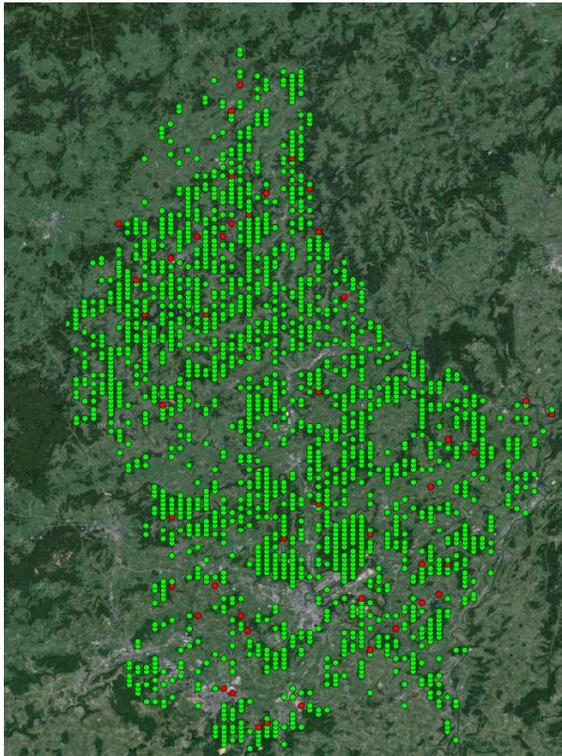
6.10 Category-specific QA/QC and verification

Processing of land use maps is verified as follows:

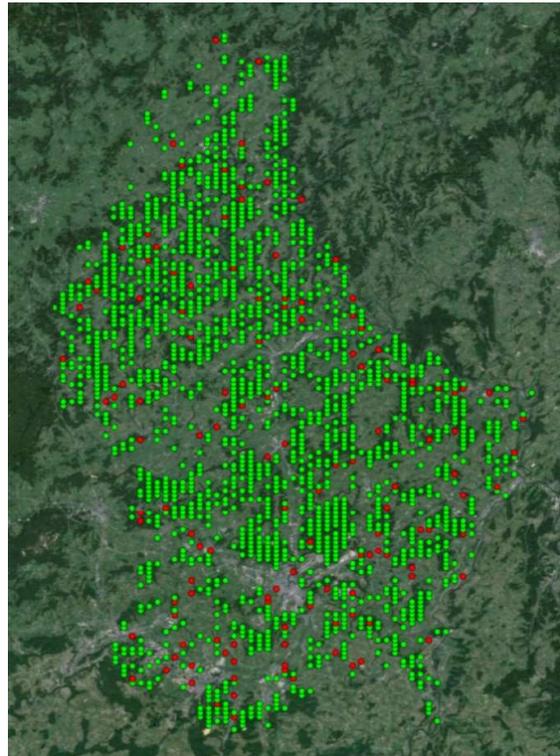
- field surveys were used during the establishment of the original land use maps in 1989, 2000 and 2007 (see section 6.1.3.1). This method allowed, for example, a better differentiation between permanent cropland (e.g. walnut and chestnut trees plantations) from other broad leaf trees in forests.
- digital sources: For the quality check of the land use map LU12 and LUC between LU07 and LU12, other digital sources were used such as digital aerial orthophotos and LUCAS 2012 data / photographs, provided by Eurostat. The quality assessment consisted in controlling 2200 randomly sampled points (200 per class) resulting in an overall accuracy of 98.01%.

Comparison with total forest area generated by land use maps and forest inventory:

Figure 6-27 – Comparison of NFI grid definition points to LUC analysis



Red points are areas defined as forest in the NFI but not in the LUC analysis (total: 45)



Red points are defined as forest in the in the LUC analysis but not in the forest inventory (total: 114)

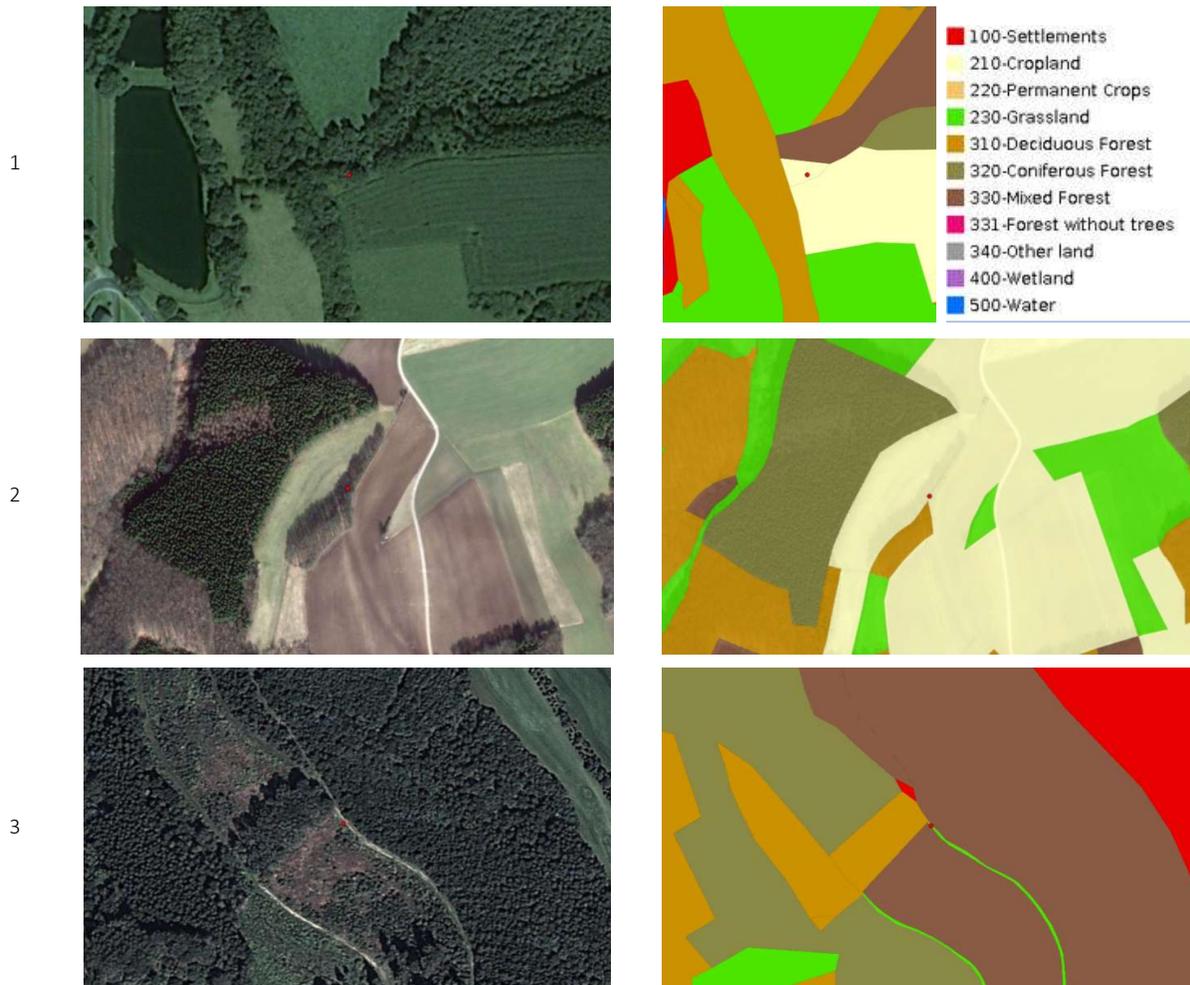
In order to compare the results of total forest area obtained via land use maps (based on aerial and satellite pictures) and the total forest area obtained via the NFI a detailed analysis has been conducted via a GIS program. For this exercise the layer of grid points of the NFI have been put in comparison to the latest land use map from 2012.

According to the data generated by the LUC analysis the forest area in the year 2012 was 96 107 ha compared to 92 150 ha estimated by the NFI. The difference of 3 957 ha (4%) is very small and can most likely be explained by the two different methodologies employed. (Note: the total forest area according to the FAOSTAT (88 700 ha) does not include “other wooded areas” and “grove area” and is hence smaller than the total forest area estimated by the NFI). Nevertheless a comparison between the two set of results was conducted in order to rule out any major definition issues:

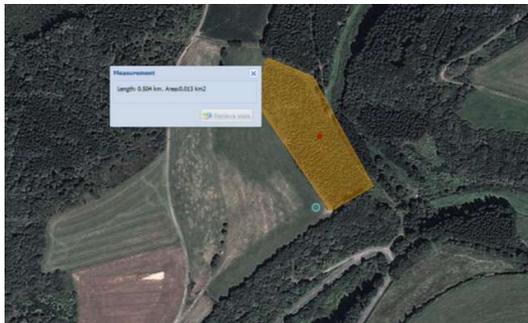
As can be seen in Figure 6-27 the difference in numbers of red points is in line with the difference in total surface area ($114-45 = 69 \rightarrow 3\,450$ ha (according to NFI calculation with 50 ha/point), compared to 3 957 ha calculated above).

The figures here below show a sample of red points in order to highlight the type of differences or errors between both methodologies.

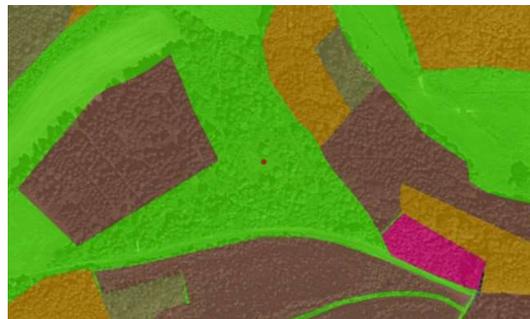
Figure 6-28 – points defined as forest in NFI but not in LUC method



4



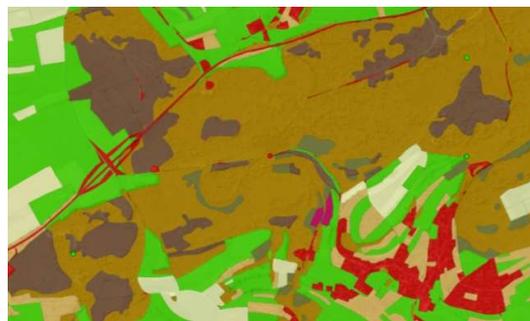
5



Figures 1, 2 and 3 show typical points that might not be defined as forest area in the LUC methodology but are limited to a very small area surrounded by forest and have almost no influence on the results. Pictures 4-5 show examples with higher influence on the results (the errors in these cases are due to the methodology of the 2007/2012 analysis which kept the underlying geometry of the 2007). Nevertheless the generated errors are small (13 ha in the case of example in figure 4).

Figure 6-29 – points defined as forest in LUC but not in NFI

6



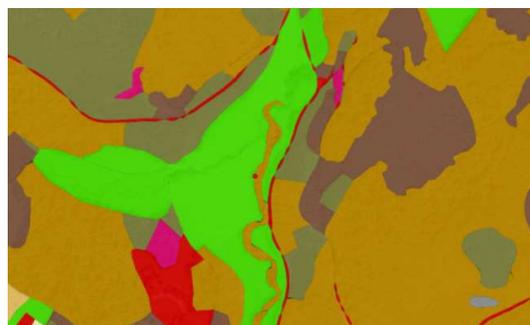
7



8



9



10



Pictures 6-8 show typical points that are situated at the border of a forest and are not considered as forest in the NFI. In those examples the precision of the results from the LUC analysis are superior to those of the NFI. Figure 9-10 show how the LUC methodology takes into account often smaller patches of forest which can lead to higher areas of land use changes as those forest areas are more likely to get cut down or to be planted (in the case of abandoned land for example).

The match between the two methodologies can be seen as satisfactory and does not highlight any need for further amendments to the LUC method used for the calculation of the LULUCF inventory.

6.11 Category-specific recalculations including changes made in response to the review process

The following changes have led to the revision of the data series for the LULUCF sector:

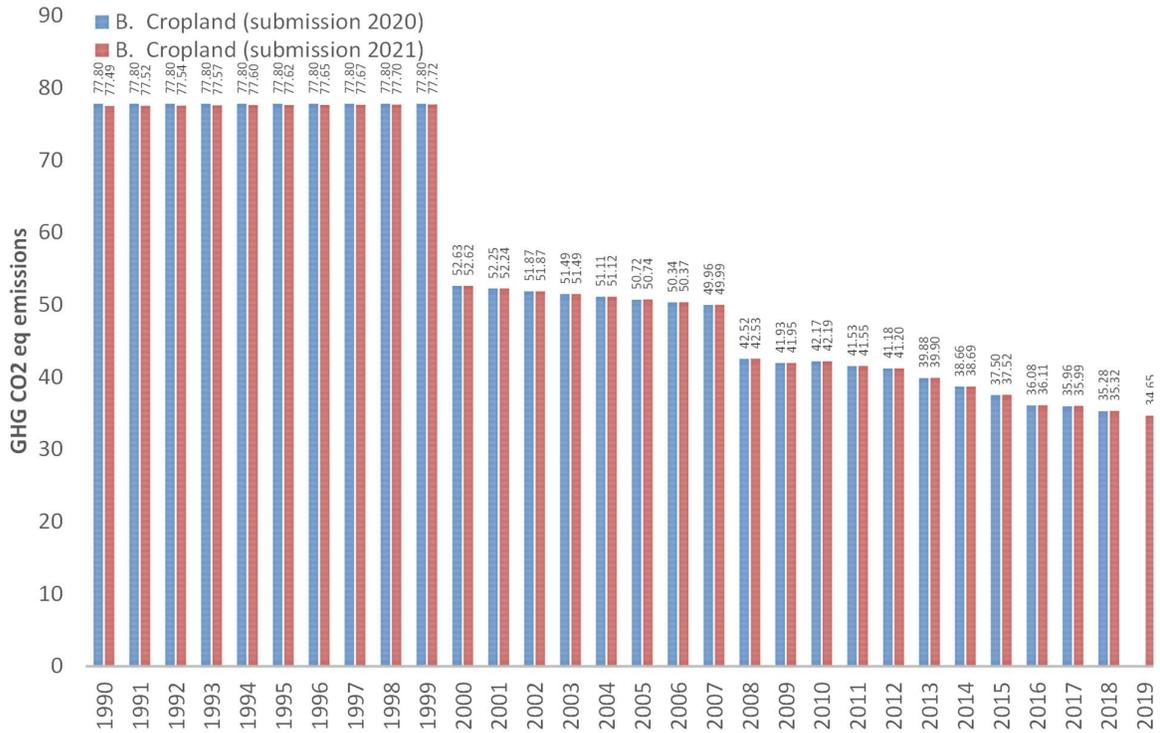
4.A Forestland:

No recalculations have occurred in the category forestland.

4.B Cropland:

In the 2020v1 calculations carbon losses of deadwood resulting from land use change from forestland to cropland a static value of dead wood carbon stock was used. In the 2021 version the dynamic value of the deadwood carbon stock, calculated in the forestland category, was used. This has led to minor changes.

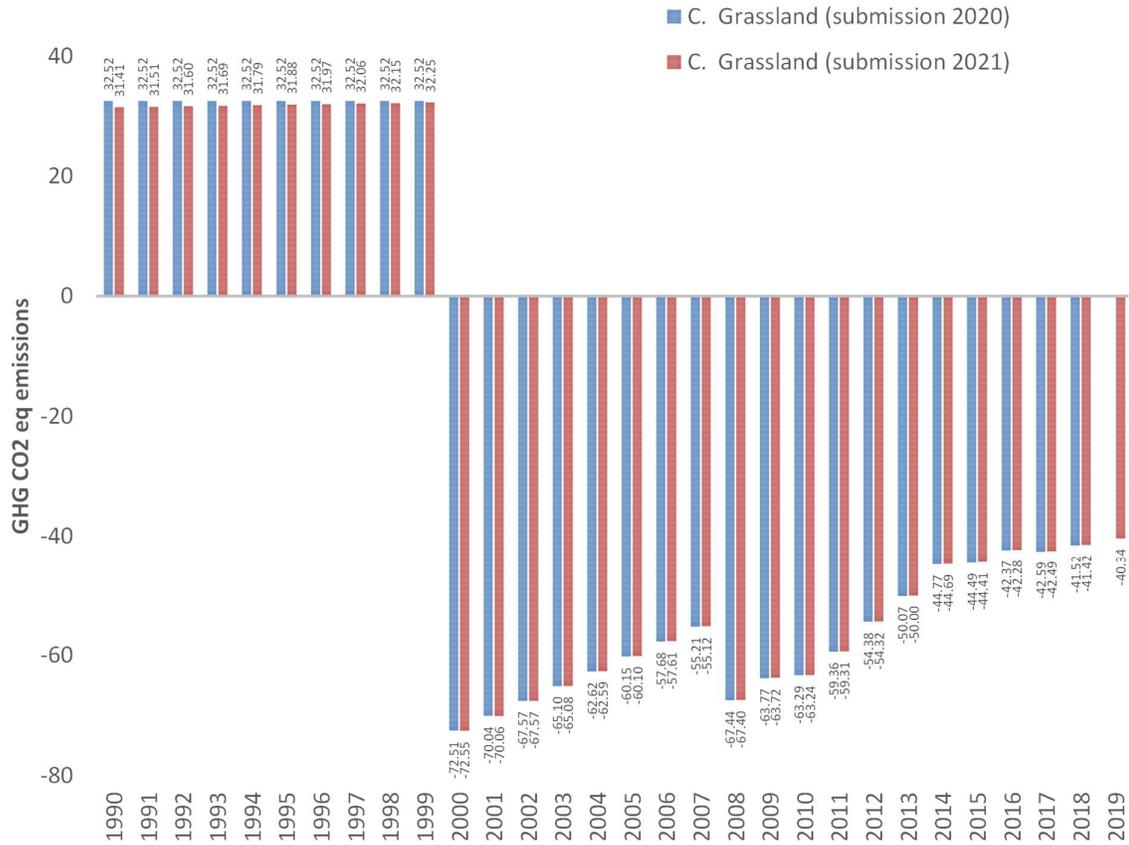
Figure 6-30: Recalculations with respect to previous submission 2010v1 in category 4B.



4.C Grassland:

In the 2020v1 calculations carbon losses of deadwood resulting from land use change from forestland to cropland a static value of dead wood carbon stock was used. In the 2021 version the dynamic value of the deadwood carbon stock, calculated in the forestland category, was used. This has led to minor changes.

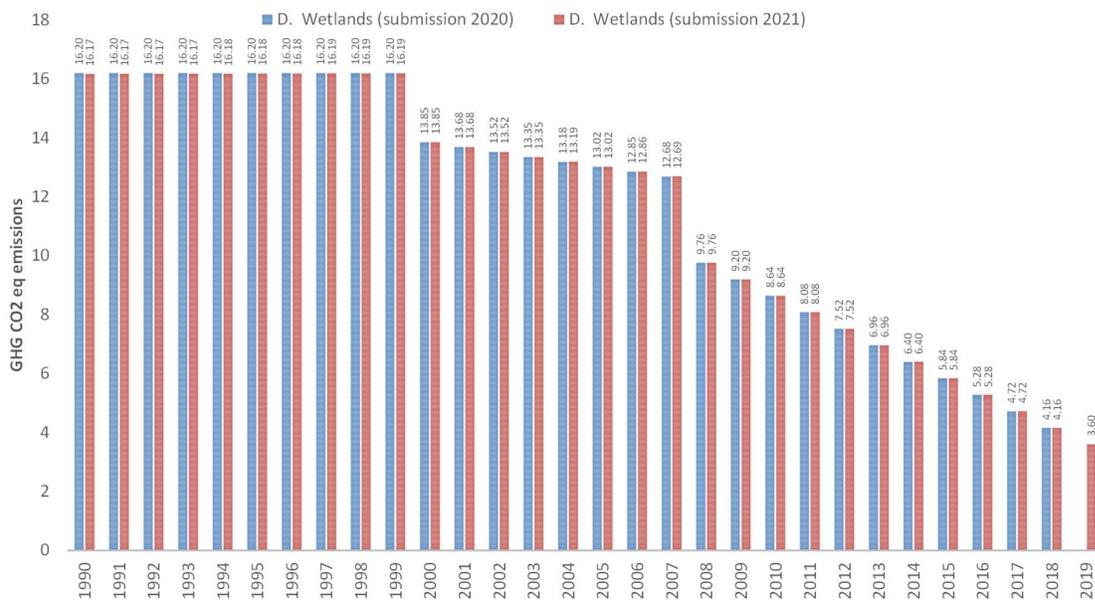
Figure 6-31: Recalculations with respect to previous submission 2010v1 in category 4C.



4.D Wetlands:

In the 2020v1 calculations carbon losses of deadwood resulting from land use change from forestland to cropland a static value of dead wood carbon stock was used. In the 2021 version the dynamic value of the deadwood carbon stock, calculated in the forestland category, was used. This has led to minor changes.

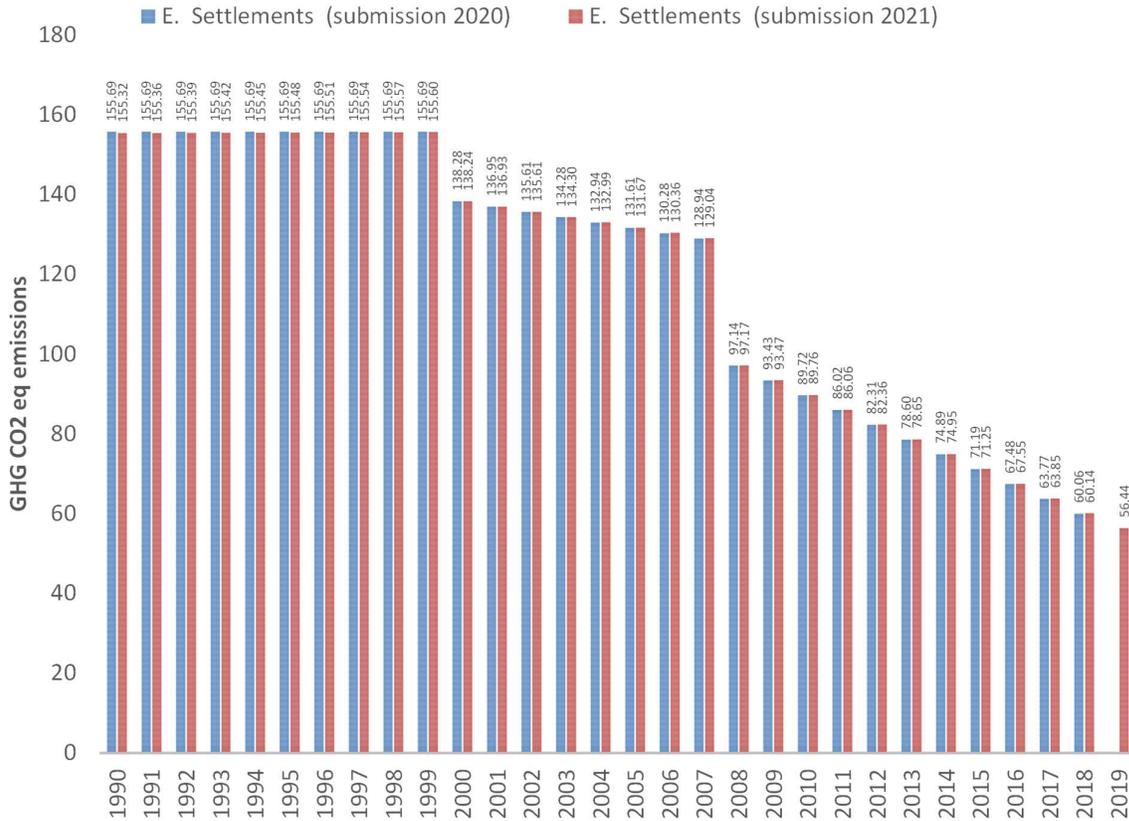
Figure 6-32: Recalculations with respect to previous submission 2020v1 in category 4D.



4.E Settlements:

In the 2020v1 calculations carbon losses of deadwood resulting from land use change from forestland to cropland a static value of dead wood carbon stock was used. In the 2021 version the dynamic value of the deadwood carbon stock, calculated in the forestland category, was used. This has led to minor changes.

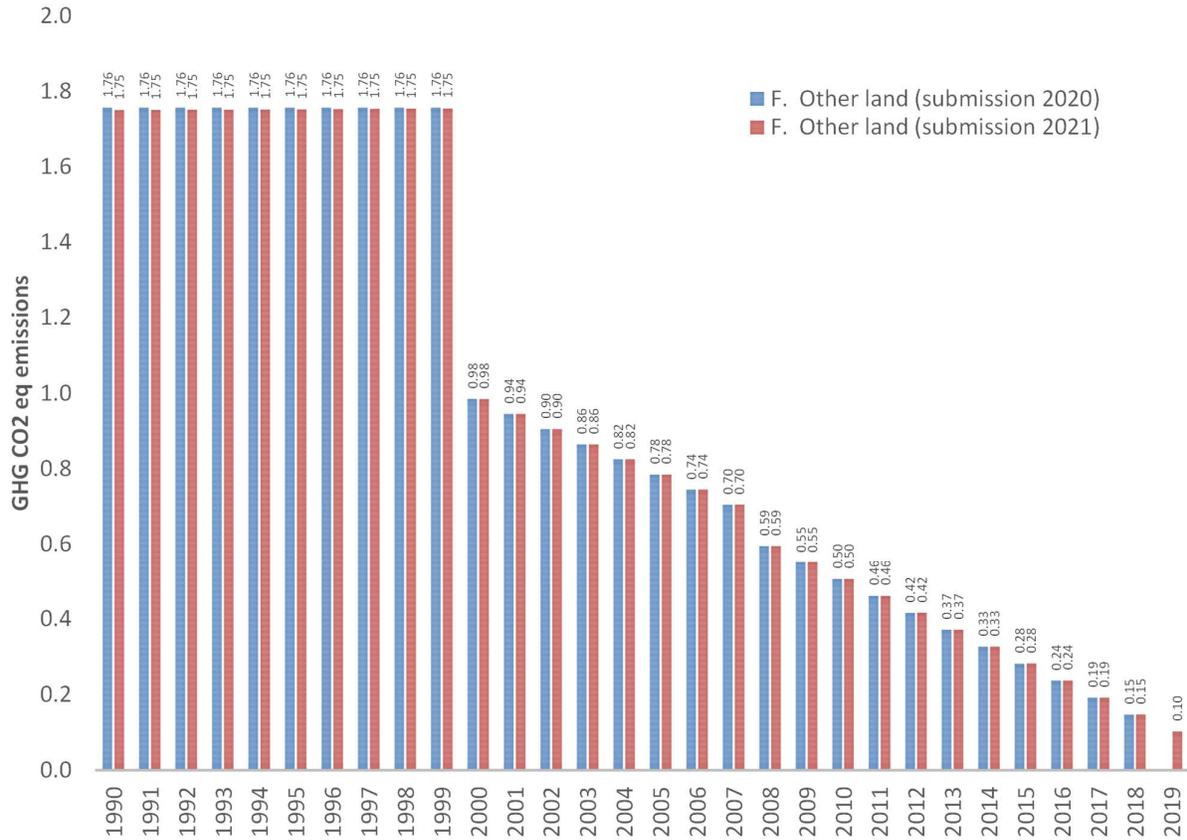
Figure 6-33: Recalculations with respect to previous submission 2020v1 in category 4E.



4.F Other land:

In the 2020v1 calculations carbon losses of deadwood resulting from land use change from forestland to cropland a static value of dead wood carbon stock was used. In the 2021 version the dynamic value of the deadwood carbon stock, calculated in the forestland category, was used. This has led to minor changes.

Figure 6-34: Recalculations with respect to previous submission 2020v1 in category 4F.



4.G Harvested Wood Products

In order to calculate the HWP carbon pool data on import and export of industrial roundwood are used to calculate the share of HWP originated from domestic harvest. The data of import and export of industrial roundwood is published by the FAO. If official data is not available FAO often uses estimates until the official data is submitted. With the latest download revised data of import and export of industrial roundwood has been made available which has led to a significant recalculation for the years 2017 and 2018. For the year 2017 the export of industrial roundwood has almost doubled (increase from 413.000m³ to 805.000m³).

Figure 6-35: Recalculations with respect to previous submission 2020v1 in category 4G.



6.12 Category-specific planned improvements

Taking into account the potential contribution of identified improvements in the total GHG emissions and the corresponding resources needed to make these improvements effective, developments presented Table 6-39 will be explored.

Table 6-39 – Planned improvements for category 4 – LULUCF

GHG source & sink category	Planned improvement
4A	Luxembourg plans to revise its OBS maps by 2020-2021
4A	Luxembourg plans to carry out a new NFI by 2025

7 Waste (CRF Sector 5)

7.1 Sector Overview

This chapter includes information on and description of methodologies used for estimating GHG emissions, as well as references to activity data and emission factors reported under CRF Sector 5 – Waste for the period 1990 to 2019. Emissions from this sector comprise emissions for the three main IPCC categories: 5A - Solid Waste Disposal, 5B - Biological Treatment of Solid Waste and 5D – Wastewater Treatment and Discharge.

GHG emissions related to 5C – Incineration and Open Burning of Waste are allocated to IPCC subcategory 1A1a – Fuel Combustion Activities – Energy Industries – Public Electricity and Heat Production (see Section 3.2.6) since energy is recovered and injected into the public electricity network from waste burned in the sole incinerator of the country.

7.1.1 Emission Trends

As shown in Figure 7-1 and Table 7-1, that provide a quick overview on Waste and Wastewater Treatment and Discharge related emission trends between 1990 and 2019, and Table 7-2 depicting the shares of each IPCC category under CRF Sector 5 for both the years 1990 and 2019, total waste related GHG emissions have decreased by 26.14% from 1990 to 2019, and decreased by 5.53% between 2018 and 2019.

Figure 7-1 – GHG Emission Trends for category 5 – Waste: 1990-2019

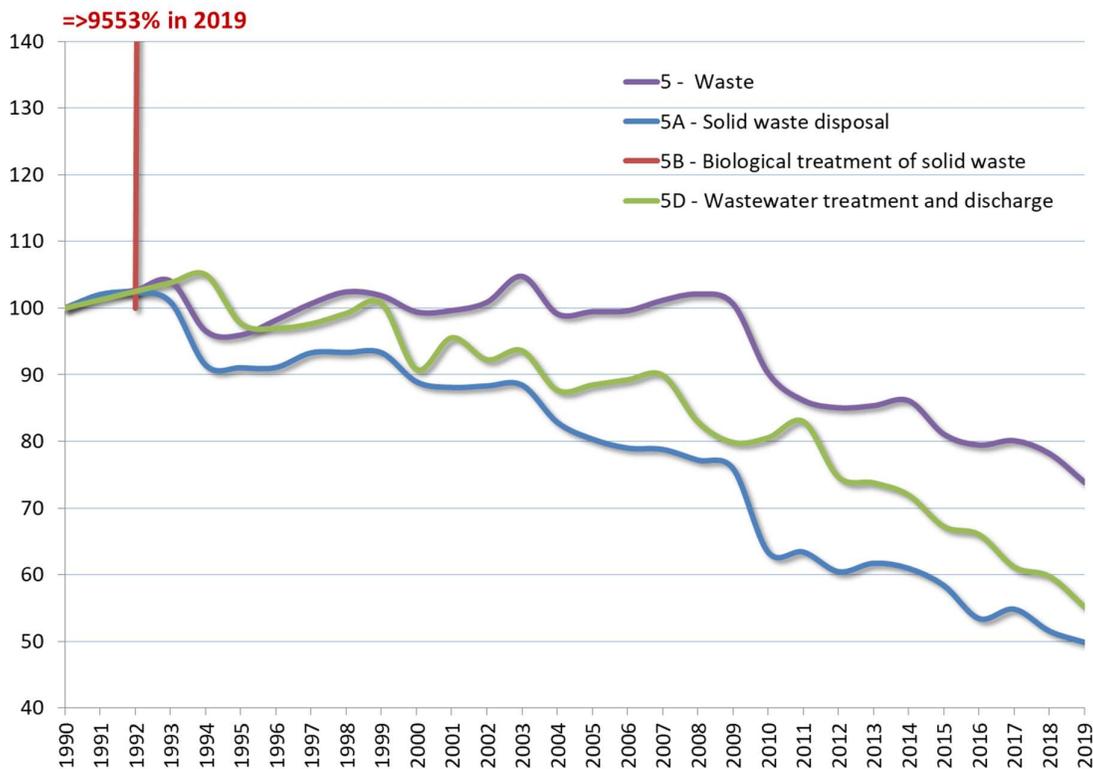
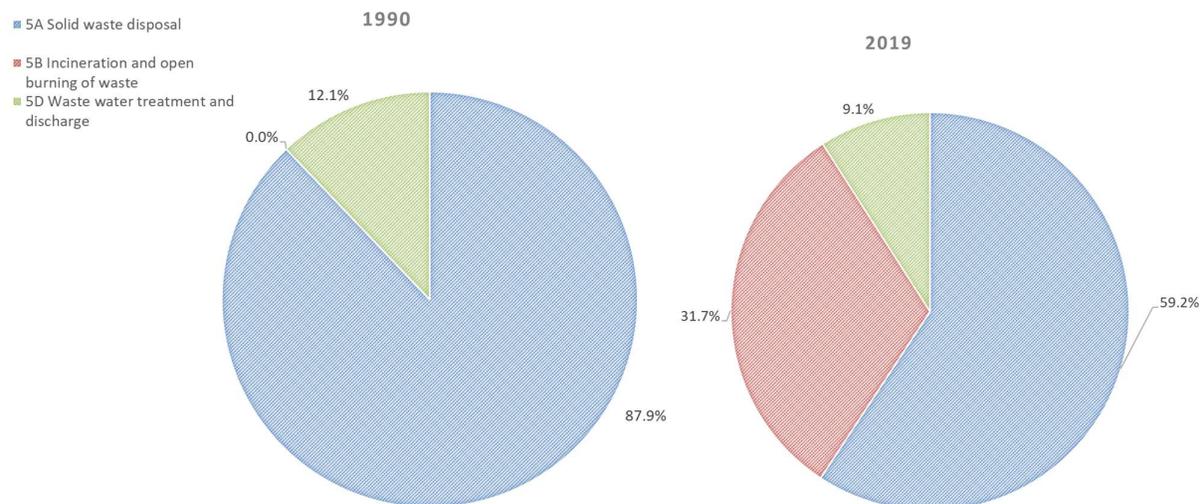


Figure 7-2 – Shares for category 5 – Waste: 1990 and 2019



The above mentioned trend evolution was mainly driven by the fact that, for IPCC category **5A – Solid Waste Disposal**, methane emissions have been reduced by 50.21% between 1990 and 2019 due to:

- an increase in aerobic treatment¹²⁰ before landfilling;
- a decrease in the quantity of waste being landfilled, notably through the development of recycling schemes, and the expansion of both the numbers of and the various waste categories collected by recycling centres;
- the recent installation of methane recovery systems at waste dumping sites;
- an increase of waste being incinerated.

No CO₂ emissions derived from non-biological or inorganic waste sources have been identified so far from waste disposal on land.

For category **5B – Biological Treatment of Solid Waste**, unlike IPCC category 5A, an increase of emissions is recorded for the years 1992 to 2019 for 5B1. With regard to compost production as well as aerobic treatment of solid waste, these activities have only started on an “industrial scale” in the early 1990s. The accelerated development of compost production from 1993-2003 explains the very high, and therefore not really exploitable, percentage growths observed for both CH₄ and N₂O. Since 2003, compost production activity has more or less stabilized (Section 7.3). In addition, as Luxembourg has committed itself under the Kyoto Protocol to an increased share of electricity produced from renewable sources, fugitive CH₄ emissions from the use of biomass in anaerobic digesters in 5B2 have accumulated (since 1992).

For this analysis, IPCC category **5C – Incineration and Open Burning of Waste** is excluded since, as indicated above, it is entirely accounted for under IPCC subcategory **1A1a – Fuel Combustion Activities – Energy Industries – Public Electricity and Heat Production**. Consequently, IE is reported for this category in CRF Table 5C (Table 7-1).

¹²⁰ Aerobic treatment refers to the cold treatment at SIGRE (until 2014), and the mechanical-biological treatment at SIDEC.

Table 7-1 – GHG Emission Trends in CO₂e for category 5 – Waste: 1990-2019

5 - Waste																
CO ₂ eq emissions (Gg) by source & sink category																
Year	5A - Solid Waste Disposal				5B - Biological Treatment of Solid Waste				5D - Wastewater Treatment and Discharge				5 - Waste			
	Total	CO ₂	CH ₄	N ₂ O	Total	CO ₂	CH ₄	N ₂ O	Total	CO ₂	CH ₄	N ₂ O	Total	CO ₂	CH ₄	N ₂ O
1990	92.98	NA	92.98	NA	0.00	NO	NO	NO	12.83	NA	7.58	5.25	105.80	NA	100.55	5.25
1991	94.91	NA	94.91	NA	0.00	NO	NO	NO	12.98	NA	7.65	5.34	107.89	NA	102.55	5.34
1992	95.18	NA	95.18	NA	0.26	NO	0.26	NO	13.15	NA	7.72	5.43	108.58	NA	103.15	5.43
1993	93.83	NA	93.83	NA	2.90	NO	1.80	1.10	13.31	NA	7.79	5.53	110.04	NA	103.41	6.63
1994	85.00	NA	85.00	NA	3.64	NO	2.23	1.41	13.47	NA	7.86	5.61	102.11	NA	95.09	7.02
1995	84.68	NA	84.68	NA	4.29	NO	2.62	1.67	12.53	NA	6.94	5.59	101.50	NA	94.24	7.26
1996	84.71	NA	84.71	NA	6.72	NO	4.04	2.68	12.44	NA	6.99	5.45	103.86	NA	95.74	8.13
1997	86.76	NA	86.76	NA	7.19	NO	4.29	2.90	12.52	NA	7.04	5.48	106.47	NA	98.09	8.39
1998	86.80	NA	86.80	NA	8.82	NO	5.21	3.60	12.72	NA	7.09	5.63	108.34	NA	99.10	9.24
1999	86.76	NA	86.76	NA	8.05	NO	4.74	3.31	12.91	NA	7.14	5.77	107.73	NA	98.64	9.09
2000	82.69	NA	82.69	NA	10.82	NO	6.56	4.26	11.64	NA	6.03	5.61	105.15	NA	95.28	9.87
2001	81.92	NA	81.92	NA	11.20	NO	6.99	4.22	12.26	NA	6.05	6.20	105.38	NA	94.96	10.42
2002	82.13	NA	82.13	NA	12.73	NO	7.93	4.80	11.83	NA	6.06	5.77	106.69	NA	96.12	10.57
2003	82.24	NA	82.24	NA	16.56	NO	10.50	6.06	12.01	NA	6.08	5.92	110.81	NA	98.82	11.99
2004	77.05	NA	77.05	NA	16.56	NO	10.79	5.77	11.24	NA	5.21	6.04	104.85	NA	93.04	11.81
2005	74.70	NA	74.70	NA	19.16	NO	12.69	6.47	11.35	NA	5.11	6.24	105.21	NA	92.50	12.71
2006	73.44	NA	73.44	NA	20.45	NO	13.74	6.71	11.45	NA	5.08	6.37	105.34	NA	92.26	13.08
2007	73.26	NA	73.26	NA	22.21	NO	14.99	7.22	11.53	NA	5.09	6.44	107.00	NA	93.34	13.66
2008	71.76	NA	71.76	NA	25.59	NO	17.36	8.23	10.64	NA	4.50	6.13	107.98	NA	93.62	14.36
2009	70.58	NA	70.58	NA	25.60	NO	17.88	7.72	10.24	NA	4.09	6.16	106.42	NA	92.55	13.87
2010	58.87	NA	58.87	NA	26.21	NO	18.37	7.84	10.33	NA	3.97	6.36	95.42	NA	81.22	14.20
2011	58.93	NA	58.93	NA	21.56	NO	15.79	5.77	10.64	NA	4.16	6.48	91.13	NA	78.87	12.26
2012	56.18	NA	56.18	NA	24.21	NO	18.27	5.94	9.57	NA	4.09	5.48	89.97	NA	78.54	11.42
2013	57.37	NA	57.37	NA	23.47	NO	17.81	5.66	9.46	NA	3.96	5.51	90.30	NA	79.13	11.17
2014	56.64	NA	56.64	NA	25.21	NO	19.13	6.08	9.23	NA	3.87	5.35	91.08	NA	79.64	11.43
2015	54.23	NA	54.23	NA	22.92	NO	18.05	4.87	8.62	NA	3.51	5.11	85.77	NA	75.79	9.99
2016	49.62	NA	49.62	NA	25.97	NO	20.43	5.54	8.47	NA	3.26	5.21	84.06	NA	73.31	10.75
2017	50.95	NA	50.95	NA	25.98	NO	20.65	5.33	7.84	NA	2.85	4.99	84.77	NA	74.45	10.32
2018	47.87	NA	47.87	NA	27.17	NO	21.66	5.51	7.67	NA	2.69	4.97	82.71	NA	72.22	10.49
2019	46.30	NA	46.30	NA	24.77	NO	19.23	5.54	7.08	NA	2.15	4.92	78.14	NA	67.68	10.47
Trend 1990-2019	-50.21%	NA	-50.21%	NA	NA	NA	NA	NA	-44.82%	NA	-71.58%	-6.21%	-26.14%	NA	-32.70%	99.36%
Trend 2018-2019	-3.29%	NA	-3.29%	NA	-8.85%	NA	-11.24%	0.51%	-7.68%	NA	-19.99%	-1.01%	-5.53%	NA	-6.30%	-0.21%

Source: Environment Agency

For IPCC category **5D – Wastewater Treatment and Discharge**, emissions decreased by 44.82% in 2019 compared to the base year 1990, and decreased by 7.68% compared to 2018. Wastewater treatment plant (WWTP) capacities expressed in population-equivalents have steadily grown (Section 7.6) over the period 1990 to 2019¹²¹, whereas nitrous oxide emissions (Table 7-1) decreased by 6.21%. With regard to wastewater treatment, technical changes therefore have an unquestionable role, as the evolution of methane emissions (-71.58% from 1990 to 2019) confirms.

7.1.2 Key Categories

The methodology and results of the key source analysis are presented in Chapter 1.5. Table 7-2 presents the key source categories of category 5 – Waste.

Table 7-2 - Key categories in category 5 – Waste.

5 - Waste						
Key sources						
IPCC Category	Category Name	GHG	LA excl. LULUCF	LA incl. LULUCF	TA excl. LULUCF	TA incl. LULUCF
5A	Solid Waste Disposal	CH ₄	95-04, 07-09	95-09, 11-13		

Source: Environment Agency

Notes: LA = Level Assessment (Tier 1) including respectively excluding LULUCF
 TA = Trend Assessment 2019 (Tier 1) including respectively excluding LULUCF

7.1.3 Completeness

Table 7-3 provides more details on the IPCC categories included under CRF Sector 5, in which emissions are not occurring for activities or processes (*NO*), emissions do not result from activities in the given source category (*NA*), emissions are considered negligible (*NE*) and/or emissions that are included elsewhere (*IE*) in the inventory.

121 This increase is notably explained by (i) the significant population growth between 1990 and 2019, and (ii) the increasing number of commuters who are crossing the border each working day (Section 2.1). Percentage growths recorded for these two variables are, as well, largely above the one estimated for N₂O emissions from WWTP.

Table 7-3 – Status of Emission Estimates for CO₂, CH₄ and N₂O in category 5 – Waste

GHG source & sink category	Description	Status		
		CO ₂	CH ₄	N ₂ O
5A - Solid Waste Disposal				
5A1	Managed waste disposal sites	NA	X	
5A2	Unmanaged waste disposal sites	NO	IE*	
5A3	Uncategorized waste disposal sites	NO	NO	
5B - Biological Treatment of Solid Waste				
5B1	Composting		X (1993-2019)	X (1993-2019)
5B1	Pre-treatment of solid waste		X (1993-2019)	X (1993-2019)
5B2	Anaerobic digestion at biogas facilities		X (1992-2019)	NE
5C - Incineration and Open Burning of Waste				
5C1	Waste incineration	IE **	IE **	IE **
5C2	Open burning of waste	NO	NO	NO
5D - Wastewater Treatment and Discharge				
5D1	Domestic wastewater		X	X
5D2	Industrial wastewater		NO	X
5D3	Other		NO	NO

Note: X indicates that emissions from this subcategory have been estimated.

The grey shaded cells are those also shaded in the CRF tables (AD has not been specified, or cells are blocked for editing).

* = Unmanaged waste disposal sites are recorded under CRF subcategory 5A1 since nowadays all the landfills are considered well-managed.

** = Waste incineration is recorded under CRF subcategory 1A1a since electricity is produced from incinerated municipal waste residues.

7.1.4 Luxembourg's Waste Generation and Management System

The common basis for activity data to estimate emissions from IPCC categories 5A – *Solid Waste*, 5B – *Biological Treatment of Solid Waste*, and 5C – *Incineration and Open Burning of Waste* is the generation of **municipal solid waste** (MSW). MSW consists of waste collected from households, as well as refuses generated by small industries, retail shops and services (private or institutional). In other words, MSW corresponds to the totality of waste collected by municipalities (Total MSW).

According to the modified Luxembourgish Law of March 21, 2012 ¹²², the collection of MSW falls within the competence of municipalities. As a result municipalities joined together in different municipal waste management syndicates. There are four inter-municipal syndicates responsible for the management of municipal solid waste:

- SIDA regrouping municipalities in the north of the country (integrated in SIDEC since 1994);

122 Loi modifiée du 21 mars 2012 relative à la gestion des déchets, et modifiant la loi du 31 mai 1999 portant institution d'un fonds pour la protection de l'environnement; la loi du 25 mars 2005 relative au fonctionnement et au financement de l'action SuperDrecksKëscht; la loi du 19 décembre 2008 a) relative aux piles et accumulateurs ainsi qu'aux déchets de piles et d'accumulateurs; b) modifiant la loi modifiée du 17 juin 1994 relative à la prévention et à la gestion des déchets; la loi du 24 mai 2011 relative aux services dans le marché intérieur <http://www.legilux.public.lu/leg/a/archives/2012/0060/2012A0670A.html>

- SIDEC regrouping the municipalities of the North;
- SIDOR regrouping the municipalities of the West, the South and the Center;
- SIGRE regrouping the municipalities of the East.

Unmanaged Landfill Sites

Before the syndicates started managing different solid waste disposal sites (SWDS), the waste was dumped in local unmanaged dumping sites within the municipalities. In 1980, the first law on waste was voted in Luxembourg. Between 1981 and 1982, around 110 permits were issued for unmanaged landfill sites. When the new waste legislation came into force in 1994, all private and municipal unmanaged landfills had to be closed. These areas were cleaned and covered in plantation in order to fit into the surrounding landscape. A cadastre was set up, with all landfill sites that could be contaminated.

Since 1994, inspections were systematically performed by the Environment Agency at 616 former landfills. The Environment Agency oversaw the work that lasted until 2005. No abnormal behaviour of these closed sites has been detected and no corrective actions were required.

As an example for a successful closing procedure is the former landfill site in Bettembourg next to the leisure park "Parc Merveilleux", visited by lots of families during the summer months. About 500 000 m³ MSW had been deposited at this site in the 1980s, and after closure, the site was equipped with a drainage system and covered with a one meter thick layer of earth. Specific analysis showed that the anaerobic fermentation process was finished, and no methane emissions stemming from the site could be detected. Hence, it was decided that these sites could be annexed to the leisure park, to host larger compounds for animals (such as a deer park).

The managed landfill sites of SIDEC and SIGRE opened in 1972 and 1979, respectively. Table 7-4 summarizes the situation for each waste management syndicate.

Table 7-4 – Municipal Solid Waste Management in Luxembourg

Syndicate	Waste Elimination Scheme	Operating Years with Regard to the GHG Inventory
SIDA	Landfill	till 1993
SIDEC	Landfill	1972-2014
	+ Methane recovery system	2002-2019
	+ Biological treatment	2007-2019
SIDOR	Incineration	1976-2019
SIGRE	Landfill	1979-2019
	+ Aerobic treatment	1993-2014
	+ Methane recovery system	2000-2019

Source: Environment Agency

Notes: SIDEC (www.sidec.lu), SIDOR (<http://sidor.lu>), and SIGRE (www.sigre.lu)

The waste management syndicates, listed in Table 7-4, exist since 1990 and have been managing their own dumping or incineration site. In 1994 the syndicate SIDA merged with SIDEC and its dumping site was subsequently closed. In 2014 there were two controlled landfill sites (one managed by SIDEC and one managed by SIGRE) and one incinerator (managed by SIDOR) in operation in Luxembourg.

In 2015, the syndicates decided to use only one controlled landfill site in Muertendall, managed by SIGRE. The landfill site managed by SIDEC was subsequently closed.

A **methane recovery system** has been in operation at the SIGRE site since 2000, and at the SIDEC site since 2002. The **aerobic treatment** in heaps has been performed at SIGRE from 1993 to 2014. Also, pre-treatment of solid waste prior landfilling of waste in tunnels has been fully operational since 2007 at SIDEC.

Figure 7-3 – Waste Flow in Luxembourg before 2015



Figure 7-4 – Waste Flow in Luxembourg after 2015



The total municipal solid waste (Total MSW, municipal waste from households and similar household waste excluding recycling), accounted for in the inventory is – upon collection – partly:

- **landfilled** – accounted under IPCC category 5A either directly¹²³ or indirectly after treatment (*i.e.* emissions occurring during biological treatment are accounted under IPCC category 5B), or
- **incinerated** (*i.e.* solid waste to be accounted for under IPCC category 1A1a as energy is recovered from incineration).

7.1.5 Legislation

The most important legislative and regulatory measures, which have reduced the waste-related emissions from **Luxembourg**, are included in the

- (i) EU Waste Framework Directive 2008/98/EC;
- (ii) Landfill Directive 1999/31/EC;
- (iii) Industrial Emissions Directive 2010/75/EU;
- (iv) *Loi modifiée du 21 mars 2012 relative aux déchets ;*
- (v) *Règlement grand-ducal du 18 décembre 2015 relatif aux avertissements taxés déterminant les modalités d'application de l'avertissement taxé et établissant un catalogue des contraventions soumises à l'avertissement taxé prévu par la loi modifiée du 21 mars 2012 relative aux déchets.*

The **Waste Framework Directive** mandates waste management as a priority to prevention (non-waste), re-use, recycling and recovery. The latter Directive, which also has introduced the “*polluter pays principle*”, has been transposed on the national level by the Luxembourgish Law of March 21, 2012 ¹²⁴.

The modern requirements for disposal sites, in order to reduce methane generation, of the **Landfill Directive** have been transposed into national legislation through the Grand-Ducal Regulation of February 24, 2003 ¹²⁵.

The aim of the **Industrial Emissions Directive**, transposed by the Law of May 9, 2014¹²⁶, is to prevent or to reduce emissions caused by the incineration of waste. This is to be achieved through the application of operational conditions, technical requirements, and emission limit values for incineration plants within the EU.

Even though the uncontrolled management of waste was already included in the law of 17 June 1994 (“Loi modifiée du 17 juin 1994 relative à la prévention et à la gestion des déchets (abrogée)”) the Article 42 of the national law of 18 December 2015¹²⁷ states clearly

123 Direct landfilling of waste concerns waste with or without mechanical sorting. Direct landfilling was completely abandoned in 2015.

124 Loi modifiée du 21 mars 2012 relative à la gestion des déchets, et modifiant la loi du 31 mai 1999 portant institution d'un fonds pour la protection de l'environnement; la loi du 25 mars 2005 relative au fonctionnement et au financement de l'action SuperDrecksKësch; la loi du 19 décembre 2008 a) relative aux piles et accumulateurs ainsi qu'aux déchets de piles et d'accumulateurs; b) modifiant la loi modifiée du 17 juin 1994 relative à la prévention et à la gestion des déchets; la loi du 24 mai 2011 relative aux services dans le marché intérieur. <http://www.legilux.public.lu/leg/a/archives/2012/0060/2012A0670A.html>

125 Règlement grand-ducal du 24 février 2003 concernant la mise en décharge des déchets. <http://www.legilux.public.lu/leg/a/archives/2003/0034/2003A05461.html>

126 Loi du 9 mai 2014 relative aux émissions industrielles. <http://legilux.public.lu/eli/etat/leg/loi/2014/05/09/n1/fo>

127 Loi du 18 décembre 2015 modifiant la loi du 21 mars 2012 relative aux déchets. <http://legilux.public.lu/eli/etat/leg/loi/2015/12/18/n17/fo>

that the abandonment, dumping or uncontrolled management of waste is prohibited. This statement includes the prohibition of open burning of waste, which is considered as an uncontrolled management of waste. This includes the ban on burning of green waste, household and non-domestic waste in the open air. Waste fines imposed for non-compliance with this provision are fixed in the Grand-Ducal Regulation of 18 December 2015¹²⁸. Indeed, a fine of 145 € is imposed for open burning of waste and even 250 € for open burning of non-domestic waste. Many municipalities have also implemented this prohibition in their respective municipal regulations.

7.2 Solid Waste Disposal (5A)

7.2.1 Source Category Description

The following section describes GHG emissions resulting from solid waste disposal on land (SWDL), which originates from waste disposal sites in Luxembourg. As there are no longer unmanaged waste disposal sites (Chapter 7.1.4 Box “*Unmanaged Landfill Sites*”), emissions from IPCC category 5A – *Solid Waste Disposal* are equal to the one deriving from IPCC subcategory 5A1 – *Managed Waste Disposal Sites*.

Municipal waste is indirectly landfilled after treatment. Indirectly landfilled waste undergoes mechanical and biological pre-treatment prior landfilling. However, the emissions deriving from the treatment processes of waste are addressed under CRF subcategory 5B1 (see Figure 7-3 and Figure 7-4).

In 2019, the source category 5A was responsible for 59.25% of emissions related to waste treatment under Section 5, and for 7.95% of the total **methane** emissions estimated for Luxembourg (15.91% in 1990). It represented 0.43% of the total **GHG** emissions (excluding LULUCF) in 2019 (0.73% in 1990). Neither CO₂ (biogenic origin), nor N₂O emissions (not significant) derived from non-biological or inorganic waste sources have been identified so far.

The source category 5A – *Solid Waste Disposal* has been identified as a **key category** for CH₄ for several years (level and trend assessment excluding LULUCF, please refer to Table 7-2).

7.2.2 Methodological Issues

7.2.2.1 Data Origin

The syndicates responsible for the MSW management submit an annual report, in which all the waste delivered to their landfill site or incineration plant is reported. The reduction of waste due to rotting losses occurring at the SIDEC site is based on measurements. The rotting losses due to the pre-treatment until 2014 at the SIGRE site has been estimated.

The IPCC category 5A covers all waste disposal which is organised *via* regional disposal districts (as listed in Table 7-5) as well as industrial waste deposited at Ronnebiërg (Box “*Industrial Waste Disposal Site Ronnebiërg*”). Today, Muertendall (managed by SIGRE in the Eastern district) is the only active landfill site.

128 Règlement grand-ducal du 18 décembre 2015 relatif aux avertissements taxés déterminant les modalités d'application de l'avertissement taxé et établissant un catalogue des contraventions soumises à l'avertissement taxé prévu par la loi modifiée du 21 mars 2012 relative aux déchets. <http://www.legilux.public.lu/leg/a/archives/2015/0256/a256.pdf>

Industrial Waste Disposal Site Ronnebjerg

The deposit of industrial waste in Ronnebjerg was in operation from approximately 1962 until 1994. At the end of 1994 Luxembourg's only industrial waste disposal site was closed and subsequently sanitised between 1997 and 2000. The landfill site was sealed and a drainage system was installed.

