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Luxembourg's National Inventory Report 1990-2018

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Convention on Climate Change
and under the Kyoto Protocol

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Project management

Dr Nora Becker – Environment Agency

Dr Marc Schuman – Environment Agency

Authors

Tom Bechet - Water Management Administration

Nora Becker - Environment Agency

Eric De Brabanter – Ministry of Sustainable Development and Infrastructures

Pierre Dornseiffer – Environment Agency

Ermin Hadzic – Environment Agency

Martine Kemmer - Environment Agency

Dominique Manetta – Water Management Administration

Marie-Josée Mangen – Rural Economics Service (Ministry of Agriculture)

Tim Mirgain – Environment Agency

Nora Schintgen - Environment Agency

Marc Schuman – Environment Agency

with the help of Umweltbundesamt (UBA) Austria: Traute Köther and Peter Weiss

and contributions from:

Willibald Croi - Luxspace Sàrl

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Questions and comments should be addressed to:

Administration de l’environnement

Unité Surveillance et évaluation de l’environnement

1, avenue du Rock'n'Roll

L - 4361 Esch-sur-Alzette

contactUSEE@aev.etat.lu

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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 2018, Luxembourg's greenhouse gas emissions amounted to a total of 10.547 million tonnes calculated in CO_2 equivalents (*CO_2e*) – excluding land-use, land-use change and forestry (*LULUCF*). Carbon dioxide (*CO_2*) was the main source of greenhouse gases (GHG) in Luxembourg. This source counted for 90.72% of the total GHG emissions (excluding LULUCF). The second source of GHG was methane (*CH_4*) with 5.57% of the total emissions excluding LULUCF. Nitrous oxide (*N_2O*) was the third source with 2.97%. Fluorinated gases (*F-gases*) only accounted for 0.74% of the total emissions excluding LULUCF, with hydrofluorocarbons (*HFCs*) representing 0.64%, and sulphur hexafluoride (*SF_6*) representing 0.10% of the national total (excl. LULUCF).

In 2018, total GHG emissions increased by 3.04% compared to 2017 and are currently 17.22% below their base year level [1]. For the different GHG, trends over the period 1990-2018 (and 2017-2018) were as follows:

- CO_2: .... -19.24% (+3.44%)
- CH_4: .... +1.03% (+1.01%)
- N_2O: .... +0.85% (+0.32%)
- F-gases: .... +360.55%[2] (-2.07%)

Carbon dioxide emissions, over the period 1990-2018, 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 5.3% compared to 2009. However, since 2005 emissions have decreased by 20.96%.

Total methane emissions have remained fairly stable over the period 1990-2018. In 2018, reduced methane emissions were observed in waste management (-27.40%) as compared to 1990;, and increasing emissions in agriculture (+6.73%) and in energy use (+8.42%), the latter being mainly due to an upward trend for fugitive emissions from natural gas distribution and use, and to a lesser extent to energy production industries and the commercial and residential sector.

Nitrous oxide emissions development between 1990 and 2018 is closely linked to an increase of liquid fuels related emissions from combustion activities (+81.91% in the Energy sector) and to emissions from the waste sector (+71.79%) that could not be balanced by declining emissions from the agriculture (-17.26%) and industrial products and product use sectors (-51.68%). Total N_2O emissions (excl. LULUCF) have increased by 0.85% since 1990.

With regard to F-gases, HFCs emissions increased by 346% in 2018 compared to the base year (1995), whereas SF_6 emissions showed a 482.90% increase between 1995 and 2018.

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 10333.88 million tonnes CO_2 eq (incl. LULUCF) in 2018. Net removals from the LULUCF sector amounted to 213.27 Gg CO_2 eq. Since 1990, net emissions have decreased by 19.53% per cent (the sector was a source of net emissions in 1990 (120.64 Gg CO_2 eq) and a source of net removals in 1991-2018).

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1 The base year for CO_2, CH_4 and N_2O is 1990. For the F-gases, the base year is 1995.

2 The trend indicated here corresponds to the period 1995 to 2017, as the base year for F-gases is 1995.

ES.2.2. KP-LULUCF activities

In 2018, Article 3.3 activities were a net sink in Luxembourg and net CO_2 removals amounted to 128 Gg CO_2e. Removals from afforestation/reforestation amounted to 164 Gg CO_2. About 2/3 of these gains were caused by the C stock increases in living biomass, 1/3 was due to increases in soil carbon and litter at the afforestation/reforestation (AR) areas. In the same year, emissions from deforestation amounted to 36 Gg CO_2. About 1/3 were due to biomass losses, and 2/3 due to C stock losses in litter and soil.

Under Article 3.4, CO_2 removals from the activity forest management amounted to 94.94 Gg CO_2eq. By taking into account the FMRL of 418 Gg CO_2eq and a technical correction of 181.68 Gg CO_2eq, the activity forest management becomes a net source of 141.38 Gg CO_2eq. Due to a lack of reliable data, emissions or sinks due to HWP could not be estimated.

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

ES.3.1. Greenhouse Gas Inventory

Table 2 splits the total GHG emissions of Luxembourg into the five CRF sectors included in the inventory. In 2018, the energy sector accounted for 83.38% 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 (6.25%) and agriculture (6.61%). The remaining sectors[3] (LULUCF (2.06%), waste[4] (0.80%) and other (NO)) were each below 5.0% of the total GHG emitted in Luxembourg in 2018.

For the different sectors, trends over the period 1990-2018 (and 2017-2018) were as follows:

- Energy: .... -11.54% (+3.61%)
- Industrial processes & product use: .. -59.58% (+0.45%)
- Agriculture: .... -0.74% (-1.04%)
- LULUCF:... -310.65% (-47.00%)
- Waste: .... -22.07% (-2.46%)
- Other: .... NA (NA)

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).

Since 1990, emission reductions were observed in all sectors except for agriculture, especially for **energy use and production** related emissions whose contribution to total GHG emissions, excluding LULUCF, ranged from 80.85% to 88.78% over the period 1990 to 2018. Within the energy sector, the fastest growing sub-sectors were energy industries (1A1) and transportation (1A3): +527.33% and +130.36%, respectively between 1990 and 2018 (-7.90% and +6.74% from 2017 to 2018). For the other sub-sectors, the observed trends between 1990 and 2018 are -81.42% for manufacturing industries (1A2), +22.39% for the other sectors (1A4), -96.23% for Other (1A5), and +59.77% for fugitive emissions from fuels (1B).[5]

Trends in **agriculture**, which was the second largest sector in 2018 in terms of GHG emissions, were overall stable between 1990 and 2018: declining GHG emissions were observed for agricultural soils (-17.41%), whereas enteric fermentation increased by 4.04%, liming by 