According to a study from 1995 the following information is available for this site:

- 1962 start of operation
- 1960-1972: estimated volume deposited 92.000m³
- 1973 land fill site official handover to waste contractor
- 1974: authorisation for sludge and residues from septic tanks
- 1976 disposal of incineration slag from waste incineration plant
- 1978 disposal of industrial inert waste: mainly polyester and polypropylene
- 1981 authorisation for municipal waste was revoked (except in case of problems with the incineration plant)
- 1972-1984: estimated volume deposited 356.000 m³
- 1983 detailed analysis of yearly waste composition: 65 891 t collected between 1/8/1982 and 31/8/1983:
 - 66,7% incineration slag;
 - 8,9% demolition waste;
 - 6,7% shredder waste;
 - 5,9% plastic, paper and cardboard;
 - 4,2% glass;
 - 3,2% sludge;
 - 1,6% grease from restaurants;
 - 1,4% waste from septic tanks;
 - 0,5% dry sludge;
 - 0,9% other.

- 1986 – 1994:

Total waste (t)	Ronnebjerg I	Monticule	Ronnebjerg II
1986	83.600		
1987	112.000		
1988	130.200		
1989	140.700		
1990	270.100		
1991	12.800	68.700	
1992		59.300	
1993		17.000	3.000
1994			20.000
Total 1986-1994	749.400	145.000	23.000

- Separate study focusing on incineration slag estimates that 472.298 t of slag were deposited between 1976 and 1988, and a further 196.472 t between 1989 and 1993.
- In conclusion of the study the composition of the total volume deposited is as follows:
 - Household waste: 20 %
 - Incineration slag: 50 %
 - Demolition waste: 6 %
 - Shredder, plastic, cardboard and glass: 15 %
 - Different types of sludge: 7 %
 - Other: 2 %

In the framework of the rehabilitation of the landfill, regular controls of the landfill condition, as well as measurements of emissions, have been performed since 2000 (except for 2001). These measurements are annually reported to the Environment Agency and used for estimating emissions. For the years before 2000, the emissions have been extrapolated based on the historic information available. The emissions from the closed landfill site for industrial waste, Ronnebjerg, have been included in the category 5A (see Table 7-9).

Table 7-5 – Total Municipal Solid Waste generated in Luxembourg by syndicates

Total MSW generated by syndicates							
Year	Total MSW Gg	SIDOR Gg	SIDEC Gg	SIGRE Gg	SIDA Gg	Population #	MSW / capita kg / hab.
1990	223.60	135.97	58.23	18.40	11.00	379 300	589.51
1991	216.80	142.26	39.34	24.60	10.60	384 400	564.00
1992	195.52	141.85	38.11	5.46	10.10	389 600	501.86
1993	200.98	134.95	39.26	13.71	13.06	394 800	509.06
1994	196.10	132.03	45.53	18.55		400 200	490.01
1995	194.76	126.09	47.31	21.36		405 700	480.06
1996	191.62	97.55	51.02	43.04		411 600	465.54
1997	192.58	115.56	42.02	35.00		416 900	461.94
1998	189.02	113.28	41.90	33.84		422 100	447.80
1999	196.81	129.69	40.55	26.57		427 400	460.48
2000	187.72	125.99	41.60	20.13		433 600	432.93
2001	190.03	124.40	43.02	22.60		439 000	432.87
2002	192.34	126.32	42.02	24.00		444 000	433.19
2003	191.18	122.86	42.45	25.87		448 300	426.45
2004	193.65	125.79	43.94	23.92		455 000	425.61
2005	196.06	121.14	42.68	32.23		461 200	425.10
2006	192.51	124.03	38.31	30.17		469 100	410.39
2007	193.48	127.69	39.40	26.40		476 200	406.31
2008	193.82	127.54	39.57	26.71		483 800	400.61
2009	194.04	126.72	39.21	28.11		493 500	393.19
2010	191.15	117.06	39.32	34.76		502 100	380.70
2011	192.09	125.36	39.39	27.34		511 800	375.32
2012	190.83	123.03	39.70	28.10		524 900	363.56
2013	185.48	119.04	39.19	27.25		537 000	345.41
2014	187.70	118.19	39.39	30.13		549 700	341.46
2015	182.41	123.47	37.47	21.48		563 000	324.00
2016	189.50	130.23	37.92	21.34		576 200	328.88
2017	189.19	130.63	37.88	20.68		590 700	320.28
2018	194.54	133.10	38.00	23.44		602 005	323.15
2019	195.65	136.64	37.72	21.30		613 894	318.71
Trend 1990-2019	-12.50%	0.49%	-35.23%	15.74%	-100.00%	61.85%	-45.94%
Trend 2018-2019	0.57%	2.66%	-0.74%	-9.17%	NA	1.97%	-1.38%

Sources: Annual reports submitted by syndicates

In order to evaluate the generation of MSW in Luxembourg Table 7-5 illustrates the production of MSW by syndicates. There are however important waste streams between the incineration plant and the two landfill sites which are not visible in this table (see Figure 7-4). With the closure of the landfill site in Fridhaff (SIDEC) in 2014 the waste from the pre-treated waste is being landfilled in the landfill site in Muertendall. The waste from the SIGRE communes is either directly transported to the SIDOR incineration plant (and reported under SIDOR) or first deposited at the SIGRE site and subsequently transported to the SIDOR site (but still reported under SIGRE). This explains the dip in the SIGRE category from 2015 and the increase in the SIDOR category. The decrease of total waste between 2014 and 2015 is a reduction of demolition waste (to specialised landfill site) and a reduction of bulk waste (separate collection and partly recycled). To sum up this table can only be analysed for the total generated MSW per capita (excluding recycling).

7.2.2.2 Methodology

Table 7-6 lists the amount of MSW managed by the solid waste disposal sites. The table is split in MSW directly deposited and indirectly deposited. The table shows waste flows including the reduction in waste due to biological treatment (rotting losses) as well as the high calorific fraction of waste (HWF="Heizwertfraktion") separated by mechanical treatment and subsequently eliminated in the incineration plant and addressed under 1A1a.

Table 7-6 - Amounts of managed waste deposited at SWDS sites

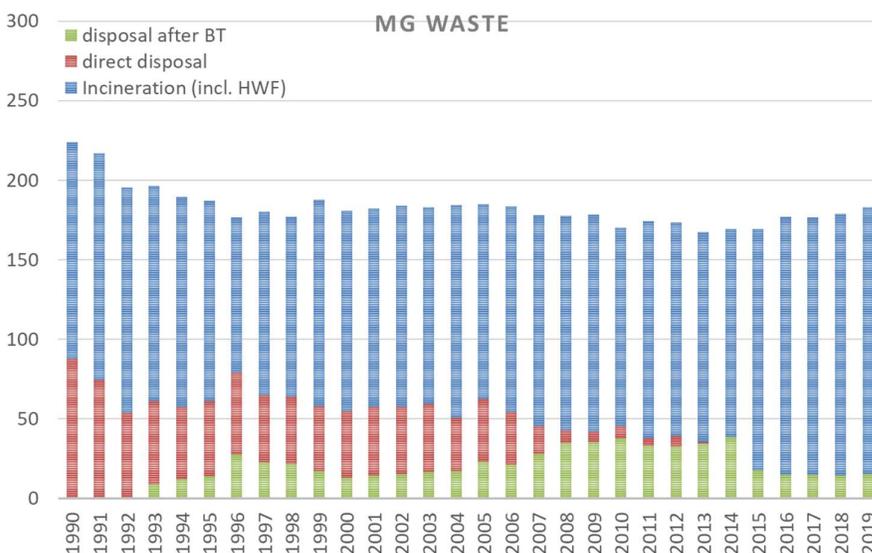
Year	Incineration (incl. HWF)	SIDA total	SIGRE - Muertendall					SIDEK - Fridhaff										direct disposal	direct disposal	disposal after BT
			Total	const. waste	rotting losses	to SIDOR	disposal after BT	Total	inert. Waste & metal	disposal before MS	disposal after MS	to SIDOR	disposal before BT	rotting losses	disposal to SIGRE	disposal after BT				
1990	136.0	11.0	18.4		0.0			58.2										58.2	87.6	
1991	142.3	10.6	24.6		0.0			39.3										39.3	74.5	
1992	141.9	10.1	5.5		0.0			38.1										38.1	53.7	
1993	134.9	13.1	13.7		-4.8		8.9	39.3										39.3	52.3	8.9
1994	132.0		18.5		-6.5		12.1	45.5										45.5	45.5	12.1
1995	126.1		21.4		-7.5		13.9	47.3										47.3	47.3	13.9
1996	97.6		43.0		-15.0		28.0	51.0										51.0	51.0	28.0
1997	115.6		35.0		-12.2		22.8	42.0										42.0	42.0	22.8
1998	113.3		33.8		-11.8		22.0	41.9										41.9	41.9	22.0
1999	129.7		26.6		-9.3		17.3	40.5										40.5	40.5	17.3
2000	126.0		20.1		-7.0		13.1	41.6										41.6	41.6	13.1
2001	124.4		22.6		-7.9		14.7	43.0										43.0	43.0	14.7
2002	126.3		24.0		-8.4		15.6	42.0										42.0	42.0	15.6
2003	123.8		25.9		-9.0		16.8	42.4	0.0			-1.0						42.4	42.4	16.8
2004	133.8		23.9	-1.2	-6.9		17.0	43.9	-2.0	3.1	0.0	-8.0	30.4					33.5	33.5	17.0
2005	122.7		32.2	-2.7	-9.1		23.2	42.7	-1.7	2.2	0.0	-1.5	37.0					39.2	39.2	23.2
2006	129.3		30.2	-2.2	-8.7		21.4	38.3	-1.7	1.2	0.0	-5.3	31.4					32.7	32.7	21.4
2007	132.4		26.4	-4.7	-6.8		19.6	39.4	-2.0	0.7	1.2	-4.7	15.5	-6.8		8.5	17.4	17.4	28.1	
2008	134.8		26.7	-3.7	-7.3		19.4	39.6	-2.0	0.4	3.1	-7.2	4.2	-7.0		15.7	7.7	7.7	35.1	
2009	136.5		28.1	-4.9	-7.4		20.7	39.2	-1.7	0.1	0.4	-9.8	5.6	-6.7		15.0	6.1	6.1	35.7	
2010	124.1		34.8	-3.8	-10.0		24.7	39.3	-1.6	0.2	1.2	-7.0	6.7	-9.5		13.0	8.1	8.1	37.7	
2011	136.7		27.3	-4.0	-7.4		19.9	39.4	-2.0	0.1	0.1	-11.3	4.4	-8.3		13.2	4.6	4.6	33.1	
2012	134.2		28.1	-5.1	-7.2		20.9	39.70	-2.1	0.0	0.0	-11.1	6.2	-8.1		12.1	6.2	6.2	33.0	
2013	132.0		27.2	-4.2	-7.1		20.1	39.2	-2.0	0.0	0.0	-13.7	0.7	-8.3		14.5	0.7	0.7	34.6	
2014	130.6		30.1	-5.7	-7.4		22.7	39.4	-2.0		0.0	-12.4	0.0	-9.1		15.9	0.0		38.6	
2015	151.6		36.5	-3.5		-15.3	17.8	39.2	-2.0			-12.9		-9.1	-15.1	0.0			17.8	
2016	162.1		35.7	-5.3		-15.6	14.8	39.6	-1.9			-16.3		-7.1	-14.4	0.0			14.8	
2017	161.4		35.1	-5.0		-15.0	15.1	37.9	-0.2			-15.8		-7.2	-14.7	0.0			15.1	
2018	164.4		36.9	-7.1		-15.2	14.6	38.0	-0.2			-16.2		-7.6	-14.1	0.0			14.6	
2019	167.5		35.2	-5.8		-13.8	15.5	37.7	-0.2			-17.1		-6.6	-13.9				15.5	
<i>Trend 1990-2019</i>	23.19%		91.04%				NA	-35.23%									-100.00%	-100.00%	NA	
<i>Trend 2018-2019</i>	-1.83%		-4.79%				6.25%	-0.74%									NA	NA	6.25%	

Sources: Annual reports submitted by syndicates

Figure 7-5 illustrates the evolution of the shares of the direct, indirectly deposited and incinerated MSW for Luxembourg.

- The sudden drop in total waste between 1992 and 1993 can be explained by the opening of one major composting facility Minett-Kompost and multiple recycling centres.
- The drop in share of direct disposal in 1995/1996 can be explained by an increased amount of waste being treated in the mechanical-biological pre-treatment at SIGRE.
- The second sudden drop in share of direct disposal in 2006/2007 is due to the biological pre-treatment of solid waste prior to landfilling at SIDEC.

Figure 7-5 – Shares of direct, indirect disposal and incineration of MSW (1990 - 2019)



From 2014 onwards no more waste has been landfilled without pre-treatment (due to the Landfill Ordinance, see Section 7.1.5).

7.2.2.2.1 Directly Deposited Waste (SIDEC)

Up to 1990 total amounts of waste and waste composition have been estimated. From 1990 onwards waste amounts are known and categorised according to the European Waste Catalogue (CED 2nd version Classification Européenne des Déchets). The fractions of waste listed are listed in Table 7-7.

The waste composition of both, residual (CED 200301 and 200399) and bulky waste (CED 200307) is analysed in a 5-year cycle. The results of the waste composition analysis are used to calculate emissions for directly deposited waste. For other waste fractions (190801, 190802, ...) degradable organic carbon (DOC) contents are estimated (Table 7-7).

Table 7-7 – Waste Fractions and Estimated Degradable Organic Carbon for directly deposited waste

<i>CED</i>	<i>Description</i>	<i>Estimated DOC</i>
200301	Mixed municipal waste	Residual waste composition
200399	Municipal waste, not otherwise specified	
200307	Bulky waste	Bulky waste composition
190801 ⁽¹⁾	Wastes from wastewater treatment plants – screenings	90 %
190802 ⁽²⁾	Wastes from wastewater treatment plants – waste from de-sanding	50 %
200303 ⁽³⁾	Street-cleaning residues	20 %
200201	Garden and park waste, biodegradable waste	100 %

Note: (1) Sächsisches Landesamt für Umwelt und Geologie 2006: Klärschlammkonzeption
(2) Hitzler Andreas: Beurteilung und Optimierung von Sandwaschanlagen im Einsatz auf Kläranlagen; Dissertation Universität Fridericiana zu Karlsruhe (TH), 2002
(3) Bayerisches Landesamt für Umwelt Infoblatt Abfallwirtschaft, Straßenkehrriecht Mai 2010

Emissions are estimated by the using of a *multiphase model (three phase model)*, an approach with which several organic element groups can be distinguished in the waste through their half-lives.

The spreadsheet based on the **First Order Decay (FOD) method** implementing the **Tier 1** methodology from the IPCC 2006 Guidelines for national GHG inventories has been used to estimate CH₄ emissions from SWDS. The method takes into account the decomposable degradable organic carbon (DDOC_m) accumulated (Equation 3.4) and the DDOC_m decomposed (Equation 3.5) under anaerobic conditions in the SWDS at the end of a given year. According to K.-U. Heyer, the anaerobic degradation proceeds relatively intensively with a higher gas production rate (K.-U. Heyer, 2013) during the first years of disposal.

7.2.2.2.2 Indirectly Deposited Waste (after biological pre-treatment)

The pre-treatment of municipal waste before disposal leads to a substantial aerobic decay of the organic component. As a consequence, the behaviour of the decay in terms of reduction of the total mass and DOC_m is changing substantially.

Since the pre-treatment (until 2014) of waste at the SWDS site Muertendall (managed by SIGRE) has been performed directly on the landfill site, the reduction of the total mass is not known and has been estimated. The resulting mass loss (Table 7-6) during the six-month rotting process is estimated to correspond to 50% of the mass of degradable organic compounds (DOC).

The waste at the site in Fridhaff (SIDEDEC) is weighed before and after treatment and hence the reduction in mass (rotting losses) is known. However the composition of the remaining waste and its fraction of degradable organic carbon content is not known. Landfill operators have determined the respiration activity of waste after mechanical and biological treatment as a parameter of biologic reactivity and the rotting state of waste under aerobic conditions. The **AT₄ parameter** indicates the amount of O₂ consumed during the decomposition of the organic fraction of waste. SIDEDEC reported that AT₄ was reduced from 90 mg O₂/g TS (untreated waste) to 17 mg O₂/g TS (pre-treated waste). This analysis is however not sufficient in order to figure out the exact fraction of degradable organic carbon content post rotting process. Hence the emissions have been calculated according to the IPCC *single-phase model* based on bulk waste. This approach is also justified because, even though the waste has been partly decomposed, the water loss also means that the concentration of biodegradable elements in the residual waste is higher. The oxidation factor (0,1) has been based on the study by

KÜHLE-WEIDEMEIER and BOGON (Kühle-Weidemeyer & Bogon, Dezember 2008). The value is justified by the fact that solid waste disposal sites in Luxembourg are operated by gradually covering different parts of the site with a layer of soil. According to the guidelines the default methane generation rate for bulk waste analysis ranges between 0.08-0.1. It can reasonably be argued that after the rotting process the remaining waste is predominantly constituted with materials that have a longer half-time value and hence the lower value of the allowed range was chosen.

7.2.2.3 Activity Data

As there are no national data on amounts of municipal waste generation available for the years 1950 to 1989, data on waste *per capita* from Germany (Prof. Dr. Dr. B.-M. Wilke, 2009) was used from 1950 (200 kg *per capita*) and 1975 (385 kg *per capita*). The first available data on waste generation is the year **1990** (590 kg MSW produced *per capita* (Table 7-5), which was similar to the IPCC default values (*i.e.* 490 kg MSW produced *per capita*, IPCC Table 2A.1)). The quantities of waste generated between 1950 and 1974 as well as between 1975 and 1989 were interpolated.

Municipal waste was completely landfilled until 1975 after which the incinerator of SIDOR started operating. The fraction of waste incinerated was attributed in relation to the population living in the SIDOR municipalities. After 1990 the exact proportion of waste going into landfill or being incinerated are known.

7.2.2.3.1 Directly Deposited Waste (SIDE C)

An overview of the composition trends of waste destined to direct disposal is given in Table 7-8.

Table 7-8 – Composition Trends of Waste destined to Direct Disposal

Year	Food	Garden	Paper	Wood	Textile	Nappies	Plastics, other inert	Total
1950-1974	20%	0%	25%	5%	0%	0%	50%	100%
1975-1980	24%	1%	25%	11%	1%	1%	37%	100%
1981-1984	24%	1%	24%	11%	1%	2%	37%	100%
1985-1991	29%	4%	20%	11%	1%	2%	33%	100%
1992 – 2003	39%	8%	16%	1%	1%	5%	30%	100%
2004	19%	6%	12%	28%	6%	3%	25%	100%
2005	17%	5%	13%	26%	6%	3%	29%	100%
2006	28%	5%	16%	13%	4%	4%	30%	100%
2007	24%	6%	16%	12%	5%	4%	33%	100%
2008	17%	7%	17%	13%	8%	4%	35%	100%
2009	28%	3%	14%	13%	4%	5%	33%	100%
2010	33%	6%	11%	12%	2%	3%	33%	100%
2011	42%	5%	10%	10%	1%	3%	29%	100%
2012	44%	5%	12%	6%	1%	4%	29%	100%
2013	46%	5%	9%	5%	1%	5%	30%	100%
since 2014	0%	0%	0%	0%	0%	0%	0%	0%

Note: Percentages of waste fractions refer to the Managed MSW to SWDS.

The following points can be highlighted with regards to this table:

- Waste composition for the period **1950-1974** has been oriented on the IPCC default values but it was assumed that the fractions “*food*”, “*paper*” and “*wood*” landfilled were lower in the after WW2 period. The difference was allocated to the fraction “*plastics, other inert*”.

- For the period **1975-1991** the default IPPC values for waste composition were used. The values were however gradually adapted to take into account the appearance of nappies in the waste streams. The remaining fractions were modified accordingly.
- Waste composition is exactly known since **1990** and is determined by periodical sampling.
- Between **1992 and 2004**, the amount of directly deposited waste corresponds to the waste deposited at the SIDEC site where the total amount of waste is directly deposited without pre-treatment. Hence the composition of deposited waste was considered to correspond to the residual waste composition analysis.
- In **2003** the MBA from SIDEC was put in service and hence the amount of directly deposited waste was strongly reduced as the majority of waste was undergoing a biological treatment. The amount of directly deposited correspond to individual fractions of waste which have been separated by mechanical sorting. Hence the proportion of wood is much higher as in previous year. The composition of waste is mainly influenced by the proportion of general waste to bulky waste. The drop in wood content observed between 2005 and 2006 is due to the fact that amount of bulky waste arriving at the SIDEC plant was halved.
- Since 2014 there is no more direct disposal in Luxembourg. The deposited waste undergoes a biological treatment before being deposited.

7.2.2.3.2 Deposited Waste after Biological Treatment

During **mechanical sorting**, the high calorific fraction¹²⁹ and metals are separated from the waste:

- The separated **high calorific fraction** of in average 13.0 Gg is destined to waste incineration at SIDOR. This is clearly made visible when looking at the time-series of waste amounts being incinerated and being landfilled (year 2007 in Figure 7-5). In 1996 the sharp increase of solid waste disposed at SIGRE and to a smaller extent at SIDEC can be explained by a sharp decrease of waste incinerated at SIDOR (shut-down for 3 months due to a fire ¹³⁰).
- In 2015 the waste produced by the municipalities of SIGRE are no longer landfilled but are instead being directly incinerated in the SIDOR facilities without any pre-treatment.

Biological pre-treatment of municipal waste leads to a substantial aerobic decay of the organic component and as a consequence, the behaviour of the decay (in terms of reduction of the total mass and DOC_m) is changing substantially. The practical reductions depend on the type and duration of MBT in question:

- At **SIDEC**, waste fractions are cycling every two weeks in heaps and are mixed with remaining lixivate collected from the landfill site. Pre-treatment of waste induces a reduction of the organic pollution of lixivate in total organic carbon (TOC). The remaining weight of waste after biological treatment is measured and hence the reduction of waste (rotting losses) is known.
- Until 2014, the aerobic treatment at the **SIGRE** landfill Muertendall was performed using forced aerated windrows of 36 tons in which large streams of waste undergo a systematic six-month-rotting process. The resulting waste was then installed directly without weighing in the landfill. The resulting **mass loss** is estimated to amount up to 50% of the mass of DOC in the deliveries where the DOC is estimated according to the waste composition (Table 7-7).

129 The deriving high calorific (combustible) fraction (> 150mm) is incinerated (addressed under CRF subcategory 1A1a) at the municipal waste incinerator SIDOR, with energy generation for electronic power supply

130 De Journal, N.200, p.7, "SIDOR: Feiern in der Zeit des Umbruchs"

The amount of MB-treated MSW finally deposited in the landfills is listed as a residue of biological treatment in Table 7-6. The drop after 2014 can be explained by the fact that solid waste generated by the SIGRE municipalities is incinerated at the SIDOR plant. The pre-treated waste from the MBA plant in SIDEC is however being landfilled in the last remaining landfill in Luxembourg, Muertendall. The emissions deriving from the pre-treatment of solid waste prior to landfilling starting from 1993 are addressed under CRF subcategory 5B1.

7.2.2.4 Parameters

Table 7-9 illustrates (i) the methane emissions from solid waste disposal, as well as (ii) the implied emission factor.

Table 7-9 – CH₄ emissions from 5A1 - Managed Waste Disposal Sites

Year	Total Gg	SIDE, SIGRE, SIDA		Ronnebiereg Gg	IEF kg / t MSW
		direct	indirect		
1990	3.72	3.53	NO	0.18	42.44
1991	3.80	3.63	NO	0.17	50.93
1992	3.81	3.65	NO	0.15	70.93
1993	3.75	3.61	0.00	0.14	56.84
1994	3.40	3.23	0.04	0.13	53.07
1995	3.39	3.18	0.09	0.12	49.32
1996	3.39	3.13	0.14	0.11	36.02
1997	3.47	3.11	0.25	0.10	45.06
1998	3.47	3.04	0.34	0.09	45.84
1999	3.47	2.98	0.41	0.08	51.71
2000	3.31	2.78	0.45	0.07	53.58
2001	3.28	2.73	0.48	0.06	49.93
2002	3.29	2.70	0.51	0.07	49.76
2003	3.29	2.69	0.54	0.06	48.15
2004	3.08	2.47	0.57	0.04	45.41
2005	2.99	2.35	0.60	0.03	39.88
2006	2.94	2.25	0.66	0.03	42.90
2007	2.93	2.20	0.70	0.03	44.54
2008	2.87	2.08	0.76	0.03	43.31
2009	2.82	1.95	0.86	0.02	41.94
2010	2.35	1.40	0.94	0.01	31.79
2011	2.36	1.32	1.03	0.01	35.32
2012	2.25	1.14	1.10	0.01	33.14
2013	2.29	1.13	1.16	0.01	34.54
2014	2.27	1.04	1.22	0.01	32.59
2015	2.17	0.86	1.30	0.01	36.80
2016	1.98	0.71	1.27	0.01	33.49
2017	2.04	0.79	1.24	0.01	34.80
2018	1.91	0.70	1.20	0.01	31.17
2019	1.85	0.67	1.17	0.01	31.38
Trend 1990-2019	-50%	-81%	NA	-97%	-26%
Trend 2018-2019	-3%	-4%	-3%	-20%	1%

Note: The amount of MSW deposited is the amount of MSW containing degradable organic carbon and thus excludes inert waste such as plastics, glass, etc. Emissions from unmanaged landfill sites (closed in 1992) are also included in reporting table 5A1.

Table 7-10 gives an overview of the parameters used for the estimation of emissions from solid waste disposal on land.

Table 7-10 – Parameters used for the Calculation of Emissions

	<i>Directly Deposited Waste</i>	<i>Deposited Waste after Biological Treatment</i>
DOC (Degradable Organic Carbon) <i>(weight fraction, wet basis)</i>	<i>“waste by composition”</i>	<i>“bulk waste data only”</i>
Food	0.15	
Garden	0.2	
Paper	0.4	
Wood	0.43	
Textile	0.24	
Nappies	0.24	
Bulk MSW		0.19
DOC_f (fraction of DOC dissimilated)	0.5	
Methane Generation Rate Constant (k) (years⁻¹)		
Food	0.185	
Garden	0.1	
Paper	0.06	
Wood	0.03	
Textile	0.06	
Nappies	0.1	
Bulk MSW		0.08
Delay Time (months)	6	
Fraction of Methane (F) in generated landfill gas	0.5 (for 1950-2009) 0.4037 (after 2010)	0.5
Conversion Factor, C to CH₄	1.33	

The kinetics of waste degradation under anaerobic conditions are dependent on the different climate zones. The climate zone for **Western Europe, Luxembourg** has been selected. While the option “waste by composition” has been selected for waste destined for **direct disposal**, the option of “bulk waste data only” has been chosen for waste after biological treatment.

Under the assumption that the SWDS environment is anaerobic and the DOC values include lignin (Oonk and Boom, 1995), the default value for DOC_f in mechanical-biological pre-treated waste applied is 0.5 (IPCC 2006, Chapter 2, Table 2.4).

For the years 1990-2009, the default setting of the IPCC was used for the fraction of methane in generated landfill gas (F= 0.5). It was adjusted from 2010 on, as from that point onwards the data on the proportion of methane in the captured landfill gas were available. The adjusted value from 2010 corresponds to the average methane content of the years 2010 - 2014.

Since the pre-treatment before disposal to solid waste disposal sites leads to substantial decay (aerobic) of organic components, including rapidly degradable waste components, a methane generation rate of 0.08 is chosen for estimating CH₄ emissions from indirectly deposited waste.

7.2.2.4.1 Methane Correction Factor (MCF)

From **1950** till the opening of SIDECS in 1972, municipal waste was deposited in unmanaged local landfills. Due to a lack of information, it was assumed that 50% were brought to unmanaged, shallow and 50% to unmanaged, deep landfills: the MCF of 0.4 and 0.8 have been applied to the activity data.

The controlled landfill of SIDEC was installed in **1972** and took over up to 20% of the total waste. When SIGRE landfill site was opened in **1979**, up to 80% of the total waste was managed by the two controlled landfill sites under anaerobic conditions. The MCF of 1 (IPCC 2006, Table 3.1) was applied to this share of activity data.

Since **1993**, all collected waste is accepted at SIDEC (until 2014) and SIGRE landfill sites which both underwent several modernization procedures (*i.e.* leachate drainage system, regulating pondage, gas ventilation system at SIDEC) over time. Independently on whether waste is (i) landfilled directly or (ii) pre-treated, the MCF of 1 is applicable to managed anaerobic landfills.

No activity data was attributed to the type “Uncategorized” and “Managed, semi-aerobic”. Table 7-11 gives an overview of the evolution of the MCF with regard to the waste management type.

Table 7-11 – Methane Correction Factors and Waste Distribution by Waste Management Type

Year	Methane Correction Factor				
	<i>Un-managed, shallow</i>	<i>Un-managed, deep</i>	<i>Managed</i>	<i>Managed, semi-aerobic</i>	<i>Uncategorized</i>
	0.4	0.8	1	0.5	0.6
1950-1971	50%	50%	0%	0%	0%
SIDEC opened					
1972	45%	45%	10%	0%	0%
1973-1978	40%	40%	20%	0%	0%
SIGRE opened					
1979-1992	10%	10%	80%	0%	0%
SIDA closed					
1993-2019	0%	0%	100%	0%	0%

Note: If parameters shown as "country-specific values" are identical to the IPCC default values, this means that the IPCC default value was used.

7.2.2.4.2 Methane Oxidation Factor

The methane oxidation factor (OX) indicates the fraction of emitted methane, which is oxidized in the surface layers of landfills. The default value of the methane oxidation factor, an OX of 0, has been used for the waste disposal from **1950** to 1993. **Since 1993**, all landfill sites (since 2014 only the SIGRE site is operational) are considered as well-managed SWDS, and the OX has been fixed to 0.1 according to the expertise of KÜHLE-WEIDEMEIER and BOGON (Kühle-Weidemeyer & Bogon, Dezember 2008). The value is justified by the fact that solid waste disposal sites in Luxembourg are operated by gradually covering different parts of the site with a layer of soil. As the MBT residues are not placed in a separate landfill but in a section which is in connection with the existing landfill or on top of raw waste, the pre-treated waste is considered as CH₄ oxidising material (similar to compost or soil), following a recommendation by the TERT during the EU ESD review. The OX factor was applied after subtraction of CH₄ recovered.

7.2.2.5 CH₄ Recovery

The methane recovery systems have been installed at the individual landfills Muertendall (managed by SIGRE) and Fridhaff (managed by SIDEDEC) in the years 2000 and 2002, respectively. Since then¹³¹, the individual landfills report the quantity of the captured landfill gas to the Environment Agency in accordance to their permits and to the statistical office for the purposes of the waste statistics, see Table 7-12. These detected quantities are included in the reported CH₄ recovery in the GHG inventory, which is taken from official waste statistics.

Table 7-12 – CH₄ Recovery from 5A1 – Managed Waste Disposal Sites
CH₄ Recovery from 5A1 - Managed Waste Disposal Sites

Year	Total Gg	SIDEC, SIGRE Gg	Ronnebiërg Gg
1990	NO	NO	NO
1991	NO	NO	NO
1992	NO	NO	NO
1993	NO	NO	NO
1994	NO	NO	NO
1995	NO	NO	NO
1996	NO	NO	NO
1997	NO	NO	NO
1998	NO	NO	NO
1999	NO	NO	NO
2000	0.15	0.15	NO
2001	0.15	0.15	NO
2002	0.14	0.14	NO
2003	0.10	0.10	NO
2004	0.30	0.30	NO
2005	0.31	0.31	NO
2006	0.34	0.34	NO
2007	0.32	0.32	NO
2008	0.31	0.31	NO
2009	0.27	0.27	NO
2010	0.28	0.28	NO
2011	0.26	0.26	NO
2012	0.34	0.34	NO
2013	0.27	0.27	NO
2014	0.26	0.26	NO
2015	0.35	0.35	NO
2016	0.43	0.43	NO
2017	0.26	0.26	NO
2018	0.28	0.28	NO
2019	0.25	0.25	NO
Trend 1990-2019	NA	NA	NA
Trend 2018-2019	-13%	-13%	NA

Source: Environment Agency

Note: The amount of MSW deposited is the amount of MSW containing degradable organic carbon and thus excludes inert waste such as plastics, glass, etc.

While the recovered CH₄ was used for the production of electricity at the SIGRE landfill Muertendall (> 50% methane), recovered gas was flared at the SIDEDEC landfill Fridhaff (35-40% methane). Methane emissions that are recovered by the systems installed at the SWDS sites, have already been subtracted from the estimated emissions in Table 7-9.

¹³¹ For the year 2000, no data is available for the landfill Muertendall, so that the IPCC default for non-monitored data was used.

7.2.3 Uncertainties and Time-Series Consistency

Uncertainties from Activity Data

The information on activity data, composition and handling of solid waste on landfills in Luxembourg resembles the situation of Austria. The uncertainty assessment is originally based on an Austrian national study (Winiwarter, 2007), and was improved and revised by expert judgement:

- In the legal framework of the EU Directive 2008/98/EC and the Landfill Directive 1999/31/EC, Luxembourg has elaborated also a similar Waste Strategy to Austria by setting up a waste national action plan¹³².
- The advanced waste collection system, often with waste collection charges, allows the evaluation of annual quantities of municipal waste.
- The activity data of the collected amount of waste is considered to be complete.
- The type and composition of waste is also characterized by: lack of hazardous waste, introduction of aerobic pre-treatment prior landfilling, and high recycling. Regularly performed residual waste and bulky waste analysis as well as inspection activity on landfill according to ISO 17020 and ISO 17025 underlines the high quality of activity data available in Luxembourg.

An overall uncertainty from activity data has been assumed of $\pm 8\%$.

Uncertainties from EFs and Methodology Applied

Under the uncertainty of the model methodology are considered:

- | | |
|---|-----------------------------------|
| • Uncertainty of DOC: | $\pm 20\%$ (Table 3.5, IPCC 2006) |
| • Uncertainty for MCF : | -10% to 0% (Table 3.5, IPCC 2006) |
| • Uncertainty for fraction of CH ₄ in generated landfill gas: | $\pm 5\%$ (Table 3.5, IPCC 2006) |
| • Uncertainty for CH ₄ recovery known for SIDEC and SIGRE:
(Uncertainty of oxidation factor included) | $\pm 10\%$ (Table 3.5, IPCC 2006) |
| • Uncertainty for half-time $t_{1/2}$: | $\pm 15\%$ (Table 3.4, IPCC 2006) |
| • Uncertainty for delay period over 50 years: | $\pm 30\%$ |

According to expert judgment, a combined uncertainty for the solid waste disposal sector (which includes the uncertainty deriving from the waste deposited, the MCF, the DOC content in the directly deposited and pre-treated waste, the CH₄ generation rate as well as the delay time) sums up to approximately 42%.

7.2.4 Category-Specific QA/QC and Verification

Category-specific QA/QC and verification include:

- Internal verifications and plausibility checks when compiling aggregated activity data on waste from the waste disposal sites.

132 Plan national de gestion des déchets 2017, <http://www.environnement.public.lu/dechets/dossiers/pngd/index.html>

- QA/QC procedures described under the Waste Statistics Regulation ¹³³ (WStatR, Regulation EC No 2150/2002), regulation under the Eurostat Directive on reporting waste data. Indeed, the same aggregated data used for the inventory is also used for reporting to Eurostat.

7.2.5 Category-Specific Recalculations Including Changes Made in Response to the Review Process

A reallocation of the methane recovery has been made in category 5A1 – *Managed waste disposal sites*. However, this modification has no impact on the total emissions. More precisely a splitting of the recovered methane in flared CH₄ and CH₄ for energy production was made for the time series 1990-2019. While the recovered methane is used for the production of energy at the SIGRE landfill Muertendall, recovered gas is flared at the SIDEC landfill Fridhaff. Table 7-13 shows the amounts of recovered methane flared and used for energy production.

Table 7-13 CH₄ recovery : flared gas and gas used for energy production

CH₄ Recovery from 5A1 - Managed Waste Disposal Sites

Year	Total	Flare	Energy production
	Gg	Gg	Gg
1990	NO	NO	NO
1991	NO	NO	NO
1992	NO	NO	NO
1993	NO	NO	NO
1994	NO	NO	NO
1995	NO	NO	NO
1996	NO	NO	NO
1997	NO	NO	NO
1998	NO	NO	NO
1999	NO	NO	NO
2000	0.15	NO	0.15
2001	0.15	NO	0.15
2002	0.14	NO	0.14
2003	0.10	NO	0.10
2004	0.30	0.20	0.10
2005	0.31	0.18	0.13
2006	0.35	0.23	0.12
2007	0.32	0.17	0.15
2008	0.31	0.18	0.13
2009	0.27	0.16	0.11
2010	0.27	0.16	0.11
2011	0.26	0.12	0.14
2012	0.35	0.23	0.12
2013	0.27	0.14	0.13
2014	0.26	0.13	0.13
2015	0.35	0.24	0.11
2016	0.43	0.38	0.05
2017	0.26	0.22	0.04
2018	0.29	0.24	0.05
2019	0.25	0.20	0.05

7.2.6 Category-Specific Planned Improvements including those in Response to the Review Process

No planned improvements are planned in this moment in time.

¹³³ <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32002R2150&from=EN>

7.3 Biological Treatment of Solid Waste (5B)

7.3.1 Source Category Description

Under the IPCC category *5B – Biological Treatment of Solid Waste*, GHG emissions originate from composting and biological pre-treatment of solid waste prior to landfill (*5B1 - Biogenic waste composted at centralised composting plants*), as well as from anaerobic treatment (*5B2 - Biogenic waste treated in biogas plants and sewage treatment plants*).

In 2019, this source category was responsible for 31.70% of the total GHG emissions from the waste sector and it represented 0.23% of the total GHG emissions in CO₂e (excluding LULUCF). For each of the gases reported in 2019:

- CH₄ represented 28.41% of waste treatment methane related emissions and 3.30% of the total methane emissions estimated for Luxembourg;
- N₂O represented 52.95% of waste treatment nitrous oxide related emissions and 1.65% of the total nitrous oxide emissions estimated for Luxembourg.

Neither CO₂ (biogenic origin), nor N₂O emissions (negligible) derived from non-biological or inorganic waste sources have been identified so far. The CRF category *5B - Biological Treatment of Solid Waste* is not a key category.

7.3.1.1 Biogenic Waste Composted at Centralised Composting Plants (5B1)

Composting is an aerobic process and a large fraction of the degradable organic carbon (DOC) in the waste material is converted into CO₂, water and heat. CH₄ is only formed in oxygen-deprived sections of the compost, and can be oxidized during aerobic treatment. Composting also produces N₂O emissions, depending on the initial nitrogen content of the material. These are reported under subcategory *5B1a - Municipal Solid Waste*.

Biological pre-treatment of solid waste prior landfilling, during which air is forcedly blown through the bulk waste to speed up its decomposition, has been systematically performed since SIGRE has first introduced aerobic treatment processes for the managed waste in 1993. Since 2015, this process is not in operation anymore at the SIGRE site. At SIDEC, a mechanical-biological treatment (MBT) plant has been installed treating mixed waste since 2007. Disposal of waste and its residues after treatment are reported under CRF category *5A*, while the CH₄ and N₂O emissions generated during the rotting process are considered under subcategory *5B1b Other – MBA treated MSW*.

7.3.1.1 Biogenic Waste Treated in Biogas Plants (5B2)

Anaerobic digestion of organic waste results in CH₄ generation which is used to produce heat and/or electricity, wherefore reporting of emissions from the process is usually done in the Energy Sector (see Section 3.2.6) according to IPCC Guidelines. Emissions of CH₄ from biogas plants due to unintentional leakages during process disturbances or other unexpected events are estimated to be between 0 and 10 % of the amount of CH₄ generated (Volume 5, Chapter 4, Paragraph 4.1, IPCC 2006). N₂O emissions from *5B2 – Biogenic Waste Treated in Biogas Plants* are assumed negligible.

Table 7-14 – CH₄ & N₂O Emission Trends for Category 5B – *Biological Treatment of Solid Waste*:

5B - Biological Treatment of Solid Waste				
<i>Emissions (Gg)</i>				
Year	CO₂	CH₄	N₂O	Total in CO₂e
1990	NO	NO	NO	NO
1991	NO	NO	NO	NO
1992	NO	0.01	NO	0.26
1993	NO	0.07	0.00	2.90
1994	NO	0.09	0.00	3.64
1995	NO	0.10	0.01	4.29
1996	NO	0.16	0.01	6.72
1997	NO	0.17	0.01	7.19
1998	NO	0.21	0.01	8.82
1999	NO	0.19	0.01	8.05
2000	NO	0.26	0.01	10.82
2001	NO	0.28	0.01	11.20
2002	NO	0.32	0.02	12.73
2003	NO	0.42	0.02	16.56
2004	NO	0.43	0.02	16.56
2005	NO	0.51	0.02	19.16
2006	NO	0.55	0.02	20.45
2007	NO	0.60	0.02	22.21
2008	NO	0.69	0.03	25.59
2009	NO	0.72	0.03	25.60
2010	NO	0.73	0.03	26.21
2011	NO	0.63	0.02	21.56
2012	NO	0.73	0.02	24.21
2013	NO	0.71	0.02	23.47
2014	NO	0.77	0.02	25.21
2015	NO	0.72	0.02	22.92
2016	NO	0.82	0.02	25.97
2017	NO	0.83	0.02	25.98
2018	NO	0.87	0.02	27.17
2019	NO	0.77	0.02	24.77
Trend 1993-2019	NA	968.30%	403.06%	753.67%
Trend 2018-2019	NA	-11.24%	0.51%	-8.85%

Source: Environment Agency

Table 7-14 shows that CH₄ and N₂O emissions, generated by 5B – *Biological Treatment of Solid Waste* increased over time as a result of the increasing amount of waste composted and undergoing biological pre-treatment prior landfilling (since 1993). In addition, as Luxembourg has committed itself under the Kyoto Protocol to an increased share of electricity produced from renewable sources, fugitive CH₄ emissions from the use of biomass in anaerobic digesters have increased (since 1992).

7.3.2 Biogenic Waste Composted at Centralised Composting Plants (5B1)

7.3.2.1 Methodological Issues

7.3.2.1.1 Data Origin

Composting

In the CRF subcategory 5B1, composting covers six composting installations that exist in Luxembourg, plus one that co-composts sewage sludge¹³⁴:

- Various local municipalities (e.g. Mondercange, Mamer, Hesperange) operate their own composting installation and all households are covered by a collection scheme for biodegradable waste which is included in the activity data for 5B1 – *Composting*. These composting installations operate in part under anaerobic conditions, with a residence time in the composter of a few weeks.
- Table 7-15 lists the amount of compostable waste collected from households and commercial activities and shows that the majority of green waste is collected in the composting installation MINETT-Kompost in Mondercange.
- Soil-Concept is a plant which co-composts sewage sludge and different organic fractions.

Activity data for compost production are taken from:

- STATEC, *Statistical Yearbook*, Table A.3306 (prepared by the Environment Agency based on annual reports from 1993-2015) for the composting installations;
- Annual reports transmitted to the Environment Agency for the Soil-Concept installation;
- Annual reports transmitted to the Environment Agency for the composting installations from 2016 on.

Soil-Concept¹³⁵

Since 1996, Soil-Concept has been working on a project with the inter-municipal syndicate SIDEN. The objective of this project was to find the most appropriate solution for upgrading sewage sludge in Luxembourg. In 2001, the culmination of the project was the identification of the process of co-composting sewage sludge with structuring organic plant waste (crushed bark and green waste). Soil-Concept aims at reducing direct spreading of sludge on agricultural lands thanks to the spreading of certified compost for soil improvement in agriculture, horticulture and viticulture. The Soil-Concept site has an acceptance capacity of 11.5 Gg of sludge and 17.7 Gg of green waste. Associated emissions are recorded in IPCC category 5B1 since these are "process" and not "spreading" emissions.

Pre-Treatment of Solid Waste Prior Landfilling

According to the national implementation of the Landfill Directive 1999/31/EC, large streams of waste undergo aerobic treatment procedures prior landfilling. The subcategory 5B1 covers the CH₄ and N₂O emissions generated during the rotting process from waste

¹³⁴ Sewage sludge is allocated to the CRF Sector 3D - Agriculture.

¹³⁵ <http://www.soil-concept.lu>

entering the pre-treatment procedure prior landfilling. By doing this, the activity data has been based on the quantity of solid waste from CRF 5A undergoing the pre-treatment procedures starting from 1993, as reported by the operators.

7.3.2.1.2 Methodology

The IPCC Tier 1 method has been applied to estimate methane and nitrous oxide emissions from compost production as well as pre-treatment of solid waste prior landfilling. CH₄ and N₂O emissions are estimated using the default method given in the following equations:

$$CH_4 \text{ emissions} = \sum_i (M_i \cdot EF_i) \cdot 10^{-3} - R$$

$$N_2O \text{ emissions} = \sum_i (M_i \cdot EF_i) \cdot 10^{-3}$$

Where:

CH ₄ emissions	=	Total CH ₄ emissions in inventory year [Gg CH ₄]
N ₂ O emissions	=	Total N ₂ O emissions in inventory year [Gg N ₂ O]
M _i	=	Mass of organic waste treated by biological treatment type i [Gg]
EF _i	=	Emission factor for biological treatment type i
i	=	Composting
R	=	Total amount of CH ₄ recovered in inventory year [Gg CH ₄] ¹³⁶

7.3.2.1.3 Activity Data

Composting

Legal Framework for Composting:

Article 20 of the waste legislation of 21 March 2012 stipulates that the management of waste on the territory of the municipalities is under their responsibility. Selective collection of biogenic waste from households is done through door-to-door pick-up (currently up to 77.5%). Green waste can also be brought in bulk to municipal and intercommunal collection points, composting facilities or container parks. To date however, not all municipalities offer the collection of organic waste from households.

In spring season 2018, the Environment Agency was working in collaboration with stakeholders (municipalities, syndicates, operators of interim storage facilities, treatment plants, waste producers) to develop a national network for the collection and recovery of substantial quantities of green waste, including viticulture, forestry and agriculture as well as orchards.

Table 7-15 lists the amount of compostable waste collected from households and commercial activities in Luxembourg.

136 So far, emission estimates for composting are not taking CH₄ recovery into account.

The following CED2 waste categories are considered as activity data under 5B1 – Composting:

CED	Description
200108	Separately collected fractions - biodegradable kitchen and canteen waste (except 15 01)
200201	Garden and park waste, biodegradable waste
200302	Other municipal waste – waste from markets
190805	Sludges from treatment of urban waste water (only Soil-Concept)

Table 7-15 – Composting Activities – activity data

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	
	tonnes wet																											
Total	5'805	6'746	8'398	7'354	16'083	26'685	27'729	37'169	34'088	38'424	53'310	51'692	54'817	57'242	58'196	59'628	63'866	62'202	38'192	41'244	38'210	40'852	38'528	47'631	48'639	50'316	51'781	
<i>kg/habitant</i>	15	17	21	18	38	63	65	85	78	87	119	114	119	122	122	123	129	124	75	79	71	74	68	83	82	85	84	
Minett-Kompost	2'904	3'630	4'534	3'767	11'773	17'345	20'520	24'146	23'234	25'421	24'462	27'514	28'746	28'743	30'173	30'614	32'237	30'868	20'371	19'546	18'793	20'452	18'285	20'181	18'787	18'865	20'182	
SICA Mamer	2'499	2'562	3'326	3'587	4'310	3'171	3'758	4'903	4'747	4'730	4'650	4'899	5'278	5'061	5'185	5'117	5'288	5'315						3'863	9'961	10'078	10'052	
SIDEC Fridhaff						6'169	3'451	8'120	5'416	5'920	6'116	6'564	6'510	6'238	6'092	5'678	5'989	5'392	5'343	6'391	6'170	6'657	6'284	7'914	4'851	4'536	6'209	
SIDEC Angelsberg									691	2'353	2'174	2'534	2'651	2'670	2'702	1'917	2'219	1'784	1'815	2'491	2'343	2'549	2'146	1'802	1'253	1'620	1'876	
Hespérange										611	742	786	743	786	830	743	682	836	862				1'443	1'188	1'298	1'681	1'105	
Ville de Luxembourg											15'297	9'439	8'083	11'108	9'733	11'921	12'187	13'767										
SIGRE Muertendall													2'763	2'679	3'525	3'551	5'203	4'394	9'826	11'953	10'904	11'194	10'369	12'683	12'489	13'537	12'358	
Pétange	402	554	538																									
	tonnes dry																											
Soil-Concept								9'370	10'574	13'607	15'484	14'460	16'225	19'922	18'223	21'600	15'650	16'171	15'979	16'198	15'309	15'812	16'998	19'963	15'524	17'079	15'829	

Source: Environment Agency

Notes: Grey cells indicate that the installation / project has not been running in the given year.

A few points are important to understand the fluctuations of organic waste streams in this table:

- Between 01/01/2011 and the 01/8/2018 the composting facility from SICA Mamer was not in operation as those waste streams were diverted to the biogas production facility in Kehlen. In 01/8/2016 the composting activity was however being restarted as composting allows also more woody organic waste to be processed.
- Between 2015 and 2016 a significant increase in composting activity can be observed. This can be attributed to the fact that a wide range of collection facilities (mainly at farms) were created for professionals and communes to dispose of green wastes (mainly hedge cuttings).

Pre-Treatment of Solid Waste Prior Landfilling

At the managed landfill site Fridhaff (managed by SIDEC), waste fractions are distributed within tunnels with forced aeration. The decomposition process takes 6 weeks, with rotations of the material every two weeks. Temperatures are rising to 60 - 70°C during the decomposition of waste.

In contrast, the pre-treatment in Muertendall (managed by SIGRE) is composed of the following steps: crushing, formation of rooting heaps with forced aeration, rotting process, and integration of waste residues into the landfill body. The decomposition lasts for up to 6 months in a 36-ton compactor. Since 2015 this process is not in operations anymore and hence the emissions have decreased (Figure 7-6).

Figure 7-6 – Emissions from Biological Treatment of Solid Waste in 5B1

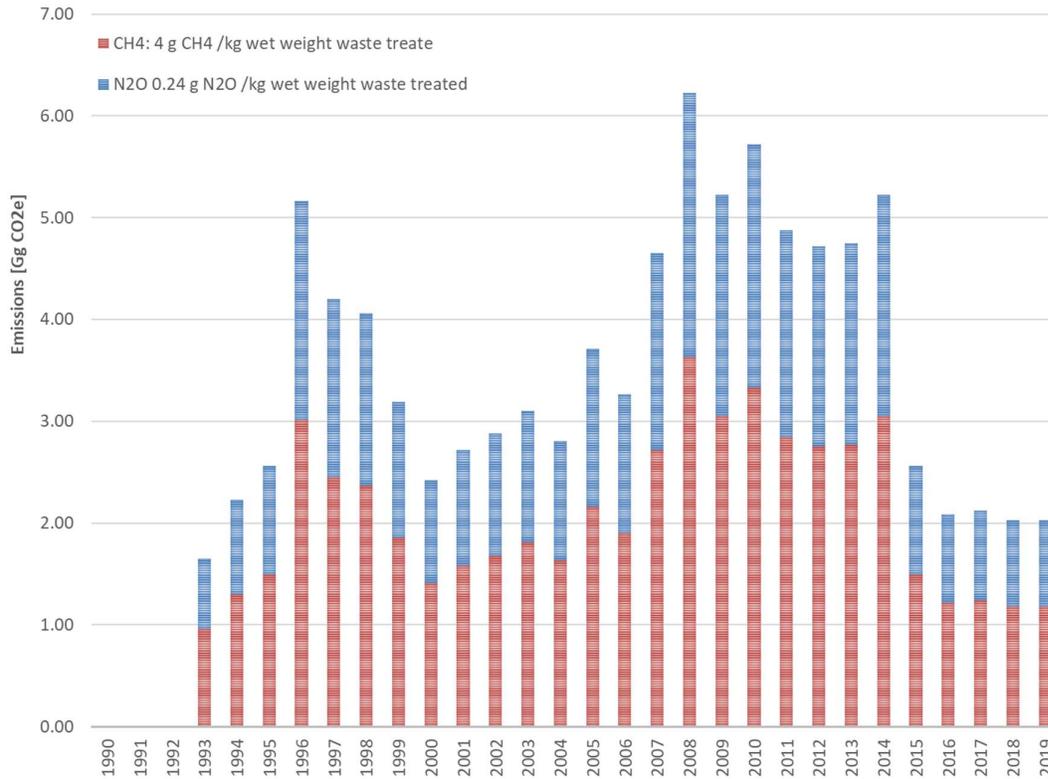


Table 7-16 lists the total emissions from 5B1 – Biogenic Waste Composted at Centralized Composting Plants.

Table 7-16– Emissions from 5B1 – Biogenic Waste Composted at Centralized Composting Plants

**5B1 - Biogenic waste composted at centralised
composting plants**

Year	Emissions (Gg)			Total in CO ₂ e
	CO ₂	CH ₄	N ₂ O	
1990	NO	NO	NO	NO
1991	NO	NO	NO	NO
1992	NO	NO	NO	NO
1993	NO	0.06	0.00	2.64
1994	NO	0.08	0.00	3.38
1995	NO	0.09	0.01	4.01
1996	NO	0.15	0.01	6.43
1997	NO	0.16	0.01	6.96
1998	NO	0.20	0.01	8.64
1999	NO	0.19	0.01	7.95
2000	NO	0.24	0.01	10.22
2001	NO	0.24	0.01	10.11
2002	NO	0.27	0.02	11.52
2003	NO	0.34	0.02	14.54
2004	NO	0.32	0.02	13.84
2005	NO	0.36	0.02	15.53
2006	NO	0.38	0.02	16.10
2007	NO	0.40	0.02	17.32
2008	NO	0.46	0.03	19.73
2009	NO	0.43	0.03	18.51
2010	NO	0.44	0.03	18.79
2011	NO	0.32	0.02	13.84
2012	NO	0.33	0.02	14.25
2013	NO	0.32	0.02	13.58
2014	NO	0.34	0.02	14.58
2015	NO	0.27	0.02	11.69
2016	NO	0.31	0.02	13.29
2017	NO	0.30	0.02	12.77
2018	NO	0.31	0.02	13.22
2019	NO	0.31	0.02	13.29
Trend 1993-2019	NA	403.06%	403.06%	403.06%
Trend 2018-2019	NA	0.51%	0.51%	0.51%

Source: Environment Agency

7.3.2.1.4 Parameters

Emission factors for **compost production** and **biological pre-treatment of solid waste prior landfilling** (Table 7-17 – Default EFs for CH₄ and N₂O emissions from 5B - Biological Treatment of Waste

) are actually default emission factors for CH₄ and N₂O emissions taken from Table 4.1 in IPCC 2006 Guidelines.

Table 7-17 – Default EFs for CH₄ and N₂O emissions from 5B - Biological Treatment of Waste

Type of Biological Treatment	CH ₄ EF <i>g CH₄/kg waste treated</i>	N ₂ O EF <i>g N₂O/kg waste treated</i>	Comment
	on a wet basis		
Composting (excluding Soil-Concept project)	4 (0.03 – 8)	0.24 (0.06 - 0.6)	Assumptions on the waste treated: 25-50% DOC in dry matter, 2% N in dry matter, moisture content 60%.
	on a dry basis		
Soil-Concept project	10 (0.08-20)	0.6 (0.2-1.6)	EFs for dry waste are estimated from those for wet waste assuming moisture content of 60% in wet waste.

7.3.3 Biogenic Waste Treated in Biogas Plants (5B2)

7.3.3.1 Methodological Issues

7.3.3.1.1 Data Origin

Luxembourg has only recently put together a preliminary list of anaerobic digestion plants based on the corresponding operating permits from the Environment Agency. While there has only been one agricultural facility in service before the year 2000, a total of 26 plants are known to be in service to date. Furthermore biogas production in sewage treatment plants have already been in operation for longer.

- Three of the 26 agricultural installations feed their cleaned and processed biogas into the local gas distribution system.
- The emissions due to the combustion of biogas (blended or not) are all considered under CRF Sector 1 - Energy. The national energy balance provides the necessary activity data (energy production), and also the split in which CRF category the biogas is combusted:
 - 1A1a – Public Electricity and Heat Production,
 - 1A4a – Commercial / Institutional, and
 - 1A4c – Agriculture / Forestry / Fishing.

7.3.3.1.2 Methodology

The IPCC methodology has been followed to estimate **CH₄ emissions** from biogas plants due to unintentional leakages, which are assumed to be between 0 and 10% of the amount of CH₄ generated (Volume 5, Chapter 4, Paragraph 4.1, IPCC 2006).

Related to the preliminary analysis, Luxembourg proposes an own estimation starting from the activity data, i.e. energy content of produced biogas in Joule available for the category 1 - Energy to derive a level of CH₄ emissions for the subcategory 5B2 - Biogenic Waste Treated in Biogas Plants.

In addition, the average fugitive emission rate has been adapted to 3.1% of the CH₄ gas production rate according to Flesch *et al.* (Flesch *et al.*, October 2011). Comparably, the value of 3% of the CH₄ gas production rate emitted through leakages has been confirmed by the review of Dumont *et al.* (Dumont *et al.*, 2011).

According to the IPCC 2006 Guidelines (Volume 5, Chapter 4, Paragraph 4.1), **N₂O emissions** for *5B2 - Biogenic Waste Treated in Biogas Plants* are assumed to be negligible.

7.3.3.1.3 Activity Data

As mentioned, Luxembourg has only recently put together a preliminary list of anaerobic digestion plants based on the corresponding operating permits. Unfortunately however, the majority of annual reports are missing for the anaerobic digestion plants for the time-series before the year 2007. From a first analysis, one can state the following:

- Biogas production from agricultural facilities and sewage treatment plants has been reported in the national energy balance starting from the year 1992.
- Three installations feed their cleaned biogas into the natural gas network. The regulation of 15 December 2011 (GDR, 12/2011) for conditions (“*Code de distribution*”) on how the biogas producers inject the cleaned biogas into the network is applicable. According to Article 12 (2) of this Grand-Ducal Regulation, the biogas producer must document to the Luxembourg Institute of Regulation¹³⁷ that CH₄ emissions from the process of treating raw biogas to biogas for injection are less than 0.5% of methane contained in the raw biogas for an amine treatment installation, and less than 1% of the methane contained in the crude biogas for a biogas pressurized treatment plant, respectively. Hence only emissions due to leakages are considered and not due to biogas processing before injection.
- The other biogas facilities encounter the emissions due to the combustion of biogas (blended or not) considered under the CRF Sector 1 - *Energy*. The national energy balance provides the necessary activity data.

The majority of the biogas plants in Luxembourg are modern. According to the report of J. Clemens (Clemens, 2014), the number of leakages however does not correlate with the number of years in service or the date of the completion of the facility.

Preliminary analysis of the annual reports (available only from 2007 on) shows that the activity data is composed of 22.36% municipal waste, 59.24% agricultural waste, and 18.40% energy plants. Relating to these specific activity data, the methane content in the biogas production can vary between 55% to 62% (mean: 58.5%, n = 100) (Agriculture, Ecosystems & Environment, 2007) in dependence of the different feedstocks. Table 7-18 shows the CH₄ leakage emissions obtained by applying the method adapted to the feedstock distribution as described under *Section 7.3.3.1.2 Methodology*.

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Table 7-18 – CH4 and N2O emissions from 5B2 – Biogenic Waste Treated in Biogas Plants

5B2 - Biogenic Waste Treated in Biogas Plants

Year	Energy content of produced biogas (GJ)	Methane Production (m ³)	Methane Production (Gg)	CH ₄ leakage (Gg)	N ₂ O (Gg)	Total in CO ₂ e (Gg)
1990	NO	0	0.00	NO	NE	NO
1991	NO	0	0.00	NO	NE	NO
1992	17'000	468'320	0.33	0.01	NE	0.26
1993	17'000	468'320	0.33	0.01	NE	0.26
1994	17'000	468'320	0.33	0.01	NE	0.26
1995	19'000	523'416	0.37	0.01	NE	0.29
1996	19'000	523'416	0.37	0.01	NE	0.29
1997	15'000	413'223	0.30	0.01	NE	0.23
1998	11'500	316'804	0.23	0.01	NE	0.18
1999	7'000	192'837	0.14	0.00	NE	0.11
2000	39'741	1'094'786	0.78	0.02	NE	0.61
2001	71'661	1'974'145	1.41	0.04	NE	1.09
2002	79'502	2'190'136	1.56	0.05	NE	1.21
2003	132'463	3'649'109	2.61	0.08	NE	2.02
2004	178'148	4'907'661	3.51	0.11	NE	2.72
2005	238'360	6'566'388	4.69	0.15	NE	3.63
2006	285'427	7'863'015	5.62	0.17	NE	4.35
2007	320'417	8'826'916	6.30	0.20	NE	4.89
2008	383'780	10'572'448	7.55	0.23	NE	5.85
2009	464'742	12'802'798	9.14	0.28	NE	7.09
2010	486'427	13'400'206	9.57	0.30	NE	7.42
2011	505'893	13'936'446	9.95	0.31	NE	7.71
2012	653'687	18'007'911	12.86	0.40	NE	9.97
2013	648'720	17'871'062	12.77	0.40	NE	9.89
2014	697'070	19'203'042	13.72	0.43	NE	10.63
2015	736'634	20'292'947	14.49	0.45	NE	11.23
2016	831'626	22'909'795	16.36	0.51	NE	12.68
2017	865'633	23'846'638	17.03	0.53	NE	13.20
2018	914'747	25'199'654	18.00	0.56	NE	13.95
2019	752'540	20'731'127	14.81	0.46	NE	11.48
Trend 1992-2019	4326.7%	4326.7%	4326.7%	4326.7%	NA	4326.7%
Trend 2018-2019	-17.73%	-17.73%	-17.73%	-17.73%	NA	-17.73%

7.3.3.1.4 Parameters

The following parameters have been used for the estimation of CH₄ leakages based on the IPCC method adapted to national circumstances:

Table 7-19 – Parameters for estimation of CH₄ Leakages

Parameter	Value	Source
CH ₄ calorific value	0.0363 GJ / m ³ CH ₄	
Molar mass of CH ₄	16 g / mol	
Molar volume of CH ₄	0.0224 m ³ / mol	
CH ₄ leakage rate	3.1%	Biomass and Bioenergy Volume 35, Issue 9, October 2011, Pages 3927–3935

7.3.4 Uncertainties and Time-Series Consistency

7.3.4.1 Biogenic Waste Composted at Centralised Composting Plants (5B1)

The uncertainties for the composted waste quantities are considered very small (< 5 %), since the relevant activity data were obtained *via* high-quality annual reporting. The uncertainties for the solid waste quantities undergoing biological treatment are considered the same as in 5A. A general uncertainty of 5% can be assumed since the activity data consists mainly of composted waste (Table 7-20).

The uncertainties from the literature vary between -100 % and +100 % for the CH₄ and N₂O emission factor (see IPCC Guidelines). As the duration of pre-treatment has an effect on the generation of emissions from waste, the emissions deriving from SIGRE are assumed to be different to the ones deriving from SIDEC.

7.3.4.2 Biogenic Waste Treated in Biogas Plants (5B2)

The activity data uncertainties for the 5B2 subsector are assumed to be equal to those for biogas in the Energy combustion sector (7%, data is obtained from the national energy balance). The uncertainty of the CH₄ emission factor corresponds to the uncertainty of the leakage factor, which can be derived from (Flesch et al., October 2011) (see Table 7-20).

Table 7-20 – Uncertainties with regard to Activity Data and Emission Factors for category 5B

Uncertainties	Activity data	Emission factor CH ₄	Emission factor N ₂ O
<i>5B1 - Biogenic waste composted at centralised composting plants</i>	± 5 %	± 100 %	± 100 %
<i>5B2 - Biogenic waste treated in biogas plants</i>	± 7%	± 68%	NA

7.3.5 Category-Specific QA/QC and Verification

No category-specific QA/QC and verification have been completed, only the tools embedded in CRF Reporter have been used.

7.3.6 Category-Specific Recalculations Including Changes Made in Response to the Review Process

For the year 2018, the waste composition analysis was updated which led to a recalculation in category 5.B.1.b – MBA treated MSW. As such emission data has decreased by 4.11% (from 2.11 Gg CO₂eq to 2.02 Gg CO₂eq). More precisely, CH₄ emissions decreased from 0.049 Gg to 0.047 Gg while N₂O emissions went from 0.0030 Gg to 0.0028 Gg. This was due to a slightly higher percentage of inert waste in MSW.

7.3.7 Category-Specific Planned Improvements

7.3.7.1 Biogenic Waste Composted at Centralised Composting Plants (5B1)

No planned improvements are foreseen for this subsector.

7.3.7.2 Biogenic Waste Treated in Biogas Plants (5B2)

No planned improvements are foreseen for this subsector.

7.4 Incineration and Open Burning of Waste (5C)

This category is presented under IPCC subcategory 1A1a – Fuel Combustion Activities – Energy Industries – Public Electricity and Heat Production (Section 3.2.6) because in the sole incinerator of the country (SIDOR site), energy from waste burning is recovered and injected into the electric public network.

7.5 Waste Water Treatment and Discharge (5D)

7.5.1 Source Category Description

Category 5D covers emissions from waste water treatment (WWT) and discharge, whether the waste water has been generated by households (reported under category 5D1 - Domestic wastewater) or by industrial enterprises (reported under category 5D2 - Industrial wastewater). Hence, it is assumed that commercial WWT is included in domestic municipal waste water treatment carried out in waste water treatment plants (WWTPs).

To summarize:

- category 5D1 covers methane and nitrous oxide emissions from waste water treatment in domestic (including septic tanks) and commercial sources. No CO₂ emissions deriving from non-biological or inorganic WWT residuals have been identified so far;
- category 5D2 covers nitrous oxide emissions from waste water treatment in industry. Methane emissions in category 5D2 are not occurring in Luxembourg as the processes in these installations are entirely aerobic;
- Emissions related to the sludge residues of domestic and commercial WWT are not accounted for in this sector. Indeed, sewage sludge spreading is accounted for in the agriculture sector (3D - Agricultural Soils), while other parts are incinerated with energy recovery and the emissions are therefore reported in the energy sector under (1A2g - Other - Manufacturing Industries and Construction). The remainder of sludge is composted and emissions are therefore reported under the category other (5B - Biological Treatment of Solid Waste).

In 2019, source category 5D was responsible for 8.35% of the total GHG emissions from the waste sector – excluding waste incineration – and it represented 0.07% of the total GHG emissions in CO₂e (excluding LULUCF):

- CH₄ from WWT represented 3.7% of waste treatment methane related emissions – excluding waste incineration – and 0.46% of the total methane emissions estimated for Luxembourg;
- N₂O from WWT represented 42.8% of waste treatment nitrous oxide related emissions – excluding waste incineration – and almost 1.33% of the total nitrous oxide emissions estimated for Luxembourg.

From 1990 to 2019, GHG emissions from 5D decreased by 45%, from 2005 to 2019, they decreased by 38% and from 2028 to 2019 by 8% (see Figure 7-7). For N₂O emissions, the detailed emission trend per WWT system is given in Figure 7-8.

None of the source categories under WWT is a key category.

Figure 7-7 – Emission trend of wastewater treatment emissions (5D)

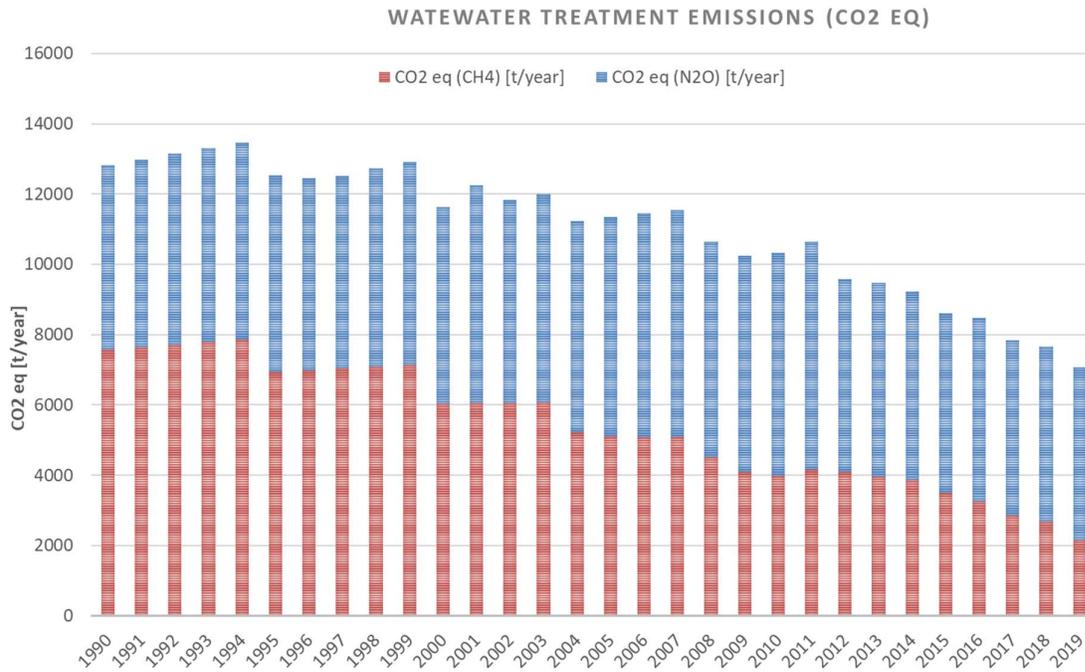
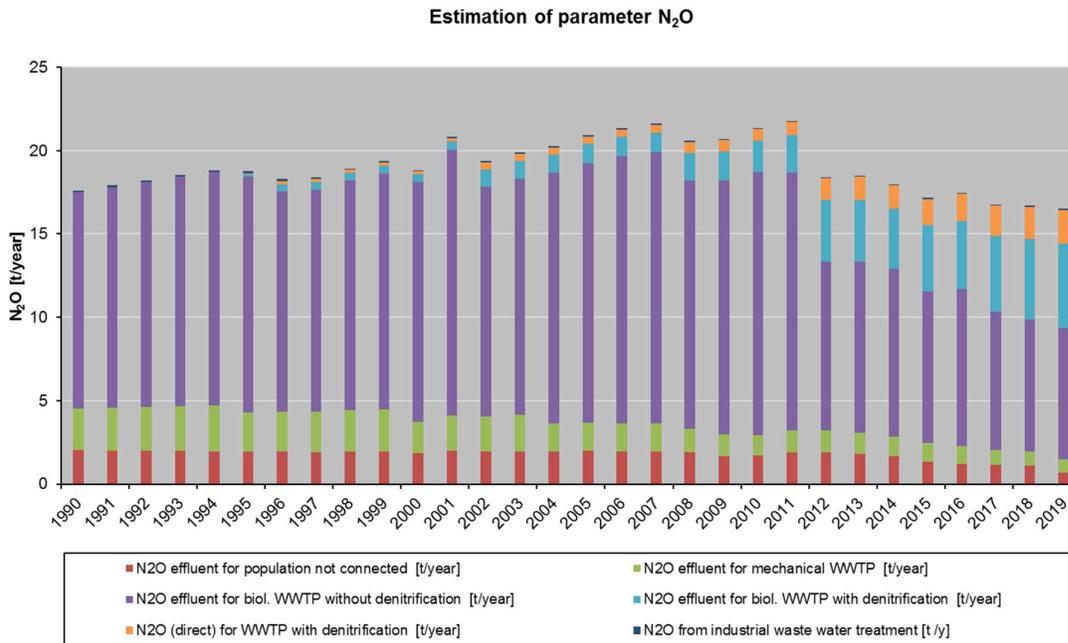


Figure 7-8 - N₂O emission trends for categories 5D1 and 5D2 WWH



Source: Water Management Agency.

7.5.2 Domestic wastewater (5D1)

7.5.2.1 Methodological Issues

In Luxembourg, domestic wastewater is treated in four different ways based on the location of the villages and municipalities. In the calculation method these four systems are considered separately:

- Septic tanks used in remote places where a connection to a waste water treatment plant (WWTP) is not possible.
- Mechanical WWTPs, which in Luxembourg are to be considered as very basic installations with no sludge digesters and which are managed from a technical point of view in the same way as septic tanks. They consist of simple volumes with a baffle and no pre- or subsequent treatment (such as screen a grit compartment, or aerobic step). In addition, the management consists of simple regular emptying. Hence, it should also be noted, that the processes in these installations are very similar to septic tanks (which is particularly important for the calculation of methane emissions). Also, all sludge, removed from these mechanical WWTPs (as well as from septic tanks), is transferred to biological WWTPs where it is further treated either aerobically, or anaerobically in a digester. This is not to be compared to modern mechanical waste water treatment plants which might be operated in other European countries.
- Biological WWTPs without denitrification.
- Biological WWTPs with denitrification.

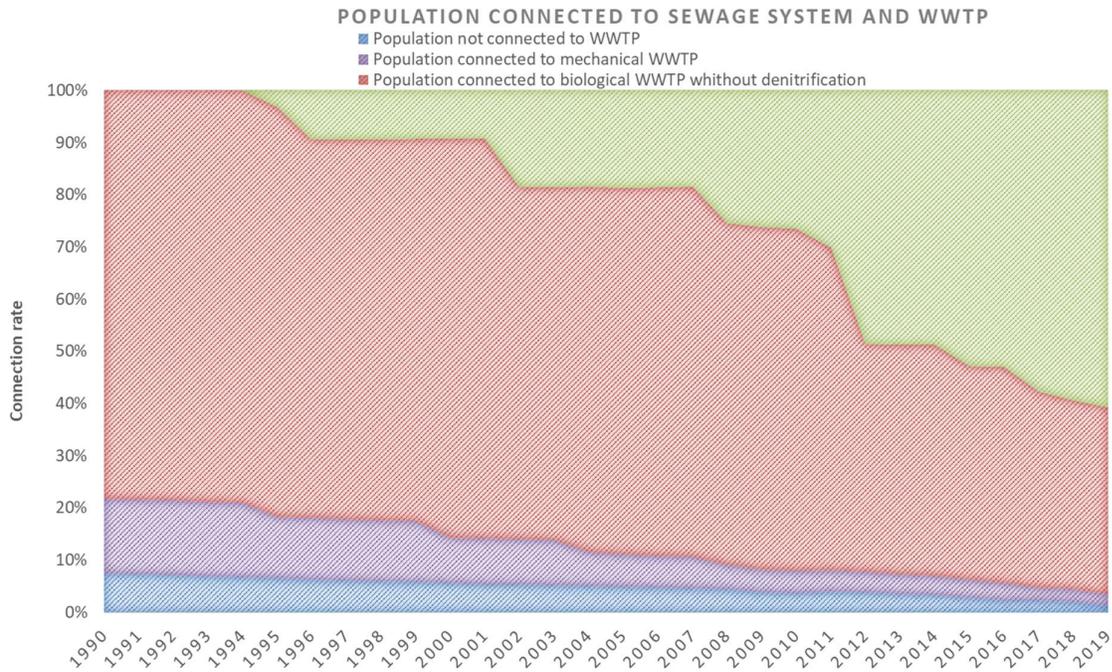
Emissions are calculated based on the population connected to these different systems. The population number connected to the different systems was derived from the population census for 1991, 2001 and 2011 which contains the detailed population of each locality in Luxembourg (years in between were interpolated, respectively extrapolated for 1990. From 2012 onwards, detailed yearly population data per locality is provided by STATEC. Each locality was attributed to a specific WWT system (septic tanks, mechanical WWTP and advanced biological WWTP with denitrification) as registered with the Water Management Administration (AGE) (see Table 7-21). The remaining population and half of the commuters (see next paragraph) was attributed to advanced biological WWTP without denitrification.

Table 7-21 - Population connected per WWT system

5.D.1 Domestic Wastewater					
Year	Population connected to WWT system				WW Population
	not connected	mec. wwtp	biological wwtp	bio. wwtp + denit.	
1990	7.84%	14.96%	77.20%	0.00%	396'950
1991	7.66%	15.05%	77.29%	0.00%	404'210
1992	7.48%	15.13%	77.39%	0.00%	411'570
1993	7.30%	15.21%	77.49%	0.00%	418'930
1994	7.13%	15.28%	77.59%	0.00%	426'490
1995	6.96%	12.57%	77.09%	3.38%	434'150
1996	6.78%	12.60%	70.45%	10.16%	442'300
1997	6.62%	12.65%	70.54%	10.18%	450'250
1998	6.47%	12.71%	70.62%	10.21%	458'850
1999	6.32%	12.75%	70.70%	10.23%	467'650
2000	6.16%	9.71%	73.86%	10.27%	478'750
2001	6.01%	9.72%	73.99%	10.27%	489'050
2002	5.88%	9.71%	63.59%	20.83%	496'450
2003	5.75%	9.73%	63.66%	20.85%	502'700
2004	5.60%	7.46%	66.16%	20.77%	512'200
2005	5.46%	7.19%	66.11%	21.24%	521'800
2006	5.30%	7.05%	66.53%	21.11%	533'600
2007	5.16%	7.05%	66.77%	21.02%	545'800
2008	5.02%	5.61%	60.11%	29.26%	558'500
2009	4.38%	5.08%	60.49%	30.05%	567'650
2010	4.23%	4.80%	60.39%	30.57%	578'050
2011	4.50%	4.76%	56.06%	34.68%	590'700
2012	4.33%	4.56%	35.27%	55.84%	604'450
2013	4.06%	4.35%	35.56%	56.03%	618'200
2014	3.90%	4.14%	35.94%	56.02%	632'350
2015	3.13%	3.98%	32.10%	60.79%	648'508
2016	2.69%	3.78%	32.48%	61.06%	664'849
2017	2.58%	2.93%	27.85%	66.63%	682'417
2018	2.35%	2.76%	26.11%	68.79%	698'055
2019	1.41%	2.60%	25.30%	70.70%	714'344
Trend					
1990-2019	-82.06%	-82.64%	-67%	NA	79.96%
2005-2019	-74.24%	-63.89%	-62%	233%	36.90%
2018-2019	-40.05%	-5.78%	-3%	3%	2.33%

Figure 7-9 provides an overview of the population of Luxembourg connected to the different types of WWT where “not connected to WWTP” (septic tanks) and “mechanical WWTP” are particularly important for the calculation of 5D1 methane emissions and centralised advanced “biological WWTPs” (with or without denitrification) are important for the calculation of 5D1 N₂O emissions. Hence, in 2012, the number of the population connected to WWTPs with denitrification increased considerably due to the fact that 3 new WWTPs with denitrification went online. Over the years, more and more localities are connected to centralised advanced biological WWTPs with denitrification.

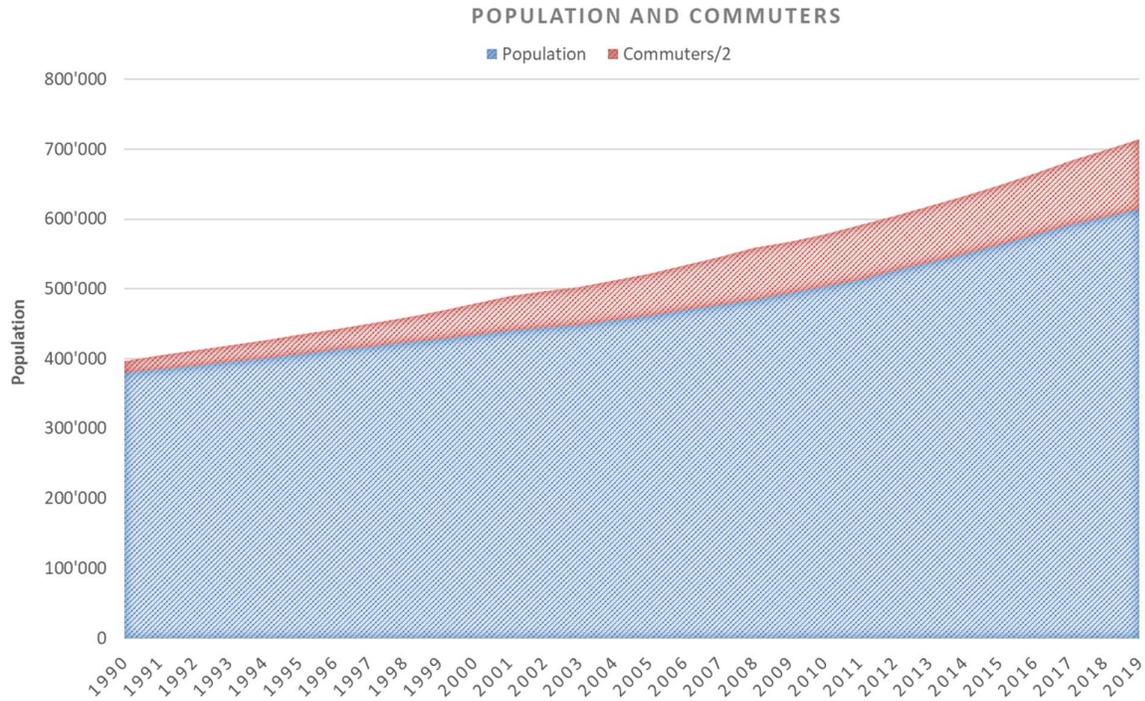
Figure 7-9 – Population connected to sewage system and biological WWTP: 1990-2019



Source: Water Management Agency.

However, as Luxembourg’s workforce is increased daily by about two hundred thousand commuters (from France, Belgium and Germany), their impact on wastewater discharge had to be taken into account. Hence, as these daily commuters only spend their working hours in the country, their number was divided by half and added to Luxembourg’s population to calculate . Figure 7-10 illustrates the population and cross-border commuters’ growth between 1990 and 2019. Hence, this consideration is particularly important for the nitrous oxide emission calculation, where daily commuters had to be taken into account, in addition to the residents of the country, when calculating the nitrogen load of the effluent. Population and commuters are provided by the STATEC.

Figure 7-10 – Resident population and cross-border commuters: 1990-2019



7.5.2.2 Methane Emissions

7.5.2.2.1 Emission trends

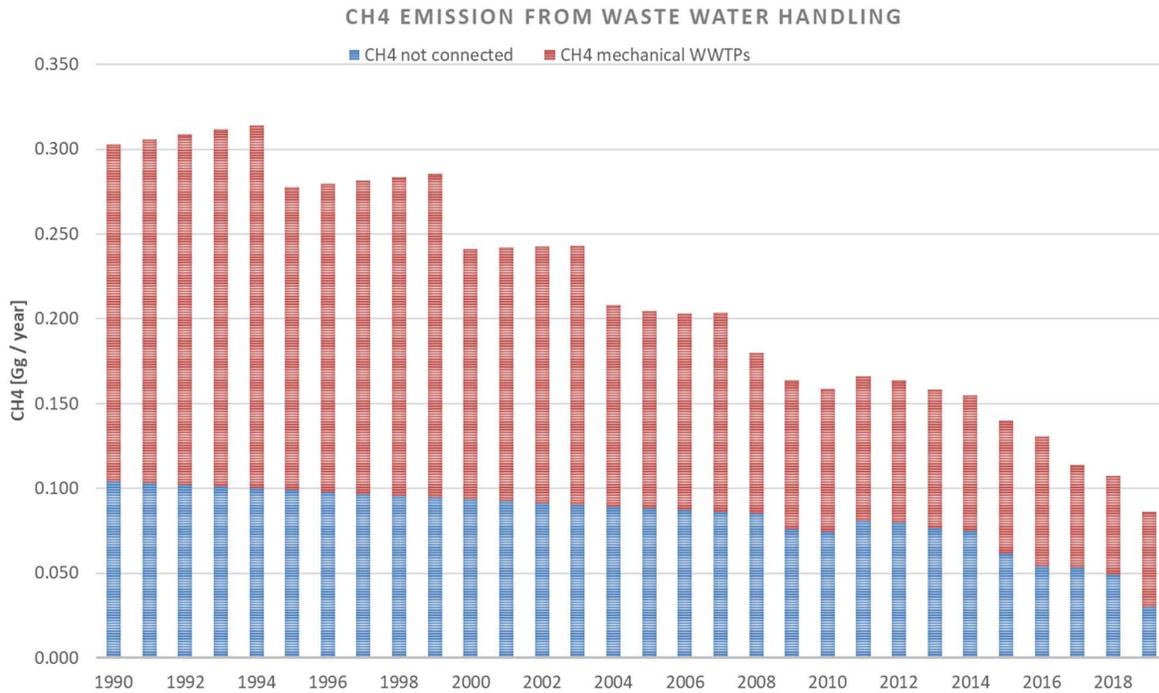
Methane emissions for category 5D1 are presented in Table 7-22 and Figure 7-11. Since 1990, emissions have been reduced by over 71%. This systematic reduction is due to the continuous efforts to reduce the use of septic tanks in remote localities and to connect these to centralised biological WWTPs. The same counts for mechanical WWTPs, which are old basic installations in Luxembourg which can be compared in their process and management to septic tanks rather than to modern biological WWTPs.

Table 7-22 – CH₄ emission trends for category 5D1 – Domestic & Commercial WWH: 1990-2019

CH ₄ emissions (tonnes)			
5.D.1 Domestic Wastewater			
Year	Mechanical	Septic Tanks	Total
1990	198.82	104.20	303.03
1991	202.70	103.14	305.84
1992	206.57	102.08	308.65
1993	210.45	101.01	311.46
1994	214.32	99.95	314.27
1995	178.72	98.89	277.61
1996	181.79	97.82	279.61
1997	184.86	96.76	281.62
1998	187.92	95.70	283.62
1999	190.99	94.63	285.63
2000	147.57	93.57	241.14
2001	149.58	92.51	242.09
2002	151.09	91.45	242.53
2003	152.85	90.38	243.23
2004	118.94	89.32	208.26
2005	116.20	88.26	204.46
2006	115.94	87.19	203.13
2007	117.58	86.13	203.71
2008	95.02	85.07	180.09
2009	87.79	75.68	163.46
2010	84.51	74.47	158.98
2011	85.47	80.88	166.34
2012	83.91	79.64	163.54
2013	81.90	76.32	158.23
2014	79.76	75.13	154.88
2015	78.57	61.70	140.27
2016	76.25	54.26	130.51
2017	60.75	53.34	114.09
2018	58.14	49.50	107.64
2019	55.86	30.26	86.12
Trend			
1990-2019	-71.91%	-70.96%	-71.58%
2005-2019	-51.93%	-65.71%	-57.88%
2018-2019	-3.92%	-38.86%	-19.99%

Source: Water Management Agency.

Figure 7-11 – CH₄ emission trends for category 5D1 – Domestic wastewater: 1990-2019



Source: Water Management Agency.

7.5.2.2.2 Methodological issues:

Municipal waste water treatment in Luxembourg uses mainly aerobic processes (see Table 7-23) such as activated sludge or bio-filtration. As a result, no or negligible methane emissions are produced, since such emissions only occur under anaerobic conditions. In the well managed advanced biological WWTPs, sludge stabilisation is carried out in order to prevent uncontrolled putrefaction. In facilities with a treatment capacity smaller than 30.000 population-equivalents (p. e.) the stabilisation is usually carried out aerobically, with oxygen and energy consumption, while for facilities with a treatment capacity larger than 30.000 p. e., the stabilisation is normally carried out anaerobically with production and recovery of methane gas. The gas produced is usually used for energy recovery in combined heat/power generating systems or may be flared.

Table 7-23 shows theoretical load that can be treated in municipal WWTPs since 1990. It also indicates the percentage of that load that is treated using aerobic procedures, *i.e.* in WWTPs applying a biological treatment to waste water.

Table 7-23 – Municipal WWTP capacities and aerobic procedures: 1990-2019

Year	Load treated in municipal WWTP 1000 population-equivalents	Aerobic procedures %
1990	591.6	84%
1991	594	85%
1992	596.5	86%
1993	600	87%
1994	605.8	88%
1995	631.6	89%
1996	782.4	91%
1997	788.4	92%
1998	793.9	92%

Year	Load treated in municipal WWTP 1000 population-equivalents	Aerobic procedures %
1999	799.4	93%
2000	806.9	94%
2001	811.8	94%
2002	816.7	94%
2003	818.7	94%
2004	820.7	95%
2005	820	95%
2006	1012	95%
2007	1016	97%
2008	1017.3	98%
2009	1066.3	98%
2010	1064.7	96%
2011	1014.4	96%
2012	1018.2	96%
2013	1034.9	96%
2014	1036.2	97%
2015	1015.7	97%
2016	980.3	97%
2017	990.6	97%
2018	1043.4	98%
2019	1092.7	98%
Trend 1990- 2019	84.71%	16.86%

Source: Water Management Agency

Treatment of human sewage from inhabitants connected to small mechanical WWTPs or septic tanks represents an exception. The percentage of organic loads discharged to these treatment units has been reduced consequently since 1990 (see also Table 7-21). Hence methane emissions are only estimated for WWT in septic tanks and mechanical WWTPs as uncontrolled anaerobic processes are likely to occur in these systems and as there is no methane recovery occurring in these systems.

The methodology used for estimating methane emissions from septic tanks and mechanical WWTPs is based on the IPCC Tier 1 method in which the relevant population connected to septic tanks and to mechanical WWTPs is considered to calculate the organic load in the wastewater. It should be noted that, in Luxembourg, mechanical WWTPs are to be considered as very basic installations with no sludge digesters and which are managed from a technical point of view in the same way as septic tanks (please refer to section 7.5.2.1 for further details).

Calculation of the organic load (BOD):

$$BOD_{sep} [kg/year] = inhabitants\ connected\ to\ septic\ tanks * 60\ g\ BOD\ (person/day) * 365\ (days) / 1000$$

$$BOD_{mec} [kg/year] = inhab.\ connected\ to\ mechanical\ WWTP * 60\ g\ BOD\ (person/day) * 365\ (days) / 1000$$

The organic load for septic tanks and mechanical WWTPs is calculated as described in the equations above, by multiplying the population connected to the different systems with the default organic load *per* person (60 g BOD/day/person, 2006 IPCC GLs, Vol. 5, Chap. 6, Table 6.4, p. 6.14).

Calculation of the methane conversion factor (MCF):

According to national expert judgment and based on the study of (Steinlechner, et al., 1994) the MCF has been adapted to the national situation in Austria, which is also applicable for Luxembourg. The MCF defines the portion of methane producing capacity (B₀) that degrades anaerobically and may vary between 0.0 (completely aerobic) to 1.0 (completely anaerobic) according to the IPCC 2006

Guidelines. When the sludge treatment process is anaerobic, the temperature has a great influence. During the winter time, the temperature decreases to 10°C in the sludge digester part of the WWTP so that the biological activity is much reduced and the MCF = 0.1. During the rest of the year, the temperature in the sludge part is closer to 20°C, which is still low for an optimal biological activity and therefore the MCF factor is 0.35 according to Steinlechner *et al.* As the mechanical waste water treatment plants are based on the same technical process as the septic tanks, the MCF factor used for both categories is the same and is calculated as follows:

$$MCF = 2/3 * 0.35 + 1/3 * 0.1 = 0.27$$

Calculation of the methane emissions:

$$CH_4 \text{ sep [t/year]} = BOD_{\text{sep}} * BO * MCF / 1000$$

$$CH_4 \text{ mec [t/year]} = BOD_{\text{mec}} * BO * MCF / 1000$$

Where:

sep = septic tanks

mec = mechanical WWTPs

BO = 0.6 kg CH₄/ kg BOD 2006 IPCC GLs, Vol. 5, Chap. 6, Table 6.2, p.6.12

60 g BOD/person per day 2006 IPCC GLs, Vol. 5, Chap. 6, Table 6.4, p.6.14 and European Directive 91/271/CEE on the treatment of urbane waste water, Article 2.6

MCF = 0.27 country-specific methane conversion factor: $0.35 * 2/3 + 0.1 * 1/3 = 0.27$ (see above)

The number of inhabitants connected to a septic tank (sep) is determined annually by the Ministry of the Environment, Climate and Sustainable Development - Water Management Administration through an inventory. The number of inhabitants from agglomerations connected to a septic tank or to a mechanical WWTP is based population statistics per locality as provided by Statec and specific connection information from the Water Management Administration (see also section 7.5.2.1).

Total methane emission from waste water handling:

$$CH_4 \text{ tot} = CH_4 \text{ sep} + CH_4 \text{ mec [t/year]}$$

Total emissions are finally calculated by adding up the emissions from septic tanks and mechanical WWTPs.

7.5.2.3 Nitrous Oxide

N₂O emissions for 5D1 are estimated for the four WWT systems as presented in section 7.5.1.

7.5.2.3.1 Emission trends

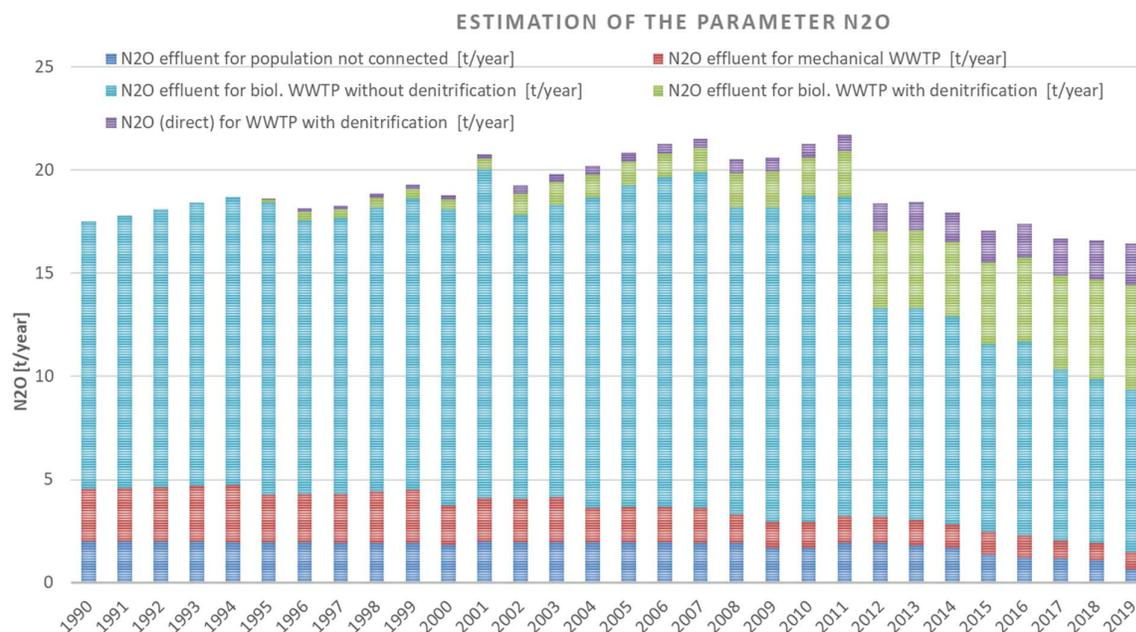
Overall, N₂O emissions have decreased 6% from 1990 to 2019 although the population and workforce have largely increased during the same period (see Table 7-24 and Figure 7-12). This increase in population and the following potential increase in emissions has been counterbalanced by the consequent move from septic tanks and basic mechanical WWTPs to advanced biological WWTPs without denitrification and also the consequent implementation of advanced biological WWTPs with denitrification since 1995. Hence, for example, in 2012, the number of the population connected to WWTPs with denitrification increased considerably due to the fact that 3 new WWTPs with denitrification went online. This consequent implementation is also best illustrated in Figure 7-12).

Table 7-24 – N₂O emission trends for category 5D1 – Domestic & Commercial WWH: 1990-2019

N ₂ O emissions (tonnes)						
Year	5.D.1 Domestic Wastewater					Total
	effluent not con.	effluent mec. wwtp	effluent wwtp -	effluent wwtp +	direct wwtp-de	
1990	2.03	2.51	12.96	NO	NO	17.50
1991	2.01	2.57	13.21	NO	NO	17.80
1992	2.00	2.63	13.47	NO	NO	18.11
1993	1.99	2.70	13.74	NO	NO	18.43
1994	1.98	2.75	13.98	NO	NO	18.71
1995	1.97	2.31	14.16	0.14	0.06	18.64
1996	1.96	2.37	13.22	0.44	0.18	18.16
1997	1.93	2.39	13.33	0.44	0.18	18.28
1998	1.94	2.48	13.77	0.46	0.19	18.84
1999	1.94	2.55	14.15	0.47	0.00	19.11
2000	1.84	1.89	14.38	0.46	0.20	18.77
2001	1.99	2.10	15.95	0.51	0.20	20.75
2002	1.96	2.10	13.76	1.04	0.41	19.28
2003	1.97	2.17	14.18	1.07	0.42	19.82
2004	1.96	1.69	15.03	1.09	0.43	20.19
2005	1.98	1.69	15.57	1.15	0.44	20.84
2006	1.96	1.70	15.99	1.17	0.45	21.27
2007	1.93	1.71	16.25	1.18	0.46	21.53
2008	1.91	1.39	14.89	1.67	0.65	20.52
2009	1.69	1.28	15.22	1.75	0.68	20.62
2010	1.70	1.26	15.79	1.84	0.71	21.30
2011	1.91	1.31	15.47	2.21	0.82	21.73
2012	1.91	1.31	10.11	3.69	1.35	18.37
2013	1.80	1.26	10.27	3.73	1.39	18.44
2014	1.68	1.16	10.06	3.62	1.42	17.94
2015	1.36	1.13	9.07	3.96	1.58	17.09
2016	1.20	1.09	9.41	4.08	1.62	17.41
2017	1.18	0.87	8.27	4.56	1.82	16.70
2018	1.10	0.84	7.94	4.83	1.92	16.62
2019	0.67	0.81	7.87	5.07	2.02	16.44
Trend						
1990-2019	-66.76%	-67.85%	-39%	NA	NA	-6.03%
2005-2019	-65.98%	-52.31%	-49%	340%	356%	-21.08%
2018-2019	-38.66%	-3.59%	-1%	5%	5%	-1.05%

Source: Water Management Agency.

Figure 7-12 – N₂O emission trends for category 5D1 – Domestic & Commercial WWH: 1990-2019



Source: Water Management Agency.

7.5.2.3.2 Methodological issues

Nitrous oxide emissions from municipal waste water have been evaluated by applying the Tier 1 method described in the 2006 IPCC Guidelines (Volume 5, Chapter 6.3). Although, this methodology is currently at discussion (e.g. the method assumes no N₂O-emissions from treatment of the older generation WWTP; the EF for advanced WWTP is very low) Luxembourg has several reasons to apply the 2006 GL:

- This is in agreement with the guidance on choice of method in the 2006 GL. Chapter 6.3.1.1 reads “it is *good practice* to estimate N₂O from domestic wastewater effluent using the method given here.” In Luxembourg, the subsector is a non-key category source, so application of a Tier-1 methodology is justified;
- almost all EU Member States follow the methodology in the 2006 IPCC GLs, which makes Luxembourg’s estimate more comparable to the estimate in other member states;
- IPCC is currently working on a 2019 Refinement. In the most recent draft the above mentioned concerns on the 2006-GL seem to be addressed. Rather than developing an own country-specific methodology Luxembourg prefers to wait for the new refinement to be made mandatory and then align its methodology with the new guidelines.

Hence, N₂O emissions from municipal waste water handling were calculated per discharge pathway (septic tanks, basic mechanical WWTPs, biological WWTP without denitrification, advanced biological WWTPs with denitrification) by taking into account the average per capita protein intake.

The average per capita protein intake was derived from FAOSTAT, which publishes values for the years 2000-2017. In this period, the protein consumption in Luxembourg decreased from an average of 119.9 g/day/person to an average of 106.65 g/day/person. As no data was available for the other years, these were extrapolated based on a moving average of the preceding (for 2018-2019), respectively subsequent (for 1990-1999) 3 years.

Determination of the N-effluent (2006 IPCC GLs, equation 6.8):

$$N\text{-effluent}(i) = P(i) * \text{Protein} * F \text{ NPR} * F \text{ ind-com} * F \text{ non-con} * (1 - N\text{-removal} (i))$$

Where:

(i) = WWT system: not connected (septic tanks), mechanical WWTPs, biological WWTPs without denitrification and biological WWTPs with denitrification.

Protein = protein intake per person (kg/year) (<http://www.fao.org>)

F ind-com = 1.25 (default fraction of industrial and commercial co-discharged protein, 2006 IPCC GLs, page 6.26)

F NPR = 0.16 kg N/kg protein (default fraction of N in protein, 2006 IPCC GLs, page 6.25)

F non-con = 1.1. (default factor to adjust for non-consumed protein, 2006 IPCC GLs, page 6.27)

N-removal(i) = percentage of N removed in the sludge (0% for septic tanks, 35% for mechanical WWTPs, 35% for biological WWTPs without denitrification, 85% for biological WWTPs with denitrification).

For all the four WWT pathways, the N-effluent was calculated in accordance with equation 6.8 of the 2006 GLs (Vol. 6. Chap. 5, Eq. 6.8, p. 6.25) and using the IPCC default values for F(NPR) (= 0.16 kg N/kg protein), F(non-con) (=1.1, since garbage disposal installations on sinks are not allowed in Luxembourg) and F(ind) (=1.25) (2006 IPCC GLs, Vol. 5, Chap. 6, Table 6.11). Concerning N removed (in the sludge) either default or country-specific values were applied depending on the WWT system:

- For septic tanks, no correction is made for N removed with sludge, because no data are available on sludge removal or N-removal from septic tanks. In line with the 2006 Guidelines, a default value of N_{sludge} of 0 was applied;
- For mechanical WWTPs and older biological WWTPs without denitrification, it is assumed that 35% of N_{effluent} is removed as N_{sludge} , so *indirect* emissions as a result of discharge of effluent of older WWTP are reduced by 35%. This 35% is based on measurements of N in the influent and effluent at several WWTPs. Calculations of sludge production at these WWTPs reveal that the majority of this 35% will be removed by sludge and this does not result in *direct* N_2O -emissions at the WWTPs. Minor part of the 35% might be removed by spontaneous nitrification/denitrification and this might result in *direct* emissions of N_2O . However, nitrate concentrations in the effluent of these WWTPs are generally low, and this is an indication that spontaneous nitrification is low as well. A sensitivity analysis reveals that the impact on *direct* N_2O -emissions of a more conservative assumption on spontaneous nitrification/denitrification (e.g. 10% out of 35% reduction in N is due to spontaneous nitrification/denitrification) results in additional N_2O -emissions below the threshold of significance for Luxembourg. Therefore, direct N_2O -emissions from these WWTPs can be neglected.
- For advanced biological WWTPs with denitrification, the guidance as provided in Box 6.1 in the IPCC guidelines, was applied and *indirect* as well as *direct* emissions were calculated using the default IPCC EFs. Hence, for the calculation of the indirect emissions, a reduction of 85% of the N-effluent in the sludge is assumed. This 85% N removal is based on measurements of N in the influent and effluent at several WWTPs with denitrification. Indeed, denitrification is a treatment requirement in Luxembourg for Urban Waste Water Treatment Plants based on the European Directive 91/271/CEE concerning urban waste water treatment. WWTPs with an organic design capacity larger than 10 000 population-equivalents (p. e.) have to meet the minimum reduction rate of 75% of total nitrogen. The objective of denitrification is to reduce the risk of eutrophication of surface waters.

Determination of indirect N_2O from waste water (2006 IPCC Guidelines, equation 6.7):

Indirect N_2O emissions for each pathway was calculated using equation 6.7 of the 2006 IPCC Guidelines (Vol. 6, Chap. 5, Eq. 6.7, p. 6.24-6.25) as detailed below:

$$N_2O(i) [t/year] = N\text{-effluent}(i) * EF\text{-effluent} / 1000 * 44/28$$

Where:

(i) = WWT system: not connected (septic tanks), mechanical WWTPs, biological WWTPs without denitrification and biological WWTPs with denitrification.

N-effluent (i) = Nitrogen content of the effluent per WWT system

EF effluent = 0.005 kg N_2O -N/kg N (default 2006 IPCC GLs, page 6.25)

44/28 = 1.57: conversion of N₂O-N to N₂O (44/28, N₂O/N))

Determination of direct N₂O from advanced biological WWTPs with denitrification:

As stated above, for advanced biological WWTPs with denitrification, direct N₂O emissions were calculated in accordance with the 2006 GLs, equation 6.9 (Vol. 6, Chap. 5, Box 6.1, Eq 6.9, p.6.26):

$$N_2O(wwtp-de) = P(wwtp-de) * F(ind-com) * EF_{plant} / 1.000.000 \quad [t/year]$$

Where:

wwtp-de = WWTPs with denitrification

P(wwtp-de) = inhabitants connected to wwtp-de

F(ind-com) = 1.25 (default fraction of industrial and commercial co-discharged protein, 2006 IPCC GLs, page 6.26)

EF_{plant} = 3.2 g N₂O / person / year (default emission factor, 2006 IPCC GLs, Table 6.11)

Determination of N₂O total emission from waste water handling:

Finally, total N₂O emissions for category 5D1 were calculated by summing up the indirect N₂O emissions from the four WWT systems and the direct N₂O emissions from biological WWTPs with denitrification:

$$N_2O_{tot} [t/year] = N_2O_{indirect} (notcon) + N_2O_{indirect} (mec) + N_2O_{indirect} (biol) + N_2O_{indirect} (wwtp-de) + N_2O_{direct} (wwtp-de)$$

Where:

notcon = not connected (i.e. septic tanks)

mec = mechanical WWTPs

biol = biological WWTPs without denitrification

wwtp-de = biological WWTPs with denitrification

7.5.3 Industrial wastewater (5D2)

In category 5D2, emissions from two industrial plants are reported (one chemical and one operating in food and beverages).

7.5.3.1 Methane Emissions

Industrial waste water treatment is carried out under aerobic conditions (activated sludge process). As only two plants fall under 5D2, one can hardly compare this specific situation to other EU Member States, which have very often a much larger number of plants in a multitude of operating modes. Indeed, Luxembourg's industrial plants are operated in aerobic mode with active injection of air/oxygen in order to exclude any anaerobic process which could occur in situ, in the same manner as the well managed advanced municipal biological WWTPs (with or without denitrification as reported in 5D1). In addition, the wastewater treated in these industrial plants is very specific to the industrial processes handled in these plants and is not to be compared to municipal WWTPs in the sense that it contains much less sludge. The sludge formed at the end of the biological process is either pumped off, thickened, dehydrated and

exported for incineration (one plant), either pumped off and transported to a biogas facility for anaerobic digestion (one plant). These sludge treatment processes are fully compatible with the IPCC guidelines and justify the use of the “NO” notation key in the CRF tables.

7.5.3.2 Nitrous Oxide Emissions

7.5.3.2.1 Emission trends

Nitrous Oxide emissions from industrial wastewater treatment have decreased by 32% over the period 1990-2019 (see Table 7-25 – N₂O emission from 5D2 - Industrial Wastewater

and Figure 7-13). From 1990 to 2014, emission originate only from one industrial WWTP. The second was put in operation in 2015. In 1998, the original WWTP was replaced by one with denitrification, and hence the N concentration in the effluent was reduced. Since 2002, N reduction is based analytical measurements of the N concentration in the flow in an flow out of the WWTP, which is also the case for the second industrial WWTP since its operational start. Hence, annual variations in N₂O emissions from industrial WWTPs are mainly due to the intensity of industrial activities and adaptations to the use of water in the processes.

Table 7-25 – N₂O emission from 5D2 - Industrial Wastewater

N ₂ O emissions (tonnes)		
5.D.2 Industrial Wastewater		
Year	N ₂ O ind	Total
1990	0.12	0.12
1991	0.12	0.12
1992	0.12	0.12
1993	0.12	0.12
1994	0.12	0.12
1995	0.12	0.12
1996	0.12	0.12
1997	0.12	0.12
1998	0.07	0.07
1999	0.07	0.07
2000	0.07	0.07
2001	0.07	0.07
2002	0.08	0.08
2003	0.07	0.07
2004	0.07	0.07
2005	0.09	0.09
2006	0.10	0.10
2007	0.08	0.08
2008	0.06	0.06
2009	0.03	0.03
2010	0.04	0.04
2011	0.04	0.04
2012	0.03	0.03
2013	0.04	0.04
2014	0.03	0.03
2015	0.07	0.07
2016	0.06	0.06
2017	0.05	0.05
2018	0.08	0.08
2019	0.08	0.08
Trend		
1990-2019	-32%	-32.25%
2005-2019	-10%	-10.19%
2018-2019	6%	5.64%

Figure 7-13 – N₂O emission trends for category 5D2 – Industrial Wastewater: 1990-2019



Source: Water Management Agency.

7.5.3.2.2 Methodological issues

N₂O emissions from industrial waste water handling are issued from two industrial plants, the first one produces plastics and, from 2015, a second one that produces milk based products. Both release N to aquatic environments. These industrial WWTPs are equipped with a biological treatment with denitrification.

Determination of N concentration:

N₂O emissions are based on the measured data of the wastewater flow in, the N concentration of the flow in and the N concentration of the Flow out for each WWTP. This data is available since 2002. For the years where no data is available an extrapolation was operated:

Year 1990 – 1997	Year 1998 - 2002	Year 2002 – 2014	Since 2015
Flow in, N concentration extrapolated by expert judgment of the water management administration based on the operational permit.	Flow in and N concentration extrapolated by expert judgment of the water management administration. In 1998, the WWTP has been upgraded allowing also denitrification.	Flow in, N concentration of flow in and flow out based on monitoring analyses.	Flow in, N concentration of flow in and flow out based on monitoring analyses (for both industrial plants).

Determination of N effluent:

The N effluent from industrial WWTPs is calculated as follows:

$$N_{\text{effluent}}(i) = \text{Inflow}(i) \text{ [m}^3/\text{h]} * N_{\text{cc}}(i) \text{ [mg/l]} * (1 - \text{FRACdenit}(i) \text{ [\%]}) * 24 \text{ [h/d]} * 365 \text{ [d/y]} / 1000 \text{ [kg/year]}$$

Where:

Inflow(i) = Average hourly flow in as measured for WWTP(i)

Ncc(i) = N concentration in flow in as measured for WWTP(i)

FRACdenit(i) = measured denitrification rate in % (% of waste water which is denitrified), the denitrification rate is calculated for each industrial WWTP using the average of the analytical results during the current year.

Determination of N₂O emissions:

N₂O from industrial WWTPs are then calculated as follows:

$$N_{2O \text{ ind}} = \text{SUM}(N_{\text{effluent}}(i)) * E_{\text{Find}} * 44/28 / 1000 \text{ [t/year]}$$

Where:

N_{effluent}(i) = amount of N in the effluent per industrial WWTP (i)

E_{Find} = 0.01 (according to (Orthofer, Knoflacher, & Züger, 1995) 1% of the denitrified N is emitted as N₂O)

44/28 = conversion of N₂O-N to N₂O (44/28, N₂O/N)

7.5.4 Uncertainties and Time-Series Consistency

- Waste water quantity: 10 % not connected to waste water treatment plants
- Emission factor for N₂O: 50% (IPCC 2006 - Guidelines)
- Emission factor for CH₄: 50%

(Treatment of uncertainties for national estimates of GHG Emission, Charles D., 1998, referenced by Wilfried Winiwarter)

For further information on uncertainties, please refer to Section 0.

7.5.6 Category-Specific QA/QC and Verification

Category-specific QA/QC procedures have been completed for the following parameters:

1) Activity data:

- Population and commuters from the STATEC (national data inventory of Luxembourg);
- Number and size of WWTP from national inventory from the Water Management Administration;
- Measured data for the denitrification efficiency;

2) Parameters and emission factor:

- References are indicated, waste expert (QA);

3) Emissions:

- References are indicated, waste expert (QA).

7.5.7 Category-specific recalculations including changes have been made in response to the review process

Following UNFCCC review and EU-ESD review recommendations, activity data and parameters used for calculating emissions from categories 5.D.1 and 5.D.2 have been updated.

5.D.1 – Domestic Wastewater

The following revisions were made:

- Separation of the different WWT systems in place in Luxembourg in the calculation method. The following systems are now considered separately:
 - Septic tanks used in remote places where a connection to a WWTP is not possible.
 - Mechanical WWTPs, which in Luxembourg are to be considered as very basic installations with no sludge digesters and which are managed from a technical point of view in the same way as septic tanks. They consist of simple volumes with a baffle and no pre- or subsequent treatment (such as screen a grit compartment, or aerobic step). In addition, the management consists of simple regular emptying. Hence, it should also be noted, it is assumed that the processes in these installations are very similar to septic tanks (which is particularly important for the calculation of methane emissions). Also, all sludge, removed from these mechanical WWTPs (as well as from septic tanks), is transferred to biological WWTPs where it is further treated either aerobically, or anaerobically in a digester. This is not to be compared to modern mechanical waste water treatment plants which might be operated in other European countries.
 - Biological WWTPs without denitrification.
 - Biological WWTPs with denitrification.
- Population numbers connected to the different WWT systems. Indeed, in previous submissions, population numbers were not correctly reflected in the years between a population census (1991, 2001, and 2011) and the date where the population was connected to a different WWT system (for example from mechanical WWTP to biological WWTP). In the present submission, this was corrected and the annual population per locality was adapted to follow the evolution of the population.
- Protein intake (N₂O emissions): New data on protein consumption for 2000-2017, available on the FAOStat website, was integrated in the calculation of NO₂ emissions. Protein consumption decreased from an average of 119.9 g/day/person to an average of 106.65 g/day/person. As no data was available for the other years, these were extrapolated based on a moving average of the preceding (for 2018-2019), respectively subsequent (for 1990-1999), 3 years. Hence, the entire time series was updated.
- % N-removal in biological WWTP with denitrification: N- removal efficiency was decreased from 100% to 85% following discussions with the TERT during the 2020 ESD review (LU-5D-2020-0006), as modern WWTP cannot achieve a 100% reduction in N in the effluent.

Hence, methane emissions from domestic wastewater were recalculated over the entire time series (1990-2018) due to the revision of population numbers connected to septic tanks and mechanical WWTPs. No revision in the methodology was operated, and in particular, the country-specific MCF for mechanical WWTPs was kept identical to the country-specific MCF for septic tanks, as the systems are very similar (LU-5D-2020-0002, LU-5D-2020-0003, LU-5D-2020-0004). For N₂O emissions, recalculations were operated over the entire time series, due to revisions in population numbers per WWT system, protein intake and N-removal efficiency (LU-5D-2020-0006). In total emissions, from 5.D.1, decreased by 0.13 Gg CO₂eq in 1990 and increased by 0.34 Gg CO₂eq in 2005 and 0.86 Gg CO₂eq in 2018 (see Table 7-26).

5.D.2 – Industrial Wastewater

The following parameter was revised based on plant specific data (two plants) instead of an average value as used in previous submissions:

- Denitrification rate for 2002-2018 as communicated by the plant operators and based on measurements. As no measurements were available for the years 1990-2001, these were extrapolated based on the average value from 2002-2007 (70% denitrification).

Hence N₂O emissions, from 5.D.2, decreased by 0.00003 Gg CO₂eq in 1990 and increased by 0.004 Gg CO₂eq in 2005 and 0.003 Gg CO₂eq in 2018 (see Table 7-26).

Table 7-26 - Recalculations in category 5.D – Wastewater treatment

Year	Recalculations			
	5.D.1		5.D.2	
	CH ₄ [kt CO ₂ eq]	N ₂ O [kt CO ₂ eq]	CH ₄ [kt CO ₂ eq]	N ₂ O [kt CO ₂ eq]
1990	0.272	-0.399	NO	-0.00003
1991	0.525	-0.405	NO	-0.00003
1992	0.778	-0.409	NO	-0.00003
1993	1.031	-0.515	NO	-0.00003
1994	1.284	-0.532	NO	-0.00003
1995	0.550	-0.469	NO	-0.00003
1996	0.821	-0.367	NO	-0.00003
1997	1.092	-0.430	NO	-0.00003
1998	1.364	-0.397	NO	-0.00002
1999	1.635	-0.455	NO	-0.00002
2000	0.744	-0.758	NO	-0.00002
2001	0.919	-0.307	NO	-0.00002
2002	1.082	-0.274	NO	-0.00457
2003	1.252	-0.337	NO	0.00312
2004	0.529	-0.340	NO	0.00314
2005	0.617	-0.274	NO	0.00427
2006	0.652	-0.342	NO	0.00118
2007	0.685	-0.436	NO	-0.00354
2008	0.394	-0.341	NO	0.00047
2009	0.315	-0.339	NO	0.00151
2010	0.288	-0.041	NO	0.00058
2011	0.025	0.144	NO	0.00092
2012	0.024	0.780	NO	0.00135
2013	0.024	0.725	NO	0.00149
2014	0.024	0.437	NO	0.00005
2015	0.005	0.526	NO	0.03458
2016	0.005	0.556	NO	0.02239
2017	0.005	0.736	NO	0.02634
2018	0.005	0.853	NO	0.03335
2019	NO	NO	NO	NO

Table 7-27 summarises the main revisions and recalculations done relevant to category 5D.

Table 7-27 - Changes in GHG inventory since submission 2020v1

GHG source & sink category	Revisions 2020v1 → 2021v1	Type of revision
5D1	Separation of the different WWT systems (septic tanks, mechanical WWTPs, biological WWTPs without denitrification and biological WWTPs with denitrification) in place in Luxembourg in the calculation method.	updated methodology
5D1	Population numbers connected to the different WWT systems	updated AD
5D1	Updated protein intake (N ₂ O emissions) data from FAOSTAT	updated AD
5D1	Updated % N-removal in biological WWTP with denitrification	updated parameter
5D2	Updated denitrification rate for 2002-2018 as communicated by the plant operators and based on measurements.	Updated parameter

7.5.8 Category-Specific Planned Improvements

Taking into account the potential contribution of identified improvements in the total GHG emissions and the corresponding resources needed to make these improvements effective, developments presented in Table 7-28 will be explored.

Table 7-28 – Planned improvements for category 5D – WWH

GHG source & sink category	Planned improvement
5D1	IPCC is currently working on a Refinement. In the most recent draft Luxembourg's concerns on the 2006-GL are addressed. Rather than developing an own CS-methodology Luxembourg prefers to wait for the new refinement to be finalised and then align the methodology with the new guidelines.

8 Other

CRF Sector 6 is not applicable to Luxembourg's inventory.

9 Indirect CO₂ and nitrous oxide emissions

No indirect CO₂ and nitrous oxide emissions have been reported.

10 Recalculations and Improvements

10.1 Explanations and justifications for recalculations, including for KP-LULUCF inventory

10.1.1 GHG inventory

Table 10-1 summarises the main revisions and recalculations done since the last submission. More details can be found in the sector chapters.

Table 10-1: Revisions and recalculations done since submission 2020

GHG source & sink category	Revisions 2020v1 → 2021v1	Type of revision
1D1a – International Aviation – jet kerosene	change of methodology for CO ₂ emissions. 1) for LTO: switched from emissions per LTO to emissions per TJ (71.5 t/TJ = default EF IPCC 2006). 2) for cruise: corrected EF from 70 to 71.5 t/TJ (IPCC 2006)	Methodology change & error correction
1D1b – International Navigation – diesel oil, biodiesel, other fossil fuels	The total amounts of gasoline, diesel oil, LPG, bioethanol and biodiesel sold in Luxembourg are obtained from the national energy balance, and the activity data is then allocated to the different road and offroad subcategories with the NEMO and GEORG models developed by TU Graz. No changes were made to the total amounts of the different fuel types, but minor reallocations were done for diesel, biodiesel and other fossil fuels from 1A3d-Domestic Navigation to 1D1b-International navigation for the years 1995-2018 (for details please refer to Table 3-77). These reallocations are due to an update of the specific fuel consumption of offroad vehicles (Schwingshackl, Rexeis, & Weller, 2020).	AD reallocation
1A1a – gaseous fuels	Revision of the natural gas activity data for 2018 from the national energy balance following an error correction of the net calorific value from 36.98 to 36.76 MJ/Nm ³ .	AD
1A1a - biomass	Revision of the wood and wood products activity data for the years 2017-2018 due to the revised energy balance from the national statistics institute.	AD
1A1a – biomass/other fuels	Error correction of the fossil carbon fraction of the Multilayer Composite Material (from 100% to a weighted function of the fossil carbon fraction of paper and plastics). This change only affects the distribution of biomass and other fuels related GHG emissions over the entire time series.	AD
1A1a – biomass/other fuels	Changes to the internal collection and evaluation procedure of external reports to unify the sources delivering the treated MSW and BW AD to the incineration plant. This changes affects the biomass and fossil fuels AD for 2002-2018.	AD
1A1a – biomass/other fuels	Publication of a new waste management study that sets 2018 up as a pillar year (see section 3.2.6.2.1). The publication affects the MSW AD for the years 2015-2018.	AD
1A1a – biomass/other fuels	Error correction of the Multilayer Composite Material NCV. For 2010-2013, the value was changed from 15 GJ/t to an interpolation between 15 and 19 GJ/t. For 2014-2018, the value was changed from 15 to 19 GJ/t.	AD
1A2	Fuel consumption data for natural gas and heating gas oil for the years 2017-2018 was revised due to the revised energy balance from the national statistics institute	AD
1A2	Revision of natural gas activity data for 2018 from the national energy balance following an error correction of the net calorific value from 36.98 to 36.76 MJ/Nm ³	AD
1A2a 1A2gviii	Revision of natural gas activity data for 1990-1994 and 1996-1999 due to the revised energy balance from the national statistics institute	AD
1A2b	Revision of natural gas activity data for 2018 following an error correction from 412 TJ to 452 TJ	AD

1A2e 1A2gviii	Revision of residual fuel oil activity data for 2002, 2003, and 2005 in 1A2e from 0 TJ to 21.7 TJ (2002), 21.0 TJ (2003), and 23.2 TJ (2005), respectively. These changes redistribute the residual fuel oil AD from sub-category 1A2gviii to 1A2e such that no effect on the total GHG emissions is observed	AD
1A2e	Revision of gas oil activity data for one installation for 2008, leading to an increase by 44 GJ	AD
1A2gviii	Revision of gas oil activity data for 2018 following an error correction from 6.7 TJ to 18.6 TJ	AD
1A2	The country-specific CO ₂ EFs for LPG were revised for the years 2017-2018 due to changes of the emission factors of the importing countries: 2017: from 65213 to 65232 kg/TJ 2018: from 65212.1277 to 65212.1283 kg/TJ	CO ₂ EF
1A2gvii	The country-specific CO ₂ EFs for motor gasoline were revised for the years 2017-2018 due to changes of the emission factors of the importing countries: 2017: from 73300 to 73181 kg/TJ 2018: from 73216 to 73093 kg/TJ	CO ₂ EF
1A2f	The country-specific CO ₂ EFs for fluff, sewage sludge, and solvents were revised for 2018 following an error correction: Fluff: from 82829 to 82199 kg/TJ Sewage sludge: from 91640 to 90794 kg/TJ Solvents: from 72780 to 73730 kg/TJ	CO ₂ EF
1A3b/c/d	The country-specific CO ₂ EFs for motor gasoline were revised for the years 2017-2018 due to changes of the emission factors of the importing countries: 2017: from 73300 to 73181 kg/TJ 2018: from 73216 to 73093 kg/TJ.	updated EF
1A3d	Error correction for CO ₂ emissions from biomass / other fossil fuels for the years 2004-2018	AD correction
1A3d	The total amounts of gasoline, diesel oil, LPG, bioethanol and biodiesel sold in Luxembourg are obtained from the national energy balance, and the activity data is then allocated to the different road and offroad subcategories with the NEMO and GEORG models developed by TU Graz. No changes were made to the total amounts of the different fuel types, but minor reallocations were done for diesel, biodiesel and other fossil fuels from 1.A.3.d-Domestic Navigation to 1.D.1.b-International navigation for the years 1995-2018 (Table 3-77). These reallocations are due to an update of the specific fuel consumption of offroad vehicles (Schwingshackl, Rexeis, & Weller, 2020).	AD reallocation
1A4a	Due to a revision of the energy balance by the national statistics institute, the following fuel consumption data were revised: <ul style="list-style-type: none"> Natural gas for 1990-1994, 1996-1999, 2017-2018; Biogas for 2017-2018; Gas oil for 2017-2018. 	AD
1A4b	Due to a revision of the energy balance by the national statistics institute, the following fuel consumption data were revised: <ul style="list-style-type: none"> Natural gas for 2017-2018; Wood & Wood Wastes for 2018. 	AD
1A4c	Due to a revision of the energy balance by the national statistics institute, the following fuel consumption data were revised: <ul style="list-style-type: none"> Natural gas for 2017-2018; Biogas for 2017-2018. 	AD
1A4	Revision of natural gas activity data for 2018 from the national energy balance following an error correction of the net calorific value from 36.98 to 36.76 MJ/Nm ³ .	AD
1A4a, 1A4b	The country-specific CO ₂ EFs for LPG were revised for the years 2017-2018 due to changes of the emission factors of the importing countries: 2017: from 65213 to 65232 kg/TJ 2018: from 65212.1277 to 65212.1283 kg/TJ	CO ₂ EF

1A4b	The country-specific CO ₂ EFs for motor gasoline were revised for the years 2017-2018 due to changes of the emission factors of the importing countries: 2017: from 73300 to 73181 kg/TJ 2018: from 73216 to 73093 kg/TJ.	CO ₂ EF
1B2biii4 & 1B2biii5- natural gas transmission and distribution	Activity data was revised for 2018 due to revisions of the national natural gas consumption in the energy balance. Emissions decreased by 0.06 Gg CO ₂ eq. and 0.13 Gg CO ₂ eq. respectively. Further, very small revisions occurred in the years 1990-1994 and 1996-1999, impacting total CO ₂ eq. emissions by less than 0.000003 Gg.	AD revision
1B2c – natural gas venting	CO ₂ and CH ₄ emissions from natural gas venting of transmission and distribution networks (sub-category 1B2c – Venting) are first estimated in submission 2021v1. This category was added to the inventory following a review recommendation in the UNFCCC Review 2018 (ARR 2018, E.26), in the EU-ESD review 2020 (LU-1B2c-2020-0001) and recently in the UNFCCC Review 2020 (preliminary finding: 2020LUXQA38).	New emission source added
2A1	for the years 1990-2011, the conversion factor was adapted from 1 to 0.93 as to avoid issues regarding overestimation.	Conversion factor
2A1	AD revision for years 1990-2013: emissions resulting from various fluxes were extrapolated based on the year 2014 and added to the emissions of the years 1990-2013, which previously did not take into account these fluxes.	AD revision
2D2	Revision of AD for the years 2017 and 2018	AD
2D3.1	update of production statistics data, import and export statistics update of emission factors and solvent content update of plant specific, information from associations of industries and statistical data for “general aspects” and “specific aspects” .	AD, EF
2D3.2	Update of emissions for the years 2014-2018 due to a revision of NO _x emission factors	AD
2F1	Error correction for the years 2014-2018	Error correction
2F2	AD revision for the year 2018	AD
3	For detailed information about all recalculations in the Agriculture sector, please refer to Annex 3A.	
4B-F	In the 2020v1 calculations carbon losses of deadwood resulting from land use change from for-estland to cropland a static value of dead wood carbon stock was used. In the 2021 version the dynamic value of the deadwood carbon stock, calculated in the forestland category, was used. This has led to minor changes.	Calculation factor
4G	In order to calculate the HWP carbon pool data on import and export of industrial roundwood are used to calculate the share of HWP originated from domestic harvest. The data of import and export of industrial roundwood is published by the FAO. If official data is not available FAO often uses estimates until the official data is submitted. With the latest download revised data of import and export of industrial roundwood has been made available which has led to a significant recalculation for the years 2017 and 2018. For the year 2017 the export of industrial roundwood has almost doubled (increase from 413.000m ³ to 805.000m ³).	AD
5A1	A splitting of the recovered methane in flared CH ₄ and CH ₄ for energy production was made for the time series 1990-2019.	Memo items
5B1b	For the year 2018, the waste composition analysis was updated which led to a recalculation in category 5.B.1.b – MBA treated MSW.	EF
5D1	Separation of the different WWT systems (septic tanks, mechanical WWTPs, biological WWTPs without denitrification and biological WWTPs with denitrification) in place in Luxembourg in the calculation method.	methodology
5D1	Population numbers connected to the different WWT systems were corrected.	AD
5D1	Update of protein intake for the entire timeseries with data from FAOSTAT	AD
5D1	Updated % N-removal in biological WWTP with denitrification	Calculation factor
5D2	Updated denitrification rate for 2002-2018 as communicated by the plant operators and based on measurements.	Calculation factor

10.1.2 KP-LULUCF inventory

Recalculations are the same as for the LULUCF sector (section 6.11).

10.2 Implications for emission levels, including on KP-LULUCF emission levels

10.2.1 GHG inventory

Table 10-2, Table 10-3, Table 10-4, Table 10-5, and Table 10-6 present the recalculations of CO₂, CH₄, N₂O, F-gases and total GHG emissions for the years 1990, 2000, 2010 and 2016-2018.

Table 10-2 – CO₂ emissions: recalculations done since submission 2020v1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	2000	2010	2016	2017	2018
	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
1. Energy	0.19	0.41	1.41	11.81	8.71	-1.59
A. Fuel Combustion (Sectoral Approach)	0.19	0.41	1.41	11.81	8.71	-1.59
1. Energy Industries	0.19	0.41	1.41	11.81	10.37	8.59
2. Manufacturing Industries and Construction	0.00	-	-	-	1.69	-1.86
3. Transport	0.00	0.00	0.00	0.00	-1.49	-1.68
4. Other Sectors	-0.01	-	-	-	-1.86	-6.63
5. Other	-	-	-	-	-	0.00
B. Fugitive Emissions from Fuels	0.00	0.00	0.00	0.00	0.00	0.00
1. Solid Fuels	NO	NO	NO	NO	NO	NO
2. Oil and natural gas and other emissions from energy production	0.00	0.00	0.00	0.00	0.00	0.00
C. CO ₂ transport and storage	NO	NO	NO	NO	NO	NO
2. Industrial Processes	-30.52	-27.73	-17.46	-3.49	-1.90	-2.33
A. Mineral industry	-30.52	-27.73	-20.81	-3.42	-1.80	-2.17
B. Chemical industry	NO	NO	NO	NO	NO	NO
C. Metal industry	-	-	-	-	-	-
D. Non-energy products from fuels and solvent use	-	-	3.36	-0.07	-0.11	-0.16
E. Electronic industry						
F. Product uses as ODS substitutes						
G. Other product manufacture and use	NO	NO	NO	NO	NO	NO
H. Other	NO	NO	NO	NO	NO	NO
3. Agriculture	6.04	5.67	4.01	4.17	4.13	3.84
A. Enteric fermentation						
B. Manure management						
C. Rice cultivation						
D. Agricultural soils						
E. Prescribed burning of savannas						
F. Field burning of agricultural residues						
G. Liming	-	-	-	-	-	-0.01
H. Urea application	NO	NO	0.00	0.00	0.00	0.00
I. Other carbon-containing fertilizers	6.04	5.67	4.01	4.17	4.13	3.85
J. Other	NO	NO	NO	NO	NO	NO
4. Land use, land-use change and forestry (2)	-16.41	-4.60	1.40	1.49	27.67	22.86
A. Forest land	-	-	-	-	-	-
B. Cropland	-2.77	-0.61	0.21	0.23	0.23	0.23
C. Grassland	-10.00	-1.75	0.67	0.71	0.72	0.73
D. Wetlands	-0.30	-0.14	0.01	0.01	0.01	0.01
E. Settlements	-3.29	-2.09	0.51	0.54	0.54	0.55
F. Other land	-0.06	-0.01	0.00	0.00	0.00	0.00
G. Harvested wood products	-	-	-	-	26.16	21.33
H. Other	NO	NO	NO	NO	NO	NO
5. Waste	NO,IE,NA	NO,IE,NA	NO,IE,NA	NO,IE,NA	NO,IE,NA	NO,IE,NA
A. Solid waste disposal	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA	NO,NA
B. Biological treatment of solid waste						
C. Incineration and open burning of waste	IE,NO	IE,NO	IE,NO	NO,IE	NO,IE	NO,IE
D. Waste water treatment and discharge						
E. Other	NO	NO	NO	NO	NO	NO
6. Other (as specified in summary 1.A)	NO	NO	NO	NO	NO	NO
Memo items:	0.00	0.00	0.00	0.00	0.00	0.00
International bunkers	8.39	20.45	27.46	32.34	36.54	37.57
Aviation	8.39	20.45	27.46	32.34	36.54	37.57
Navigation	0.00	0.00	0.00	0.00	0.00	0.00
Multilateral operations	NO	NO	NO	NO	NO	NO
CO₂ emissions from biomass	2.54	5.41	10.93	33.48	32.32	36.38
CO₂ captured	NO	NO	NO	NO	NO	NO
Long-term storage of C in waste disposal sites	NE	NE	NE	NE	NE	NE
Indirect N₂O						
Total CO₂ equivalent emissions without LULUCF	-24.30	-21.65	-12.04	12.49	10.94	-0.08
Total CO₂ equivalent emissions with LULUCF	-40.71	-26.25	-10.64	13.98	38.61	22.78
Total CO₂ equivalent emissions, including indirect CO₂,	NA	NA	NA	NA	NA	NA
Total CO₂ equivalent emissions, including indirect CO₂, with	NA	NA	NA	NA	NA	NA

Table 10-3 – CH₄ emissions: recalculations done since submission 2020v1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	2000	2010	2016	2017	2018
	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
1. Energy	0.01	0.01	0.03	0.02	0.02	0.02
A. Fuel combustion (sectoral approach)	0.00	0.00	0.00	0.01	0.01	0.01
1. Energy industries	-	-	0.00	0.01	0.01	0.01
2. Manufacturing industries and construction	0.00	-	-	-	0.00	0.00
3. Transport	0.00	0.00	0.00	0.00	0.00	0.00
4. Other sectors	0.00	-	0.00	0.00	0.00	0.01
5. Other	-	-	-	-	-	-
B. Fugitive emissions from fuels	0.01	0.01	0.02	0.01	0.01	0.01
1. Solid fuels	NO	NO	NO	NO	NO	NO
2. Oil and natural gas and other emissions from energy production	0.01	0.01	0.02	0.01	0.01	0.01
C. CO ₂ transport and storage						
2. Industrial processes	NO	NO	NO	NO	NO	NO
A. Mineral industry						
B. Chemical industry	NO	NO	NO	NO	NO	NO
C. Metal industry	NO	NO	NO	NO	NO	NO
D. Non-energy products from fuels and solvent use	NO	NO	NO	NO	NO	NO
E. Electronic industry						
F. Product uses as ODS substitutes						
G. Other product manufacture and use	NO	NO	NO	NO	NO	NO
H. Other	NO	NO	NO	NO	NO	NO
3. Agriculture	0.05	0.07	0.06	0.10	0.11	0.11
A. Enteric fermentation	-	-	-	0.00	0.00	0.00
B. Manure management	0.05	0.07	0.06	0.10	0.11	0.11
C. Rice cultivation	NO	NO	NO	NO	NO	NO
D. Agricultural soils	NO	NO	NO	NO	NO	NO
E. Prescribed burning of savannas	NO	NO	NO	NO	NO	NO
F. Field burning of agricultural residues	NO	NO	NO	NO	NO	NO
G. Liming						
H. Urea application						
I. Other carbon-containing fertilizers						
J. Other	NO	NO	NO	NO	NO	NO
4. Land use, land-use change and forestry (2)	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE
A. Forest land	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE
B. Cropland	NO	NO	NO	NO	NO	NO
C. Grassland	NO	NO	NO	NO	NO	NO
D. Wetlands	NO	NO	NO	NO	NO	NO
E. Settlements	NO	NO	NO	NO	NO	NO
F. Other land	NO	NO	NO	NO	NO	NO
G. Harvested wood products						
H. Other	NO	NO	NO	NO	NO	NO
5. Waste	0.04	0.03	0.02	0.00	0.00	0.00
A. Solid waste disposal	0.03	0.00	0.00	0.00	0.00	0.00
B. Biological treatment of solid waste	NO,IE	-	-	-	-	0.00
C. Incineration and open burning of waste	IE,NO	IE,NO	IE,NO	NO,IE	NO,IE	NO,IE
D. Waste water treatment and discharge	0.01	0.03	0.01	0.00	0.00	0.00
E. Other	NO	NO	NO	NO	NO	NO
6. Other (as specified in summary 1.A)	NO	NO	NO	NO	NO	NO
Total CH₄ emissions without CH₄ from LULUCF	0.11	0.11	0.10	0.12	0.13	0.13
Total CH₄ emissions with CH₄ from LULUCF	0.11	0.11	0.10	0.12	0.13	0.13
Memo items:	0.00	0.00	0.00	0.00	0.00	0.00
International bunkers	0.00	0.00	0.00	0.00	0.00	0.00
Aviation	0.00	0.00	0.00	0.00	0.00	0.00
Navigation	0.00	0.00	0.00	0.00	0.00	0.00
Multilateral operations	NO	NO	NO	NO	NO	NO
CO₂ emissions from biomass						
CO₂ captured						
Long-term storage of C in waste disposal sites						
Indirect N₂O						

Table 10-4 – N₂O emissions: recalculations done since submission 2020v1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	2000	2010	2016	2017	2018
	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
1. Energy	0.00	0.00	0.00	0.00	0.00	0.00
A. Fuel combustion (sectoral approach)	0.00	0.00	0.00	0.00	0.00	0.00
1. Energy industries	0.00	-	0.00	0.00	0.00	0.00
2. Manufacturing industries and construction	0.00	-	-	-	0.00	0.00
3. Transport	0.00	0.00	0.00	0.00	0.00	0.00
4. Other sectors	0.00	-	-	-	0.00	0.00
5. Other	-	-	-	-	-	-
B. Fugitive emissions from fuels	NO	NO	NO	NO	NO	NO
1. Solid fuels	NO	NO	NO	NO	NO	NO
2. Oil and natural gas and other emissions from energy production	NO	NO	NO	NO	NO	NO
C. CO ₂ transport and storage	-	-	-	-	-	-
2. Industrial processes	-	-	-	-	-	-
A. Mineral industry	-	-	-	-	-	-
B. Chemical industry	NO	NO	NO	NO	NO	NO
C. Metal industry	NO	NO	NO	NO	NO	NO
D. Non-energy products from fuels and solvent use	NO	NO	NO	NO	NO	NO
E. Electronic industry	-	-	-	-	-	-
F. Product uses as ODS substitutes	-	-	-	-	-	-
G. Other product manufacture and use	-	-	-	-	-	-
H. Other	NO	NO	NO	NO	NO	NO
3. Agriculture	0.03	0.03	0.06	0.06	0.06	0.06
A. Enteric fermentation	-	-	-	-	-	-
B. Manure management	-0.01	0.00	0.00	0.00	0.00	0.00
C. Rice cultivation	-	-	-	-	-	-
D. Agricultural soils	0.03	0.03	0.05	0.05	0.06	0.05
E. Prescribed burning of savannas	NO	NO	NO	NO	NO	NO
F. Field burning of agricultural residues	NO	NO	NO	NO	NO	NO
G. Liming	-	-	-	-	-	-
H. Urea application	-	-	-	-	-	-
I. Other carbon-containing fertilizers	-	-	-	-	-	-
J. Other	NO	NO	NO	NO	NO	NO
4. Land use, land-use change and forestry (2)	-	-	-	-	-	-
A. Forest land	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE
B. Cropland	-	-	-	-	-	-
C. Grassland	-	-	-	-	-	-
D. Wetlands	-	-	-	-	-	-
E. Settlements	-	-	-	-	-	-
F. Other land	-	-	-	-	-	-
G. Harvested wood products	-	-	-	-	-	-
H. Other	NO	NO	NO	NO	NO	NO
5. Waste	0.00	0.00	0.00	0.00	0.00	0.00
A. Solid waste disposal	-	-	-	-	-	-
B. Biological treatment of solid waste	NA,NO	-	-	-	-	0.00
C. Incineration and open burning of waste	IE,NO	IE,NO	IE,NO	NO,IE	NO,IE	NO,IE
D. Waste water treatment and discharge	0.00	0.00	0.00	0.00	0.00	0.00
E. Other	NO	NO	NO	NO	NO	NO
6. Other (as specified in summary 1.A)	NO	NO	NO	NO	NO	NO
Total direct N₂O emissions without N₂O from LULUCF	0.03	0.03	0.06	0.06	0.06	0.06
Total direct N₂O emissions with N₂O from LULUCF	0.03	0.03	0.06	0.06	0.06	0.06
Memo items:	0.00	0.00	0.00	0.00	0.00	0.00
International bunkers	0.00	0.00	0.00	0.00	0.00	0.00
Aviation	0.00	0.00	0.00	0.00	0.00	0.00
Navigation	0.00	0.00	0.00	0.00	0.00	0.00
Multilateral operations	NO	NO	NO	NO	NO	NO
CO₂ emissions from biomass	0.00	0.00	0.00	0.00	0.00	0.00
CO₂ captured	0.00	0.00	0.00	0.00	0.00	0.00
Long-term storage of C in waste disposal sites	0.00	0.00	0.00	0.00	0.00	0.00
Indirect N₂O	NE,NO	NE,NO	NE,NO	NO,NE	NO,NE	NO,NE

Table 10-5 – F-gas emissions: recalculations done since submission 2020v1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Base year (1990	2000	2010	2016	2017	2018
	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
Emissions of HFCs - (kt CO2 equivalent)	-	0.00	0.00	-0.88	-1.01	-2.94
Emissions of PFCs - (kt CO2 equivalent)	NO	NO	NO	NO	NO	NO
Unspecified mix of HFCs and PFCs - (kt CO2 equivalent)	NO	NO	NO	NO	NO	NO
Emissions of SF6 - (kt CO2 equivalent)	-	-	-	-	-	-
Emissions of NF3 - (kt CO2 equivalent)	NO	NO	NO	NO	NO	NO

Table 10-6 – Total GHG emissions: recalculations done since submission 2020v1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	2000	2010	2016	2017	2018
CO ₂ equivalents	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
1. Energy	0.41	0.76	2.15	12.71	9.57	-0.74
A. Fuel combustion (sectoral approach)	0.19	0.42	1.54	12.35	9.21	-0.91
1. Energy industries	0.19	0.41	1.54	12.35	10.87	9.08
2. Manufacturing industries and construction	0.00	-	-	-	1.70	-1.86
3. Transport	0.01	0.01	0.00	0.00	-1.49	-1.68
4. Other sectors	-0.01	-	0.00	0.00	-1.87	-6.45
5. Other	-	-	-	-	-	0.00
B. Fugitive emissions from fuels	0.21	0.33	0.61	0.36	0.36	0.17
1. Solid fuels	NO	NO	NO	NO	NO	NO
2. Oil and natural gas and other emissions from energy production	0.21	0.33	0.61	0.36	0.36	0.17
C. CO ₂ transport and storage	NO	NO	NO	NO	NO	NO
2. Industrial processes	-30.52	-27.73	-17.46	-4.37	-2.91	-5.27
A. Mineral industry	-30.52	-27.73	-20.81	-3.42	-1.80	-2.17
B. Chemical industry	NO	NO	NO	NO	NO	NO
C. Metal industry	-	-	-	-	-	-
D. Non-energy products from fuels and solvent use	-	-	3.36	-0.07	-0.11	-0.16
E. Electronic industry	NO	NO	NO	NO	NO	NO
F. Product uses as ODS substitutes	-	0.00	0.00	-0.88	-1.01	-2.94
G. Other product manufacture and use	-	-	-	-	-	-
H. Other	NO	NO	NO	NO	NO	NO
3. Agriculture	15.77	16.10	22.32	23.35	23.86	23.30
A. Enteric fermentation	-	-	-	-0.02	-0.04	-0.07
B. Manure management	-0.45	1.15	2.10	3.10	3.27	3.45
C. Rice cultivation	NO	NO	NO	NO	NO	NO
D. Agricultural soils	10.18	9.28	16.21	16.10	16.51	16.08
E. Prescribed burning of savannas	NO	NO	NO	NO	NO	NO
F. Field burning of agricultural residues	NO	NO	NO	NO	NO	NO
G. Liming	-	-	-	-	-	-0.01
H. Urea application	NO	NO	0.00	0.00	0.00	0.00
I. Other carbon-containing fertilizers	6.04	5.67	4.01	4.17	4.13	3.85
J. Other	NO	NO	NO	NO	NO	NO
4. Land use, land-use change and forestry (2)	-16.41	-4.60	1.40	1.49	27.67	22.86
A. Forest land	-	-	-	-	-	-
B. Cropland	-2.77	-0.61	0.21	0.23	0.23	0.23
C. Grassland	-10.00	-1.75	0.67	0.71	0.72	0.73
D. Wetlands	-0.30	-0.14	0.01	0.01	0.01	0.01
E. Settlements	-3.29	-2.09	0.51	0.54	0.54	0.55
F. Other land	-0.06	-0.01	0.00	0.00	0.00	0.00
G. Harvested wood products	-	-	-	-	26.16	21.33
H. Other	NO	NO	NO	NO	NO	NO
5. Waste	0.67	-0.05	0.34	0.51	0.76	0.78
A. Solid waste disposal	0.79	-0.04	0.10	-0.02	0.05	0.10
B. Biological treatment of solid waste	NA,NO,IE	-	-	-	-	-0.15
C. Incineration and open burning of waste	IE,NO	IE,NO	IE,NO	NO,IE	NO,IE	NO,IE
D. Waste water treatment and discharge	-0.13	-0.01	0.25	0.54	0.71	0.82
E. Other	NO	NO	NO	NO	NO	NO
6. Other (as specified in summary 1.A)	NO	NO	NO	NO	NO	NO
Memo items:						
International bunkers	8.92	20.91	27.71	32.62	36.80	37.82
Aviation	8.91	20.91	27.71	32.62	36.80	37.82
Navigation	0.00	0.00	0.00	0.00	0.00	0.00
Multilateral operations	NO	NO	NO	NO	NO	NO
CO₂ emissions from biomass	2.54	5.41	10.93	33.48	32.32	36.38
CO₂ captured						
Long-term storage of C in waste disposal sites						
Indirect N₂O						
Total CO₂ equivalent emissions without land use, land-use	-13.68	-10.92	7.36	32.21	31.28	18.07
Total CO₂ equivalent emissions with land use, land-use change	-30.09	-15.52	8.76	33.70	58.95	40.93
Total CO₂ equivalent emissions, including indirect CO₂	NA	NA	NA	NA	NA	NA
Total CO₂ equivalent emissions, including indirect CO₂, with	NA	NA	NA	NA	NA	NA

Table 10-7 presents the absolute and relative recalculation differences of national total GHG emissions (excl. LULUCF) for 1990-2018 (in Gg CO₂eq and in %). Table 10-8 shows the absolute recalculations by gas and by sector.

Table 10-7 - Recalculation differences of national total GHG emissions (without LULUCF).

year	total GHG emissions excl. LULUCF			
	submission 2020v1	submission 2021v1	recalculation difference	recalculation difference
	Gg CO ₂ eq	Gg CO ₂ eq	Gg CO ₂ eq	%
1990	12741.06	12727.38	-13.68	-0.11%
1991	13382.78	13371.04	-11.74	-0.09%
1992	13146.80	13134.73	-12.06	-0.09%
1993	13293.45	13286.22	-7.23	-0.05%
1994	12468.53	12458.12	-10.41	-0.08%
1995	10091.81	10084.08	-7.73	-0.08%
1996	10155.26	10148.60	-6.66	-0.07%
1997	9503.14	9495.63	-7.51	-0.08%
1998	8622.18	8614.78	-7.40	-0.09%
1999	9087.98	9079.66	-8.32	-0.09%
2000	9669.11	9658.18	-10.92	-0.11%
2001	10158.18	10151.68	-6.50	-0.06%
2002	10934.88	10928.76	-6.11	-0.06%
2003	11376.30	11366.29	-10.01	-0.09%
2004	12766.97	12745.15	-21.82	-0.17%
2005	13009.12	12971.26	-37.86	-0.29%
2006	12838.07	12797.36	-40.71	-0.32%
2007	12253.93	12212.64	-41.29	-0.34%
2008	12135.10	12106.74	-28.36	-0.23%
2009	11587.58	11580.40	-7.18	-0.06%
2010	12169.06	12176.42	7.36	0.06%
2011	12046.25	12052.77	6.52	0.05%
2012	11773.25	11807.44	34.19	0.29%
2013	11234.48	11270.40	35.91	0.32%
2014	10776.85	10807.26	30.40	0.28%
2015	10290.10	10324.43	34.33	0.33%
2016	10050.69	10082.90	32.21	0.32%
2017	10235.70	10266.98	31.28	0.30%
2018	10547.15	10565.23	18.07	0.17%

Table 10-8 - Recalculation differences of national emissions by gas (without LULUCF) and by sector.

recalculation difference (2021v1 vs. 2020v1)					recalculation difference (2021v1 vs. 2020v1)					
total GHG emissions excl. LULUCF (Gg CO ₂ eq)					Gg CO ₂ eq (sum of all GHGs)					
year	CO ₂	CH ₄	N ₂ O	F-gases	year	1 - Energy	2 - IPPU	3 - Agriculture	4 - LULUCF	5 - Waste
1990	-24.30	2.64	7.97	-	1990	0.41	-30.52	15.77	-16.41	0.67
1991	-22.65	3.03	7.88	-	1991	0.42	-29.13	16.17	-16.26	0.80
1992	-22.46	3.21	7.18	-	1992	0.42	-29.43	15.99	-16.10	0.96
1993	-18.06	3.37	7.46	-	1993	0.43	-24.44	15.75	-15.95	1.03
1994	-21.47	3.52	7.55	-	1994	0.43	-27.53	15.50	-15.80	1.20
1995	-18.59	2.85	8.01	-	1995	0.46	-24.53	15.88	-15.65	0.47
1996	-18.30	3.27	8.37	-	1996	0.47	-24.18	16.12	-15.50	0.94
1997	-19.14	3.62	8.02	-	1997	0.48	-24.96	15.75	-15.35	1.23
1998	-19.14	3.81	7.94	-	1998	0.68	-25.06	15.52	-15.20	1.45
1999	-20.14	4.14	7.67	3.53E-06	1999	0.74	-26.26	15.61	-15.05	1.60
2000	-21.65	2.77	7.95	4.96E-06	2000	0.76	-27.73	16.10	-4.60	-0.05
2001	-18.92	3.14	9.27	4.12E-06	2001	0.79	-24.16	16.11	-3.07	0.75
2002	-19.47	3.95	9.40	6.51E-06	2002	1.01	-24.97	16.28	-1.53	1.56
2003	-17.10	3.97	10.12	1.02E-05	2003	1.27	-21.91	16.05	0.00	1.57
2004	-15.40	3.01	10.56	8.38E-06	2004	4.22	-24.04	17.46	1.54	0.53
2005	-18.43	2.74	11.62	7.51E-06	2005	1.52	-23.58	17.61	3.07	0.39
2006	-16.53	2.78	12.34	-	2006	3.34	-23.34	18.29	4.61	0.30
2007	-16.62	3.16	13.44	8.63E-06	2007	3.12	-23.05	19.36	6.14	0.54
2008	-11.56	3.00	14.81	7.96E-06	2008	3.03	-17.87	20.57	2.21	0.52
2009	-9.48	2.77	15.53	7.29E-06	2009	4.60	-17.33	21.30	2.65	0.25
2010	-12.04	2.62	16.78	6.62E-06	2010	2.15	-17.46	22.32	1.40	0.34
2011	-12.17	2.28	16.41	1.99E-04	2011	6.41	-22.00	21.94	1.42	0.16
2012	14.80	2.44	16.95	5.28E-06	2012	5.01	6.57	21.75	1.43	0.87
2013	16.70	2.52	16.69	4.61E-06	2013	7.37	6.17	21.57	1.45	0.80
2014	10.83	2.71	17.09	-0.22	2014	7.58	0.02	22.37	1.46	0.44
2015	14.82	2.88	17.50	-0.87	2015	12.02	-1.10	23.01	1.48	0.40
2016	12.49	3.12	17.47	-0.88	2016	12.71	-4.37	23.35	1.49	0.51
2017	10.94	3.26	18.09	-1.01	2017	9.57	-2.91	23.86	27.67	0.76
2018	-0.08	3.29	17.81	-2.94	2018	-0.74	-5.27	23.30	22.86	0.78

Figure 10-1 - Recalculation differences of national emissions by gas (without LULUCF, 2021v1 vs. 2020v1).

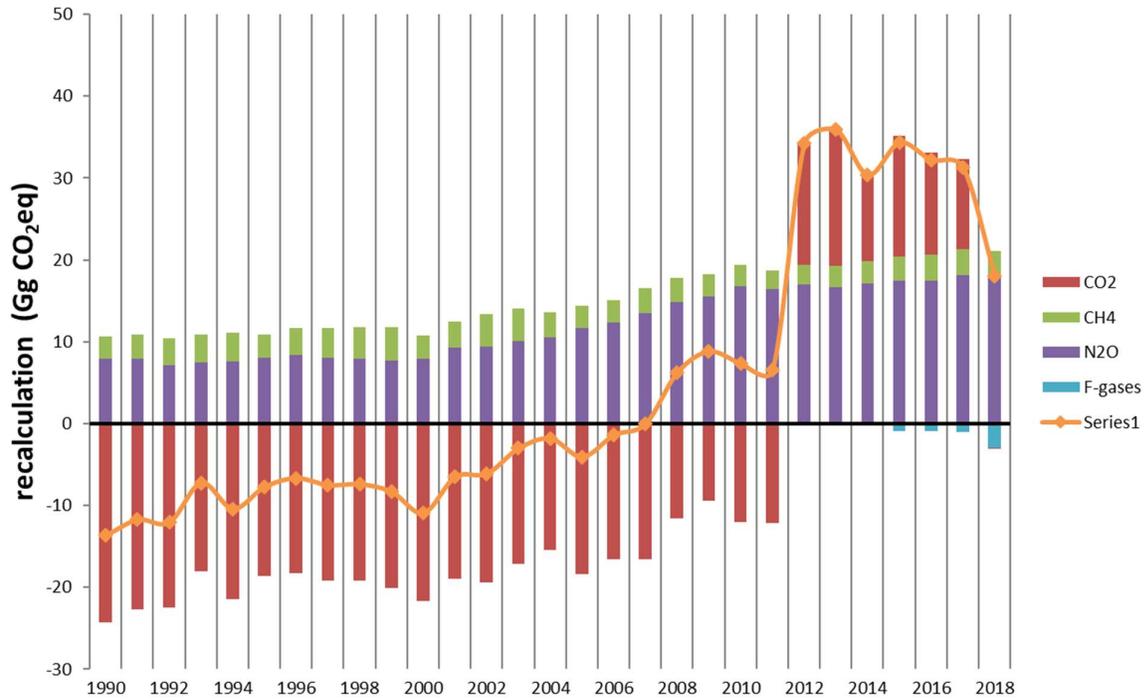
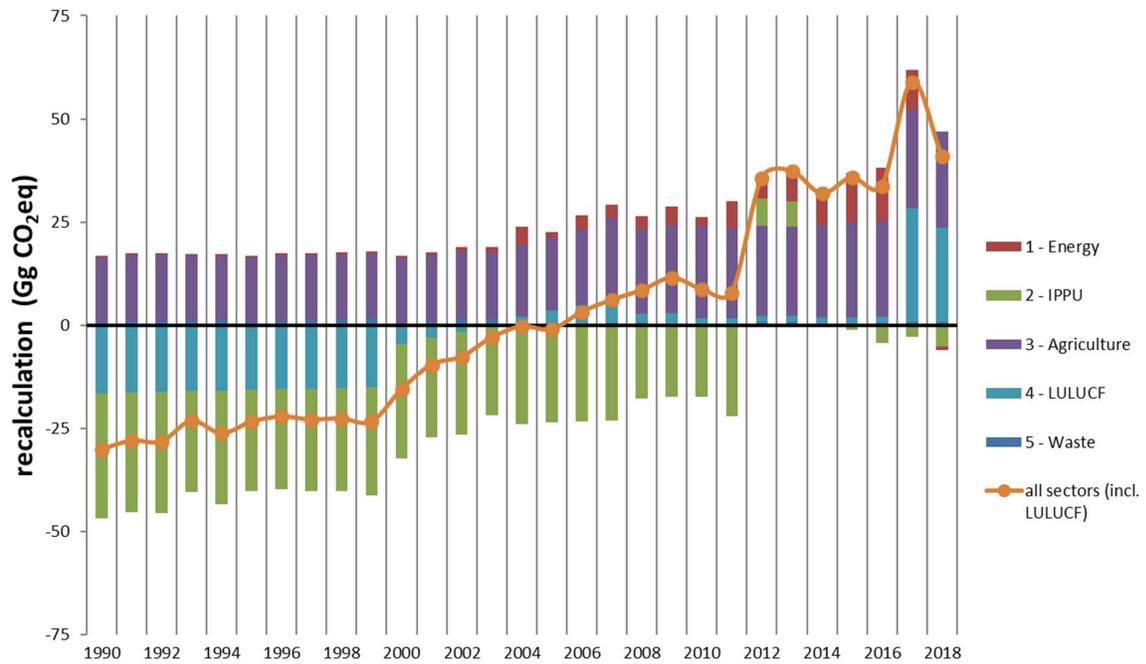


Figure 10-2 - Recalculation differences of national emissions by sector (2021v1 vs. 2020v1).



10.2.2 KP-LULUCF inventory

Recalculations are the same as for the LULUCF sector (section 6.11).

10.3 Implications for emission trends, including time series consistency, and also for the KP-LULUCF inventory

10.3.1 GHG inventory

The impact of the recalculations presented in the previous sections is presented in Table 10-9. The GHG emission trend from 1990-2018 of the national total (including LULUCF) has changed from -2508.44 Gg CO₂eq in submission 2020v1 to -2437.42 Gg CO₂eq in submission 2021v1.

Table 10-9: Emission trends 1990-2018 in submissions 2021v1 and 2020v1.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Submission 2021 v1			Submission 2020 v1		
	1990	2018	trend 1990-2018	1990	2018	trend 1990-2018
	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
1. Energy	10301.39	9111.46	-1189.93	10300.98	9112.19	-1188.79
A. Fuel combustion (sectoral approach)	10281.79	9080.31	-1201.48	10281.59	9081.22	-1200.38
1. Energy industries	35.84	232.68	196.85	35.64	223.60	187.96
2. Manufacturing industries and construction	6265.75	1162.44	-5103.31	6265.75	1164.30	-5101.45
3. Transport	2617.11	6027.05	3409.94	2617.10	6028.73	3411.63
4. Other sectors	1359.97	1658.02	298.05	1359.98	1664.47	304.49
5. Other	3.12	0.12	-3.01	3.12	0.12	-3.01
B. Fugitive emissions from fuels	19.60	31.15	11.55	19.39	30.98	11.59
1. Solid fuels	NO	NO	NO	NO	NO	NO
2. Oil and natural gas and other emissions from energy production	19.60	31.15	11.55	19.39	30.98	11.59
C. CO ₂ transport and storage	NO	NO	NO	NO	NO	NO
2. Industrial processes	1608.85	657.31	-951.54	1639.38	662.58	-976.79
A. Mineral industry	592.93	432.15	-160.78	623.45	434.32	-189.12
B. Chemical industry	NO	NO	NO	NO	NO	NO
C. Metal industry	984.91	114.39	-870.52	984.91	114.39	-870.52
D. Non-energy products from fuels and solvent use	20.54	31.43	10.89	20.54	31.59	11.05
E. Electronic industry	NO	NO	NO	NO	NO	NO
F. Product uses as ODS substitutes	0.00	60.14	60.14	0.00	63.08	63.08
G. Other product manufacture and use	10.47	19.20	8.73	10.47	19.20	8.73
H. Other	NO	NO	NO	NO	NO	NO
3. Agriculture	711.34	713.75	2.41	695.57	690.44	-5.13
A. Enteric fermentation	387.78	403.37	15.59	387.78	403.44	15.66
B. Manure management	78.47	90.65	12.18	78.91	87.20	8.29
C. Rice cultivation	NO	NO	NO	NO	NO	NO
D. Agricultural soils	238.80	204.91	-33.89	228.62	188.82	-39.79
E. Prescribed burning of savannas	NO	NO	NO	NO	NO	NO
F. Field burning of agricultural residues	NO	NO	NO	NO	NO	NO
G. Liming	0.26	10.97	10.71	0.26	10.98	10.72
H. Urea application	NO	0.00	NE	NE	NE	NE
I. Other carbon-containing fertilizers	6.04	3.85	NO	NO	NO	NO
J. Other	NO	NO	NO	NO	NO	NO
4. Land use, land-use change and forestry (2)	84.84	-190.42	-275.26	101.25	-213.28	-314.53
A. Forest land	-188.74	-259.27	-70.53	-188.74	-259.27	-70.53
B. Cropland	75.03	35.52	-39.51	77.80	35.28	-42.51
C. Grassland	22.52	-40.79	-63.32	32.52	-41.52	-74.04
D. Wetlands	15.90	4.17	-11.73	16.20	4.16	-12.04
E. Settlements	152.40	60.61	-91.79	155.69	60.06	-95.63
F. Other land	1.70	0.15	-1.55	1.76	0.15	-1.61
G. Harvested wood products	2.11	7.21	5.10	2.11	-14.12	NO
H. Other	NO	NO	NO	NO	NO	NO
5. Waste	105.80	82.71	-23.09	105.14	81.93	-23.20
A. Solid waste disposal	92.98	47.87	-45.10	92.18	47.77	-44.41
B. Biological treatment of solid waste	NA,NO,IE	27.17	NA	NA,NO,IE	27.32	NA
C. Incineration and open burning of waste	IE,NO	NO,IE	NO,IE	IE,NO	NO,IE	NO,IE
D. Waste water treatment and discharge	12.83	7.67	-5.16	12.95	6.84	-6.11
E. Other	NO	NO	NO	NO	NO	NO
6. Other (as specified in summary 1.A)	NO	NO	NO	NO	NO	NO
Memo items:						
International bunkers	398.45	1854.50	1456.05	389.54	1816.68	1427.14
Aviation	398.37	1854.35	1455.99	389.45	1816.53	1427.08
Navigation	0.09	0.15	0.06	0.09	0.14	0.06
Multilateral operations	NO	NO	NO	NO	NO	NO
CO₂ emissions from biomass	161.59	952.82	791.23	159.05	916.44	757.39
CO₂ captured	NO	NO	NO	NO	NO	NO
Long-term storage of C in waste disposal sites	NE	NE	NE	NE	NE	NE
Indirect N₂O	NE,NO	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE
Indirect CO₂ ⁽³⁾	NE,NO	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE
Total CO₂ equivalent emissions without land use, land-use change and	12727.38	10565.23	-2162.16	12741.06	10547.15	-2193.91
Total CO₂ equivalent emissions with land use, land-use change and forestry	12812.22	10374.80	-2437.42	12842.31	10333.88	-2508.44
Total CO₂ equivalent emissions, including indirect CO₂, without land use,	NA	NA	NA	NA	NA	NA
Total CO₂ equivalent emissions, including indirect CO₂, with land use, land-	NA	NA	NA	NA	NA	NA

10.3.3 KP-LULUCF inventory

No changes have occurred since submission 2020v1.

10.4 Recommendations, including in response to the review process, and planned improvements to the inventory, including for KP-LULUCF inventory

10.4.1 GHG inventory

Table 10-10 summarises the planned improvements.

Table 10-10– Planned improvements

GHG source & sink category	Planned improvements	Tentative timeframe
Solid fuels – reference approach	Investigate the significant difference for solid fuels between the reference approach and the sectoral approach, and adapt the methodology if necessary	2022
1A4a, 1A4b	collecting information helping to refine the fuel consumption split between the commercial/institutional sectors, on the one hand, and the residential sector, on the other hand.	2022
1B2a5	Assess whether these emissions occur and, if appropriate, estimate and report fugitive emissions from the infrastructure supporting the transport, distribution, storage and sale of refined fuel oils.	2022
2D2	Obtaining country specific data for the years 1990 to 1998, alternatively improvements to the estimations of the activity data and emissions concerning those years will be performed.	2022
2F2, 2F4	continue the quest for country-specific data	2022
3A	Investigation on country-specific data for GE and DE% are planned, and if data and manpower available, will both be improved in future submissions.	2022
3B	With additional data on manure management system collected during the 2020 agriculture census - additional changes will be made in future submissions, ones analysed.	2022
3D	An update of the manure management system using data collected in the 2020 agriculture census is planned for the following submissions. The data availability on energy crops in the earlier years is rather scarce, and used quantities are probably an underestimation. Alternative data sources will be investigated. Furthermore, in the next submission the EF for grazing will be update to the 2019 EMEP/EEA guidelines. As the area cultivated by Luxemburgish farmers, i.e. the area derived from the agriculture census, is - in particularly in recent years –overestimating the agriculture area in Luxemburg alternative data sources are currently investigated, and adaptations are planned for the submission 2022.	2022
3I	Looking for additional information/data source allowing to eventually confirm, respectively to revise, if not applicable, the assumption that 100% of CAN would be presented as CaCO ₃ .	2022
4A	Luxembourg plans to revise its OBS maps by 2020-2021	2022
4A	Luxembourg plans to carry out a new NFI by 2025	2025
5D1	IPCC is currently working on a Refinement. In the most recent draft Luxembourg's concerns on the 2006-GL are addressed. Rather than developing an own CS-methodology Luxembourg prefers to wait for the new refinement to be finalised and then align the methodology with the new guidelines.	

10.4.2 KP-LULUCF inventory

The same improvements as those presented in section 6.12 are planned (Table 10-11).

Table 10-11 – Planned improvements for the KP-LULUCF inventory

GHG source & sink category	Planned improvement
4A	Luxembourg plans to revise its OBS maps by 2020-2021
4A	Luxembourg plans conduct a new NFI by 2025

11 KP-LULUCF

11.1 General information

11.1.1 Definition of forest

The LU89, LU99, LU07 and LU12 land use maps are the main data providers for the greenhouse gas reporting of IPCC category forestland. The National Forest Inventory (NFI) of Luxembourg is the main data provider for the development of carbon stock factors. Consequently, and for reason of consistency, the applied forest definition for the reporting follows the definition used within the IFN and the LU maps. The selected parameters are:

Land Use Class	Definition
ForestLand	All forest and wooded land according to the FAO TBRA2000 definition: <ul style="list-style-type: none"> • Minimum land area: 0.05 ha • Minimum crown cover: 10 % • Minimum height: 5 m. In the geodata set, Forest land has been sub-divided into the forest types as defined below.
Conifers:	Including all forest land with > 10 % crown cover and on which more than 75 percent of the tree crown cover consists of coniferous species.
Deciduous:	Including all forest land with > 10 % crown cover and on which more than 75 percent of the tree crown cover consists of broadleaved species
Mixed (coniferous and deciduous):	with > 10 % crown cover and less than 75 % crown cover of one class.

Permanently unstocked basal areas, which are directly connected with forest in terms of space and forestry enterprise and contribute directly to its management (such as forestal hauling systems, wood storage places, forest glades, forest roads), also represent forests. Areas which are used in short rotation with a rotation period of up to thirty years as well as forest arboretums, forest seed orchards, Christmas tree plantations and plantations of woody plants for the purpose of obtaining fruits such as walnut or sweet chestnut do not account as forests but represent cropland. Rows of trees (except shelter belts for wind protection) and areas with woody plants in a park structure are not forest land.

Areas are assigned to the activities "afforestation" and "deforestation" if they have been afforested or deforested since 1.1.1990. Such areas remain in those assigned categories until the end of the commitment period. As a result, the areas of said categories increase constantly.

In general, reforestation requirements apply in Luxembourg, meaning that clear-cut forest areas and thinned forest stands have to be reforested or replenished and continue to fall into forest and do not represent AR events. Forest areas that have temporarily no forest cover as a result of natural disturbances, continue to fall within the definition of forest and must be reforested. No deforestation as a result of natural disturbances takes place in Luxembourg.

11.1.2 Elected activities under Article 3.4

As reported in the Initial Report, Luxembourg has decided, during the first commitment period, not to elect any of the activities under Article 3.4 of the Kyoto Protocol. According to Article 3 (4) of the Kyoto Protocol Luxembourg has to carry out accounting for its forestry activities (forest management) in the second commitment period. Due to a lack of reliable data Luxembourg is reporting emissions from harvested wood products as instantaneous oxidation. Furthermore Luxembourg has elected the option natural disturbances but not the provision for carbon equivalent forests.

Figure 11-1 – Activity coverage relating to activities under Art. 3.3 and 3.4 (CRF table NIR-1)

Activity	CHANGE IN CARBON POOL REPORTED ⁽¹⁾							GREENHOUSE GAS SOURCES REPORTED ⁽²⁾											
	Above-ground biomass	Below-ground biomass	Litter	Dead wood	Soil		HWP ⁽⁴⁾	Fertilization ⁽⁵⁾			Drained, rewetted and other soils ⁽⁶⁾		Nitrogen mineralization in mineral soils ⁽⁸⁾	Indirect N ₂ O emissions from managed soil ⁽⁵⁾	Biomass burning ⁽⁹⁾				
					Mineral	Organic ⁽³⁾		N ₂ O	CH ₄ ⁽⁷⁾	N ₂ O	N ₂ O	N ₂ O			CO ₂ ⁽¹⁰⁾	CH ₄	N ₂ O		
Article 3.3 activities																			
Afforestation and reforestation	R	R	R	R	R	NO	IO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Deforestation	R	R	R	R	R	NO	IO	NO	NO	NO	R	NO	NO	NO	NO	NO	NO	NO	NO
Article 3.4 activities																			
Forest management	R	R	R	R	R	NO	IO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Cropland management	NR	NR	NR	NR	NR	NO			NO		NA		NO	NO	NO	NO	NO	NO	NO
Grazing land management	NR	NR	NR	NR	NR	NO			NO		NA		NO	NO	NO	NO	NO	NO	NO
Revegetation	NR	NR	NR	NR	NR	NO			NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Wetland drainage and rewetting	NR	NR	NR	NR		NO		NO	NO	NO		NO	NO	NO	NO	NO	NO	NO	NO

11.1.3 Description of how the definitions of each activity under Article 3.3 have been implemented and applied consistently over time

11.1.3.1 Afforestation, reforestation and deforestation (ARD)

The area of forest land reported for Afforestation/Reforestation (AR) and Deforestation (D) under the Kyoto Protocol is based on the area reported for Land use changes from and to forests in the UNFCCC greenhouse gas inventory by taking the different time frame (ARD areas starting with 1.1.1990) as well as the permanence of ARD areas into account.

In other words, annual areas from Annual Cropland converted to Forestland, Perennial Cropland converted to Forestland, Grassland converted to Forestland, Wetlands converted to Forestland, Settlements converted to Forestland, Other land converted to Forestland are summed and considered as AR. And reciprocally, Forestland converted to Annual Cropland, Perennial Cropland, Grassland, Wetland, Settlements and Other land are considered as D.

Afforestation is defined as "the direct human-induced conversion of land that has not been forested for a period of at 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources." Reforestation differs from afforestation solely with regard to the time since the area was last forested and occurs on land that has not been forest since 31 December 1989. Since the reporting period for Luxembourg begins with base year 1990, and since adequate data for differentiation of land-use forms are available only for the period as of 1989, afforestation and reforestation are considered together in the present context (and hereafter are both referred to as afforestation).

Table 11-1 - Areas of LUC from and to forests and ARD areas since 1990

	Forest management	Art. 3.3 D areas since 1990	Art. 3.3 AR areas since 1990	4A1. Forest land remaining forest land followed for 20 years	LULUCF - LUC to Forest followed for 20 years
1990	92.62	-0.44	0.70	79.31	14.00
1991	92.18	-0.88	1.40	79.57	14.00
1992	91.73	-1.32	2.10	79.83	14.00
1993	91.29	-1.77	2.80	80.09	14.00
1994	90.85	-2.21	3.50	80.35	14.00
1995	90.41	-2.65	4.20	80.61	14.00
1996	89.97	-3.09	4.90	80.87	14.00
1997	89.53	-3.53	5.60	81.12	14.00
1998	89.08	-3.97	6.30	81.38	14.00
1999	88.64	-4.42	7.00	81.64	14.00
2000	88.52	-4.55	7.18	82.21	13.48
2001	88.39	-4.69	7.36	82.79	12.96
2002	88.26	-4.83	7.53	83.36	12.43
2003	88.13	-4.96	7.71	83.93	11.91
2004	88.01	-5.10	7.89	84.50	11.39
2005	87.88	-5.23	8.06	85.08	10.86
2006	87.75	-5.37	8.24	85.65	10.34
2007	87.62	-5.51	8.42	86.22	9.82
2008	87.58	-5.55	8.47	86.88	9.17
2009	87.54	-5.59	8.52	87.54	8.52
2010	87.50	-5.62	8.58	88.20	7.88
2011	87.47	-5.66	8.63	88.87	7.23
2012	87.43	-5.70	8.68	89.53	6.58
2013	87.39	-5.74	8.73	90.19	5.93
2014	87.35	-5.78	8.79	90.85	5.29
2015	87.31	-5.82	8.84	91.51	4.64
2016	87.27	-5.86	8.89	92.17	3.99
2017	87.23	-5.90	8.95	92.83	3.34
2018	87.19	-5.94	9.00	93.49	2.70
2019	87.15	-5.98	9.05	94.15	2.05

Table 11-1 provides an overview of the areas as they are followed under both methodologies. FM, AR and D are determined according to the activity based accounting as defined under KP. The categories forestland remaining forestland and LUC to forest are calculated under the land based accounting method as defined under the rules of UNFCCC.

11.1.3.2 Forest management (FM)

In Luxembourg, all forest areas that have been forest since 1990 are considered managed within the meaning of the Marrakesh Accords and are reported under forest management according to Art. 3.4 KP.

The areas considered under forest management in KP are different from the forest areas considered under the UNFCCC category “forest land remaining forest land”. Under KP land use changes to forest are reported under ARD and remain in that category. Under UNFCCC calculations land-use changes to forest land are, after a period of 20 years, reported under the category “forest land remaining forest land”. Under UNFCCC land use changes are also considered that occurred before 1990. Areas that have been converted to forest land between 1970 and 1990 are subsequently reported under forest management under KP but under LUC to forest land under UNFCCC for a transition period of 20 years. As a consequence the area of the category “forest land remaining forest land” under UNFCCC is higher than the area of the category forest management for the period 1990-2010 and smaller for the period after 2010. The area of forest management equals at each year the sum of forest land remaining forest land and LUC area to forest (total forest area) minus afforestation area since 1.1.1990.

Due to unreliable and incomplete data on harvested wood products in Luxembourg, the emissions contribution from harvested wood products in Luxembourg, are considered as instantaneous oxidation.

11.1.3.3 Cropland management (CM)

Luxembourg has not elected CM.

11.1.3.4 Grazing land management (GM)

Luxembourg has not elected GM.

11.1.3.5 Description of precedence conditions and/or hierarchy among Article 3.4 activities, how they have been consistently applied in determining how land was classified

Luxembourg has defined the hierarchy of activities relative to Art. 3.4 of the Kyoto Protocol according to the provisions of the IPCC KP Supplement (2014). The activity forest management is binding, and thus has priority over the voluntary activities cropland management and grazing land management. In the first commitment period, Luxembourg did not elect forest management voluntarily. The hierarchy makes it possible to carry out consistent reporting for the first and second commitment periods.

According to the provisions of the IPCC KP Supplements (2014), forest management (FM) can take place only on lands that meet the definition of forest. The forest areas reported under FM are the forest areas reported, likewise to the Convention, under forest land remaining forest land, plus the areas assigned to the categories of LUC to forest land (Convention) minus the areas of the category of af-/reforestation (Kyoto Protocol). The total forest area under the Convention and the total forest area under the Kyoto Protocol are the same. All Luxembourg forest lands are considered managed within the meaning of the provisions of the Marrakesh Accords.

11.2 Land-related information

The land related information for the years 1989 and 2007 to support the KP reporting in Luxembourg was generated in the framework of the ESA funded “GMES Service Element Forest Monitoring in Luxembourg” carried out by LuxSpaceS.à.r.l. Data related to the year 1999 could be included due to an accompanying measure financed by the “Ministry of sustainable Development and Infrastructures” and implemented by LuxSpace. In 2012, new data was acquired and processed by the same company and in the same way as for the previous land use maps to ensure time series consistency.

11.2.1 Spatial assessment unit used for determining the area of the units of land under Article 3.3

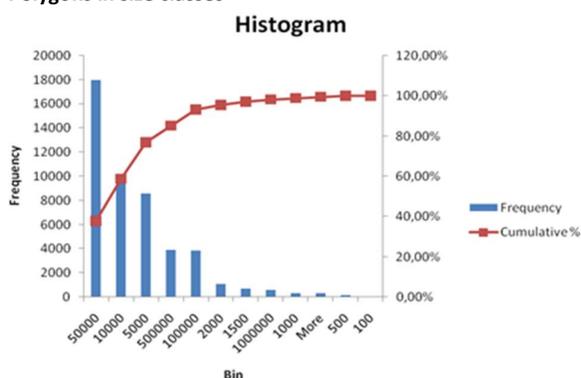
The base data used for this reporting is the so-called OBS map data “Occupation Biophysiques du Sol” that is a detailed land use/land cover map in digital format covering the entire territory of Luxembourg. Three versions of the OBS map data set exist. The first OBS data set, the OBS89, was collected in the field for several years and published in 1989 by the Environment Ministry (now called the “Ministry of sustainable Development and Infrastructures”). The second data set for the OBS99 was collected based on aerial Colour Infra Red Ortho-photos and some field surveying for validation and completion. The third set, and currently the most recent, is the OBS07, which is an update of the OBS99 using Very High Resolution satellite images (1m pixel size) of the US commercial Earth observation satellite IKONOS.

The Minimum Mapping Unit (MMU) of the OBS89 is unknown. Table 11-2 and Figure 11-2 provide information about the frequency distribution of polygon areas.

Table 11-2 -OBS89 data: Frequency of Polygons in size classes & cumulative percentages

Area (m ²) smaller than	Nr of Polygons	Cumulative %
100	73	0,15%
500	173	0,52%
1000	334	1,22%
1500	720	2,73%
2000	1063	4,96%
5000	8609	23,03%
10000	10005	44,02%
50000	18008	81,82%
100000	3846	89,89%
500000	3936	98,15%
1000000	575	99,35%
More	308	100,00%

Figure 11-2 - Histogram of OBS89 data: Frequency of Polygons in size classes

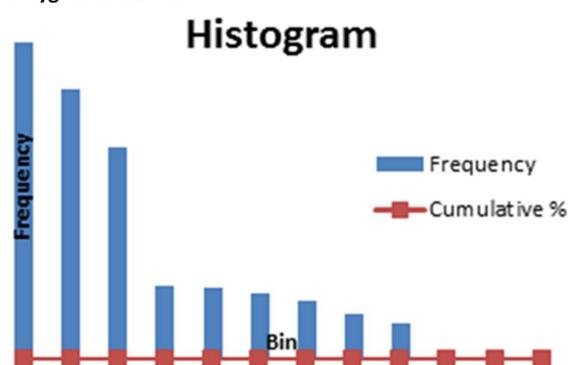


The OBS99 MMU is in principle 2 500 m² (0.25 ha) but adapted for important but small areas, i.e. wetlands and little lakes/ponds to 1 500 m² (0.15 ha). Linear structures and parts of it are mapped as areas if their width is larger than 20m, other parts (<20m) are taken from the BD-L-TC and presented as lines. Figure 11-3 and Table 11-3 provide information about the frequency distribution of polygon areas.

Table 11-3 - OBS99 data: Frequency of Polygons in size classes & cumulative percentages

Area (m ²) smaller than	Nr of Polygons	Cumulative %
100	116	0,10%
500	3609	3,18%
1000	7220	9,35%
1500	7522	15,78%
2000	6693	21,50%
5000	27358	44,88%
10000	21546	63,29%
50000	32140	90,76%
100000	5867	95,77%
500000	4653	99,75%
1000000	243	99,96%
More	48	100,00%

Figure 11-3 - Histogram of OBS99 data: Frequency of Polygons in size classes

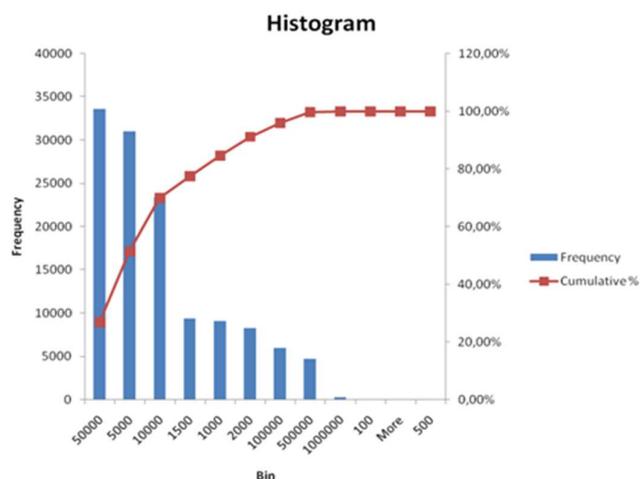


The OBS07 MMUs correspond to those of the OBS99 with changes from OBS99 to OBS07 mapped with a MMU of 500 m². Table 11-4 and Figure 11-4 provide information about the frequency distribution of polygon areas.

Table 11-4 - OBS07 data: Frequency of Polygons in size classes & cumulative percentages

Area (m ²) smaller than	Nr of Polygons	Cumulative %
100	56	0,04%
500	36	0,07%
1000	9049	7,27%
1500	9377	14,72%
2000	8256	21,29%
5000	31000	45,93%
10000	23388	64,52%
50000	33643	91,27%
100000	5993	96,04%
500000	4693	99,77%
1000000	247	99,96%
More	47	100,00%

Figure 11-4 - Histogram of OBS07 data: Frequency of Polygons in size classes



11.2.2 Methodology used to develop the land transition matrix

The generation of the LULUCF maps is based on the OBS and RE data. Data processing of OBS89, OBS99 and OBS07 follows the same processing scheme.

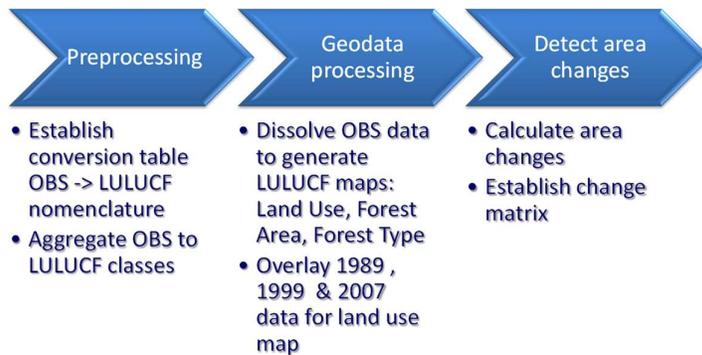
The original OBS categories for the years 1989, 1999 and 2007 were assigned to the relevant classes of the LULUCF nomenclatures. The correspondence of OBS89 respectively OBS99/07 classification to the LULUCF nomenclature has been established in close

collaboration with the relevant administrations and experts. The conversion tables from OBS89-99-07 to LULUCF are presented in the section above. For RE data, the areas were directly assigned to the corresponding land use classes of the LULUCF nomenclature

After aggregation of the class assignments according to the LULUCF nomenclature (for OBS data), the next step in geo data processing (using Geographic Information System software “ArcGIS”) is to dissolve the polygons to the respective classes, i.e. all neighbouring polygons belonging to the same LULUCF class were aggregated to one single polygon. This process results in land use maps, i.e. LU89, LU99, LU07 and LU12.

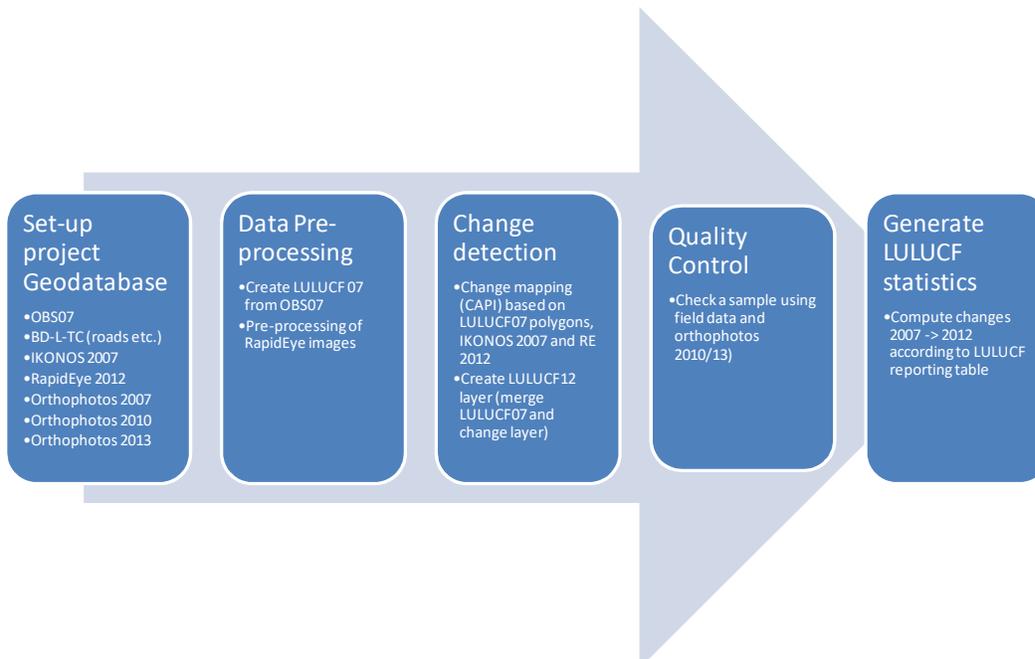
In order to preserve the detail in the data for the generation of the area statistics, no generalisation was performed before the change detection. Change detection of Land Use / Forest types between the selected reference years 1989, 1999 and 2007 has been carried out by overlay (intersect) of the Land Use maps LU89, LU99 and the LU07 data sets. Figure 11-5 shows the processing steps.

Figure 11-5 – Processing chain for the creation of the land transition matrix (LULUCF maps)



For the change detection between the reference years 2007 and 2012, the overlay (intersect) of land use maps LU07 and LU12 has been carried out using the following processing steps. (Figure 11-6)

Figure 11-6 – Processing chain for the creation of LU12 and change detection between LU07 and LU12



The resulting maps of the intersection show the differences in land use and the changes from which land use class to which other one. The total area as computed from the GIS data sets differs slightly from the official area of the Luxembourg territory. This is simply due to resolution /scale and data processing inaccuracies in the data sets. Therefore, the areas derived from the geodata have been put in relation to the official area of Luxembourg (258 600 ha). It means that all areas resulting from the geodata processing are proportional to the official territory of Luxembourg that is 2 586km². From this data the change statistics are derived and illustrated in the change matrix.

An exception to the use of the LU maps has been made for LUC areas between cropland and grassland. When using LU figures, the LUC areas between cropland and grassland are too high because the areas with more than one land use change within 20 years are taken into account as LUC areas, whereas according to IPCC-GPG they should stay in their main category. In Luxembourg, and especially in the northern part of Luxembourg (Oesling), a crop rotation including temporary grass is largely used by the farmers. In this crop rotation, the changes temporary grass to annual crops are recorded as LUC grassland to cropland and the changes annual crops to temporary grass as LUC grassland to cropland when using OBS. An alternative way to estimate the LUC between cropland and grassland was found, using administrative data of the Ministry of Agriculture coming from the administration of the “aid scheme for the maintenance of the landscape and the natural environment and for encouraging an agriculture respecting the environment” an agro-environmental aid scheme administered by the Service d’Economie Rurale, an administration of the Ministry of Agriculture. As within this aid scheme a land use change from permanent grassland to cropland is not allowed, except in special circumstances and after a special authorization and as this aid scheme is largely taken up by the farmers, it was possible to estimate the annual LUC grassland to cropland (269 ha). As the part of permanent grassland in the utilised agricultural area is relatively stable, the annual LUC cropland to grassland is estimated to be of the same amount (269 ha). The LUC areas grassland to cropland respectively cropland to grassland going beyond 269 ha according to OBS are allocated to the category “cropland remaining cropland”. For the years 2009-2018 detailed information on land use changes between cropland and grassland were extracted from the LPIS (see section 6.1.3.4).

11.2.3 Information on the size and geographical location of forest areas that have lost forest cover but which are not yet classified as deforested

With regards to clear cut areas (areas that lost forest cover but are not classified as “Deforested”), there are 2 distinct classes in the OB89 nomenclature:

- 32414 "végétation des coupes forestières",
- 32415 "recrus divers".

In addition to these polygons, so-called “new clear cut” areas were identified using Earth observation satellite data from the French SPOT1 satellite recorded in 1989.

With regard to clear cut areas (areas that lost forest cover but are not classified as “Deforested”), please refer to section 11.3.3 for more details

11.2.5 Method used to develop the land-transition matrix for GM an CM

Luxembourg has not elected CM and GM.

11.2.6 Maps and/or database to identify the geographical locations, and the system of identification codes for the geographical locations

The data sets used for the KP reporting is spatially explicit map data from the so-called OBS map "Occupation Biophysique du Sol" that is a detailed land use / land cover map in digital format covering the entire territory of Luxembourg.

Biophysical Land Cover Map 1989 at scale 1:10.000 - "Occupation Biophysique du Sol" OBS89

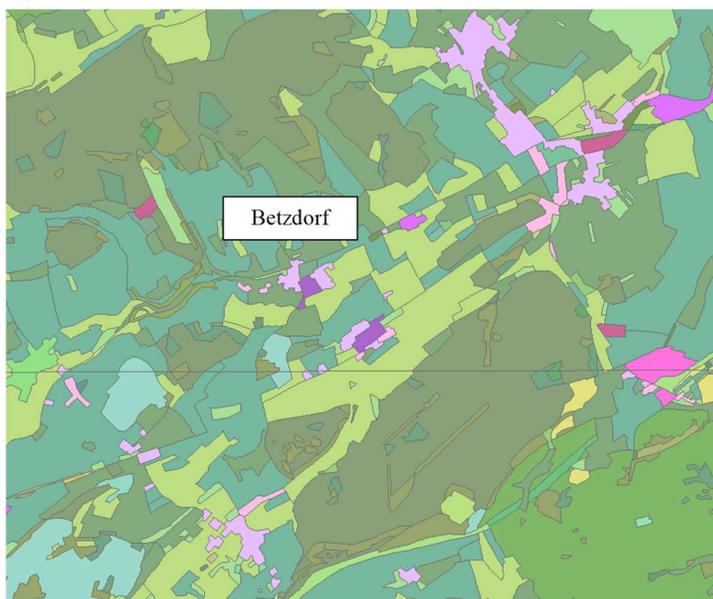
The first biophysical land cover map covering the entire Luxembourg territory consisted in a mapping and data collection in the field. Based on prepared aerial ortho photos showing delineated areas, experts from the "OekoFonds" and the association "Hellëf fir d'Natur" mapped/classified the areas during field work according to a 6-level nomenclature with 5 main classes:

Table 11-5 – OBS89 Nomenclature at level1 and number of classes in levels 2-6

Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Artificial areas	4	11	22	27	
Agricultural areas	3	4	9	10	3
Forest and semi-natural areas	3	9	27	37	
Wetlands	1	1	5	6	
Water surfaces	1	5	7	12	
Landscape elements	2	6	11		
Number of classes:	14	36	81	92	3

The OBS data has been provided by ANF as a shape file. The Minimum Mapping unit corresponds in principle to a scale 1:10.000, but in the data set there are about 250 polygons smaller than 500 m², 580 polygons smaller than 1000 m² of a total of 47650 polygons. There is no further detailed description or information on accuracy of the OBS89 available. In addition to this base, a SPOT satellite image mosaic of 1989 was used to identify new clear cut areas that are forest land without forest cover, which were not mapped in the OBS89 data but identified by photo-interpretation of the satellite imagery.

Figure 11-7 – Subset of the OBS89 with its 158 classes



The data has been used for LULUCF mapping for the year 1989.

Biophysical Land Cover Map 1999 – “Occupation Biophysique du Sol” OBS99

In 1999, the Ministry of sustainable Development and Infrastructure carried out an update of the OBS89 based on photo-interpretation of aerial Colour Infra-Red orthophotos covering the complete national territory in conjunction with the necessary field survey. The number of classes has been reduced to simplify the map and due to restrictions of the methodology (not all classes of OBS 89 could be photo interpreted). The aerial photographs were recorded in May (southern part of the country, optimal time for grassland and cropland before first cutting) and June 1999 (northern part, optimal time for forest areas during full developed vegetation period) at scale 1:15.000. The Minimum Mapping Unit is in principle 2500 m² (0.25 ha) but adapted for important but small areas, i.e. wetlands and little lakes/ponds to 1500 m² (0.15 ha). Linear structures and parts of it are mapped as areas if their width is larger than 20m, other parts (<20m), they are taken from the BD-L-TC and presented as lines.

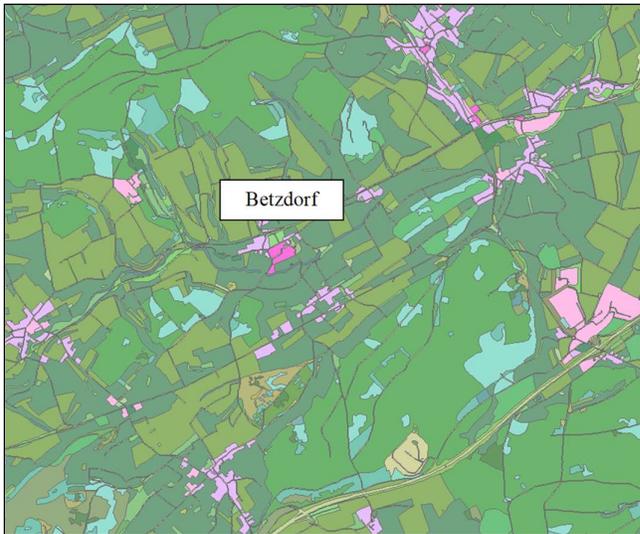
The map includes 4 landscape element categories (isolated tree, group of isolated trees, tree rows, hedges) and in total 77 land use/cover classes, divided in 5 broad categories (Table 11-6).

Table 11-6 – OBS99 Nomenclature at level1 and number of classes in levels 2-5

Built-up and artificial areas (32 classes)	Agricultural areas (8 classes)
Forests and semi-natural areas (26 classes)	Wetlands (3 classes)
Water areas (18 classes)	

Concerning the nomenclature, the document describing the content of the OBS99 classes and showing examples of aerial photos has been made available by the Nature and Forestry Agency (ANF).

Figure 11-8 – Subset of the OBS99 with its 76 classes

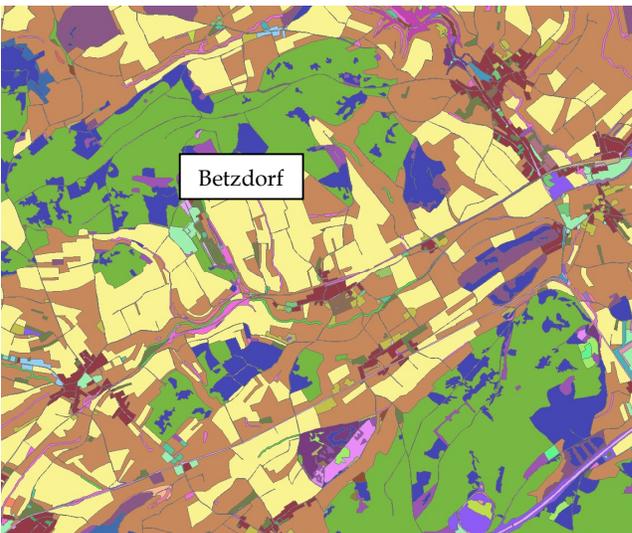


The data has been used for LULUCF mapping for the year 1999.

Biophysical Land Cover Map 2007 – “Occupation Biophysique du Sol” OBS07

In the framework of the ESA funded GSE-LUX-Land information service, this map has been generated by the service provider ESRI-BeLux. According to the accepted Integrated Approach for the “GSE extensions for Luxembourg”, the detailed Biophysical Land Cover Map (OBS) of Luxembourg from 1999 was updated using the Very High Resolution IKONOS satellite image data acquired in July/August 2007. The Minimum Mapping Unit (MMU) corresponds to those of the OBS99 with changes from OBS99 to OBS07 mapped with a MMU of 500m². According to the GSE Land quality assurance and control procedures, the data has been validated by a third party, i.e. Geoville (Luxembourg), and accepted by the users, i.e. the Regional Planning Department of the Luxembourg Ministry of the Interior.

Figure 11-9 – Subset of OBS07 with its 76 classes



RapidEye Satellite land use map LU12

The RapidEye (RE) space segment is composed of five sun-synchronous Earth observation satellites providing large area, multi-spectral images with frequent revisits in high resolution (5m).

	RapidEye characteristics
Launch date	28/08/2008, constellation of 5 satellites
Orbit	Sun synchronous, 11:00h desc. Node, 96,7 minutes period, 630 km altitude
Sensor bands	Multispectral 5 bands, 6.5*6.5m ² native sensor resolution, or resampled to 5m pixelsize 1: Blue 440-510nm 2: Green 520-590nm 3: Red 630-690nm 4: Red Edge 690-730nm 5: Near IR 760-880nm
Swath-width	77km
Revisit Frequency	Daily

In preparation for this project, multi-temporal RapidEye images have been acquired in March, April and in August 2012 covering the entire Luxembourg territory. Multi-temporal imagery analysis means that the interpretation is based on at least 2 images over the Area of Interest (AOI) at different points in time, best in accordance with the vegetation period and the harvesting time. This allows a better distinction between cropland (i.e. arable land that is ploughed: bare in spring and after harvest) and grassland (permanent grass vegetation).

The acreage of the Area of Interest, i.e. the entire territory of the Grand Duchy of Luxembourg, is about 2586 km². As the change detection is based on the LU07 (OBS07) data layer, it is of utmost importance that the relevant data layers do exactly overlay ("fit") onto each other. The RE images were geo-rectified and projected onto the Luxembourg cartographic projection.



Mosaicked RapidEye images acquired in spring 2012



Mosaicked RapidEye images acquired in August 2012

Activity-specific information

11.2.7 Methods for carbon stock changes and GHG emission and removal estimates

11.2.7.1 Description of the methodologies and the underlying assumptions used

The methodologies and assumptions used for the reporting under the Kyoto Protocol Art. 3.3. and Art. 3.4 are equivalent to those used to calculate the UNFCCC categories 4.A.1 Forest Land remaining Forest Land, 4.A.2 Land converted to Forest Land and Forest Land converted to other land (4.B.2.1 & 4.C.2.1 & 4.D.2.2.1 & 4.E.2.1 & 4.F.2.1). The methods to derive the activity data were described before in chapter 11.2.

Afforestation

Table 11-7 gives an overview of the parameters used for biomass and soil in AR areas. Above-growth and below-growth factors have been extracted from NFI (see Table 6-17 (in t d.m/ha*y) and default conversion factor of 0.47)). Carbon stock change factors in soil have been extracted from the soil map (Table 6-27).

Table 11-7 – C stock change factors in AR areas

Afforestation/Reforestation	C before LUC (tC/ha)	Biomass ag & bg growth		Soil	
		Age class: 0-20 years (t C/ha*y)	Age class: 20-40 years (tC/ha*y)	C stock change after 20 years of LUC (tC/ha)	annual C stock change (tC/ha*yr)
Annual Cropland converted to Forestland	5.00	3.12	4.66	35.68	1.78
Perennial Cropland converted to Forestland	6.41	3.12	4.66	24.74	1.24
Grassland converted to Forestland	6.35	3.12	4.66	9.51	0.48
Wetlands converted to Forestland	0.00	3.12	4.66	111.09	5.55
Settlements converted to Forestland	4.34	3.12	4.66	67.85	3.39
Other land converted to Forestland	0.00	3.12	4.66	111.09	5.55

Table 11-8 - Carbon-stock change as a result of afforestation

	Biomass growth (GgC)		DOM (GgC)		LUC from CL (GgC)		LUC from GL (GgC)		LUC from wetland (GgC)		LUC from settlements (GgC)		LUC from other (GgC)	
	above	below	litter	dead wood	Bio- mass	Soil	Bio- mass	Soil	Bio- mass	Soil	Bio- mass	Soil	Bio- mass	Soil
1990	1.82	0.37	0.67	0.13	-0.80	0.24	-2.10	0.16	0	0.10	-0.62	0.48	0	0.34
2013	26.30	5.27	5.70	1.76	-0.05	1.76	-0.26	1.46	0	0.70	-0.01	4.31	0	2.06
2014	27.34	5.47	5.08	1.60	-0.05	1.54	-0.26	1.32	0	0.60	-0.01	3.84	0	1.72
2015	28.38	5.67	4.45	1.42	-0.05	1.32	-0.26	1.19	0	0.50	-0.01	3.36	0	1.39
2016	29.41	5.87	3.83	1.25	-0.05	1.10	-0.26	1.05	0	0.40	-0.01	2.88	0	1.05
2017	30.45	6.08	3.21	1.06	-0.05	0.87	-0.26	0.91	0	0.29	-0.01	2.40	0	0.71
2018	31.49	6.28	2.59	0.87	-0.05	0.65	-0.26	0.77	0	0.19	-0.01	1.93	0	0.37
2019	32.52	6.48	1.97	0.67	-0.02	0.43	-0.26	0.64	0	0.09	-0.01	1.45	0	0.03

Deforestation

Table 11-9 gives similar information for D areas. In addition to losses of biomass in connection with conversion of forest land, losses in the areas of dead wood, litter and mineral soils are also considered. In the case of biomass, dead wood and litter, it is assumed that the pertinent losses take the form of emissions in the year of conversion. Emissions from mineral soils take place for a transition time of 20 years.

Table 11-9 – C stock change factors in D areas

Deforestation	C _{average} before LUC (tC/ha)	Biomass		Dead wood & litter		Soil	
		Growth (tC/ha*yr)	C stock change after 20 years of LUC (tC/ha)	annual C stock change (tC/ha*yr)			
Forestland converted to Annual Cropland	119.70	5.00	-35.68	-1.78			
Forestland converted to Perennial Cropland	119.70	0.21	-24.74	-1.24			
Forestland converted to Grassland	119.70	6.35	-9.51	-0.48			
Forestland converted to Wetlands	119.70	0.00	-111.09	-5.55			
Forestland converted to Settlements	119.70	1.29 / 0.15	-67.85	-3.39			
Forestland converted to Other land	119.70	1.29	-111.09	-5.55			

Remark: Transition period = 20 years

Note: Biomass growth values for Forestland converted to Settlements correspond to annual and perennial plants, respectively.

Table 11-10 - Carbon-stock change as a result of deforestation

	Biomass loss (GgC)		Loss of DOM (GgC)		LUC to CL (GgC)		LUC to GL (GgC)		LUC to wetland (GgC)		LUC to settlements (GgC)		LUC to other (GgC)		N ₂ O (Gg N ₂ O)
	above	below	litter	dead wood	Bio-mass	Soil	Bio-mass	Soil	Bio-mass	Soil	Bio-mass	Soil	Bio-mass	Soil	
1990	-40.2	-8.7	-8.5	-1.7	0.30	-0.12	1.71	-0.13	0.00	-0.04	0.13	-0.30	0.00	-0.01	-0.001
2013	-4.2	-0.9	-0.8	-0.2	0.06	-1.04	0.12	-1.02	0.00	-0.46	0.24	-3.77	0.00	-0.06	-0.010
2014	-4.2	-0.9	-0.8	-0.2	0.06	-0.92	0.12	-0.90	0.00	-0.42	0.24	-3.52	0.00	-0.05	-0.009
2015	-4.2	-0.9	-0.8	-0.2	0.06	-0.81	0.12	-0.78	0.00	-0.37	0.25	-3.27	0.00	-0.05	-0.008
2016	-4.2	-0.9	-0.8	-0.2	0.05	-0.70	0.12	-0.66	0.00	-0.33	0.25	-3.02	0.00	-0.04	-0.008
2017	-4.2	-0.9	-0.8	-0.2	0.05	-0.58	0.12	-0.54	0.00	-0.29	0.25	-2.76	0.00	-0.03	-0.007
2018	-4.2	-0.9	-0.8	-0.3	0.05	-0.47	0.12	-0.42	0.00	-0.25	0.25	-2.51	0.00	-0.02	-0.006
2019	-4.2	-0.9	-0.8	-0.3	0.04	-0.35	0.12	-0.30	0.00	-0.20	0.25	-2.26	0.00	-0.01	-0.005

In the columns, showing the carbon stock changes for each type of land-use change, the gain in biomass is shown depending on the type of land the forest is being changed into. The losses of biomass due to forest removal are summed up under the category for biomass loss.

Forest management

The definition of forest management according to KP comprises all forest minus the forest areas which have been afforested or reforested since 1.1.1990 (Luxembourg has not elected carbon equivalent forests). The calculation for biomass gain and loss as well as carbon gain and loss in soils according to GPG differentiate between mature forests (older than 20 years) and forest that have been newly planted. Carbon stock changes of forests that have been planted between 1970 and 1990 have to be calculated separately within the forest management category. Those areas have been highlighted in grey in Table 11-11. Areas included in the AR category remain in the AR category and do not transit to the FM category, not even after a period of 20 years.

For established forests it is assumed that the carbon content of litter does not change. It is assumed that litter levels (default value of 19,6 tC/ha) are reached after a transition period of 20 years. Dead wood levels are also assumed to be constant apart from the period between 2000 and 2010 where the national forest inventory highlighted an increase in dead wood following a change in harvesting practices.

In order to avoid double accounting the biomass loss due to deforestation has been subtracted from the harvest figures.

Table 11-11 - Carbon-stock change as a result of forest management

	forestland						LUC to forestland prev.1990 (GgC) ¹³⁸				
	Biomass gains (GgC)		Biomass loss (GgC)		DOM (GgC)		Biomass gains (GgC)				
	above	below	above	below	litter	dead wood	above	below	soil	litter	dead wood
1990	239.61	50.85	-236.80	-50.87	0.00	0.00	34.58	6.97	25.09	12.77	3.13
2013	222.24	47.73	-132.90	-28.20	0.00	0.00					
2014	221.22	47.56	-150.31	-31.77	0.00	0.00					
2015	220.21	47.38	-162.07	-34.21	0.00	0.00					
2016	219.20	47.21	-140.94	-29.75	0.00	0.00					
2017	218.19	47.03	-164.43	-35.08	0.00	0.00					
2018	217.18	46.86	-204.27	-43.84	0.00	0.00					
2019	216.16	46.69	-176.25	-37.93	0.00	0.00					

Harvested wood products

According to 2013 Revised Guidelines: “It is good practice to apply the Tier 1 method as outlined in this section (i.e. reporting no net-emissions from HWP) only in the case that transparent and verifiable activity data for the default categories sawnwood, wood-based panels and paper and paperboard as outlined in section 2.8.1.1 are not available.

As described under the submission for UNFCC (chapter 1.8) the data on Harvested wood products is not very reliable and hence the pool of harvested wood products is reported as instantaneous oxidation.

11.2.7.2 Justification when omitting any carbon pool or GHG emissions/removals from activities under Article 3.3

No carbon pool is omitted.

There is no practice of biomass burning at ARD areas in Luxembourg.

Furthermore, a proposed new forestry code in Luxembourg (Loi sur les forêts déposé le 28/2/2018) Art. 17. prohibits fertilisation in forests : *La fertilisation en forêt dans le but d’augmenter la croissance des arbres est interdite*. Previous to 2018 fertilisation was not common practice in Luxembourg (expert judgement (EJ_KP_01)). So, fertilisation at AR areas do not occur..

¹³⁸ Carbon gain due to Land converted to forestland before 1990 and not reported under afforestation.

11.2.7.3 Information on whether or not indirect and natural GHG emissions and removals have been factored out

Due to a lack of available methods in the IPCC GPG and elsewhere, indirect and natural GHG emissions/removals have not been factored out.

11.2.7.4 Changes in data and methods since the previous submission (recalculations)

The changes mentioned in 4A Forestland also effect KP estimates for Forest Management (FM):

No changes have occurred

11.2.7.5 Uncertainty analysis

The details of the underlying calculations and associated errors on emission factors and activity data can be found in section 6.8.

Figure 11-10 - Uncertainty analysis for FM

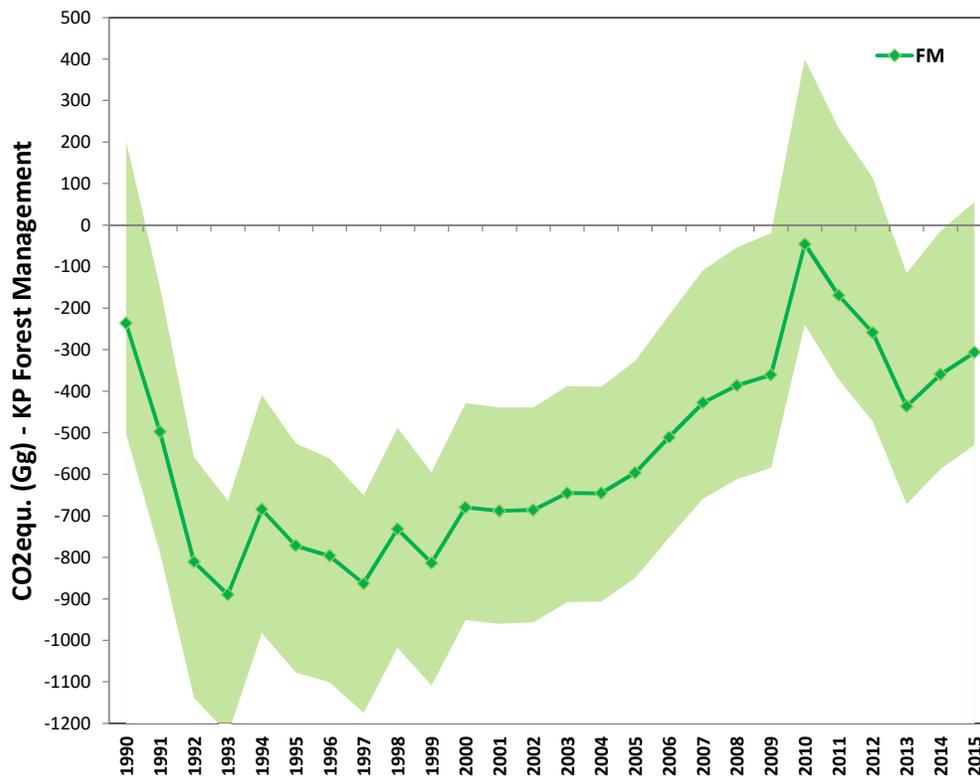


Figure 11-11 - Uncertainty analysis for D

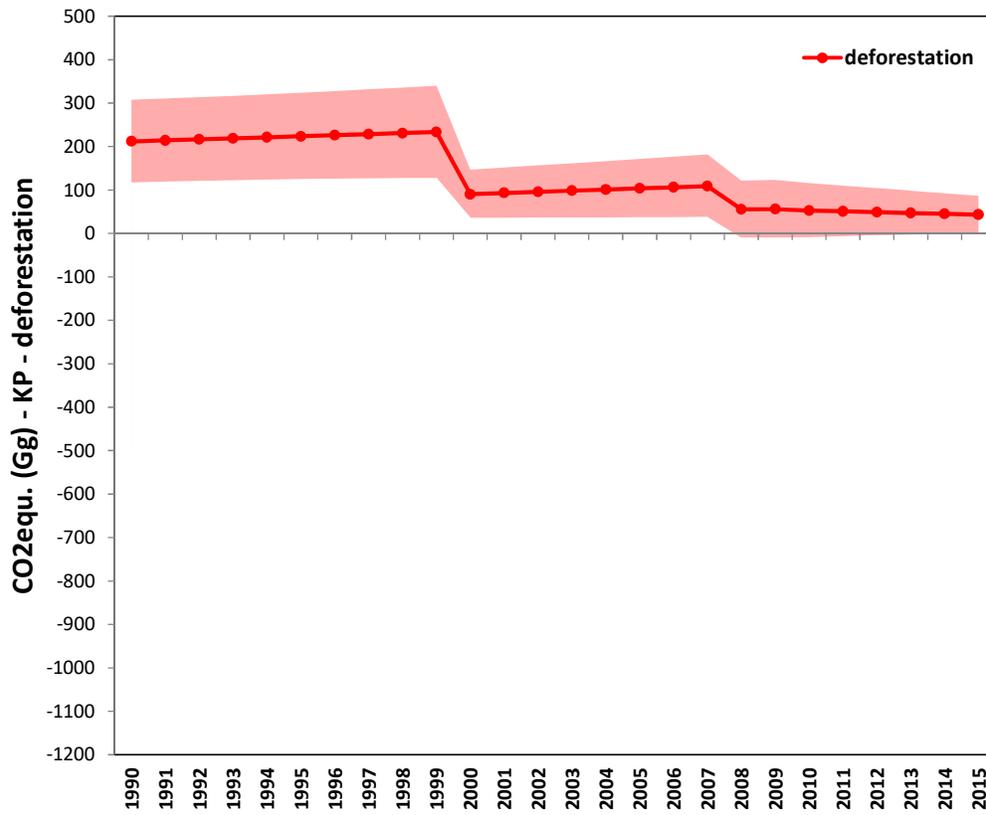
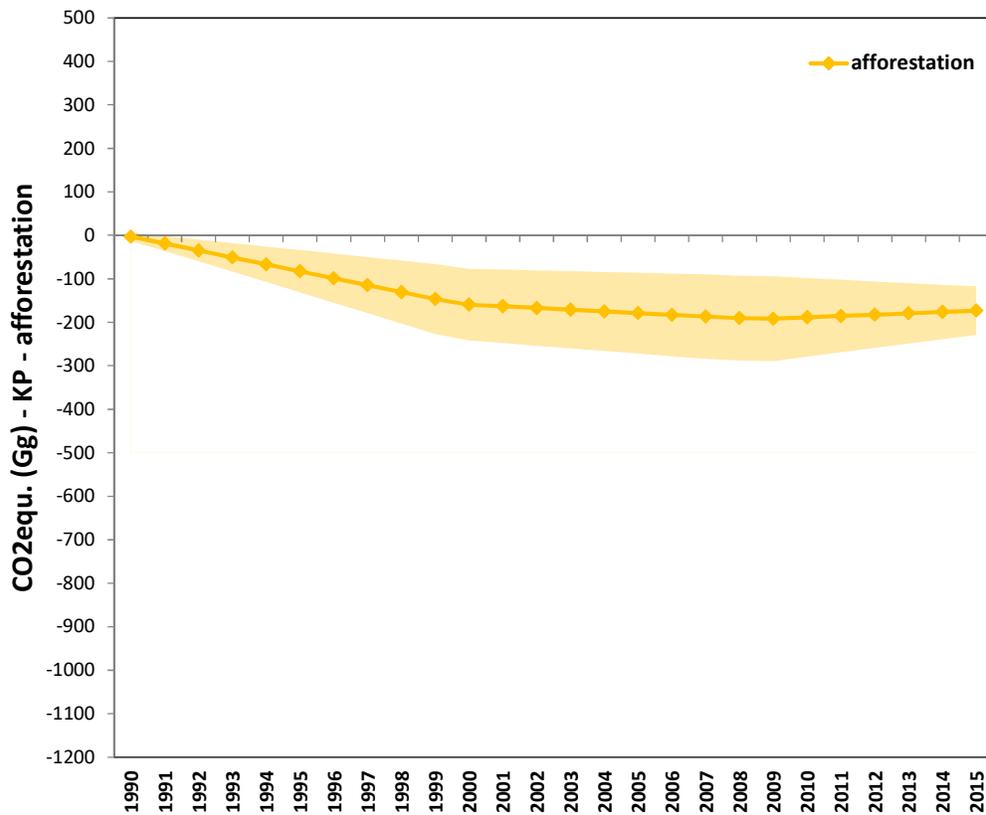


Figure 11-12 - Uncertainty analysis for AR



In the afforestation sector the absolute figures of uncertainty estimation are very low in the first years (starting in 1990). In this regard the afforestation sector is different from the two other sectors (FM, D). In the first years the afforestation sector is characterised with very low values of removals and the resulting carbon removals (and associated uncertainties) are hence very low. This is very different to the FM sector where overall balance of carbon emissions and removals can be close to zero with however a relative high uncertainty. In the latter case the high uncertainty can be attributed to the high uncertainty of the individual removals and emission.

11.2.7.6 Information on other methodological issues

The methods used to estimate emissions/removals from ARD activities are of the same tier method as those used for the UNFCCC reporting.

11.3 Article 3.3

11.3.1 Information that demonstrates that activities under Article 3.3 began on or after 1 January 1990 and before 31 December 2012 and are direct human-induced

The LU89, LU99, LU07 and LU12 land use maps are the main data providers for the greenhouse gas reporting of IPCC category forestland. The LU89, LU99, LU07 and LU12 maps represent the land use status in 1989, 1999, 2007 and 2012, respectively. Thus, the LU99 allows determining the differences in land use since the 1st of January 1990 and 1999, the LU07 between 1999 and 2007, and the LU12 between 2007 and 2012.

Luxembourg considers all LUC from and to forest land since 1990 as detected by the LU maps as “direct human induced” ARD lands. In addition, it might be noteworthy to mention that the total forestland area of Luxembourg is to be considered as “managed forest”, so that the definition of forest management, as defined in the Marrakesh Accords, is applicable: “a system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of forest in a sustainable manner”.

Information that demonstrates that activities under Article 3.3 are directly human-induced is derived from the National Nature Conservation Act ([Loi du 19 janvier 2004 concernant la protection de la nature et des ressources naturelles \(telle qu'elle a été modifiée\)](#)) downloadable in French). More specifically, chapter 4 of the act regulates the protection of fauna and flora, and in particular articles 13 and 17 state the following:

*"No change of use of forestland is permitted, except if the minister authorises it in the case of a general interest, or in view of an enhancement of agricultural structures. However, if such authorisation is given, compensating reforestation must be undertaken elsewhere (see note at the end of this section)."*¹³⁹

The total AR areas since 1990 are approximately as large as the D areas since 1990 which is the result of the Nature Conservation Act that leads to direct human induced “compensating reforestations” (AR in sense of Kyoto-Protocol) under this Act when deforestations are allowed.

139 Please note that the cited text is a translation/interpretation from French to English of some text passages of the legal text from art. 13 and art. 17. The relevant French legal text is cited in section 11.4.4)

However, the LU maps (1) have an excellent fit with the time period under consideration for the Kyoto Protocol, (2) assessed the land use in the total area in Luxembourg and (3) detected rather balanced ARD areas in the observed time period which is in line with the legal situation in Luxembourg that requests “compensation reforestations” after deforestations. Therefore, Luxembourg considers all LUC from and to forest lands as observed by the LU maps as “direct human induced” ARD lands.

Luxembourg is also a densely populated, intensively managed country in which all areas nation-wide are subject to land-use plans. Preparation of, and compliance with, plans is monitored by the relevant competent authorities and of individual municipalities. Thus it may be assumed that all afforested areas fulfil the “directly human-induced” requirement, since the act of permission, as well as the act of mandating in a legally binding manner and the preparation and establishment of regional and landscape plans all presuppose active decisions by humans.

Maintenance of agricultural land in good agricultural and environmental conditions

The European Council Regulation (EC) no 1782/2003 establishing common rules for direct support schemes under the common agricultural policy and establishing certain support schemes for farmers and amending regulations, cf. articles 3 and 5 of this regulation:

“Article 3 – Main requirements

- 1. A farmer receiving direct payments shall respect the statutory management requirements referred to in Annex III, according to the timetable fixed in that Annex, and the good agricultural and environmental condition established under Article 5.*
- 2. The competent national authority shall provide the farmer with the list of statutory management requirements and good agricultural and environmental condition to be respected.*

“Article 5 – Good agricultural and environmental condition

- 1. Member States shall ensure that all agricultural land, especially land which is no longer used for production purposes, is maintained in good agricultural and environmental condition. Member States shall define, at national or regional level, minimum requirements for good agricultural and environmental condition on the basis of the framework set up in Annex IV, taking into account the specific characteristics of the areas concerned, including soil and climatic condition, existing farming systems, land use, crop rotation, farming practices, and farm structures. This is without prejudice to the standards governing good agricultural practices as applied in context of Council Regulation (EC) No 1257/1999 and to agri-environment measures applied above the reference level of good agricultural practices.”*

This European legislation was enforced by a national regulation with the *Règlement grand-ducal modifié du 25 novembre 2011 portant application, au Grand-Duché de Luxembourg, du régime de paiement unique, de la conditionnalité et du système intégré de gestion et de contrôle dans le cadre de la politique agricole commune.*, cf. article 18 paragraph 2 and Annex II of this regulation :

« Art. 18. (1) Les dispositions à respecter dans le cadre de l'interdiction de réduction, de destruction ou de changement de biotopes prévue à l'article 17 de la loi modifiée du 19 janvier 2004 concernant la protection de la nature et des ressources naturelles sont fixées à l'annexe I.

(2) Les exigences minimales pour les bonnes conditions agricoles et environnementales sont fixées à l'annexe II. »

Nevertheless, Luxembourg will continue to validate and, if needed, improve its reporting of ARD lands on the basis of all available statistics, data and administrative documents.

11.3.2 Information on how harvesting or forest disturbance that is followed by the re-establishment of forest is distinguished from deforestation

Art 13 of the National Nature Conservation Act states *that 3 years after a clear cut on forestland, the owner is pledged to reinstate the forestland* (see section 11.3.4 for the original French text). This means that areas of forestland, where a clear-cut has occurred, has to be considered as forestland, as no other use of forestland after a clear-cut is permitted. In addition, after a period of three years, the owner is forced to take measures to restore forestland, if it hasn't occurred already. So no deforestation can occur by law, except if permitted by a ministerial act. If this is the case, this is documented by the Ministry.

The OBS, which is the basis of the land use and land use change assessment in Luxembourg, takes these provisions into account and assesses clear-cut forest areas as forest land. Indeed, for the generation of the OBS, a specific photo-interpretation manual providing instructions for the OBS mapping (based on aerial orthophotographs and field surveys) including real world pictures was used. This manual was compiled by Hansalufbild GmbH (Germany), the service provider who generated the OBS99 map (a pdf copy in German can be obtained upon request). In this mapping manual, two categories namely WSF (other forest areas (felled-area flora, wind throws), translated from German: *“sonstige Forstflächen (Schlagflur, Windbruch)”*) and WAU (forest plantings (plantings, thickets, natural regenerations), translated from German: *“Forstliche Pflanzung (Aufforstung, Dickungen, Naturverjüngung)”*) correspond to clear-cut areas. These areas are to be considered as forestland as they belong to the general category “forest”. Opposed to these, are areas where no trees could be detected during the subsequent mapping exercise (in this case the LU07 mapping), and where another land use could be identified (for example sealed surfaces). These areas were then obviously not counted to forest land but to their new land use category (for “sealed areas” this would be “settlements”). In other words, if for a given area, which was classified in “forest land” in LU99, and in the following LU07 has been classified to another land use, then this area is assigned to “deforestation”. If the same forest area, meaning an area with trees, was identified at a later stage as an area with no trees, and no other land use could be detected, then this area was identified as WAU respectively WSF and classified to “forest land”.

11.3.3 Information on the size and geographical location of forest areas that have lost forest cover but which are not yet classified as deforested

With regards to clear cut areas (areas that lost forest cover but are not classified as “Deforested”), there are 2 distinct classes in the OBS89 nomenclature:

- ... « 32414 végétation des coupes forestière » and
- « 32415 recrus divers ».

In addition to these polygons, so-called “new clear cut” areas were identified using Earth observation satellite data from the French SPOT1 satellite recorded in 1989.

With regards to clear cut areas (areas that lost forest cover but are not classified as “Deforested”), there is one distinct class in the OBS99/07 nomenclature, i.e. “3134 Autres surfaces forestières (coupes rases, chablis)”. The relevant areas were assigned to Forest Areas without trees, assuming crown coverage of <10% (code 331).

Table 11-12 – Areas having lost forest cover but not classified as deforested (1989, 1999, 2007, 2012)

OBS Class	LU class	Area in OBS89 (ha)	Area in OBS99 (ha)	Area in OBS07 (ha)	Area in LU12 (ha)
32414 Vegetation des coupes forestière	331 Forest Areas without trees	3912			
32415 Recrus divers	331 Forest Areas without trees	2699			
New Clear Cut areas (as identified from satellite images)	331 Forest Areas without trees	444			
3134 Autres surfaces forestières (coupes rases, chablis)	331 Forest Areas without trees		1441	1307	
	331 Forest Areas without trees				2380

11.3.4 Articles 13 and 17 of the National Nature Conservation Act

[Loi du 19 janvier 2004 concernant la protection de la nature et des ressources naturelles \(telle qu'elle a été modifiée\):](#)

« **Art. 13.** Tout changement d'affectation de fonds forestiers est interdit, à moins que le Ministre ne l'autorise, dans l'intérêt général ou en vue de l'amélioration des structures agricoles.

Le Ministre imposera des boisements compensatoires quantitativement et qualitativement au moins égaux aux forêts supprimées et cela sur le territoire de la commune ou de la commune limitrophe. Il peut substituer la création d'un autre biotope ou habitat approprié au sens de l'article 17 au boisement compensatoire.

Le Ministre peut déroger à l'alinéa qui précède dans l'intérêt de la conservation des habitats de l'annexe 1.

Après toute coupe rase le propriétaire ou le possesseur du fonds est tenu de prendre, dans un délai de 3 ans à compter du début des travaux d'abattage, les mesures nécessaires à la reconstitution de peuplements forestiers équivalant, du point de vue production et écologie, au peuplement exploité.]

Art. 17. Il est interdit de réduire, de détruire ou de changer les biotopes tels que mares, marécages, marais, sources, pelouses sèches, landes, tourbières, couvertures végétales constituées par des roseaux ou des joncs, haies, broussailles ou bosquets.

Sont également interdites la destruction ou la détérioration des habitats de l'annexe 1 et des habitats d'espèces des annexes 2 et 3.

Sont interdits pendant la période du 1er mars au 30 septembre:

a) la taille des haies vives et des broussailles à l'exception de la taille des haies servant à l'agrément des maisons d'habitation ou des parcs, ainsi que de celle rendue nécessaire par des travaux effectués dans les peuplements forestiers;

b) l'essartement à feu courant et l'incinération de la couverture végétale des prairies, friches ou bords de champs, de prés, de terrains forestiers, de chemins et de routes.

Le Ministre peut exceptionnellement déroger à ces interdictions pour des motifs d'intérêt général.

Le Ministre imposera des mesures compensatoires comprenant, si possible, des restitutions de biotopes et d'habitats quantitativement et qualitativement au moins équivalentes aux biotopes et habitats supprimés ou endommagés. »

11.3.5 Information on emissions and removals of greenhouse gases from lands harvested during the first commitment period following afforestation and reforestation on these units of land since 1990 consistent with the requirements under paragraph 4 of the annex to decision 16/CMP.1 (paragraph 8 (c) of the annex to 15/CMP.1)

The average age for these lands during the first commitment period is 10 years. No forest land in Luxembourg is clear-cut or even thinned by the age of 10 years. The first thinning is usually made after the age of 20 years depending on growth and the type of trees planted.

11.4 Article 3.4

11.4.1 Information that demonstrates that activities under Article 3.4 have occurred since 1 January 1990 and are human-induced

Forest management

Since an integrated procedure is used for surveying forest lands, land-use changes and the carbon-stock changes caused by relevant activities, the statements made in section 11.3.1 also apply for the activity "forest management".

Luxembourg is a small country and in general the pressure on land is very high. This means that the pressure on the use of wood out of forests is also very high. A more recent development has however seen the promotion of "forests without yield" (RFI- reserve forestière intégrale) in the sense that no harvest activity is taking place and the forests are left untouched in order to increase biological diversity. The total area of these forests is 1 250 ha (2014) which represents 1,1 % of the total forest area in Luxembourg. Those areas still fulfil the criteria for "forest management" as according to Decision 16/CMP.1, "Forest Management" is a *system of practices for stewardship and use of forestland aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner.*

11.4.2 Information relative to cropland management and grazing land management for the base year

Luxembourg has not elected CM and GM.

11.4.3 Forest management

The requirement that forests are to be managed sustainably, with a view to fulfilling ecological (including biological diversity), economic and social functions is anchored in the National Nature Conservation Act ([Loi du 19 janvier 2004 concernant la protection de la nature et des ressources naturelles \(telle qu'elle a été modifiée\)](#) downloadable in French). More specifically, chapter 4 of the act regulates the protection of fauna and flora.

In order to encourage a sustainable exploitation of forest, subsidies can be granted for certain types of forest management in private forests ([Règlement grand-ducal du 13 mars 2009 concernant les aides aux mesures forestières en agriculture et en forêt](#) downloadable in French)

The sustainable exploitation of public forests is safeguarded by the following legislative texts:

- Ordonnance du 13 août 1669 sur le fait des Eaux et Forêts (Extrait)
- Loi du 8 octobre 1920 concernant l'aménagement des bois administrés (telle qu'elle a été modifiée)
- Arrêté ministériel du 8 mai 1922 concernant le service d'aménagement des bois administrés (tel qu'il a été modifié)
- Instructions du 18 novembre 1952 concernant l'aménagement des forêts soumises au régime forestier
- Instructions du 11 mars 1987 modifiant et complétant celles du 18 novembre 1952 concernant l'aménagement des forêts soumises au régime forestier
- Circulaire ministérielle du 3 juin 1999 concernant les lignes directrices d'une sylviculture proche de la nature

A new forestry code is currently being developed which will update the current legislation and put an even stronger focus on sustainable forestry and protection of fauna and flora. This new code is expected to be published and put in legislation during the course of the year 2018.

11.4.3.1 Demonstration of methodological consistency between the FMRL and accounting for FM and technical corrections on the FMRL

Pursuant to resolution 2 / CMP.793, for the second commitment period of the Kyoto Protocol, anthropogenic greenhouse-gas emissions from sources and sinks that result from forest management under Article 3.4, are to be accounted against the Forest Management Reference Levels (FMRL). In each case, the FMRL contains a value that projects the average annual net emissions from forest management, in the second commitment period, from historic data and political decisions.

For Luxembourg, a FMRL of $-0.418 \text{ MtCO}_{2\text{eq}}$ per year was calculated, during the submission of information on forest management reference levels, by the European Union. Luxembourg did not submit a calculation of a FMRL as can be seen on the UNFCCC website <http://unfccc.int/bodies/awg-kp/items/5896.php> and as a consequence the FMRL calculated for the submission under the EU has been taken for Luxembourg.

The IPCC KP Supplements require a technical correction of the FMRL if methodological changes result in calculation of the time series, if new historical data become available or if pools are included in current reporting that have not been taken into account in the FMRL. Those conditions are fulfilled as the current FMRL does not use the methodological approach employed in Luxembourg and hence a technical correction of the FMRL was carried out.

11.4.3.2 Technical correction of the FMRL

11.4.3.2.1 Projections for the category Forest Management

The carbon storage and emissions in forests are governed by the balance of the yearly biomass growth of trees on the one hand and removals of harvested wood on the other hand. The yearly biomass growth in forests is based on the age and type of forest trees and is hence predictable and well documented in the NFI. The harvest rate or wood removal is however less predictable as it is based on a range of factors such as:

- Forest age structure
- Species composition
- Harvest policy
- Location of forest (accessibility of the forest – hillside location)
- Amount of natural unmanaged forest
- Wood price and demand
- Natural disturbances
- Financial incentives

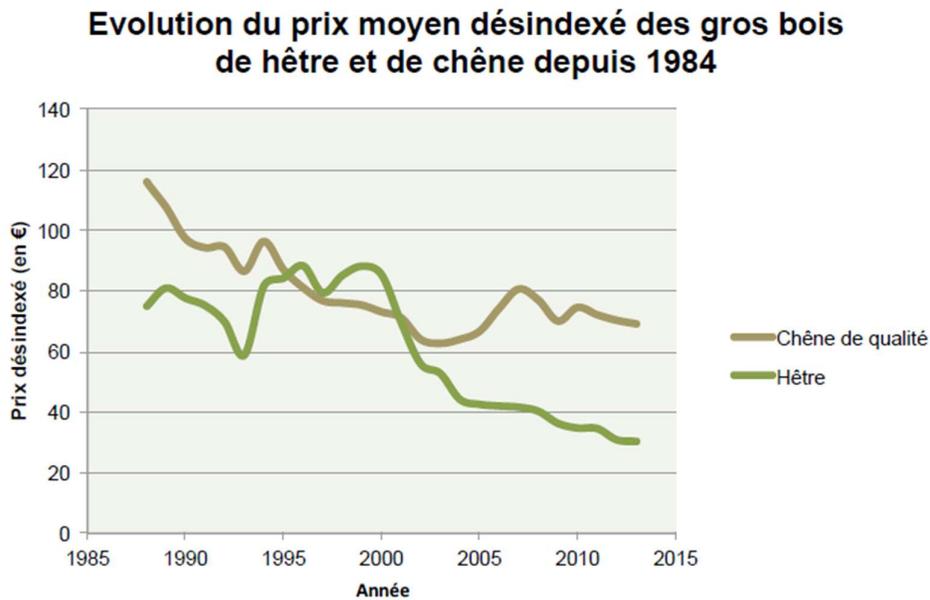
Age structure, species composition and past management practices are all known factors that change slowly and can be used for simple predictions of wood harvest. Future wood demand and management are driven by policies and market demand which are unknown and may change rapidly. Those latter factors increase the uncertainty of the prediction models.

In order to make projections a number of hypotheses have to be made with regards to those individual parameters.

The forest age structure is a good indicator for the amount of wood reserves available for harvest as it forecasts when the wood is ready to harvest. This is often referred to as unavoidable harvest and is the main rationale behind using a Forest Management Reference Level. As will be highlighted in this report, the mere availability of wood, that is ready to be harvested, does however not necessarily mean that the harvest will take place. Trees can remain in the forest for a much longer time after their optimal harvest age and can thus act as available wood reserve for years to come. With regards to forests under private ownership, harvest rates of mature forest are mainly driven by wood price and legislation. Harvest rates in forests under public ownership are also driven by wood prices but are mainly driven by harvest policy, which increasingly take into account environmental concerns.

11.4.3.2.2 Wood Price

Figure 11-13 - Price evolution for beech (green) and oak (brown) wood (in Belgium)



Source: Fédération Nationale des experts forestiers, 2017)

As the wood market in Luxembourg is highly entangled with the Belgium market, prices in Belgium are a good indication for prices in Luxembourg. The figure here above shows the price evolution of oak and beech in real terms (without indexation). Both price categories have seen a sharp decline over the last two decades and are still below their levels of 1990. The financial crisis seems to have exasperated this trend. Considering that prices have been low for a long time it is possible to imagine that a lot of forest owners have been deferring harvest in the hope that prices would recover. A slight recovery in wood prices might prompt those land owners to increase harvest.

11.4.3.2.3 Wood demand for energy use (heating purposes)

Due to the renewable energy policy pursued by Luxembourg wood demand for energy use is likely to increase over the next years.

With regards to new residential buildings the legislation favours the use renewable energies by taking into account the type of heating source in the calculation of the energy performance certificate. Furthermore the subsidies on pellets wood boilers are very interesting and are available for existing buildings as well as new buildings.

Figure 11-14 - Cumulated number of small scale residential central wood burners (based on subsidy application)

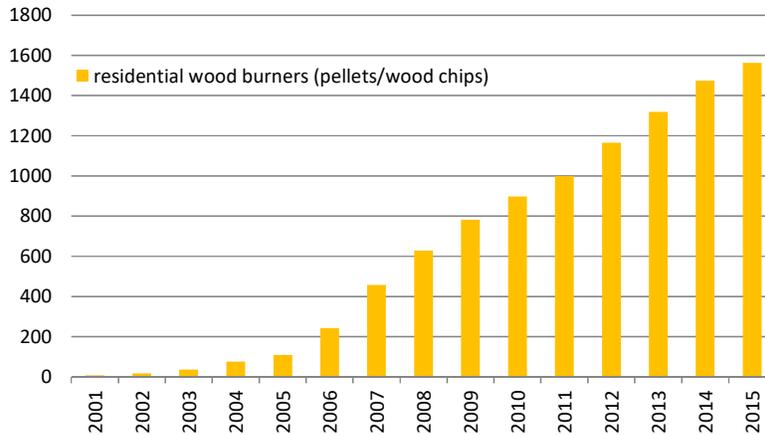


Figure 11-14 gives an overview of the evolution of the number of subsidies payed for central wood (pellets of wood chips) burners used in residential buildings. This statistic does not include wood stoves but only central burners which act as sole heating system. The figure shows a steady increase of those heating systems in the last years. The total number of 1 242 represents however only a fraction of the total building stock in Luxembourg. It is also important to highlight that, unlike PV-panels, building owners will only consider purchasing heating systems, based on pellets, when their existing heating system becomes redundant. With a typical life expectancy of 20-30 years for heating systems, subsidies for renewable energies will only be taken on gradually and hence the upward trend seen in this chart is likely to increase.

Figure 11-15 - Cumulated number of large scale (>50 kW) communal wood burners and corresponding wood consumption

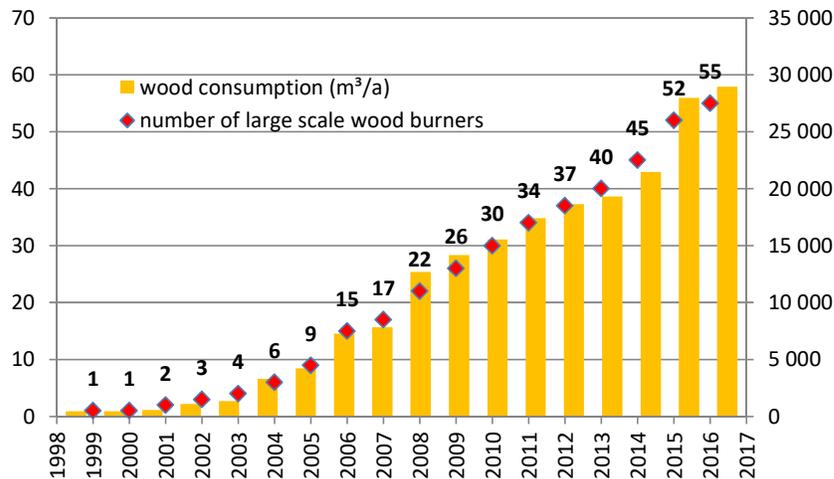


Figure 11-15 shows the evolution of the number and the consumption of large scale wood chips burners (large scale privately owned pellets burners are not included) operating in Luxembourg. Between 2010 and 2015 the installed power of those heating systems has tripled and hence the quantity of wood consumed for energy purposes has increased from an initial value of less than 5 000 m³ in 2005 to almost 30 000 m³ in 2014. The wood consumption does not include the consumption of recently installed burners as no data is yet available and hence the real consumption is most likely higher. The use of locally sourced renewable energies (on the territory of the individual communes) is a very attractive option for communes which like to improve their environmental credentials. This is particularly important as a lot of forests are under communal ownership. Nevertheless the total number of wood burners installed is high (55) compared to the total number of communes (105) and a certain slowdown in the number of such systems installed can be expected.

A study on potential use of renewable energy, (Biermayr, et al., 2007), conducted in 2007 and revised in 2015 (Schön & Reitze, 2015) predicts the quantity of wood used for energy purposes could potentially increase to 185 000 m³ by 2020. This figure also includes wood used for heating purposes in small wood stoves (+/- 15%) which does however seem slightly inflated.

Overall the analysis of these figures show that the demand of wood for energy purposes is expected to remain high and even increase over the years to come.

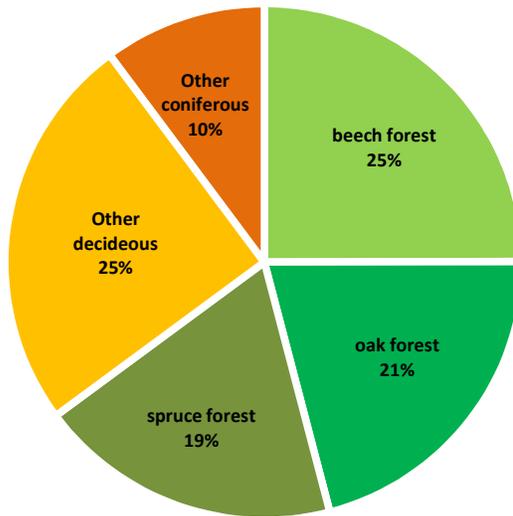
11.4.3.2.4 Projected harvest rate

In Luxembourg all forest, under public ownership, have to submit, once every 10 year, a report providing a detailed forest description (species composition, age structure, forest management) as well as the projected harvest rates for the next 10 years. Data projections for harvest rates in the public forests are hence available for approximatively the next 5 years. The calculation method, used to estimate the harvest rate, is prescribed and will, for this reason, be used for the purpose of calculating a FMRL. Forests under private ownership are not required to submit those forest management plans. In deciduous forests, harvest rates in private forests (3.3 m³/ha/a) are lower compared to public forests (4,8 m³/ha/a) but are essentially the same in coniferous forests (8,7 m³/ha/a). The reasons for the reduced harvest rate in private deciduous forest are not known but can most likely be attributed to the depressed wood prices. The calculation method will nevertheless be applied to the total forest in Luxembourg and a correction factor (= 3.3/4.8) will be applied to the proportion of private deciduous forests.

In the following analysis the method proscribed by the ANF to establish these reports will be used to estimate harvest rates. It is hence assumed that management practices are not likely to change during the next decade. The method used and recommended by the forest agency is based on (Dubourdieu, 1997).

11.4.3.2.4.1 Species composition of forests in Luxembourg

Figure 11-16 - Forest tree species composition



Individual tree species have different rotation periods, different forest management practices and different maturity ages. Figure 11-16 represents the forest composition according to the different species. Beech (*Fagus sylvatica* L.) is the most important broadleaf tree species in Luxembourg and represents 25 % of the different forest types and is also commonly found in deciduous mixed forest (category other deciduous). Oak forests are also strongly represented but a distinction has to be made between oak forests and coppice oak forests (which lower harvest rates) that can be found in the North of the country. With regards to coniferous forests in Luxembourg Norway spruce (*Picea abies*) is the most commonly found tree.

11.4.3.2.4.2 Calculation method

Harvest rates are typically determined by the age and the diameter of individual trees. The maturity age is the age of optimal harvest and depends on the type of trees and the intended use of wood. Trees planted for the purpose of energy use have a lower maturity age than trees planted for the use of construction timber. Apart from the coppice oak forests in the north of Luxembourg the majority of forest in Luxembourg have been planted in order to produce high quality wood and have thus quite high maturity ages. Wood can however be extracted from forest throughout their lifetime as regularly thinning is necessary in order to produce high quality wood. The wood harvested during thinning exercised is not only used for heating purposes but also in the wood industry (paper, heating, oriented strand board (OSB),...).

Once a forest has reached its maturity age the total wood stock could be harvested at once (clearfelling) and a new forest could be planted. In terms of forest management there is a clear shift away from clear-cut system to the selective felling of timber. Also, current legislation does not allow clearfelling in deciduous forests and only allows clearfelling in coniferous forest that are older than 50 years. In public forests deciduous forests that have reached their maturity age are generally fell over a period of 30 years and coniferous forest over a period of 10 years.

In order to sustainably exploit forest it is preferable to have an evenly distributed tree age structure. This will lead to a constant year on year harvest rate and will make the forest less vulnerable to natural disasters like windfall. In order to achieve an evenly distributed age structure the yearly forest area to be exploited is generally limited to the total forest area divided by the maturity age. This practice will lead to some parts of the forest to exceed the maturity age. There is a concern that ageing forest might be more prone to diseases and that productivity lessens. On the other hand, forest that have passed their optimum harvest rate, often still have a very high ecological value in terms of the divers fauna and flora that inhabits old and dying tree stems. The current forest management practice being practiced in Luxembourg accepts the perceived drawbacks of ageing forests and favours a sustainable management of the forests.

In order to estimate the harvest rate the method described by (Dubourdieu, 1997) and applied for the establishment of public forest management plans is used. First the maximum surface area to harvest in order to balance out the age structure is determined by the following formula:

$$S_e = s/A$$

where :

S_e = surface to balance (“surface d’équilibre”)

s = total forest surface area of a given tree species

A = maturity age

The first formula determines the harvest rates for forests that have reached their maturity age and are completely harvested over a period of 10 years (in general coniferous forests). These forests area are referred to as strict regeneration.

$$P_{strict} = V_{strict}/d + Z * b$$

where :

P_{strict} = annual harvest potential (“possibilité annuelle pour régénération stricte”)

V_{strict} = total wood stock volume

d = considered period (10 years)

Z = coefficient depending on whether the regeneration effort is fast or slow. Z equals 0,5 when the regeneration effort is fast which is generally the case in the strict regeneration group

b = growth rate in regeneration group

Deciduous forest, having reached their maturity age, are generally harvested over a period of 30 years and are then referred to as extended regeneration group. The harvest potential over a 10 year period for an extended regeneration group is calculated as follows:

$$P_{\text{elargi}} = \frac{V_s}{d} + Z * s * b_o + K * \frac{V'}{d} + (S - s) * b'o$$

where :

P_{elargi} = annual harvest potential on regeneration group

d = considered period (10 years)

S = total surface area of considered group

s = surface to be regenerated over the considered period of time (considering that the total surface is supposed to be regenerated over a period of 30 years $s = S/3$)

V = total wood stock on surface S

V_s = total wood stock volume on surface s ($V_s = V/3$)

V' = surplus on wood stock on the remaining surface area $S-s$

b_o and $b'o$ = annual growth rate on surface area s and $S-s$

Z = coefficient depending on whether the regeneration effort is fast or slow. Z equals 0,5 when the regeneration effort is fast which is generally the case in the strict regeneration group

$K = 0,2$ in order to consider that 20% of wood is harvested in order to prepare for regeneration

The remaining forests that have not reached their maturity age are thinned on a regular base (typically after the age of 40 years for deciduous forests and 20 years of coniferous forests) and hence a harvest rate can be calculated. Those forests are referred to as an improvement group (“quartier d’amélioration”) and the harvest rate are dependent on the age structure and species and have been extracted from harvest tables.

Table 11-13 - Rotation age by tree species

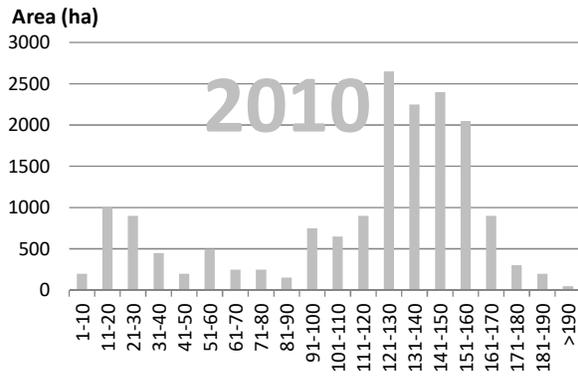
	Rotation age (years)
Beech (<i>Fagus sylvatica</i> L.)	160
Oak	200
Norway spruce (<i>Picea abies</i> (L.)	70
Other deciduous	80
Other coniferous	80

The maturity ages are prescribed for public forests (Code de l’environnement 2011 – Vol 3 - Instructions du 18 novembre 1952 concernant l’aménagement des forêts soumises au régime forestier.). Oak: 140-200 years, beech: 140-160 years, other deciduous: 80 years, pine: 80-120 years, spruce: 70-100 years and fir: 100-140 years.

11.4.3.2.4.3 Beech forests

Beech (*Fagus sylvatica* L.) is the most important broadleaf tree species in Luxembourg and is a major contributor to present and future harvest rates.

Figure 11-17- Age structure for beech forests



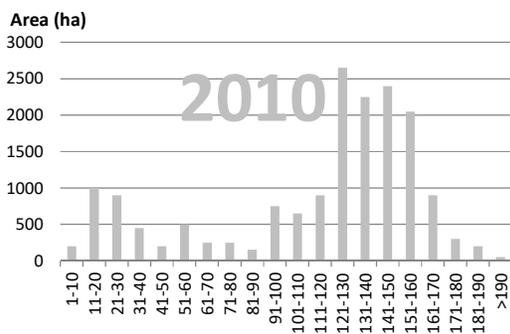
Analysing the age structure in Figure 11-17 of beech forests in Luxembourg it becomes apparent that the proportion of mature forests (120–180 years) is very high and the proportion of middle aged forests (41–80 years) is very low. Considering the uneven age structure in beech forest it would be necessary to limit harvest rates in order to guarantee a healthy harvest in the future.

One problem with ageing beech trees is that older trees, of larger dimensions, are capable of forming coloured heartwood, which is usually developed as red heart. The occurrence of larger red hearts reduces the value of beechwood considerably as red heartwood is poorly suitable to serial production due to instability in colour and appearance structure. This means that there is a strong incentive to harvest beech wood at its maturity rate. Figure 11-18 compares the evolution of the age structure for the two possible harvest scenarios:

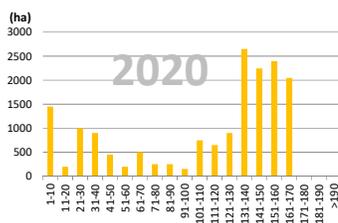
- Harvest rate a tree maturity where beech trees are harvested as soon as the age of 160 years is reached
- Harvest rate limited to S_e in order to balance out age structure

Projections have been extended to 2080 in order to highlight the evolution of age structure.

Figure 11-18 - Possible harvest management scenarios for beech forests



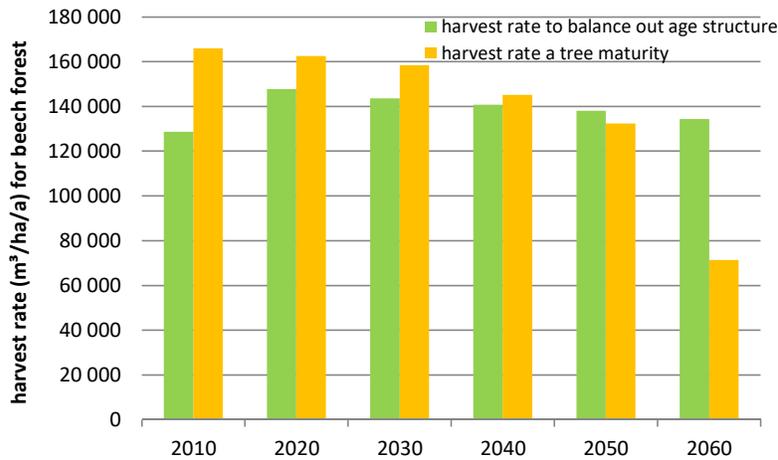
Harvest at tree maturity (160 years)



Harvest in order to even out age class structure



Figure 11-19 - Potential harvest rate for beech forests



The two scenarios illustrate well the difference between a maximum short term harvest at tree maturity and a sustainable harvest aimed at balancing out forest age structure. The difference is most noticeable during the period of 2010-2020 as well as in the period after 2050 where a significant drop in harvest rate would be noticed for the scenario at tree maturity. On average, between 2010 and 2040, the difference between the two scenarios amounts to 18 000 m³/ha/a. The difference is however not as pronounced as Figure 11-19 would lead to imagine because both scenarios have a base harvest for thinning purpose which can amount to over 50 % of total wood harvest.

11.4.3.2.4.4 Oak forests

In Luxembourg there are two types of oak forest. On the one hand there are common high oak forest for timber production but on the other hand there are also coppice oak forests (“Lohhecken”).

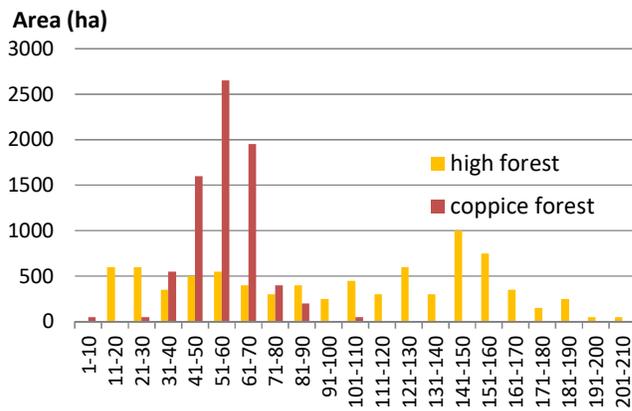
In Europe, oak used to be a common source of tanbark, used by tanneries in order to produce leather. The bark is taken from young branches and twigs in oak coppices and the remaining wood used generally as fire wood. According to (Hermes S. , 2006) production of oak bark used to be around 7 810 Tons in 1947 and has continuously fallen since the introduction of more efficient chemical tanning products. Wood production in these forests is not very high as the high production of bark removes a lot of nutrients from the forest soil.

Figure 11-20 - Illustration of coppice oak forests (Lohhecken) in Luxembourg (Hermes S. , 2006)



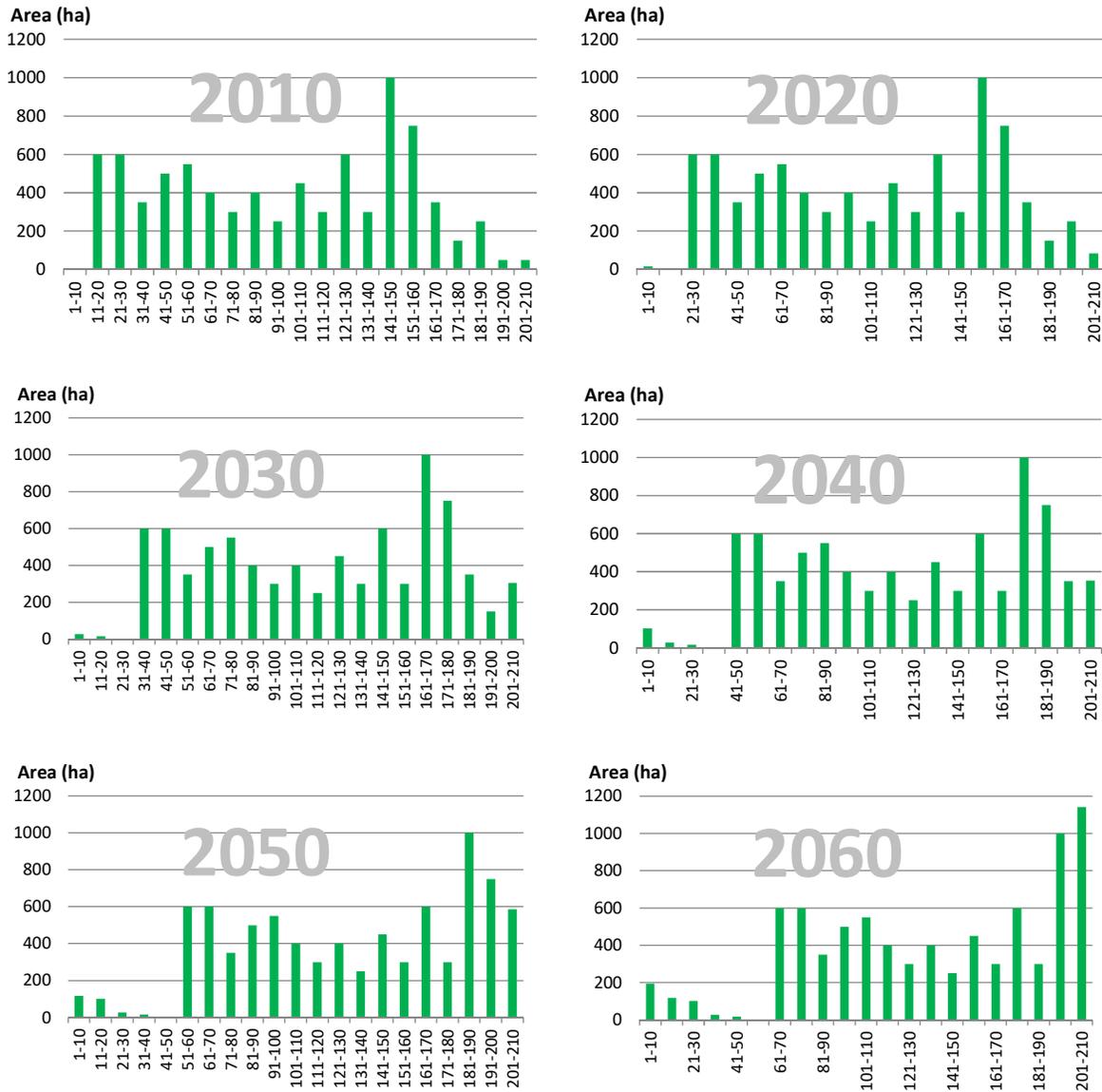
Wood growth in coppice oak forest can be estimated at around 4,1 – 4,6 m³/ha/a, but according to the results of the NFI harvest rates is estimated at about 1 m³/ha/a which highlights the fact that these forest are very underutilised. This harvest rate will be used for further calculations and will be set to a constant value for the years leading up to 2050. It would however be imaginable that some of these forests will be completely harvested. This could lead to a harvest of 75-115 m³/ha, which spread over the period of 30 years could potentially increase the harvest rate by up to 25 000 m³/a. It is however more likely that these forests will gradually evolve in high forests. Considering their young age (see Figure 11-21) it will likely take a few more decades before higher harvest rates can be expected in those forests.

Figure 11-21 - Age structure for coppice oak forest and oak high forest in Luxembourg



The age structure of the oak high forest in Luxembourg shows, in comparison to beech forest, a relative balanced age structure between 0 and 160 years. The maturity age of oak forests is however 200 years which means that in the next 40 years the harvest rates in oak forests will be very low.

Figure 11-22 - Evolution of age structure of high stand oak forests

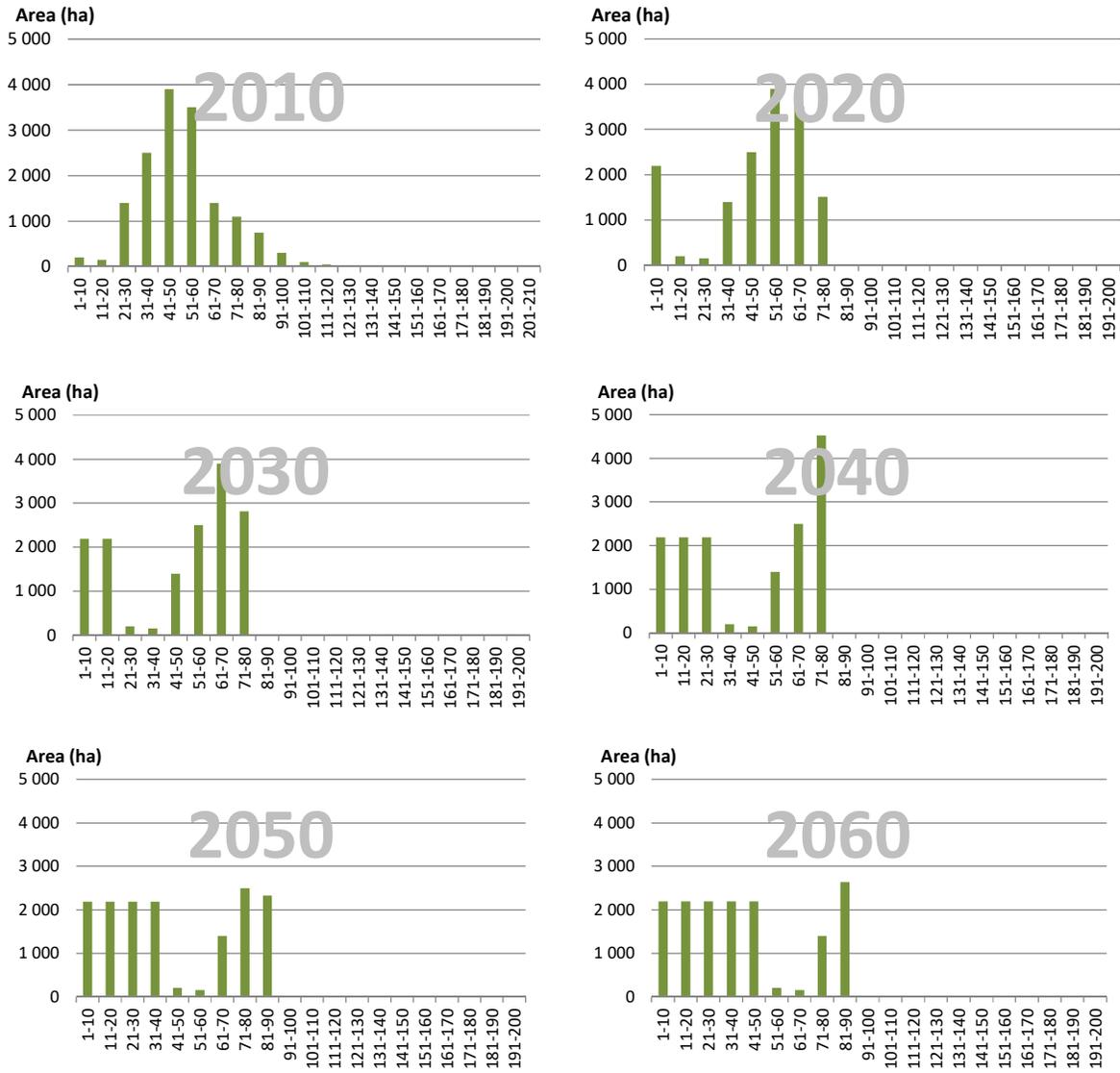


11.4.3.2.4.5 Spruce forests

The strong increase in wood harvest from 2010 onwards is partly due to higher harvest rates in private coniferous forests which have reached the legal threshold of 50 years (in Luxembourg clear cutting in coniferous forests is not allowed before the age of 50 years).

The evolution of age structure in spruce forests shows a medium wood production for the next decades to come.

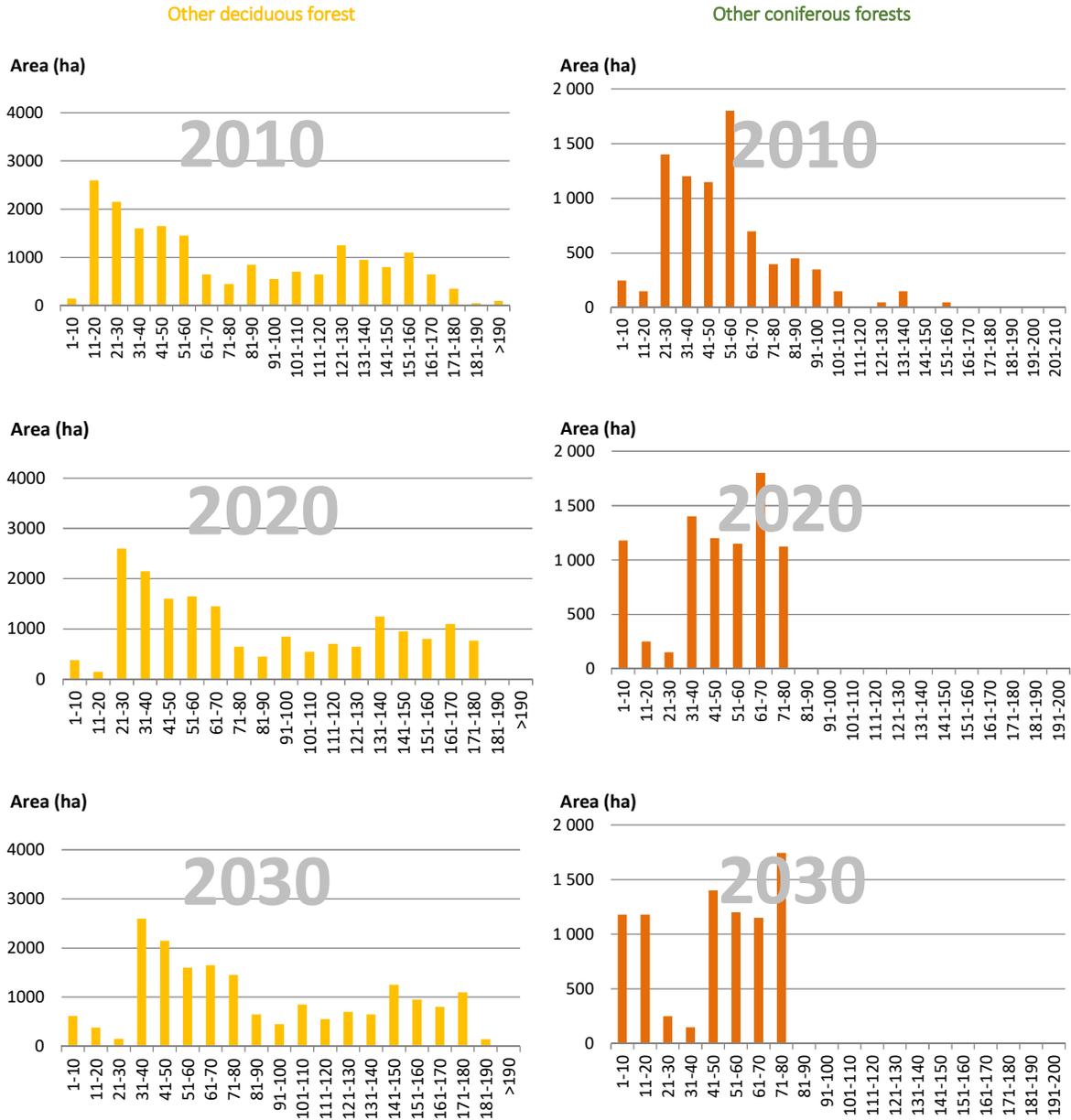
Figure 11-23 - Evolution of age structure of high stand oak forests

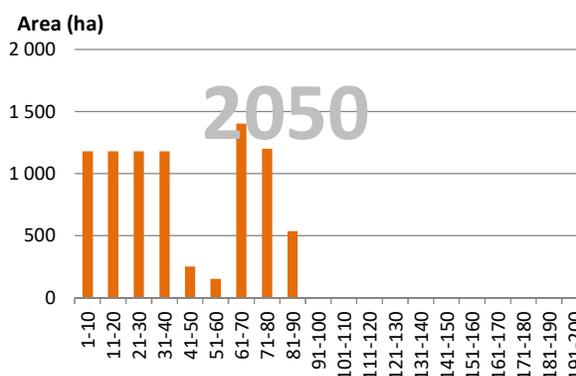
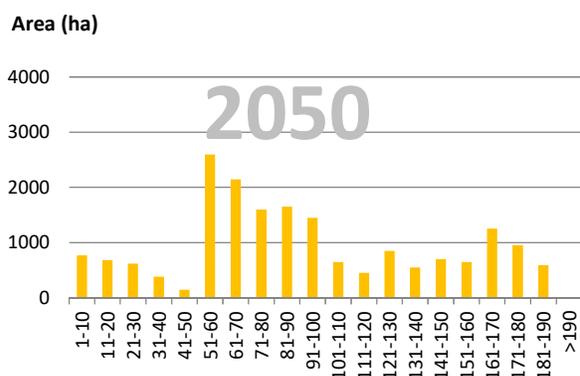
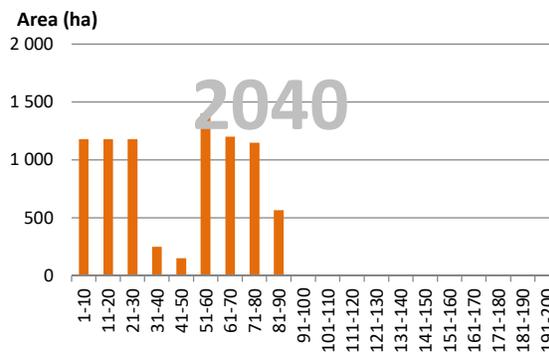
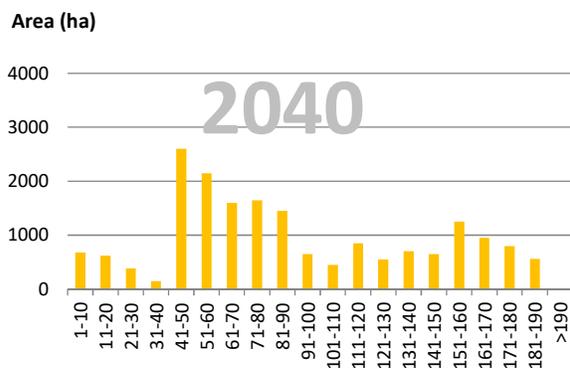


11.4.3.2.4.6 Other forests

The category other forests is split between deciduous and coniferous forest which have both different age class structures and hence different harvest potentials

Figure 11-24 - Evolution of age structure of other deciduous and coniferous forests





11.4.3.2.4.7 Projected harvest rate

According to (Genot & Kalmes, 2014) 1 250 ha of forests are declared as nature reserve (RFI-réserve forestière intégrale) and can hence not be exploited. In the medium to long term the forest agency is aiming to increase this to 5% of the total forest area (4 500 ha).

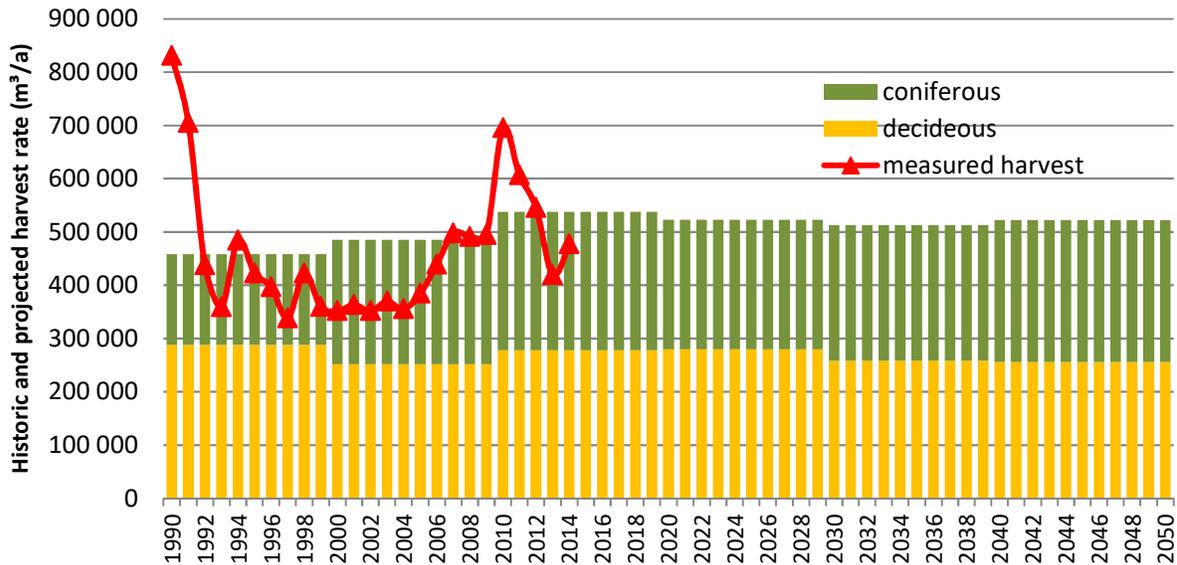
According to the same study a further 4 640 ha are situated on a slope > 60 % and can hence only be exploited with great difficulty. The conservative approach is taken that those forest areas are considered unmanaged and the assumption is taken that carbon emission and removals are in balance. This is not entirely correct as it is likely that over the years an accumulation of dead wood and increase in soil carbon content can be observed on those areas. Nevertheless dead wood and soil carbon content are measured during NFI. A higher average dead wood content on the remaining forests and is thus accounted for under the measurements from the NFI.

Table 11-14 - Area of forestland used for projection between 2013-2020

	Surface area (kha) average 2013-2020
Forest management	
managed	78,26
RFI	9,14
Afforestation (since 1990)	8,68
Deforestation (since 1990)	5,77

The calculated harvest rate is multiplied with the ratio of forest management area + afforestation area – RFI area to forest areas used to determine the harvest rate. The ratio also includes the ratio of coniferous trees to deciduous trees that originates from the NFI. Afforested areas are included in the NFI and hence it is better to include them within the applied ratio. This is possible as no harvest is expected before 2020 in the AF category. After this date the harvest would have to be split between FM and AF.

Figure 11-25 - Projected and measured harvest rate



The harvest rate have strong year on year fluctuations which can obviously not be modelled. The harvest projections show that, in the long term, an increase in deciduous wood is compensated by a reduction in coniferous wood. This can be explained by the high proportion of old beech forests which have reached their maturity age. For coniferous forest recent legislation enabled the clearfelling of forest older than 50 years which lead to an increase in harvest. Hence a further significant increase in harvest from coniferous forests is not expected.

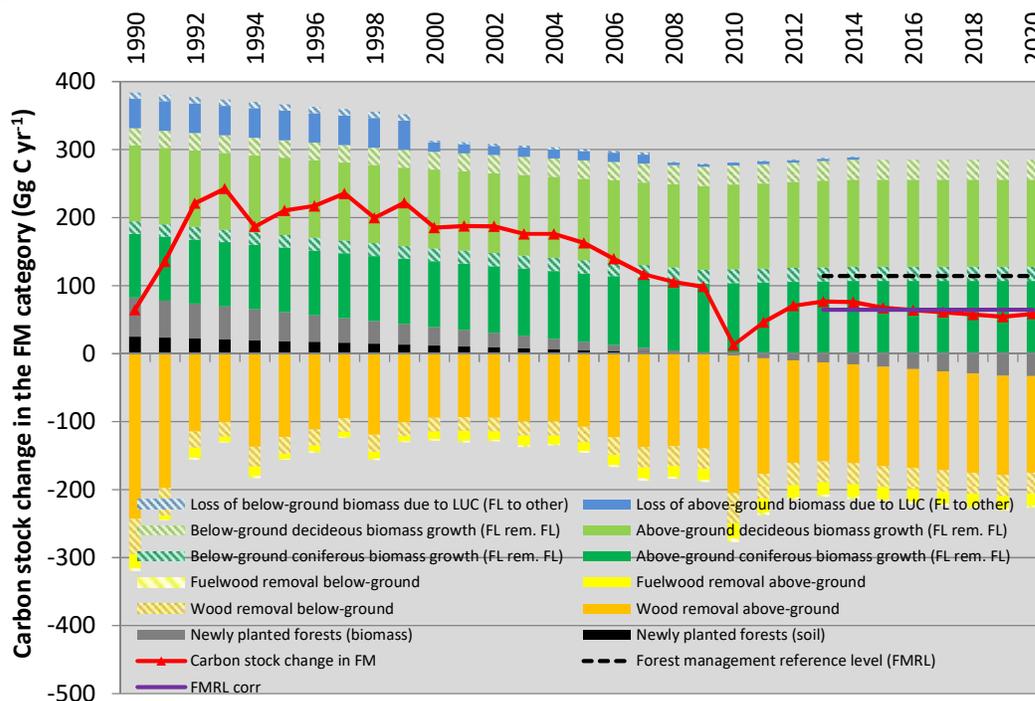
11.4.3.2.5 Projected emissions for Forest Management (activity-based approach)

The definition of forest management according to KP comprises all forest minus the forest areas which have been afforested or reforested since 1990 (Luxembourg has not elected carbon equivalent forests). The calculation for biomass gain and loss as well as carbon gain and loss in soils according to GPG UNFCC differentiate between mature forests (older than 20 years) and forest that have been newly planted. Carbon stock changes of forests that have been planted between 1970 and 1990 have to be calculated separately within the forest management category. Areas included in the AR category remain in the AR category and do not transit to the FM category. Not even after a period of 20 years.

For established forests it is assumed that the carbon content of litter does not change. It is assumed that litter levels (default value of 19,6 tC/ha) are reached after a transition period of 20 years. Dead wood levels are also assumed to be constant apart from the period between 2000 and 2010 where the national forest inventory highlighted an increase in dead wood following a change in harvesting practices.

In order to avoid double accounting the biomass loss due to deforestation has been subtracted from the harvest figures.

Figure 11-26 - Projected emissions in FM and FMRL corr.



The following points are important when analysing Figure 11-26:

- Growth rate in forests are easy to predict and are more or less constant over the years. The harvest rate, on the other hand, has strong year on year fluctuations and is the strongest contributor to changes in emissions.
- The emissions are based on the assumption that there is no afforestation or deforestation after 2013.
- The wood removals, due to deforestation area, are reported under deforestation and are hence subtracted from the total wood removals. In order to do this they are reported as sinks in this chart and represented by the blue bars.
- The projected emissions for the FM sector (as defined under KP) are calculated based on the emissions of the forestland remaining forestland (FL rem. FL) as submitted under UNFCCC. In order to convert the emissions from the category FL rem. FL to FM all emissions due to areas that have been afforested after 1990 (and are reported under afforestation under KP) have to be subtracted. This is shown in the figure by the grey bars.
- Previous to 2010 the emissions, due to newly planted forests, are still positive as the biomass growth in areas that have been newly planted previous to 1990 (and reported under FM) outweigh the biomass growth of areas that have been afforested after 1990 and are reported under the afforestation category. (Biomass growth is calculated as biomass growth from FL remaining FL + biomass growth from other categories converted to FL – biomass growth of afforestation). Between 2010 and 2020 the removals due to the afforestation areas are increasing because growth rate for forest older than 20 years are higher than for younger ones. This has a strong influence when comparing the emission in FM to the FMRL (forest management reference level) represented by the black dotted line.
- The average removals, for the years 2013-2020, calculated according to the estimates of this study amount to -64.45 GgCyr⁻¹.

Table 11-15 - Summary table of technical correction of FMRL

	Emissions and removals
FMRL	- 418 GgCO ₂ eq.yr ⁻¹
FMRL _{corr}	- 236 GgCO ₂ eq.yr ⁻¹
Difference in % = 100*((FMRL _{corr} -FMRL)/FMRL)%	- 43%
Technical Correction = FMRL _{corr} -FMRL	182 GgCO ₂ eq.yr ⁻¹
FM reported during the commitment period (2019)	- 215 GgCO ₂ e
Accounting Parameter = reported FM – (FMRL + Technical Correction)	21 GgCO ₂ e

11.4.3.3 Provision for carbon equivalent forests

Luxembourg has not elected the provision for carbon equivalent forests.

11.4.3.4 Provision for natural disturbances

For the second commitment period, Luxembourg has decided to elect the provision for the treatment of natural disturbance emissions for FM under Article 3.4 and or AR under Article 3.3 as set out in the Annex to Decision 2/CMP.7. (According to Annex I to Decision 2/CMP.8, a Party's report to facilitate the calculation of the assigned amount pursuant to Article 3, paragraphs 7bis, 8 and 8bis *shall contain an indication of whether it intends to apply the provisions to exclude emissions from natural disturbances for the accounting for afforestation and reforestation under Article 3, paragraph 3, of the Kyoto Protocol and/or forest management under Article 3, paragraph 4, of the Kyoto Protocol during the second commitment period, in accordance with decision 2/CMP.7.*)

Luxembourg has developed a background level and a margin for natural disturbances according to the methodology described in IPCC KP Supplements (2014):

Step 1: Define the type of natural disturbances that the Party wishes to exclude from accounting:

The calculation of carbon emissions and removals in forests is entirely based on the results of two consecutive national forest inventories (NFI). EF for biomass, growth rate and more importantly harvest are all based on those results. When the third NFI will be carried out, carbon losses (eg due to forest fires or biomass burning) will impact the new EF (eg dead wood) and hence be accounted for.

As most European countries, LU forests have also suffered from insect infestation (bark beetles) over the last years. During the previous review there must have been a misunderstanding as it is not mandatory to burn the damaged wood. It is common practice to remove the damaged wood out of the forest and use it in biomass combustion plants with energy recovery (generally urban district heating plants). The emissions of combustion plants are calculated in the energy sectors and the removal of wood is accounted as harvest in LULUCF. Since the last review the forest agency has elaborated a guide (<https://environnement.public.lu/dam-assets/fr/forets/publications/Borkenkafermanagement.pdf>) on how to combat bark beetles infestation. The guide underpins the need to use damaged wood as biomass and is consistent with waste legislation that prohibits burning of green waste.

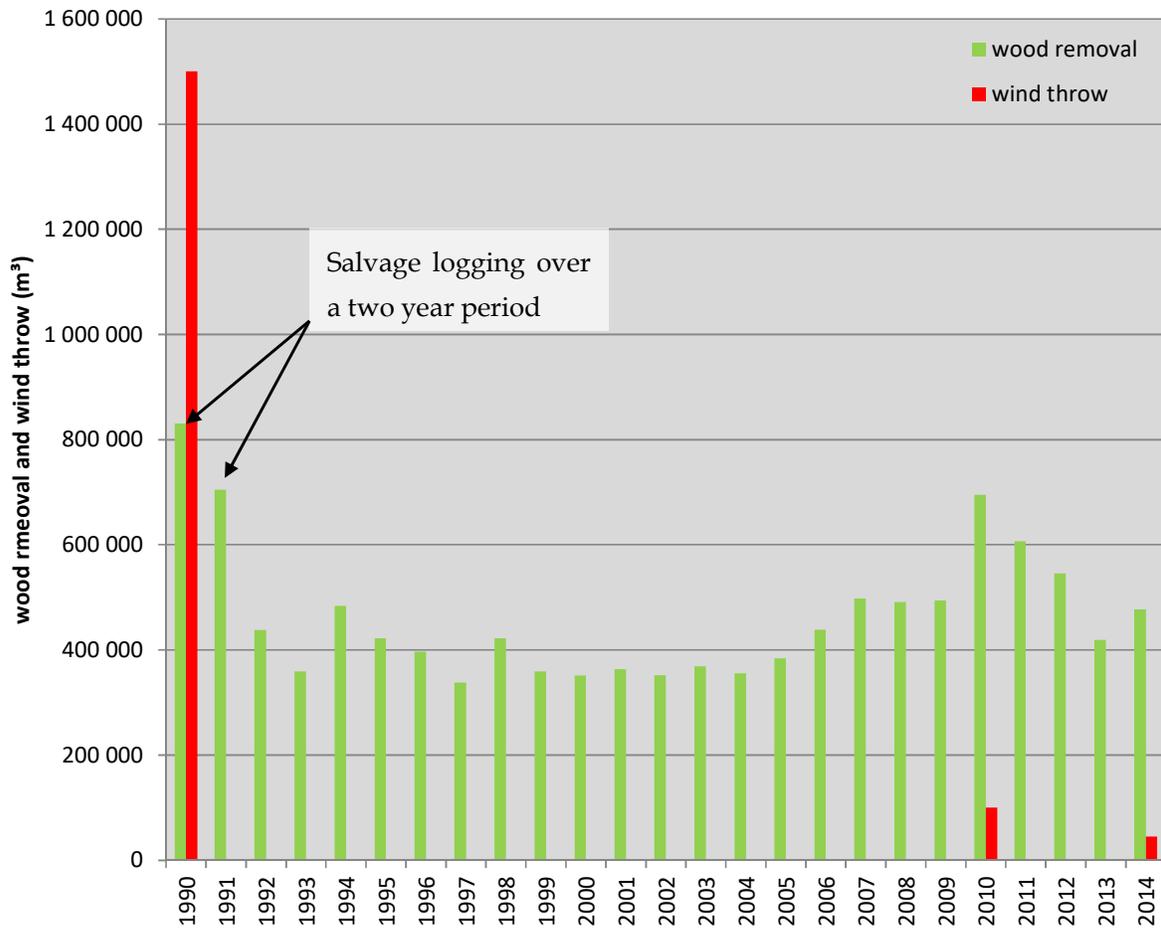
LU has conducted a more detailed research on forest fires (non intentional fires, wildfires) as official data on forest fire is not collected, as forest fires generally do not occur. Over the last years a couple of minor forest fires were reported by news outlets. According to those news articles the fires were quickly contained and the biggest one (which was also the only one with a weblink (<https://5minutes.rtl.lu/actu/luxembourg/a/1385250.html>) was limited to 10ha. Considering the small size of those fires, no assessment in terms of carbon loss (depending on tree species and mainly age structure) was carried out. It seems however reasonable to assume that the resulting carbon loss will be insignificant. Carbon loss due to a forest fire of 10 ha is estimated at 400 t CO₂eq. Compared to total country wide emissions of 10'333 kt CO₂eq (excluding LULUCF) this amounts to 0.004% which is below the threshold of 0.05%. Considering that a forest fire of 10 ha was an individual event in 2018, LU does not calculate this category for the whole timeseries.

For the calculation of the CO₂ Emission Equation 2.27 (IPPC guidelines LULUCF chapter 2) was used with the following default parameters: MB=50.4 (Table 2-4 page 2.45 *all other temperate forests* - tonnes dry matter per ha); CF=0.45 (Table 2-6 *all other temperate forests*); Gef (g kg⁻¹ dry matter burned; Table 2.5 *extra tropical forests*; Gef (CO₂)=1569; Gef(N₂O)=0.26; Gef(Ch₄)=4.7. Afer closer inspection of arial pictures from 2018 the area was estimated at 4 ha which reduces the emissions to a even smaller value.

Extreme weather events, like wind storm, on the other hand, can have wide reaching consequences for Luxembourg. Due to the small size of the country one major storm can have a severe impact on the total forest population in Luxembourg. Hence the definition of natural disturbances for Luxembourg will be limited to extreme weather events.

Step 2: Establish a consistent and initially complete time series of annual emissions for the calibration period for each disturbance type.

Figure 11-27 - Data on wood removal and wood loss through wind storms



Data on wood loss due to wind storms are available for following storms: Viven, Wiebke (1990), Klaus (2009) and Xynthia (2010) and have been collected by the forest agency. Figure 11-27 is showing wood loss due to wind throw (red bars) as well as wood removal due to forest management (green bars). Wind storms do not occur on an annual basis and hence a number of years show zero emissions due to windstorms. The most severe windstorm was windstorm Viven, Wiebke in 1990. The following wood losses due to

the wind storms in 2010 and 2014 were only minor. The data on wood removal highlights how, after the wind storm of 1990, salvage logging has been taking place over two years. In Luxembourg wood lost through the wind storms is in general salvaged. Emissions from and associated with salvage logging cannot be excluded from accounting during the commitment period and consequently historical emissions from natural disturbances should exclude emissions from salvage logging.

Step 3: Develop the background level using the default or alternative method: Due to the small number of natural disturbances over the course the analysed time series the default method cannot be used as the standard deviation is always greater than the mean average over the remaining values (and this by excluding one, two or all three values). An alternative method would set the background level to the minimum level of historical time series which is zero. Considering the small number of samples this seems to be the only method available.

Step 4: Develop the margin

The margin is twice the standard deviation excluding outliers. If the background level is set equal to zero then the margin is zero.

Step 5: Ensuring that the method applied does not lead to the expectation of net credits or net debts.

With a baseline of zero as well as a margin of zero it does not seem possible to achieve net credits or debts by accounting for natural disturbances.

To sum up, historical data shows that damage caused by wind storms is the major cause of natural disturbances. In the past, most wood lost has however been recovered through salvage logging and hence the provision for natural disturbances could not have been applied. It seems also unlikely that Luxembourg will apply the provision in the future. The provision has to be regarded more as a safeguard in case of major storm events might hit Luxembourg in the future and affect most of the forest areas.

11.4.3.5 Information about harvested wood products under Article 3.4

For Luxembourg, the wood harvest can be fully assigned to the two activities forest management and deforestation. Nevertheless due to the incomplete dataset on HWP (especially with regards to import and exports figures) all wood harvested for the production of HWP is considered as instantaneous oxidation. Further information, and details on the calculations carried out for Luxembourg, are provided in Chapters 6.8.

11.5 Other information

11.5.1 Key category analysis for Article 3.3 activities and any elected activities under Article 3.4

Land use changes to forestland and FM are considered key categories.

Table 11-16 – Overview of key categories for LULUCF activities under the Kyoto Protocol (CRF – NIR 3 table)

KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	CRITERIA USED FOR KEY CATEGORY IDENTIFICATION			Comments ⁽⁴⁾
		Associated category in UNFCCC inventory ⁽¹⁾ is key (indicate which category)	Category contribution is greater than the smallest category considered key in the UNFCCC inventory ⁽²⁾ (including LULUCF)	Other ⁽³⁾	
Specify key categories according to the national level of disaggregation used ⁽¹⁾					
Afforestation and Reforestation					
CO2	CO2	Land converted to forest land	Yes	none	no comments
Deforestation					
CO2	CO2	grassland, Land converted to other land, Land converted to settlements, Land converted to wetlands	Yes	none	no comments
Forest Management					
CO2	CO2	Forest land remaining forest land	Yes	none	no comments

The calculations of the data for category 5 are verified as follows:

- Are the correct values used (check for transcription errors ...)?
- Check of plausibility of input data (time-series, order of magnitude, values of neighbouring countries ...)
- Is the data set complete for the whole time series?
- Check of calculations, units...
- Check of plausibility of results (time-series, order of magnitude, values of neighbouring countries ...)
- Correct transformation/transcription into CRF
- Where possible, data is checked with data from other sources, order of magnitude checks ...
- Are all references clearly made?
- Are all assumptions documented?

Consistency and completeness checks have been performed using the tools embedded in CRF Reporter.

11.6 Information related to Article 6

There are no Article 6 activities concerning the LULUCF sector in Luxembourg.

12 Information on accounting of Kyoto units

12.1 Background information

Annex I Parties are required to report from their national registry the holding and transactions of Kyoto units in the previous calendar year, i.e. 2020, and inform about related issues. The following chapters serve this purpose.

12.2 Summary of information reported in the SEF tables

The standard electronic format (SEF) for providing information on ERU's, CERs, tCERs, ICERs, AAUs and RMUs for the year 2020 will be submitted to the UNFCCC on April 15th, 2021 (RREG1_LU_2020_1_1.xlsx and RREG1_LU_2020_2_1.xlsx) together with this report.

12.3 Discrepancies and notifications

Further information on KP units referring to the respective paragraphs of decision 15/CMP.1 is reported in the following list:

- Paragraph 12: No discrepant transactions occurred in 2020.
- Paragraph 13: No CDM notification occurred in 2020.
- Paragraph 14: No CDM notification occurred in 2020.
- Paragraph 15: No non-replacements occurred in 2020.
- Paragraph 16: No invalid units exist as of 31 December 2020.
- Paragraph 17: No actions were taken or changes made to address discrepancies for the period under review.

12.4 Publicly accessible information

The public reports can be consulted directly at:

<https://ets-registry.webgate.ec.europa.eu/euregistry/LU/public/reports/publicReports.xhtml> Reports are provided according to Annex XVI of the Commission Regulation 2216/2004 amended by Regulation 916/2007, Regulation 994/2008 and Regulation 920/2010.

12.5 Calculation of the commitment period reserve (CPR)

In accordance with decision 11/CMP.1, paragraph 6, and decision 1/CMP.8, paragraph 18, 'each Party included in Annex I shall maintain, in its national registry, a commitment period reserve which should not drop below 90 per cent of the Party's assigned amount calculated pursuant to Article 3(7) and (8) of the Kyoto Protocol, or 100 per cent of eight times its most recent inventory, whichever is lowest'. Luxembourg has interpreted the 'most recent inventory' as the year 2019, as submitted to the UNFCCC on 15th April 2021.

Therefore Luxembourg's commitment period reserve is calculated as follows¹⁴⁰:

Either:

¹⁴⁰ https://unfccc.int/files/national_reports/annex_i_ghg_inventories/national_inventories_submissions/application/zip/lux-2016-ir-15mar17.zip

Luxembourg's Adjusted Assigned Amount x 90%

$$72\,732\,011 \times 0.90 = 65\,458\,810 \text{ assigned amount units}$$

Or:

2019 Total Emissions x Total years of the second commitment period

$$10\,430\,408 \times 8 = 83\,443\,264 \text{ assigned amount units}$$

Since the lower of the two numbers is the one corresponding to 90 per cent of Luxembourg's assigned amount, Luxembourg's Commitment Period Reserve is therefore 65 458 810 tonnes CO₂ eq. (or assigned amount units).

12.6 KP-LULUCF accounting

Luxembourg selected accounting of the KP-LULUCF activities at the end of the commitment period.

12.7 FM cap

For the second commitment period, additions to the assigned amount of a Party resulting from forest management shall, in accordance with paragraph 13 of the annex to decision 2/CMP.7, not exceed 3.5 per cent of the national total emissions excluding LULUCF in the base year times eight.

Luxembourg has elected 1990 as a base year for its GHG. For SF₆ Luxembourg has however chosen 1995 as a base year and hence the calculation of the FM cap for the second commitment period corresponds to:

	Emissions and removals
Total CO ₂ equivalent emissions without land use, land-use change and forestry (1990)	12727.38 ktCO ₂ eq
Emissions of HFCs and PFCs - 1990	0.0000715 kt CO ₂ eq
Emissions of HFCs and PFCs - 1995	15.1516 kt CO ₂ eq
Emissions of SF ₆ - 1990	1.2834 kt CO ₂ eq
Emissions of SF ₆ - 1995	1.7503 kt CO ₂ eq
FM cap = 0.035*(12727.38 -0.0000715-1.2834+15.1516+1.7503)*8	3571.87 kt CO ₂ eq

13 Information on changes in national system

The national system is unchanged compared to the description given in the previous National Inventory Report.

14 Information on changes in national registry

The following changes to the national registry of Luxembourg have occurred in 2020. Note that the 2020 SIAR confirms that previous recommendations have been implemented and included in the annual report.

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(a) Change of name or contact	None
15/CMP.1 annex II.E paragraph 32.(b) Change regarding cooperation arrangement	No change of cooperation arrangement occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(c) Change to database structure or the capacity of national registry	<p>There has been a new EUCR release (version 11.5) after version 8.2.2 (the production version at the time of the last Chapter 14 submission).</p> <p>Due to the new release, some changes were applied to the database. The updated database model is provided in Annex A. No change was required to the application backup plan or to the disaster recovery plan.</p> <p>No change to the capacity of the national registry occurred during the reported period.</p>
15/CMP.1 annex II.E paragraph 32.(d) Change regarding conformance to technical standards	<p>The changes that have been introduced with version 11.5 compared with version 8.2.2 of the national registry are presented in Annex B.</p> <p>It is to be noted that each release of the registry is subject to both regression testing and tests related to new functionality. These tests also include thorough testing against the DES and are carried out prior to the relevant major release of the version to Production (see Annex B).</p> <p>No other change in the registry's conformance to the technical standards occurred for the reported period.</p>
15/CMP.1 annex II.E paragraph 32.(e) Change to discrepancies procedures	No change of discrepancies procedures occurred during the reported period.

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(f) Change regarding security	The use of soft tokens for authentication and signature was introduced for the registry end users.
15/CMP.1 annex II.E paragraph 32.(g) Change to list of publicly available information	No change to the list of publicly available information occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(h) Change of Internet address	No change to the registry internet address during the reported period.
15/CMP.1 annex II.E paragraph 32.(i) Change regarding data integrity measures	No change of data integrity measures occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(j) Change regarding test results	No change during the reported period.

15 Information on minimization of adverse impacts in accordance with Article 3, paragraph 14

23. Each Party in Annex I shall provide information relating to how it is striving, under Article 3, paragraph 14, of the Kyoto Protocol, to implement its commitments mentioned in Article 3, paragraph 1 of the Kyoto Protocol in such a way as to minimize adverse social, environmental and economic impacts on developing country Parties, particularly those identified in Article 4, paragraphs 8 and 9, of the Convention.

The Kyoto Protocol is, in principle and in general, designed to minimize adverse effects on specific sectors, specific industries or specific trade partners of a Party, including the adverse effects of climate change, on international trade, and social, environmental and economic impacts on other parties. This is due to the fact that it does not limit action to a single gas or sector, that the use of its flexible mechanisms guarantees that possible impacts are distributed on various fields of action, that the Clean Development Mechanism aims at both promoting sustainable development in countries with continuing development needs and at reducing greenhouse gas emissions, and that it requests action to support the least developed countries. By striving to implement all the features that the Protocol has integrated Luxembourg is naturally working to minimize not only adverse effects of climate change but also any adverse effects due to the reduction of greenhouse gases.

Luxembourg is strongly promoting long term sustainable development and will hence have scarcely direct or indirect negative effects. In cases where adverse effects could occur, the following measures are/were undertaken:

Adverse effects of climate change

Emission Trading could lead to carbon leakage and higher emissions in countries which do not have comparable environmental standards. To minimize that risk, according to EU Directive 2003/87/EC emission allowances are granted for free to companies with specific characteristics.

Social, environmental and economic impacts on developing countries

JI/CDM projects may in principle have negative side effects in the host countries. For example, projects for the production of biofuels might add to deforestation of forests and/or result in higher prices for food. Luxembourg's JI/CDM program therefore has demanding social and environmental criteria to be eligible as a Luxembourgish JI/CDM project. The favored project categories reflect the high priority that is given to technology transfer projects.

Ensuring that any consequences of economic affairs are addressed, Luxembourg is improving its policies to eliminate potential negative impacts.

24. Parties included in Annex II, and other Parties included in Annex I that are in the position to do so, shall incorporate information on how they give priority, in implementing their commitments under Article 3, paragraph 14, to the following actions, based on relevant methodologies referred to in paragraph 11 of decision 31/CMP.1

(a) The progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsidies in all greenhouse-gas-emitting sectors, taking into account the need for energy price reforms to reflect market prices and externalities.

Market imperfections:

Luxembourg has reformed its energy markets to a large extent to reduce market imperfections and in order to comply with European legislation:

- Directive 2003/54/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92EC.
- Directive 2003/55/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in natural gas and repealing Directive 98/30EC.
- Council Directive 90/377/EEC of the 29 June 1990 concerning a Community procedure to improve the transparency of gas and electricity prices charged to industrial end-users.
- Regulation (EC) No 1228/2003 of the European Parliament and of the Council of 26 June 2003 on conditions of access to the network for cross-border exchanges in electricity.
- Directive 2004/17/EC of the European Parliament and of the Council of 31 March 2004 coordinating the procurement procedures of entities operating in the water, energy, transport and postal services sectors.

Fiscal incentives:

Several fiscal incentives have been put in place, aiming at reducing the use of fossil fuels:

- vehicle tax reform (RGD 22 December 2006): the tax is based on CO₂ emissions from road vehicles.
- raising excise duties on fuels for transport purposes: By the 1st of January 2007, the excise rate on gasoline was increased by 2ct€/liter. For diesel, the excise rate was increased in two stages: 1.25ct€/liter on 1.1.2007, and by a further 1.25 ct€/liter on 1.1.2008. This autonomous addition to the existing excise rates is used to finance the Kyoto fund set up in Luxembourg to deal with the Kyoto "flexible mechanisms" and is labeled "climate change contribution". Indeed, increasing excise rates on road fuels lead to an increase of fuel retail prices and thus, set an incentive for consumers to lower demand.

Subsidies:

Several subsidies have been put in place in the residential, commercial and institutional sectors, aiming at reducing the use of fossil fuels:

- promotion of energy efficiency and the use of renewable energy sources in the residential sector (solar heaters, heat pumps, photovoltaics, biomass boilers and wood stoves).
- program encouraging refurbishment of existing residential buildings to increase energy efficiency.
- program encouraging the construction of highly energy efficient residential buildings.
- establishment of an energy pass certifying the energy class of residential, commercial and institutional buildings.
- promoting low energy electrical appliances.

(b) Removing subsidies associated with the use of environmentally unsound and unsafe technologies.

So far, no subsidies for environmentally unsound technologies have been identified.

(c) Cooperating in the technological development of non-energy uses of fossil fuels, and supporting developing country Parties to this end.

This technological field is not a high priority in Luxembourg's research policy.

(d) Cooperating in the development, diffusion and transfer of less-greenhouse-gas-emitting advanced fossil-fuel technologies, and/or technologies, relating to fossil fuels, that capture and store greenhouse gases, and encouraging their wider use; and facilitating the participation of the least developed countries and other non-Annex I Parties in this effort.

(e) Strengthening the capacity of developing country Parties identified in Article 4, paragraphs 8 and 9, of the Convention for improving efficiency in upstream and downstream activities relating to fossil fuels, taking into consideration the need to improve the environmental efficiency of these activities.

(f) Assisting developing county Parties which are highly dependent on the export and consumption of fossil fuels in diversifying their economies.

For (d) to (e) please refer to Luxembourg's 7th national communication, p.209-213.

16 Other information

n/a

17 References

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ANNEXES TO THE NATIONAL INVENTORY REPORT

Annex 1: Key categories

The method used to identify key source categories follows the Tier 1 method (quantitative approach) as described in the IPCC 2006 Guidelines, Volume 1, Chapter 4. The analysis includes all greenhouse gases reported by Luxembourg under the UNFCCC (CO₂, CH₄, N₂O, HFC, and SF₆). All IPCC categories are included. Key categories were identified for the inventory excluding LULUCF and for the full inventory including LULUCF categories. For KP-LULUCF, a quantitative key category analysis was done as described in the IPCC Good Practice Guidance for LULUCF (Section 5.4.2. and Table 5.4.1.). Further details can be found in section 1.5 of Luxembourg's NIR.

The results of the key category analyses of Luxembourg's GHG and KP-LULUCF inventories (including "Table NIR.3") are presented in Table 1-6 to

Table 1-11.

Annex 2: Detailed discussion of methodology and data for estimating CO₂ emissions from fossil fuel combustion

Please refer to sections 3.2.5 to 3.2.11 for methodology descriptions.

Annex 3: Other detailed methodological descriptions for individual source or sink categories, including for KP-LULUCF activities

Annex 3A - Recalculations of GHG Emissions for sector 3- Agriculture

This section describes in detail the changes made to the inventory since the last submission to the UNFCCC (April 2019).

Summary

Sector specific recalculations generated an overall reduction in annual GHG emissions varying between -2.5% - 0.4%. Table A3-1 holds the results of the recalculation performed.

Apart from the suggestions made by the different reviewers, additional improvements were applied in the current submission, namely:

- Manure management systems were updated using information collected in the 2016 agriculture census on grazing times for dairy cows, suckler cows, horses, sheep, goats and cervidae, affecting both the CH₄ emissions (i.e. enteric fermentation (3A) and manure management (3Ba)) and N₂O emissions (manure management (3Bb) and agriculture soil (3D)).
- In the current submission the assumption for cattle slurry stored in open tanks with respect of having a natural crust was revised affecting both the CH₄ emissions (i.e. manure management (3Ba)) and N₂O emissions (manure management (3Bb) and agriculture soil (3D)).
- The used N excretion (N_{ex}) for suckler cows were updated, affecting N₂O emissions (manure management (3Bb) and agriculture soil (3D)).
- The Tier 2 N mass-flow in the manure management systems was updated according to the 2019 EMEP guidelines, i.e. revisions of some formulas and used EFs. Additionally was the N quantity which is added via bedding material corrected (step 7), affecting N₂O emissions (i.e. manure management (3Bb) and agriculture soil (3D)).
- Furthermore in step 11 was the digestate created by the anaerobic digestion of manure, that is returned from 5.B.2 added to the Tier 2 N mass flow in the manure management systems, affecting N₂O emissions from agriculture soil (3D).
- An error in the GE estimation for dairy cows, suckler cows and mature sheep was corrected, affecting only slightly the CH₄ emissions (3.A).
- The annual amount of animal manure N applied to soils (kg N per year) were revised as erroneously the mass returned to soil was used rather than the mass applied to soil, affecting N₂O emissions from agriculture soil (3D).
- Furthermore, the N applied to soils from digestate originating from energy crops and other waste was taken into consideration in the emissions calculations, both air pollutants (NH₃ and NO_x) and GHG emissions, and hence impacting direct and indirect N₂O emissions from agriculture soils (3D).
- The NH₃ emissions originating from synthetic N-fertilizer, were derived using a Tier 2 methodology (used to be Tier 1) with consequently lower NH₃ emissions; further were the EF for NH₃-N for slurry application with trailing shoe revised; Both revision were impacting the indirect N₂O emissions occurring after atmospheric depositions of nitrogen compounds (3D2).
- The provisional activity data for sewage sludge for the year 2018 were replaced by published data, affecting only slightly N₂O emissions from agriculture soil (3D).
- The activity data for liming for 2018 had to be updated, affecting only slightly CO₂ emissions from liming (3G).
- Information on urea and other carbon-containing fertilizer were collected, and CO₂ emissions associated with the application of urea (3H) and CO₂ emissions associated with the application of carbon-containing fertilizer (3I) were calculated and presented for the first time in the current submission.

Full details and the recalculated emissions are given hereafter in details. There are more improvements to follow in the following submissions, but a lack of data, requiring additional data collection, and reduced manpower did not allow to fully implemented all desired changes in the current submission.

Table A3-1: Recalculation GHG Emissions in CO2 equivalent (Gg) for sector 3 – Agriculture

3- Agriculture Sector						
GHG Emissions (Gg CO ₂ eq.) by source category						
Year	CRF 3 (excluding LULUCF)		Impact of recalculation	CRF 3 (including LULUCF)		Impact of recalculation
	New	Old	%	New	Old	%
1990	711.3	696.9	2.1	711.3	696.95	2.1
1991	725.4	710.9	2.0	725.4	710.87	2.0
1992	714.3	700.0	2.0	714.4	700.01	2.1
1993	710.0	695.9	2.0	710.0	695.86	2.0
1994	700.2	686.3	2.0	700.2	686.29	2.0
1995	717.9	703.8	2.0	718.0	703.75	2.0
1996	725.8	711.4	2.0	725.9	711.45	2.0
1997	715.4	701.4	2.0	715.5	701.41	2.0
1998	709.9	696.1	2.0	710.0	696.12	2.0
1999	717.7	703.9	2.0	717.7	703.89	2.0
2000	710.6	696.3	2.1	710.7	696.29	2.1
2001	694.5	680.2	2.1	694.6	680.18	2.1
2002	677.7	663.1	2.2	677.8	663.09	2.2
2003	640.7	626.2	2.3	640.7	626.18	2.3
2004	661.9	646.0	2.5	662.0	645.98	2.5
2005	646.5	630.4	2.6	646.5	630.37	2.6
2006	638.5	621.7	2.7	638.5	621.73	2.7
2007	653.8	636.1	2.8	653.9	636.08	2.8
2008	668.9	649.9	2.9	668.9	649.87	2.9
2009	671.7	652.0	3.0	671.8	652.00	3.0
2010	682.2	661.5	3.1	682.2	661.48	3.1
2011	669.7	649.3	3.1	669.7	649.31	3.1
2012	656.1	635.9	3.2	656.2	635.89	3.2
2013	666.4	646.4	3.1	666.5	646.38	3.1
2014	681.9	661.2	3.1	681.9	661.20	3.1
2015	695.7	674.4	3.2	695.8	674.43	3.2
2016	711.5	689.8	3.1	711.5	689.81	3.1
2017	721.5	699.4	3.2	721.6	699.41	3.2
2018	713.7	692.2	3.1	713.7	692.23	3.1
2019	712.3			712.3		

Source: SER

General

Revision of the manure management system

In previous submissions there were the manure management systems for the years 2011-2018 the same as in 2010, (Gargano et al., 2014) the last available data on the manure management systems.

Information on the proportion of excreta deposited during grazing, referred hereafter as manure management system (MMS) – pasture (MMS- pasture(i)) for dairy cows, suckler cows, horses and sheep were revised in the current submission. The yearly agricultural

census in 2016 had been extended by a survey on animal grazing. The collected data on animal grazing were linked at the level of individual herd sizes¹⁴¹ to obtained average grazing time for an average animal of livestock i , whereby i stands for livestock category, and as such allowing to calculate MMS-pasture for dairy cows, for suckler cows, for horses, for sheep and for goats. The proportion of excreta deposited during grazing decreased for dairy cows from 24.7% in 2010 to 20.4% in 2016. Whereas for suckler cows and horses, the proportion of excreta deposited during grazing increased from 49.3% and 49.3% in 2010 to 54.8% and 57.8% in 2016, respectively. The proportion of excreta deposited during grazing remained unchanged for sheep (75.36% in 2010 versus 75.3% in 2016). Further was the proportion of excreta deposited during grazing for goats in 2016 0.3%. The 2016 data were used as such for the year 2016, whereas for the years 2011–2015, data were interpolated by assuming that the observed decrease/increase between 2010 and 2016 was linear. For goats, where for simplicity reason it had been assumed that 100% of the goats would be kept inside (and hence MMS-pasture would be 0%) since the installation of the first professional dairy farmer with a few hundred dairy goats in 2001/2002, MMS-pasture was corrected and assumed to be 0.3% since 2002.

The proportion of excreta deposited during housing was adapted accordingly to the new MMS-pasture. Whereas within $x_{build}(i)$ the same distribution between MMS-liquid (i); MMS-feed (i) and MMS-solid (i) were assumed as observed in 2010. (Gargano et al. 2014).

Without new data, the manure management systems for the years 2017–2019 were assumed to be the same as derived for 2016..

The adapted manure management system affected 3A, 3Ba, 3Bb and 3D. For recalculations see Table A3-3, Table A3-4, Table A3-5 and Table A3-6, respectively.

Revision of slurry storage systems

In the last submission it was assumed that cattle slurry stored in slurry tanks without cover would have always a natural crust. This was changed to 80% with natural crust and 20% without natural crust, similar to the assumption made in the manure management N-flow tool from the European Environment Agency version 10 February 2020.

The adapted slurry storage system affected only marginal 3Ba, 3Bb and 3D, for recalculations see Table A3-4, Table A3-5 and Table A3-6, respectively.

Revision of N.ex for suckler cow

In the previous submission, the N.ex for suckler cows was assumed to be 82 kg N/animal/year, based on the N.ex used in the German emission calculations. (Rösemann et al. 2019, KTBL 2006). This value was updated in the current submission to 90.7 kg/suckler cow, as during a recent quality check from the German inventory, the old value turned out to be an underestimation (Haenel, et al., 2020). The used value is slightly higher than in the Dutch emission calculations (i.e. 81.5 kg N/suckler cow/year in 2017) (CBS, 2018), but is slightly lower than the N.ex used in the French emission calculations, (i.e. 107.3 kg N/suckler cow/year), (CITEPA, 2019) who have, next to the Limousin breed – the pre-dominant breed in Luxembourg -, also other heavier breeds.

¹⁴¹ Opposite to EUROSTAT where data are linked to the agricultural holding (Glossary: Farm structure survey (FSS) - Statistics Explained (eu-ropa.eu))

The adapted N_{ex} for suckler cow affected 3Bb and 3D,. For recalculations see Table A3-5 and Table A3-6.

Revision of the N flows in the manure management system

The Tier 2 N mass-flow in the manure management systems was updated according to the 2019 EMEP guidelines, (EMEP 2019a).

In particular in step 7 and step 11 were adaptations made, namely:

In Step 7, the estimates for N added straw in animal bedding for livestock category I in litter-based housing system were erroneously considered for all housed animals, rather than just for the proportion of animals kept in litter-based housing systems.

Furthermore the formula for $m_{ex-build_solid_TAN}$ and $m_{ex-build_solid_N}$, where adapted according to the 2019 guidelines.

They used to be:

$$m_{ex-build_solid_TAN(i)} = \left\{ \left(m_{build_solid_TAN(i)} - E_{build_solid_NH3-N(i)} \right) * (1 - f_{imm}) \right\}$$

$$m_{ex-build_solid_N(i)} = \left\{ \left(m_{build_solid_N(i)} + m_{bedding_N(i)} + f_{imm} \right) - E_{build_solid(i)} \right\}$$

And were changed to

$$m_{ex-build_solid_TAN(i)} = \left\{ m_{build_solid_TAN(i)} - \left(E_{build_solid_NH3-N(i)} + (m_{bedding_N(i)} * f_{imm}) \right) \right\}$$

$$m_{ex-build_solid_N(i)} = \left\{ m_{build_solid_N(i)} + m_{bedding_N(i)} - E_{build_solid(i)} \right\}$$

In Step 11, the total-N and TAN (m_{applic_N} and m_{applic_TAN}) that is applied to the field was calculated. However, in earlier submission without adding the digestate created by the anaerobic digestion of manure, that is returned from 5.B.2.

The formulas used to be:

$$m_{applic_slurry_TAN(i)} = mm_{storage_slurry_TAN(i)} - E_{storage_slurry(i)}$$

$$m_{applic_slurry_N(i)} = mm_{storage_slurry_N(i)} - E_{storage_slurry(i)}$$

And were changed to:

$$m_{applic_slurry_TAN(i)} = mm_{storage_slurry_TAN(i)} + mm_{dig_TAN(i)} - E_{storage_slurry(i)}$$

$$m_{applic_slurry_N(i)} = mm_{storage_slurry_N(i)} + mm_{dig_N(i)} - E_{storage_slurry(i)}$$

According to the 2019 EMEP guidelines,(EMEP 2019a) the used NH₃-N emission factors (EF) for NH₃ emissions from buildings and from solid manure storage were revised for certain animal categories. The old (EMEP 2016) and the new EFs are summarized in Table A3-2 hereafter.

Table A3-2: Old and new NH₃-N emission factors in NRF 3B

3 – Agriculture sector

Emission factors for NH₃-N (NRF 3B) for diverse sources for animal category i

Animal category	Buildings with slurry	Buildings with solid MS	Storage of solid manure
-----------------	-----------------------	-------------------------	-------------------------

	Old	New	Old	New	Old	New
Non-dairy cattle (including calves)	0.2	0.24	0.19	0.08	0.27	0.32
Lactating dairy cows	0.2	0.24	0.19	0.08	0.27	0.32
Sows	0.22	0.35	0.25	0.24	0.45	0.29
Fattening pigs/weaners	0.28	0.27	0.27	0.23	0.45	0.29
Sheep	NO	NO	NC	NC	0.28	0.32
Broilers	NO	NO	0.28	0.21	0.17	0.3
Laying hens	NO	NO	0.41	0.2	0.14	0.08
Deer (using sheep as proxy)	NO	NO	NC	NC	0.28	0.32

The revised N-flows in the manure management system as well as the revised EF affected 3Bb and 3D. For recalculations see Table A3-4 and Table A3-5.

Methane emissions from enteric fermentation (CRF 3A)

The GEI in MJ/day/animal was calculated for cattle and sheep according to equation 10.16 in the 2006 IPCC guidelines (IPCC 2006a):

$$GE_i = \left(\frac{\left(\frac{NE_m + NE_a + NE_l + NE_p}{REM} \right) + \left(\frac{NE_g + NE_{wool}}{REG} \right)}{\frac{DE\%_i}{100}} \right)$$

However, in the spreadsheet was the reference for $NE_{a(i)}$ erroneously fixed, why using the same value throughout the whole time period. This was corrected.

In addition, was the manure management system adapted for the years 2011-2018, namely the proportion of animals grazing, respectively in kept inside (for more details see above).

The recalculated methane emissions from enteric fermentation for cattle and for sheep varied only marginal, see Table A3-3.

Table A3-3: Recalculation of methane emission from enteric fermentation in Gg (CO₂-equivalent)

3 - Agriculture Sector															
CH ₄ Emissions (Gg CO ₂ eq.) by source & sink category															
Year	3A-Cattle		Impact of recalculation	3A- Sheep		Impact of recalculation	3A-Swine		Impact of recalculation	3A-Others		Impact of recalculation	3A - Enteric Fermentation		Impact of recalculation
	New	Old	%	New	Old	%	New	Old	%	New	Old	%	New	Old	%
1990	15.3	15.3	0.00	0.04	0.04	0.000	0.09	0.09	0.000	0.03	0.03	0.000	15.5	15.5	0.000
1991	15.5	15.5	0.00	0.05	0.05	0.000	0.08	0.08	0.000	0.04	0.04	0.000	15.6	15.62	0.000
1992	14.9	14.9	0.00	0.04	0.04	0.000	0.08	0.08	0.000	0.04	0.04	0.000	15.0	15.01	0.000
1993	15.0	15.0	0.00	0.04	0.04	0.000	0.09	0.09	0.000	0.04	0.04	0.000	15.2	15.17	0.000
1994	14.9	14.9	0.00	0.05	0.05	0.000	0.08	0.08	0.000	0.04	0.04	0.000	15.1	15.08	0.000
1995	15.4	15.4	0.00	0.05	0.05	0.000	0.09	0.09	0.000	0.04	0.04	0.000	15.6	15.59	0.000
1996	15.6	15.6	0.00	0.04	0.04	0.000	0.09	0.09	0.000	0.04	0.04	0.000	15.8	15.82	0.000
1997	15.3	15.3	0.00	0.05	0.05	0.000	0.09	0.09	0.000	0.05	0.05	0.000	15.5	15.51	0.000
1998	15.2	15.2	0.00	0.05	0.05	0.000	0.10	0.10	0.000	0.05	0.05	0.000	15.4	15.36	0.000
1999	15.2	15.2	0.00	0.05	0.05	0.000	0.10	0.10	0.000	0.06	0.06	0.000	15.4	15.36	0.000
2000	15.0	15.0	0.00	0.05	0.05	0.000	0.10	0.10	0.000	0.07	0.07	0.000	15.2	15.20	0.000
2001	15.1	15.1	0.00	0.05	0.05	0.000	0.10	0.10	0.000	0.06	0.06	0.000	15.3	15.30	0.000
2002	14.6	14.6	0.00	0.05	0.05	0.000	0.10	0.10	0.000	0.07	0.07	0.000	14.8	14.79	0.000
2003	14.1	14.1	0.00	0.06	0.06	0.000	0.11	0.11	0.000	0.07	0.07	0.000	14.3	14.34	0.000
2004	13.9	13.9	0.00	0.06	0.06	0.000	0.12	0.12	0.000	0.08	0.08	0.000	14.2	14.17	0.000
2005	13.9	13.9	0.00	0.06	0.06	0.000	0.13	0.13	0.000	0.09	0.09	0.000	14.2	14.20	0.000
2006	13.8	13.8	0.00	0.06	0.06	0.000	0.12	0.12	0.000	0.09	0.09	0.000	14.1	14.06	0.000
2007	14.3	14.3	0.00	0.06	0.06	0.000	0.12	0.12	0.000	0.09	0.09	0.000	14.5	14.5	0.000
2008	14.8	14.8	0.00	0.06	0.06	0.000	0.11	0.11	0.000	0.10	0.10	0.000	15.0	15.0	0.000
2009	14.9	14.9	0.00	0.06	0.06	0.000	0.11	0.11	0.000	0.10	0.10	0.000	15.1	15.1	0.000
2010	15.1	15.1	0.00	0.06	0.06	0.000	0.11	0.11	0.000	0.11	0.11	0.000	15.4	15.4	0.000
2011	14.6	14.6	0.00	0.06	0.06	0.000	0.12	0.12	0.000	0.11	0.11	0.000	14.9	14.9	0.004
2012	14.3	14.3	0.01	0.05	0.05	0.000	0.12	0.12	0.000	0.12	0.12	0.000	14.6	14.6	0.006
2013	14.6	14.6	0.01	0.06	0.06	0.000	0.11	0.11	0.000	0.11	0.11	0.000	14.9	14.9	0.006
2014	15.1	15.1	0.00	0.06	0.06	-0.001	0.12	0.12	0.000	0.11	0.11	0.000	15.4	15.4	0.005
2015	15.5	15.5	0.01	0.06	0.06	-0.001	0.13	0.13	0.000	0.11	0.11	0.000	15.8	15.8	0.005
2016	15.8	15.8	-0.01	0.06	0.06	-0.001	0.13	0.13	0.000	0.11	0.11	0.000	16.1	16.1	-0.005
2017	16.0	16.0	-0.01	0.06	0.06	-0.001	0.13	0.13	0.000	0.11	0.11	0.000	16.3	16.3	-0.010
2018	15.8	15.9	-0.02	0.06	0.06	-0.001	0.12	0.12	0.000	0.11	0.11	0.000	16.1	16.1	-0.017
2019	15.8			0.06			0.11			0.11			16.1		

Source: SER.

Note: Here "Others" summarize the emissions from the livestock categories poultry (i.e. laying hens, broilers and other poultry), ostriches, horses, goats, cervidae and rabbits.

Methane emissions from manure management (3Ba)

The manure management system was adapted for the years 2011-2018 (for more details see the general section in Annex 3B), as was the assumption w.r.t. natural crust of cattle slurry stored in open tanks (for more details see the general section in Annex 3B) , both affecting the methane emissions from manure management.

The recalculated total methane emissions from manure management resulted in a slight increase of the emissions, with 1.7% being the maximum, see Table A3-4.

Table A3-4: Recalculation of methane emission from manure management in Gg (CO₂-equivalent) for 1990-2019

3 - Agriculture Sector																														
CH ₄ Emissions (Gg CO ₂ eq.) by source & sink category																														
Year	3Ba-Cattle			Impact of recalculation			3Ba-Sheep			Impact of recalculation			3Ba-Swine			Impact of recalculation			3Ba-Others			Impact of recalculation			3Ba - Manure management			Impact of recalculation		
	New	Old	%	New	Old	%	New	Old	%	New	Old	%	New	Old	%	New	Old	%	New	Old	%	New	Old	%	New	Old	%	New	Old	%
1990	1.5	1.5	0.0	0.001	0.001	0.000	0.35	0.35	0	0.01	0.01	0	1.9	1.9	0.0															
1991	1.8	1.8	0.0	0.001	0.001	0.000	0.31	0.31	0	0.01	0.01	0	2.1	2.1	0.0															
1992	1.8	1.8	0.0	0.001	0.001	0.000	0.32	0.32	0	0.01	0.01	0	2.1	2.1	0.0															
1993	1.8	1.8	0.0	0.001	0.001	0.000	0.34	0.34	0	0.01	0.01	0	2.2	2.2	0.0															
1994	1.9	1.9	0.0	0.001	0.001	0.000	0.33	0.33	0	0.01	0.01	0	2.2	2.2	0.0															
1995	2.0	2.0	0.0	0.001	0.001	0.000	0.34	0.34	0	0.01	0.01	0	2.3	2.3	0.0															
1996	2.0	2.0	0.0	0.001	0.001	0.000	0.34	0.34	0	0.01	0.01	0	2.3	2.3	0.0															
1997	2.0	2.0	0.0	0.001	0.001	0.000	0.36	0.36	0	0.01	0.01	0	2.4	2.4	0.0															
1998	2.0	2.0	0.0	0.001	0.001	0.000	0.37	0.37	0	0.01	0.01	0	2.4	2.4	0.0															
1999	2.2	2.2	0.0	0.001	0.001	0.000	0.39	0.39	0	0.01	0.01	0	2.6	2.6	0.0															
2000	2.2	2.2	0.0	0.001	0.001	0.000	0.37	0.37	0	0.01	0.01	0	2.5	2.5	0.0															
2001	2.2	2.2	0.0	0.001	0.001	0.000	0.36	0.36	0	0.01	0.01	0	2.5	2.5	0.0															
2002	2.1	2.1	0.0	0.001	0.001	0.000	0.37	0.37	0	0.01	0.01	0	2.4	2.4	0.0															
2003	2.0	2.0	0.0	0.001	0.001	0.000	0.38	0.38	0	0.01	0.01	0	2.4	2.4	0.0															
2004	1.9	1.9	0.0	0.001	0.001	0.000	0.42	0.42	0	0.01	0.01	0	2.3	2.3	0.0															
2005	1.9	1.9	0.0	0.001	0.001	0.000	0.45	0.45	0	0.01	0.01	0	2.3	2.3	0.0															
2006	1.8	1.8	0.0	0.001	0.001	0.000	0.42	0.42	0	0.01	0.01	0	2.3	2.3	0.0															
2007	1.9	1.9	0.0	0.001	0.001	0.000	0.41	0.41	0	0.01	0.01	0	2.3	2.3	0.0															
2008	1.9	1.9	0.0	0.001	0.001	0.000	0.40	0.40	0	0.01	0.01	0	2.3	2.3	0.0															
2009	1.9	1.9	0.0	0.001	0.001	0.000	0.39	0.39	0	0.01	0.01	0	2.3	2.3	0.0															
2010	1.9	1.9	0.0	0.001	0.001	0.000	0.38	0.38	0	0.01	0.01	0	2.3	2.3	0.0															
2011	1.8	1.8	0.3	0.001	0.001	0.000	0.40	0.40	0	0.01	0.01	0	2.2	2.2	0.2															
2012	1.8	1.8	0.5	0.001	0.001	0.000	0.40	0.40	0	0.01	0.01	0	2.2	2.2	0.4															
2013	1.8	1.8	0.8	0.001	0.001	0.000	0.39	0.39	0	0.01	0.01	0	2.2	2.2	0.7															
2014	1.9	1.9	1.1	0.001	0.001	-0.001	0.39	0.39	0	0.01	0.01	0	2.3	2.3	0.9															
2015	2.0	1.9	1.4	0.001	0.001	-0.001	0.43	0.43	0	0.01	0.01	0	2.4	2.4	1.2															
2016	2.0	2.0	1.9	0.001	0.001	-0.001	0.42	0.42	0	0.01	0.01	0	2.5	2.4	1.6															
2017	2.1	2.0	1.9	0.001	0.001	-0.001	0.44	0.44	0	0.01	0.01	0	2.5	2.5	1.6															
2018	2.1	2.0	2.1	0.001	0.001	-0.001	0.41	0.41	0	0.01	0.01	0	2.5	2.5	1.7															
2019	2.1			0.001			0.38			0.01			2.5																	

Source: SER.

Note: In the previous submission, only provisional data were available for the 2017 livestock numbers, these figures, were, where necessary, updated.

N₂O emissions from manure management (3Bb)

The adapted manure management system, the revised assumption w.r.t. natural crust of cattle slurry stored in open tanks, the updated N.ex for suckler cows and the revised N-flows for the manure management (all described in detail in the general section in Annex 3B) affected the direct and indirect N₂O emissions from manure management.

The recalculated N₂O emissions from manure management, both direct and indirect together, resulted in an average reduction of 0.9%, varying over the years from minimum -5.6% to maximum 2.2%, see Table A3-5.

Table A3-5: Recalculation of N₂O emissions from manure management in Gg (CO₂-equivalent) for 1990-2019

3 - Agriculture									
N ₂ O Emissions (Gg CO ₂ eq.) by source & sink category									
Year	3B3 - Direct emissions		Impact of recalculation	3B3 - Indirect emissions		Impact of recalculation	CRF 3Bb		Impact of recalculation
	New	Old	%	New	Old	%	New	Old	%
1990	0.07	0.07	0	0.03	0.04	-17	0.10	0.11	-6
1991	0.07	0.07	0	0.03	0.04	-14	0.10	0.10	-5
1992	0.06	0.06	0	0.03	0.03	-13	0.09	0.10	-4
1993	0.06	0.06	0	0.03	0.03	-12	0.09	0.10	-4
1994	0.06	0.06	0	0.03	0.03	-12	0.09	0.10	-4
1995	0.06	0.06	0	0.03	0.03	-11	0.10	0.10	-4
1996	0.07	0.07	0	0.03	0.03	-11	0.10	0.10	-4
1997	0.06	0.06	0	0.03	0.03	-10	0.09	0.10	-4
1998	0.06	0.06	0	0.03	0.03	-10	0.09	0.10	-3
1999	0.06	0.06	0	0.03	0.03	-7	0.09	0.09	-3
2000	0.06	0.06	1	0.03	0.03	-7	0.09	0.09	-2
2001	0.06	0.06	1	0.03	0.03	-8	0.09	0.09	-2
2002	0.06	0.06	2	0.03	0.03	-8	0.09	0.09	-1
2003	0.06	0.05	3	0.03	0.03	-8	0.08	0.08	-1
2004	0.06	0.06	3	0.03	0.03	-8	0.09	0.09	-1
2005	0.06	0.05	4	0.03	0.03	-8	0.08	0.08	0
2006	0.06	0.05	5	0.03	0.03	-8	0.08	0.08	0
2007	0.06	0.06	6	0.03	0.03	-8	0.09	0.09	1
2008	0.06	0.06	7	0.03	0.03	-9	0.09	0.09	1
2009	0.06	0.06	8	0.03	0.03	-9	0.09	0.09	2
2010	0.06	0.06	8	0.03	0.03	-9	0.09	0.09	2
2011	0.06	0.06	8	0.03	0.03	-9	0.09	0.09	2
2012	0.06	0.05	8	0.03	0.03	-10	0.09	0.08	2
2013	0.06	0.05	8	0.03	0.03	-10	0.09	0.09	2
2014	0.06	0.06	8	0.03	0.03	-10	0.09	0.09	2
2015	0.06	0.06	8	0.03	0.03	-10	0.09	0.09	2
2016	0.06	0.06	8	0.03	0.03	-9	0.09	0.09	2
2017	0.06	0.06	8	0.03	0.03	-9	0.09	0.09	2
2018	0.06	0.06	8	0.03	0.03	-9	0.09	0.09	2
2019	0.06			0.03			0.09		

Source: SER.

N₂O emissions from managed soil (3D)

N₂O emissions from animal manure for category 3D has changed to previous submission, partly because the adapted manure management system, the revised assumption w.r.t. natural crust of cattle slurry stored in open tanks, the updated N_{ex} for suckler cows and the revised N-flows for the manure management (all described in detail in the general section in Annex 3B) affected the quantities of animal manure applied to soil, respectively the urine and dung deposited by grazing animals. In addition was in step 11 the digestate created by the anaerobic digestion of manure, that is returned from 5.B.2, added (described in detail in the general section in Annex 3B and in the IIR 2021,(Schuman et al., 2021) and hence impacting the N in animal manure applied to soil.

Furthermore, the annual amount of animal manure N applied to soils (kg N per year) were revised as erroneously the mass returned to soil was used rather than the mass applied to soil, impacting the N in animal manure applied to soil.

In the current as well as in the previous submission was the annual amount of animal manure N applied to soils (F_{AM}), in kg N per year, calculated following the N flow shown in Figure A3-2. However, in the previous submission was the mass returned to soil used rather than the mass applied to soil. Hence using the formula:

$$F_{AM} = \left[\sum_i ([m_{returned_slurry_N(i)} + m_{returned_solid_N(i)}] * n_i) \right]$$

with:

$m_{returned_slurry_N(i)}$ the net amount of N returned to soil from liquid manure/slurry (expressed in kg N per year per head/place) for animal category i ;

$m_{returned_solid_N(i)}$ the net amount of N returned to soil from solid manure (expressed in kg N per year per head/place) for animal category i ;

n_i the number of animals in livestock category i ;

This corresponds to step 13 described in section 5.2.6.

In the current submission the mass applied to soil is used, corresponding to step 11 in the N flow described in section 5.2.6. Hence the annual amount of animal manure N applied to soils (F_{AM}), in kg N per year, was calculated in the current submission using the following formula:

$$F_{AM} = \left[\sum_i ([m_{applic_slurry_N(i)} + m_{applic_solid_N(i)}] * n_i) \right]$$

with:

$m_{applic_slurry_N(i)}$ the net amount of N applied to the field from liquid manure (expressed in kg N per year per head/place) for animal category i ;

$m_{applic_solid_N(i)}$ the net amount of N applied to the field from solid manure (expressed in kg N per year per head/place) for animal category i ;

n_i the number of animals in livestock category i

N₂O emissions from urine and dung N deposited on pasture by grazing animals (FPRP) has changed to previous submission, partly because the revised N_{ex} for suckler cows and partly because of adapted manure management system.

Digestate originating from energy crops and other waste was added as an additional source of organic N additions to soil in this year inventories, impacting the different N emissions, and hence direct and indirect N₂O emissions. For a description of the applied methodology see the details provided in section 5.6 for N₂O emissions and the IIR 2021 (Schuman et al.; 2021) for attributable NH₃ and NO_x emissions.

The provisional activity data for sewage sludge for the year 2018 (a-five year average) was replaced by published data.

Indirect N₂O emissions has changed to previous submission, because of:

- the adapted amount of animal manure N applied to soil (explained earlier in this section);
- the adapted amount of N deposited in urine and dung by grazing animals (explained earlier in this section)
- the adapted sewage sludge data (only 2018 data)
- the additional N input from digestate originating from energy crops and other waste, and hence an additional component in F_{ON} (i.e. annual amount of organic N additions), saying that
 - o in previous submission F_{ON}, consisted of animal manure, sewage sludge and compost; whereas in the current submission F_{ON}, consisted of animal manure, including digestate originating from animal manure, sewage sludge, compost and digestate originated from energy crops and other waste,
 - o The NH₃ emissions originating from synthetic N-fertilizer, were derived using a Tier 2 methodology (used to be Tier 1) with consequently lower NH₃ emissions (for more details see IIR 2021 (Schuman et al., 2021).
 - o The EF for NH₃-N for slurry application with trailing shoe revised (for more details see IIR 2021 (Schuman et al., 2021).

The recalculated emissions for managed soils increased on average by 6.1% (range 3.7% - 8.8%), see Table A3-6.

Table A3-6: Recalculation of N₂O emissions from managed soils (CRF 3D) in Gg (CO₂-equivalent) for 1990-2019

3 - Agriculture									
N ₂ O Emissions (Gg CO ₂ eq.) by source & sink category									
Year	3D -Direct emissions		Impact of recalculation %	3D- Indirect emissions		Impact of recalculation %	3D - Managed soil (total)		Impact of recalculation %
	New	Old		New	Old		New	Old	
1990	0.63	0.59	6	0.17	0.17	-2	0.80	0.77	4
1991	0.65	0.61	6	0.18	0.18	-2	0.82	0.79	4
1992	0.66	0.63	5	0.18	0.18	-2	0.84	0.81	4
1993	0.64	0.60	6	0.17	0.18	-2	0.81	0.78	4
1994	0.62	0.58	6	0.17	0.17	-2	0.78	0.75	4
1995	0.62	0.59	6	0.17	0.17	-2	0.79	0.76	4
1996	0.62	0.59	6	0.17	0.17	-1	0.79	0.76	4
1997	0.62	0.58	6	0.17	0.17	-1	0.78	0.75	4
1998	0.61	0.57	6	0.17	0.17	-1	0.77	0.74	4
1999	0.62	0.59	6	0.17	0.17	-2	0.79	0.76	4
2000	0.61	0.58	6	0.17	0.17	-1	0.78	0.75	4
2001	0.57	0.53	6	0.16	0.16	0	0.72	0.69	5
2002	0.56	0.53	6	0.15	0.15	0	0.72	0.68	5
2003	0.50	0.47	7	0.14	0.14	1	0.64	0.61	6
2004	0.57	0.53	7	0.16	0.15	1	0.72	0.69	5
2005	0.52	0.49	7	0.15	0.14	3	0.67	0.63	6
2006	0.52	0.48	8	0.14	0.14	3	0.67	0.62	7
2007	0.53	0.49	8	0.15	0.14	4	0.67	0.62	7
2008	0.53	0.49	9	0.15	0.14	5	0.68	0.63	8
2009	0.53	0.49	9	0.15	0.14	6	0.68	0.63	8
2010	0.54	0.50	9	0.15	0.14	7	0.69	0.64	9
2011	0.54	0.50	9	0.15	0.14	6	0.69	0.64	8
2012	0.53	0.49	9	0.15	0.14	6	0.68	0.63	8
2013	0.53	0.49	9	0.15	0.14	6	0.68	0.62	8
2014	0.53	0.49	9	0.15	0.14	7	0.68	0.62	9
2015	0.53	0.48	9	0.15	0.14	7	0.68	0.62	9
2016	0.55	0.51	9	0.15	0.14	6	0.70	0.65	8
2017	0.55	0.51	9	0.15	0.14	7	0.70	0.65	9
2018	0.54	0.49	9	0.15	0.14	7	0.69	0.63	9
2019	0.54			0.15			0.69		

Source: SER.

CO₂ emissions from liming (3G)

The activity data for liming for 2018 had to be updated, as erroneously one of the two main suppliers had 2019 data provided, rather than 2018 data, resulting in a slight change in the 2018 CO₂ emissions from liming.

The recalculated figures are presented in Table A3-7, with a marginal change in 2018.

Table A3-7: Recalculation of CO₂ emissions from managed soil in Gg (CO₂-equivalent)

3 - Agriculture CO ₂ Emissions (Gg by source & sink category)			
Year	3G - Liming		Impact of recalculation %
	New	Old	
1990	0.26	0.26	0
1991	0.46	0.46	0
1992	0.66	0.66	0
1993	1.02	1.02	0
1994	1.49	1.49	0
1995	1.22	1.22	0
1996	1.07	1.07	0
1997	1.59	1.59	0
1998	2.19	2.19	0
1999	1.22	1.22	0
2000	2.04	2.04	0
2001	2.48	2.48	0
2002	3.15	3.15	0
2003	3.05	3.05	0
2004	2.62	2.62	0
2005	4.23	4.23	0
2006	3.30	3.30	0
2007	3.34	3.34	0
2008	3.10	3.10	0
2009	4.41	4.41	0
2010	3.81	3.81	0
2011	5.29	5.29	0
2012	5.48	5.48	0
2013	6.29	6.29	0
2014	6.95	6.95	0
2015	7.36	7.36	0
2016	6.99	6.99	0
2017	8.80	8.80	0
2018	10.97	10.98	-0.10
2019	10.38		

Source: SER.

CO₂ emissions from urea application (3H)

An alternative data source could be identified and collected data on urea allowed to estimate CO₂ emissions occurring from urea application (CRF 3H) for the first time in the current submission. For details on the used activity data and the applied methodology see section 5.10.

CO₂ emissions from carbon-containing fertilizer (3I)

An alternative data source could be identified and collected data on carbon-containing fertilizer allowed to estimate CO₂ emissions from carbon-containing fertilizer (3 I) for the first time in the current submission. For details on the used activity data and the applied methodology see section 5.11.

Annex 3B – Uncertainty calculations for sector 3 - Agriculture

Models are not an exact representation of real life and therefore their estimates are to a certain extent uncertain. The model used for the uncertainty calculations for sector 3 – Agriculture uses Monte Carlo simulation technique, and was built in MS Excel using the add-in software Palisade @Risk 7.5. A probability distribution was chosen for most parameters to manage uncertainty, whereby using mostly either a Pert-distribution or a uniform-distribution. A value was drawn from such distributions iteratively using Latin Hypercube sampling with 10,000 iterations. The 95% uncertainty interval (95% UI), corresponding to the 2.5th and 97.5th percentiles of the results' distribution was computed to define the uncertainty, for the agriculture sector as a whole, as well as for the separate CRF categories.

A detailed description of the parameters values used for the uncertainty analysis is given hereafter.

General aspects

Livestock numbers, manure management system (MMS), N excretion rates, and N flow were used in several categories in the agricultural emission calculations and are therefore summarized in this section.

Livestock numbers

Despite the high coverage, and despite using the “SANITEL” database¹⁴² for cattle, a certain uncertainty remains when using agricultural census. Uncertainties for cattle were obtained by comparing average annual “SANITEL” livestock numbers with the one extracted for the agriculture census (in recent years, livestock numbers on 1st April). For pigs we compared the 1st December census with the spring census. For goats, the reported monthly animal registers as delivered by the farmers within the “landwirtschaftliche Testbetriebsnetz (LTBN)¹⁴³” were consulted.¹⁴⁴ According to these data, there was one goat kit born for two dairy goat ewes kept.¹⁴⁵ Taking the number of dairy goat ewes and multiplying them by 0.5, the number of goat kits were estimated and compared with the numbers reported in the agricultural census in different years. For all other animal categories, no data was available, and expert judgement¹⁴⁶ was used to determine the uncertainty.

¹⁴² In Luxemburg each single cattle has to be registered and is followed from birth or import until end of life (slaughter or natural death) or export, whatever comes first. All those movements are registered in the “SANITEL” database (ASV 2018).

¹⁴³ The LTBN is situated in the division «Division de la gestion, de la comptabilité et de l'entraide agricoles», at the Service d'Economie Rurale. This division gets from about 840 farms farm accountancy data (<https://agriculture.public.lu/de/betriebsfuhrung/buchfuhrung.html>). Out of these farms, a representative sample of 450 farms are selected (<https://agriculture.public.lu/de/betriebsfuhrung/buchfuhrung/testbetriebsnetz.html>) to form the sample size shared with the FADN (Farm Accountancy data network); for more details see: <https://ec.europa.eu/agriculture/rica/>.

¹⁴⁴ Pers. Communication : Marc Schmit and Paul Jacqué, Service d'Economie Rurale - Division de la gestion, de la comptabilité et de l'entraide agricoles, December 2018.

¹⁴⁵ This observation was confirmed by the goat farmers (Own survey conducted in November 2018 between goat famers keeping in 2017 approximately 70% of all female dairy goats).

¹⁴⁶ R. Barthelmy and M.-J. Mangen; Service d'Economie Rurale – Division des statistiques agricoles, des relations extérieures et des marchés agricoles, January 2019

The uncertainty of livestock numbers was simulated by multiplying the livestock numbers as obtained from the census by the uncertainty parameters presented in table A3-8.

Table A3-8: Uncertainty in livestock numbers

	Uncertainty			Distribution used	Notes
	Min	ML	Max		
Calves < 1 year ⁴⁾	99%	100%	100%	Pert	The weighted yearly average correspond to 99% of the census data ¹⁾
Female young female cattle 1-2 years	99%		101%	Uniform	¹⁾
Heifers > 2 years	100%		105%	Uniform	¹⁾
Fattening bulls 1-2 years	98%	100%	100%	Pert	¹⁾
Mature male cattle > 2 years	95%		102%	Uniform	¹⁾
Lactating dairy cows ⁵⁾	99%	100%	101%	Pert	¹⁾
Suckler cows ⁴⁾	98%	100%	100%	Pert	¹⁾
Sows	95%		105%	Uniform	^{2,3)}
Fattening pigs	95%		105%	Uniform	^{2,3)}
Weaners	95%		105%	Uniform	^{2,3)}
Mature sheep	90%	100%	100%	Pert	³⁾ ; Similar as for goats
Sheep lambs < 1 year ⁶⁾	75%		125%	Uniform	³⁾ ; Similar as for goats
Mature goats	90%	100%	100%	Pert	³⁾ ; The maximum of mature goats kept on the farms is reached in spring, i.e. the time when the census is conducted
Goats - kit < 1 year ⁷⁾	75%		125%	Uniform	³⁾
Horses	95%		105%	Uniform	³⁾
Broilers	95%		105%	Uniform	³⁾
Laying hens	90%		110%	Uniform	³⁾
Other poultry	90%		110%	Uniform	³⁾
Ostriches	90%		110%	Uniform	³⁾
Rabbits - Breeding animals	90%		110%	Uniform	³⁾
Other rabbits	90%		110%	Uniform	³⁾
Deer	90%		110%	Uniform	³⁾

- 1) Based on SANITEL data, and comparing with census data.
- 2) Comparing December census data with spring census data.
- 3) Expert Judgement (R. Barthelmy & MJ Mangen, Service d'économie rurale – Division des statistiques agricoles, des relations extérieures et des marchés agricoles; January 2019).
- 4) The percentage of female calves was modelled with minimum 64%, most likely 66% and maximum 68%, based on SANITEL data, according to which in 2017, 66% of the calves would have been female calves.
- 5) For the period 2008-2017 the percentage of culled cows ($P_{\text{cull cows}}$) was modelled as a Pert-distribution with most likely 9.15%, minimum 7.1% and maximum 10.8% of the total consisting of lactating dairy cows and non-lactating dairy cows (STATEC 2018).

- 6) The percentage of fattening lambs being slaughtered was modelled as uniform distribution with minimum 75% and maximum 85%. Slaughter age was 6 months (most likely), with minimum 5 months and maximum 7 months (modelled using a Pert-distribution).
- 7) The percentage of goat kits being slaughtered was modelled as uniform distribution with minimum 45% and maximum 55%. Slaughter age was 1.5 months (most likely), with minimum 1.25 months and maximum 1.75 months (modelled using a Pert-distribution).

Nitrogen excretion factor (N.ex)

Except for dairy cows was the assumed $N.ex_i$ per head, respectively per place per year for animal category i (i = are all the different animal categories considered in the emission calculations, except for lactating dairy cows) multiplied by an uncertainty factor with most likely 100%, minimum 80% and maximum 120%, and modelled using a pert-distribution.

For lactating dairy cows, the calculated daily milk yield, the assumed milk protein and the assumed milk urea, - all factors determining the N.ex per lactating dairy cow per year - were considered to be to some extent uncertain. The daily milk yield was calculated by dividing the national milk production by the number of lactating dairy cows. The national milk production in itself was an estimation, including the quantity delivered to the dairy industry, the quantity directly sold at the farm gate, and quantities of milk used on the farm. The quantity delivered to the dairy industry (i.e. 97% in 2016)¹⁴⁷ was considered to be the minimum of the national milk production; 100% was seen as most likely value and 103%¹⁴⁸ was set as maximum. The uncertainty was modelled using a Pert-distribution. The uncertainty of the urea measurements is $\pm 10\%$ (Source: Tom Engel, pers. communication 9th November 2018; Tom Engel, personal communication Administration des service technique de l'agriculture (ASTA) - Service d'analyse du lait) and was therefore modelled as being uniformly distributed with minimum 90% and maximum 110%. The uncertainty range for milk protein and milk fat were assumed to be minimum 99%, most likely 100% and maximum 101%.

Manure management system

Information on manure management system were available from previous submission. In order to be able to estimate the uncertainty certain re-arrangements had to be made. These were:

- The proportion of excreta deposited during grazing ($x_{\text{grazing } i}$) for animal category i = MMS-pasture.
- The proportion of livestock manure handled as slurry for animal category i ($x_{\text{slurry } i}$) = $[(MMS\text{-liquid}_{(i)} + MMS\text{-feed}_{(i)}) / (MMS\text{-liquid}_{(i)} + MMS\text{-feed}_{(i)} + MMS\text{-solid}_{(i)})]$
- The proportion of liquid livestock manure stored on the farms ($x_{\text{slurry_storage } i}$) = $[(MMS\text{-liquid}_{(i)}) / (MMS\text{-liquid}_{(i)} + MMS\text{-feed}_{(i)})]$.

¹⁴⁷ About 3% of the milk production in 2016 was used on farms to feed calves or by the farmers family (Source: unpublished FADN data). These 3% were used to estimate the national milk production. Personal communication: Fränk Steichen; SER – Statistiques agricoles, marches agricoles et relations extérieures; 29-02-2019

¹⁴⁸ Assuming that not 3% of the national milk production, but the double would be used on the farm or by the farmers family.

The proportion of excreta deposited during grazing ($x_{\text{grazing } i}$) for animal category i (i = are all the different animal categories considered in the emission calculations) was multiplied by an uncertainty factor with most likely 100%, minimum 90% and maximum 110%, and modelled using a pert-distribution. The proportion of excreta deposited within buildings ($x_{\text{building } i}$) was the remaining proportion that animals were not grazing ($x_{\text{building } i} = 100\% - x_{\text{grazing } i}$).

The proportion of livestock manure handled as slurry for animal category i ($x_{\text{slurry } i}$) was multiplied by an uncertainty factor with most likely 100%, minimum 80% and maximum 120%, and modelled as a pert-distribution. The proportion of livestock manure handled as solid ($x_{\text{solid } i}$) was calculated using the following formula: $x_{\text{solid } i} = 100\% - x_{\text{slurry } i}$.

The proportion of liquid livestock manure stored on the farm for animal category i ($x_{\text{slurry_storage } i}$) was multiplied by an uncertainty factor with most likely 100%, minimum 80% and maximum 120%, and was modelled as a pert-distribution. The proportion of liquid livestock manure used to feed bio digester was calculated: $x_{\text{slurry_digester } i} = 100\% - x_{\text{slurry_storage } i}$.

No uncertainty was modelled for the proportion of solid manure stored on the farm ($x_{\text{solid_storage } i}$) as $x_{\text{solid_storage } i}$ corresponds to $x_{\text{solid } i}$, presuming that neither solid manure would be directly spread on the fields, nor would solid manure be used as feeding material for the bio digester. None of these two is common praxis in Luxembourg, why assumed that they would not occur.

The different manure management system were then calculated using the following formulas:

$$\text{MMS-pasture}_{(ij)} = x_{\text{grazing } i} \cdot$$

$$\text{MMS-liquid}_{(ij)} = (x_{\text{slurry_storage } i} / (x_{\text{building } i})).$$

$$\text{MMS-feed}_{(ij)} = (x_{\text{slurry_digester } i} / (x_{\text{building } i})).$$

$$\text{MMS-solid}_{(ij)} = (x_{\text{solid } i} / (x_{\text{building } i})).$$

Storage of slurry

There are three types of storage systems, namely slurry tank without cover ($P_{\text{slurry_tank_open}}$), slurry tank with fixed cover ($P_{\text{slurry_tank_closed}}$) and slurry stored underneath slatted floor ($P_{\text{slurry_tank_underneath}}$).

The data was collected during the 2010 SPAM, with a response rate of >95%. The used parameters in the stochastic analysis are summarized in Table A3-9.

Table A3-9: Uncertainty of the methane emission factor for swine, goats, horses and deer

	Uncertainty			Distribution used	Notes
	Min	ML	Max		
Slurry tank – open ($P_{\text{Slurry_tank_open}}$)	10%	10.8%	12%	Pert	Assuming -1% and +1%
Slurry tank with fixed cover ($P_{\text{Slurry_tank_covered}}$)	13%	14.8%	16%	Pert	Assuming -1% and +1%
Slurry storage underneath slatted floor >1 month ($P_{\text{Slurry_tank_underneath}}$)				Calculated	$P_{\text{Slurry_tank_underneath}} = 100\% - P_{\text{Slurry_tank_open}} - P_{\text{Slurry_tank_covered}}$

In case of cattle slurry stored in an open tank, it was assumed that most likely 80% of the stored slurry would be covered with a natural crust, minimum 75% and maximum 85% ($P_{\text{Slurry_tank_open_NaturalCrust(cattle)}}$). The percentage of cattle slurry stored in open tank without having a natural crust were calculated ($P_{\text{Slurry_tank_open_withoutNaturalCrust(cattle)}} = 100\% - P_{\text{Slurry_tank_open_NaturalCrust(cattle)}}$).

Methane emissions from enteric fermentation (3A)

The uncertainty w.r.t. livestock numbers and manure management system were described in detail in the previous section (i.e. general aspects). The uncertainty of the used emission factors is described in the current section.

Enteric fermentation for cattle and sheep were estimated using a Tier 2 methodology. For all other animals a Tier 1 methodology was applied.

Tier 1

Methane emissions from enteric fermentation for swine, goats, horses and deer was estimated using a Tier 1 methodology. The uncertainty range of the methane emission factors (EF) was based on the IPCC guideline (IPCC 2006a) for developed countries and assuming an uncertainty of $\pm 40\%$ for swine, goats, horses, and deer, resulting in the values presented in table A3-10.

Table A3-10: Uncertainty of the methane emission factor for swine, goats, horses and deer

Animal category	CH ₄ EF (kg CH ₄ /head/year)		Distribution used	Source
	Min	Max		
Swine (i.e. sows, fattening pigs & weaners)	0.9	2.1	Uniform	Table 10.10 (IPCC 2006a)
Goats (mature goats & lambs)	3	7	Uniform	Table 10.10 (IPCC 2006a)
Horses	10.8	25.2	Uniform	Table 10.10 (IPCC 2006a)
Deer	12	24	Uniform	Table 10.10 (IPCC 2006a)

Tier 2

Methane emissions from enteric fermentation for cattle and sheep were estimated using a Tier 2 methodology.

Gross energy (GE) for cattle and sheep

The uncertainty for gross energy (GE) for cattle and sheep was assumed to be $\pm 20\%$, and was modelled by multiplying the estimated GE_i by an uncertainty factor that was uniformly distributed with minimum 80% and maximum 120%.

The digestibility energy (DE%) factor was assumed to vary by $\pm 5\%$.

Methane conversion factor (Y_m)

The methane conversion factor (Y_m) for cattle was modelled as a uniform-distribution with a minimum value of 5.5 and a maximum value of 7.5.

The methane conversion factor (Y_m) for mature sheep was modelled as a uniform-distribution with a minimum value of 5.5 and a maximum value of 7.5, and for lambs younger than 1 year Y_m was modelled as uniformly distributed with a minimum value of 3.5 and a maximum value of 5.5.

Methane emissions from manure management (3Ba)

The uncertainty w.r.t. livestock numbers and manure management system were described in detail in the first section of Annex 3B (i.e. general aspects). The uncertainty of the used emission factors is described in the current section.

Methane emission from manure management for deer was estimated using a Tier 1 methodology. For all other animals a Tier 2 methodology was applied.

Tier 1

The uncertainty range of the methane emission factors for manure management for deer was based on the IPCC 2006 guidelines, Table 10.16 (IPCC 2006a) whereby assuming an uncertainty of $\pm 30\%$, which was modelled as pert-distribution with as a minimum value of 0.154, a most likely value of 0.22, and a maximum value of 0.286.

Tier 2

Except for swine and cattle was the uncertainty range for maximum methane producing capacity for manure produced by livestock category i ($B_{o(i)}$) based on IPCC 2006 guidelines (IPCC 2006b). A similar uncertainty range ($\pm 15\%$) was used for B_o swine and cattle, whereby assuming an uniform distribution. The used values are summarized in table A3-11.

Table A3-11: Uncertainty of methane producing capacity for manure produced by livestock category i ($Bo(i)$)

Animal category i	$Bo(i)$		Distribution used	Note/Source:
	Min	Max		
Cattle	0.19125	0.25875	Uniform	+/-15% (IPCC 2006a)
Swine	0.25925	0.35075	Uniform	+15%(IPCC 2006a)
Sheep	0.1615	0.2185	Uniform	(IPCC 2006a); Table 10.A9
Goats	0.153	0.207	Uniform	(IPCC 2006a); Table 10.A9)
Horses	0.255	0.345	Uniform	(IPCC 2006a); Table 10.A9
Broilers	0.306	0.414	Uniform	(IPCC 2006a); Table 10.A9
Laying hens	0.3315	0.4485	Uniform	(IPCC 2006a); Table 10.A9
Other poultry	0.306	0.414	Uniform	(IPCC 2006a); Table 10.A9
Ostriches	0.2125	0.2875	Uniform	(IPCC 2006a); Table 10.A9
Rabbits (breeding female animals and other rabbits)	0.272	0.368	Uniform	(IPCC 2006a); Table 10.A9

The uncertainty range for daily volatile solid excreted for livestock category i (VS_i) was based on IPCC 2006 guidelines (IPCC 2006b).

The used values are summarized in Table A3-12.

Table A3-12: Uncertainty for daily volatile solid excreted for livestock category i (VS_i)

Animal category i	VS_i		Distribution used	Source: (IPCC 2006a)
	Min	Max		
Sows	0.345	0.575	Uniform	Table 10.A8
Fattening pigs	0.225	0.375	Uniform	Table 10.A7
Weaners	0.225	0.375	Uniform	Table 10.A7
Horses	1.065	3.195	Pert	Table 10.A9
Goats (Mature goats and lambs)	0.15	0.45	Uniform	Table 10.A9
Broilers	0.005	0.015	Uniform	Table 10.A9
Laying hens	0.01	0.03	Uniform	Table 10.A9
Other poultry	0.01	0.03	Uniform	Table 10.A9
Ostriches	0.58	1.74	Uniform	Table 10.A9
Rabbits (breeding female animals and other rabbits)	0.05	0.15	Uniform	Table 10.A9

VS_i for cattle and sheep was calculated according to equation 10.24 in the IPCC 2006 guidelines (IPCC 2006a). The uncertainty for VS_i for lactating dairy cows was assumed to be $\pm 20\%$, according to Table 10.A4 in the IPCC 2006 guidelines (IPCC 2006a), and was modelled by multiplying the estimated VS_i by an uncertainty factor that was uniformly distributed with minimum 80% and maximum 120%. The uncertainty for VS_i for cattle was assumed to be $\pm 35\%$, according to Table 10.A5 in the IPCC 2006 guidelines (IPCC 2006a), and was modelled by multiplying the estimated VS_i by an uncertainty factor that was uniformly distributed with minimum 65% and maximum 135%. The uncertainty for VS_i for sheep was assumed to be $\pm 50\%$, according to Table 10.A9 in the

IPCC 2006 guidelines (IPCC 2006a), and was modelled by multiplying the estimated VS_i by an uncertainty factor that was uniformly distributed with minimum 50% and maximum 150%.

And as already indicated in the previous section (Methane emissions from enteric fermentation), the digestibility energy (DE%) was assumed to vary by $\pm 5\%$.

N₂O emissions from manure management (3Bb)

Activity data for direct N₂O emissions from manure management

The uncertainty w.r.t. livestock numbers, N_{ex} and manure management system were described in detail in the first section of Annex 3B (i.e. general aspects).

Emission factors for direct N₂O emissions from manure management

The uncertainty range of the default emission factors (EF) for direct N₂O emissions from manure management as presented in Table 10.21 from the IPCC 2006 guidelines (IPCC 2006a) were assumed to be a factor 2. Assuming that EFs would be uniformly distributed, the minimum was equal to the default value divided by 2, and the maximum was equal to the default value multiplied by 2.

Nitrogen loss due to volatilization of NH₃ and NO_x from manure management – activity data

The assumed uncertainty range around the estimated Nitrogen loss due to volatilization of NH₃ and NO_x, as obtained from IIR 2021 (Schuman et al. 2021), was $\pm 25\%$ for NH₃ associated Nitrogen losses and -50% to $+100\%$ for NO_x associated Nitrogen losses, both were based on the 2019 EMEP guidelines (EMEP 2019a). The uncertainty was modelled by multiplying the NH₃ associated Nitrogen losses by an uncertainty factor that was uniformly distributed with minimum 75% and maximum 125%, and by multiplying the NO_x associated Nitrogen losses by an uncertainty factor that was uniformly distributed with minimum 50% and maximum 200%.

Nitrogen loss due to volatilization of NH₃ and NO_x from manure management – emission factors

The uncertainty range used for the Emission factor – N volatilization and re-deposition for indirect soil N₂O emissions was based on Table 11.3 of the 2006 IPCC guidelines (IPCC 2006b) and modelled as uniformly distributed with minimum 0.002 and maximum 0.05.

N₂O emissions from managed soils (3D)

Activity data for direct N₂O emissions from managed soils

Areas of cultivated crops were derived from the Agricultural census. Up to the year 2006 was the agricultural census based on self-reported data from the farmers for the 15th of May of each year¹⁴⁹ by STATEC (Institut national de la statistique et des études économiques du Grand-Duché de Luxembourg), lately in collaboration with the SER (Service d'Economie Rurale)¹⁵⁰. Since 2007 were the data extracted from the data collected from the forms filled in by the farmers to apply for e.g. direct payments and other subsidies, respective for the compulsory accident insurance. There were controls conducted over the year. The uncertainty of annual area for the different cultivated crops was therefore assumed to be uniformly distributed by $\pm 1\%$.

The uncertainty of the harvest annual dry matter yield for winter wheat, barley, oats, triticale and rapeseed was assumed to be uniformly distributed by $\pm 10\%$. For those crops, large quantities were sold at farm-gate with high quality data collected within the Luxembourgish LTBN, the source used to estimate annual harvest yields (Fränk Steichen, December 2018; Personal communication; Service d'économie rurale – Division des statistiques agricoles, des relations extérieures et des marchés agricoles). For all other crops, the uncertainty of the harvest annual dry matter yield was assumed to be uniformly distributed with a range of $\pm 20\%$.

The uncertainty for the total quantity of N from synthetic fertilizers was modelled as uniformly distributed by $\pm 10\%$ (EMEP 2019b) When reallocating the total N quantity to the different synthetic N fertilizers, an uncertainty range of $\pm 10\%$ was assumed, except for Calcium ammonium nitrate (CAN). The estimated quantities of CAN were calculated by subtracting all other N-fertilizer from the total quantity of N from synthetic fertilizer. Total quantity and the different synthetic N-fertilizers, both are derived from the Luxembourgish LTBN data.

Activity data for sewage sludge and compost were based on annual reports with information on produced quantities and average N-content, as well as quantities (or proportion) delivered to the agriculture sector. The uncertainty on the quantities of N applied from sewage sludge and N applied from compost was therefore assumed to be $\pm 25\%$ (EMEP 2019b). A similar uncertainty was assumed for the quantities of mineralisation of N in soil ($\pm 25\%$), and for activity data on quantities of waste and energy crops used in biodigestate, ($\pm 25\%$) and later applied as other organic N fertilizer on managed soils.

The uncertainty range of the slope and the intercept used when estimating the above-ground residues dry matter was based on the values provided in Table 11.2 from the IPCC 2006 guidelines (IPCC 2006b). The used values for the slope and for the intercept are summarized in Table A3-13 and Table A3-14. No data was provided for rape, why using the values for grains as a proxy, similar to Haenele et al. 2018.

¹⁴⁹ Up to 2011 this was the 15th of May, and since 2012 it is the 1st of April

¹⁵⁰ A short description of the underlying legislation and other details can be found on: <https://statistiques.public.lu/en/methodology/methodes/entreprises/Agriculture/agriculture/index.html> accessed on 5-12-2018.

Table A3-13: Uncertainty of the slope used for estimating above-ground residues dry matter

Crop	Slope		Distribution used	Source: (IPCC 2006b)
	Min	Max		
winter_wheat	1.5617	1.6583	Uniform	Table 11.2
spring_wheat	1.2255	1.3545	Uniform	Table 11.2
rye and mix-cereals	0.545	1.635	Uniform	Table 11.2 (all grains)
Barley	0.9016	1.0584	Uniform	Table 11.2
oat	0.8645	0.9555	Uniform	Table 11.2
triticale	1.0682	1.1118	Uniform	Table 11.2 (all grains)
rape	1.0682	1.1118	Uniform	Table 11.2 (all grains)
potatoes	0.031	0.169	Uniform	Table 11.2
Pulses	0.9153	1.3447	Uniform	Table 11.2
grain maize	0.9991	1.0609	Uniform	Table 11.2
maize for silage	0.9991	1.0609	Uniform	Table 11.2
fodder beet	0.031	0.169	Uniform	Table 11.2 (Tubers)
clover, grass-clover leys, fodder production on arable land	0.15	0.45	Uniform	Table 11.2 (non-N-fixing forage)
pasture and meadows	0.15	0.45	Uniform	Table 11.2

Table A3-14: Uncertainty of intercept used for estimating above-ground residues dry matter

Crop	Intercept		Distribution used	Source: (IPCC 2006b)
	Min	Max		
winter_wheat	0.3	0.5	Uniform	Table 11.2
spring_wheat	0.555	0.945	Uniform	Table 11.2
rye and mix-cereals	0.8272	0.9328	Uniform	Table 11.2 (all grains)
Barley	0.3481	0.8319	Uniform	Table 11.2
oat	0.8188	0.9612	Uniform	Table 11.2
triticale	0.8272	0.9328	Uniform	Table 11.2 (all grains)
rape	0.8272	0.9328	Uniform	Table 11.2 (all grains)
potatoes	0.318	1.802	Uniform	Table 11.2
pulses	0.374	1.326	Uniform	Table 11.2
grain maize	0.4941	0.7259	Uniform	Table 11.2
maize for silage	0.4941	0.7259	Uniform	Table 11.2
fodder beet	0.318	1.802	Uniform	Table 11.2 (tubers)
clover, grass-clover leys, fodder production on arable land pasture and meadows				Most likely value used as no range provided

The uncertainty range for the ratio of below-ground residues to above-ground biomass (R_{BG-BIO}) was based on the values provided in Table 11.2 from the IPCC 2006 guidelines (IPCC 2006b). The used values are summarized in Table A3-15.

Table A3-15: Uncertainty for the ratio of below-ground residues to above-ground biomass (R_{BG-BIO})

Crop	R_{BG-BIO}		Distribution used	Source: (IPCC 2006b)
	Min	Max		
winter_wheat	0.1357	0.3243	Uniform	Table 11.2
spring_wheat	0.2072	0.3528	Uniform	Table 11.2
rye and mix-cereals	0.1848	0.2552	Uniform	Table 11.2 (all grain)
Barley	0.1474	0.2926	Uniform	Table 11.2
oat	-0.05	0.55	Uniform	Table 11.2
triticale	0.1848	0.2552	Uniform	Table 11.2 (all grain)
rape	0.1848	0.2552	Uniform	Table 11.2 (all grain)
potatoes	0.2	0.2	Uniform	Table 11.2
pulses	0.1045	0.2755	Uniform	Table 11.2
grain maize	0.1628	0.2772	Uniform	Table 11.2
maize for silage	0.1628	0.2772	Uniform	Table 11.2
fodder beet	0.2	0.2	Uniform	Table 11.2 (tubers)
clover, grass-clover leys, fodder production on arable land	0.4	1.2	Uniform	Table 11.2
pasture and meadows	0.4	1.2	Uniform	Table 11.2

The uncertainty range of the emission factor for N additions from crop residues as a result of loss of soil carbon was based on Table 11.1 from the 2006 IPCC guidelines and assumed to be uniformly distributed with minimum 0.003 and maximum 0.03 (IPCC 2006b).

Emission factors for direct N₂O Emissions from managed soils

The uncertainty range of the emission factor (EF) for N additions from synthetic N fertilisers; animal manure (including biodigestate originating from animal manure), sewage sludge, compost, biodigestate originating from energy crops and waste and N mineralised from mineral soil as a result of loss of soil carbon was based on Table 11.1 from the 2006 IPCC guidelines, and assumed to be uniformly distributed with minimum 0.003 and maximum 0.03 (IPCC 2006b).

The uncertainty range of the emission factor for N₂O emissions from urine and dung N deposited on pasture from cattle, poultry and pigs was based on Table 11.1 from the 2006 IPCC guidelines, and was assumed to be uniformly distributed with minimum 0.007 and maximum 0.06 (IPCC 2006b). The uncertainty range of the emission factor for N₂O emissions from urine and dung N deposited on pasture from sheep and “other animals” was based on Table 11.1 from the 2006 IPCC guidelines, and was assumed to be uniformly distributed with minimum 0.003 and maximum 0.03 (IPCC 2006b).

Indirect N₂O emissions from managed soils - Activity data

The assumed uncertainty range around the estimated Nitrogen loss due to volatilization of NH₃, as obtained from IIR 2021 (Schuman et al. 2021), was +/- 50% for NH₃ associated Nitrogen losses (EMEP 2019b). The uncertainty was modelled by multiplying the NH₃ associated Nitrogen losses by an uncertainty factor that was uniformly distributed with minimum 50% and maximum 150%.

The uncertainty range around the estimated Nitrogen loss due to volatilization of NO_x , as obtained from IIR 2021 (Schuman et al, 2021), was derived by assuming an EF for NO emissions from N applied in fertilizer, animal manure (including biogas originating from animal manure), compost and other organic waste (i.e. biogas originating from energy crops and other waste) of minimum 0.05, most likely 0.04 and maximum 0.104 (Pert-distribution) (EMEP 2019b), and by assuming an EF for NO emissions from N deposited during grazing, N applied in sewage sludge and N in crop residues of minimum 0.008, most likely 0.04 and maximum 0.1624 (EMEP 2019b).

The uncertain range of the fraction of all N added to/mineralized in managed soils ($\text{Fra}_{\text{CLeach}}$) was based on Table 11.3 of the 2006 IPCC guidelines (IPCC 2006b) and modelled as uniformly distributed with minimum 0.1 and maximum 0.8.

Indirect N_2O emissions from managed soils - Emission factors

The uncertainty range for the EF for indirect N_2O emissions originating from atmospheric deposition of N volatilised from managed soils was based on Table 11.3 from the 2006 IPCC guidelines, and was assumed to be uniformly distributed with minimum 0.002 and maximum 0.05 (IPCC 2006b).

The uncertainty range used for the EF for indirect N_2O emissions originating from leaching and runoff from managed soils was based on Table 11.3 of the 2006 IPCC guidelines (IPCC 2006b) and modelled as uniformly distributed with minimum 0.0005 and maximum 0.025.

CO₂ emissions from liming (3G)

Activity data

The uncertainty range for the quantities of dolomite and for limestone, both based on data collected by interviews with the main sellers, was assumed to be uniformly distributed by $\pm 20\%$.

Emission factors

The uncertainty range for the EFs for limestone and dolomite was based on the 2006 IPCC guidelines on page 11.27 (IPCC 2006b)), with minimum -50%, whereas the default value was used as most likely and maximum value (Pert-distribution).

CO₂ emissions from urea application (3H)

Activity data

The quantities of urea was indirectly derived from the estimated total quantity of N from synthetic N fertilizer (see above “activity data for N₂O emissions from managed soils). But to take into consideration that the N-content in urea might vary, the uncertainty of the N-content was assumed to be minimum 45%, most likely 46%¹⁵¹ and maximum 47% (Pert-distribution).

Emission factors

The same uncertainty range as for liming was assumed for the EF for urea fertilisation (2006 IPCC guidelines on page 11.32 (IPCC 2006b)), with minimum -50% and the default value as most likely and maximum value (using a pert distribution).

CO₂ emissions from carbon-containing fertilizer (3I)

Activity data

The quantities of Calcium ammonium nitrate (CAN) was indirectly derived from the estimated total quantity of N from synthetic N fertilizer (see above “activity data for N₂O emissions from managed soils). But to take into consideration that the N-content in CAN might vary, the uncertainty w.r.t. N-content of CAN was modelled as minimum 22%, most likely 27%¹⁵² and maximum 28% using a Pert-distribution. Furthermore, the CaO content was modelled as minimum 10%, most likely 12%¹⁵³ and maximum 14%, using a Pert-distribution.

Emission factors

The uncertainty range for the EFs for other carbon-containing fertilizer was based on the 2006 IPCC guidelines on page 11.27 (IPCC 2006b)), with minimum -50%, whereas the default value was used as most likely and maximum value (Pert-distribution).

¹⁵¹ <https://de.eurochemagro.com/produkte/stickstoff-einzelduenger/harnstoff/>

¹⁵² https://de.eurochemagro.com/uploads/PDS_27N-weiss_KAS_5572_ANT_Deutschland.pdf#zoom=FitV

¹⁵³ https://de.eurochemagro.com/uploads/PDS_27N-weiss_KAS_5572_ANT_Deutschland.pdf#zoom=FitV

Changes of uncertainty calculations for sector 3 – Agriculture since last submission

Apart from the changes described in detail in Annex 3A, which too, had to some extent an impact on the results of the uncertainty calculation, there were three main changes, namely:

- **N₂O Emissions from manure management (3Bb)**

In the last submission, the estimation of nitrogen loss due to volatilization of NH₃ and NO_x from manure management were adapted from a TIER 1 to a TIER 2 methodology. However, this fact was not adapted in the uncertainty calculation, whereby uncertainty ranges for most of the NH₃-N EFs and NO_x-N EFs were used when estimating NH₃ emissions from buildings and storage and NO_x emissions from storage. In addition, were the nitrogen loss due to volatilization of NH₃ and NO_x multiplied with an uncertainty factor. This error was corrected for the current submission. In the current submission deterministic values for the NH₃-N EFs and NO_x-N EFs for emissions from buildings and storage are used (for more details see IIR 2021 (Schuman et al., 2021)), and the assumed uncertainty range around the estimated Nitrogen loss due to volatilization of NH₃ and NO_x, as obtained from IIR 2021 (Schuman et al. 2021), was +- 25% for NH₃ associated Nitrogen losses and -50% to +100% for NO_x associated Nitrogen losses. The uncertainty was modelled by multiplying the NH₃ associated Nitrogen losses by an uncertainty factor that was uniformly distributed with minimum 75% and maximum 125%, and by multiplying the NO_x associated Nitrogen losses by an uncertainty factor that was uniformly distributed with minimum 50% and maximum 200%.

- **N₂O Emissions from managed soils (3D)**

In the last submission, the estimation of nitrogen loss due to volatilization of NH₃ and NO_x from managed soils were adapted from a TIER 1 to a TIER 2 methodology. However, this fact was not adapted in the uncertainty calculation, whereby uncertainty ranges for most of the NH₃-N EFs and NO_x-N EFs were used when estimating NH₃ and NO_x emissions from managed soils. In addition, were the nitrogen loss due to volatilization of NH₃ and NO_x multiplied with an uncertainty factor. This error was corrected for the current submission. In the current submission the assumed uncertainty range around the estimated Nitrogen loss due to volatilization of NH₃, as obtained from IIR 2021 (Schuman et al., 2021) was +- 50% for NH₃ associated Nitrogen losses (EMEP 2019b). The uncertainty was modelled by multiplying the NH₃ associated Nitrogen losses by an uncertainty factor that was uniformly distributed with minimum 50% and maximum 150%. The uncertainty range around the estimated Nitrogen loss due to volatilization of NO_x, as obtained from IIR 2021 (Schuman et al. 2021) was derived by assuming an EF for NO emissions from N applied in fertilizer, animal manure (including biogas originating from animal manure), compost and other organic waste (i.e. biogas originating from energy crops and other waste) of minimum 0.05, most likely 0.04 and maximum 0.104 (Pert-distribution (EMEP 2019b)), and by assuming an EF for NO emissions from N deposited during grazing, N applied in sewage sludge and N in crop residues of minimum 0.008, most likely 0.04 and maximum 0.1624 (EMEP 2019b).

- **CO₂ Emissions from managed soils (3G)**

According to the 2006 IPCC guidelines on page 11.27 (IPCC 2006b)), the uncertainty for the EFs for limestone and dolomite is -50%. In previous submission the uncertainty range for the EFs for limestone and dolomite was therefore modelled with

minimum -50% and the default value as maximum using an uniform distribution. But this seems inappropriated as the default value as “most likely” value was not taken into account. In the current submission, the uncertainty range for the EFs for limestone and dolomite was therefore modelled with minimum -50%, whereas the default value was used as most likely and maximum value (Pert-distribution).

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Annex 4: CO₂ reference approach and comparison with sectoral approach, and relevant information on the national energy balance

Please refer to section 3.2.1 for a comparison of the reference approach and the sectoral approach.

The following tables summarize the data of the national energy balance (2000-2019). The data was submitted to AEV by Statec in November 2020.

Solid fuels (all) (tons)	2000	2005	2010	2015	2017	2018	2019
Total imports	187249	130641	113335	83873	78072	72576	73378
Total exports	2	2	1	12	42	40	11
Stock changes							
Gross inland deliveries	187248	130639	113334	83860	78031	72536	73367
Final consumption	187248	130639	113334	83860	78031	72536	73367
Total Industry	184438	129312	112266	82838	77343	72118	72921
other extractive industries	0	0					
food, beverages and tobacco	0	0					
textiles and leather	0	0					
wood and wood products	0	0					
pulp, paper and printing	0	0					
chemical and petro-chemical	0	0					
non-metallic mineral products	128192	89783	76056	62462	62820	58649	59344
iron and steel	45778	33006	26676	11871	5666	5187	5270
machinery	0	0					
transportation equipment	0	0					
other industries	0	0					
construction	10467	6523	9535	8505	8857	8282	8308
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential	2810	1328	1068	1023	687	418	445
Agriculture							
Non specified (others)							

Natural gas (m³)	2000	2005	2010	2015	2017	2018	2019
Total imports	757984857	1336605223	1364362316	874777108	791802470	778526375	779365513
Total exports							
Stock changes							
Gross inland deliveries	757984857	1336605223	1364362316	874777108	791802470	778526375	779365513
Final consumption	682619208	716627094	769927158	679641776	707004070	704083278	706465351
Total Industry	338053394	373871820	352929621	312969552	301731953	312913179	305871659
other extractive industries	51175	742055	405678	571726	99688	31814	33795
food, beverages and tobacco	8538974	6042655	4345036	6892147	6672682	4901788	4465280
textiles and leather	30709656	28092391	21283224	30794000	31137296	31001783	29668964
wood and wood products	292540	502126	214565	675831	1672817	397682	109720
pulp, paper and printing	5471186	8365197	2390990	2580026	2234514	713104	757510
chemical and petro-chemical	10400534	15567451	10477927	17613655	14561536	9884359	10278364
non-metallic mineral products	95851071	90463858	87738236	79606801	75049048	81564236	80602813
iron and steel	163666827	202470750	205986749	156010777	152889096	171485103	164764712
machinery	3330984	1590720	975226	3191385	2649903	845668	898329
transportation equipment	113808	338426	268440	401032	343856	109735	116569
other industries	16669159	16643239	14945081	9364137	8237423	8386828	10764224
construction	2844436	2910652	2564132	4777927	5772144	3459613	3271727
Total energy sector				0	0	0	0
Total transportation sector	2862172	1145907	2836975	1845318	1418659	1599544	1687814
Commercial and public services	164827432	109884658	152657606	115025877	100582721	113407432	119665757
Residential	176848039	231695729	261466366	249800387	303269919	276162201	279239148
Agriculture	28171	28979	36589	643	818	922	973
Non specified (others)							

Biogas (m³)	2000	2005	2010	2015	2017	2018	2019
Total imports							
Total exports							
Stock changes							
Gross inland deliveries	2016273	12093349	24860513	32958691	38393351	40473569	35200786
Final consumption	1158777	6950200	10908529	12923428	15702182	15849536	10712822
Total Industry				2574914	2637019	2554376	1542800
other extractive industries				4704	871	260	170
food, beverages and tobacco			0	56704	58317	40014	22523
textiles and leather				253353	272128	253074	149649
wood and wood products				5560	14620	3246	553
pulp, paper and printing				21227	19529	5821	3821
chemical and petro-chemical				144914	127262	80688	51843
non-metallic mineral products				654954	655899	665826	406556
iron and steel				1283557	1336191	1399869	831064
machinery				26257	23159	6903	4531
transportation equipment				3299	3005	896	588
other industries				77042	71992	68463	54294
construction				39310	50446	28242	16502
Total energy sector				0	0	0	0
Total transportation sector				15182	12399	13057	8513
Commercial and public services	777886	1152283	1417588	2878899	3109169	2884050	2777124
Residential				2055198	2650460	2254370	1408467
Agriculture	380891	5797917	9490942	5399234	7293135	8143683	4975919
Non specified (others)							

Motor gasoline (tons)	2000	2005	2010	2015	2017	2018	2019
Total imports	595007	494066	346851	275034	292725	315897	332470
Total exports	3000	1000	0	0	0	0	0
Stock changes	10203	-8073	-4467	-9506	508	-3203	-811
Gross inland deliveries	581804	501139	351318	284540	292217	319100	333281
Final consumption	581804	501139	351318	284540	292217	319099	333281
Total Industry	733	2602	2082	1914	1614	1729	1742
other extractive industries	25	41	35	65	8	9	9
food, beverages and tobacco	60	99	73	62	51	55	55
textiles and leather	3	7	6	4	77	82	83
wood and wood products	18	31	21	20	15	16	16
pulp, paper and printing	15	32	14	5	4	4	4
chemical and petro-chemical	46	128	66	14	23	25	25
non-metallic mineral products	28	9	5	122	73	78	79
iron and steel	109	166	148	72	62	66	67
machinery	21	44	37	27	22	24	24
transportation equipment	4	12	17	1	1	2	2
other industries	16	45	5	76	55	59	60
construction	386	1986	1518	1316	1127	1207	1216
Total energy sector	180	562	137	73	76	58	57
Total transportation sector	455863	384807	266371	199798	193914	219558	227648
Commercial and public services	5004	11937	14157	13840	12313	13189	13289
Residential	120025	101231	68571	68915	84299	84566	90545
Agriculture							
Non specified (others)							

Biogasoline (tons)	2000	2005	2010	2015	2017	2018	2019
Total imports	0	0	1103	10796	10502	15449	26624
Total exports	0	0	0	0	0	0	0
Stock changes	0	0	-14	-373	18	-157	-65
Gross inland deliveries	0	0	1117	11169	10484	15606	26689
Final consumption	0	0	1117	11169	10484	15606	26689
Total Industry	0	0	7	75	58	85	139
other extractive industries	0	0	0	3	0	0	1
food, beverages and tobacco	0	0	0	2	2	3	4
textiles and leather	0	0	0	0	3	4	7
wood and wood products	0	0	0	1	1	1	1
pulp, paper and printing	0	0	0	0	0	0	0
chemical and petro-chemical	0	0	0	1	1	1	2
non-metallic mineral products	0	0	0	5	3	4	6
iron and steel	0	0	0	3	2	3	5
machinery	0	0	0	1	1	1	2
transportation equipment	0	0	0	0	0	0	0
other industries	0	0	0	3	2	3	5
construction	0	0	5	52	40	59	97
Total energy sector	0	0	0	3	3	3	5
Total transportation sector	0	0	847	7843	6957	10738	18230
Commercial and public services	0	0	45	543	442	645	1064
Residential	0	0	218	2705	3024	4136	7251
Agriculture	0	0	0	0	0	0	0
Non specified (others)	0	0					

Diesel (tons)	2000	2005	2010	2015	2017	2018	2019
Total imports	997105	1839706	1748205	1562486	1535324	1626309	1667000
Total exports	2000	2000	0	593	580	1621	2907
Stock changes	5409	23781	-6786	-1933	-174	-5050	2778
Gross inland deliveries	989696	1813925	1754991	1563826	1534918	1629739	1661315
Final consumption	989698	1813925	1754991	1563826	1534918	1629739	1661315
Total Industry	22183	78704	62640	57896	48822	52295	52690
other extractive industries	753	1226	1047	1959	241	259	261
food, beverages and tobacco	1819	2994	2193	1872	1540	1649	1662
textiles and leather	104	199	172	130	2329	2495	2514
wood and wood products	545	923	624	602	458	491	495
pulp, paper and printing	441	963	435	149	116	124	125
chemical and petro-chemical	1392	3859	1988	438	699	749	754
non-metallic mineral products	856	262	161	3695	2213	2371	2389
iron and steel	3287	5024	4445	2185	1869	2002	2017
machinery	649	1320	1123	811	679	728	733
transportation equipment	123	375	498	37	44	47	47
other industries	490	1376	145	2288	1678	1797	1811
construction	11673	60089	45674	39806	34077	36501	36777
Total energy sector	979	3089	4143	2195	2312	1747	1735
Total transportation sector	865100	1559012	1471167	1298517	1283515	1374299	1426245
Commercial and public services	27279	65578	76769	75450	67126	71901	72445
Residential	59907	90923	119714	111661	114802	111913	90614
Agriculture	14250	16620	20557	18107	18340	17584	17585
Non specified (others)							

Gasoil (tons)	2000	2005	2010	2015	2017	2018	2019
Total imports	336101	294331	238262	244240	265002	263538	275775
Total exports	6000	6000	1978	48	64	164	370
Stock changes	29706	-11189	-10748	-5309	-7065	-669	10707
Gross inland deliveries	300395	299520	247032	249501	272003	264043	264698
Final consumption	298973	298947	246575	249055	271451	263661	264289
Total Industry	21818	17710	10029	7949	14961	15281	19147
other extractive industries	763	164	89	444	441	450	564
food, beverages and tobacco	2283	1412	729	1212	3354	3426	4292
textiles and leather	502	837	508	80	206	210	264
wood and wood products	336	285	133	20	37	38	47
pulp, paper and printing	470	348	93	33	45	46	57
chemical and petro-chemical	5148	4099	1768	2084	884	903	1132
non-metallic mineral products	840	506	196	1122	2892	2954	3701
iron and steel	8478	2439	1782	434	1008	1030	1291
machinery	1866	1695	1437	527	1548	1581	1981
transportation equipment	95	378	312	7	190	194	244
other industries	160	105	29	186	334	341	427
construction	836	5360	2684	1629	3498	3572	4476
Total energy sector	371	445	321	73	148	125	69
Total transportation sector	3584	3047	2371	3078	2487	2540	3183
Commercial and public services	56623	53940	46086	65732	100141	102284	128161
Residential	216577	223804	187768	172223	153713	143431	113729
Agriculture	0	0	0	0	0	0	0
Non specified (others)							

Biodiesel (tons)	2000	2005	2010	2015	2017	2018	2019
Total imports	0	570	45519	83539	117149	123639	126008
Total exports	0	0	0	32	44	123	220
Stock changes	0	0	-175	-103	-13	-384	210
Gross inland deliveries	0	570	45694	83610	117118	123899	125578
Final consumption	0	570	45694	83610	117118	123899	125578
Total Industry	0	0	1626	3093	3724	3975	3982
other extractive industries	0	0	27	105	18	20	20
food, beverages and tobacco	0	0	57	100	117	125	126
textiles and leather	0	0	4	7	178	190	190
wood and wood products	0	0	16	32	35	37	37
pulp, paper and printing	0	0	11	8	9	9	9
chemical and petro-chemical	0	0	52	23	53	57	57
non-metallic mineral products	0	0	4	197	169	180	181
iron and steel	0	0	115	117	143	152	152
machinery	0	0	29	43	52	55	55
transportation equipment	0	0	13	2	3	4	4
other industries	0	0	4	122	128	137	137
construction	0	0	1186	2127	2599	2775	2780
Total energy sector	0	0	107	117	176	133	131
Total transportation sector	0	570	38363	69412	97942	104483	107812
Commercial and public services	0	0	2017	4055	5120	5465	5475
Residential	0	0	3091	5966	8757	8507	6848
Agriculture	0	0	531	967	1399	1337	1329
Non specified (others)	0	0					

Residual fuel oil (tons)	2000	2005	2010	2015	2017	2018	2019
Total imports	6469	2217	2276	998	2380	2740	2076
Total exports				0	34	24	52
Stock changes	0	-1					
Gross inland deliveries	6469	2218	2276	998	2346	2716	2024
Final consumption	6469	2218	2276	998	2346	2716	2024
Total Industry	6469	2218	2276	998	2346	2716	2024
other extractive industries							
food, beverages and tobacco	6469	2218	2276	0	0	0	0
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries				998	2346	2716	2024
construction							
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential							
Agriculture							
Non specified (others)							

LPG (tons)	2000	2005	2010	2015	2017	2018	2019
Total imports	30202	16609	12800	11876	10133	8041	9525
Total exports	6025	4555	1304	2243	1083	79	78
Stock changes			16	-40	-30	0	0
Gross inland deliveries	24177	12054	11480	9673	9080	7962	9447
Final consumption	24177	12054	11480	9673	9080	7962	9447
Total Industry	56	440	36	20	37	0	0
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical		3		0	0	0	0
non-metallic mineral products	54	11	0	0	3	0	0
iron and steel			36	1	14	0	0
machinery	0	412					
transportation equipment							
other industries							
construction	2	14		19	21	0	0
Total energy sector				40	0	76	0
Total transportation sector	1998	1245	1352	676	632	336	294
Commercial and public services	19882	8124	8029	8546	8085	7211	8539
Residential	2241	2245	2063	431	326	415	614
Agriculture							
Non specified (others)							

Lubricants (tons)	2000	2005	2010	2015	2017	2018	2019
Total imports	7047	6194	13364	9480	9037	10109	8918
Total exports			3970	1731	1129	1001	966
Stock changes	-55	41	-31	13	-15	-23	-2
Gross inland deliveries	7102	6153	9425	7736	7923	9131	7954
Final consumption							
Total Industry							
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential							
Agriculture							
Non specified (others)							
Total non-energy use	7102	6153	9425	7736	7923	9131	7954

Bitumen (tons)	2000	2005	2010	2015	2017	2018	2019
Total imports	33315	11784	20758	22908	19802	17910	17657
Total exports	2719	1275	114	2039	17	333	132
Stock changes	0	0					
Gross inland deliveries	30596	10509	20644	20869	19785	17577	17524
Final consumption							
Total Industry							
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential							
Agriculture							
Non specified (others)							
Total non-energy use	30596	10509	20644	20869	19785	17577	17524

Other kerosene (tons)	2000	2005	2010	2015	2017	2018	2019
Total imports	1170	1685	642	840	501	448	638
Total exports			0	0	0	0	0
Stock changes	-13	11	-26	12	3	-29	-9
Gross inland deliveries	1183	1674	668	828	498	477	647
Final consumption	1183	1674	668	828	498	477	647
Total Industry							
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential	1183	1674	668	828	498	477	647
Agriculture							
Non specified (others)							

Aviation gasoline (tons)	2000	2005	2010	2015	2017	2018	2019
Total imports	266	145	352	220	222	235	208
Total exports			0	0	0	0	0
Stock changes	2	0	0	0	0	0	0
Gross inland deliveries	264	145	352	220	222	235	208
Final consumption	264	145	352	220	222	235	208
Total Industry							
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector	264	145	352	220	222	235	208
Commercial and public services							
Residential							
Agriculture							
Non specified (others)							

Jet kerosene (tons)	2000	2005	2010	2015	2017	2018	2019
Total imports	317804	419704	422170	443594	579625	598346	581765
Total exports			0	0	22288	0	0
Stock changes	6169	-899	3422	-921	-394	1469	-1630
Gross inland deliveries	311635	420603	418748	444515	557731	596877	583395
Final consumption	311635	420603	418748	444515	557731	596877	583395
Total Industry							
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector	311635	420603	418748	444515	557731	596877	583395
Commercial and public services							
Residential							
Agriculture							
Non specified (others)							

Biomass (all wood) (GJ)	2000	2005	2010	2015	2017	2018	2019
Total imports	3626	30110	95615	1273222	1199168	879369	435559
Total exports	5393	62162	135574	899344	920276	863981	588130
Stock changes							
Gross inland deliveries	640646	1587606	1706714	2548326	3006910	3670295	4382751
Final consumption	635882	1541040	1611302	1756677	1678800	1484565	788960
Total Industry		880933	863371	807701	727688	442124	141769
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products		880933	863371	807701	727688	442124	141769
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector							
Commercial and public services	3626	3154	5811	9974	787	1087	552
Residential	632256	656953	742120	939001	950326	1041354	646639
Agriculture							
Non specified (others)							

Biomass (fuel wood) (GJ)	2000	2005	2010	2015	2017	2018	2019
Total imports	3626	9245	67694	54240	84793	90615	55186
Total exports	5393	48612	69625	118418	127	16132	639
Stock changes							
Gross inland deliveries	635882	649812	737410	644968	651265	759187	375091
Final consumption	635882	649812	737410	644968	651265	759187	375091
Total Industry							
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector							
Commercial and public services	3626	3154	5811	9974	787	1087	552
Residential	632256	646658	731599	634993	650478	758100	374539
Agriculture							
Non specified (others)							

Biomass (pellets) (GJ)	2000	2005	2010	2015	2017	2018	2019
Total imports		20865	27921	118371	132244	133935	108663
Total exports		13549	65949	213092	467584	438052	335780
Stock changes							
Gross inland deliveries		10296	15196	293303	455577	725338	754486
Final consumption		10296	10521	267069	286774	277366	255753
Total Industry							
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products							
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential		10296	10521	267069	286774	277366	255753
Agriculture							
Non specified (others)							

Biomass (wood chips) (GJ)	2000	2005	2010	2015	2017	2018	2019
Total imports				1100611	982131	654819	271710
Total exports				567834	452565	409797	251710
Stock changes							
Gross inland deliveries	4764	927498	954107	1610056	1900068	2185770	3253174
Final consumption		880933	863371	844640	740761	448011	158116
Total Industry		880933	863371	807701	727688	442124	141769
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products		880933	863371	807701	727688	442124	141769
pulp, paper and printing							
chemical and petro-chemical							
non-metallic mineral products							
iron and steel							
machinery							
transportation equipment							
other industries							
construction							
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential				36939	13073	5888	16347
Agriculture							
Non specified (others)							

Annex 5: Assessment of completeness and (potential) sources and sinks of greenhouse gas emissions and removals excluded for the annual inventory submission and also for the KP-LULUCF inventory

Please refer to section 1.8, and in particular Table 1-14, for information about the completeness assessment of Luxembourg's greenhouse gas and KP-LULUCF inventories.

Annex 6: Additional information to be considered as part of the annual inventory submission and the supplementary information required under Article 7, paragraph 1, of the Kyoto Protocol or other useful reference information

n/a

Annex 7: Tables 6.1 and 6.2 of the IPCC good practice guidance

Please refer to section 0 for a detailed description of the uncertainty analysis of Luxembourg's greenhouse gas inventory.

Table 1-13 contains the information required by Table 6.1 of the IPCC good practice guidance.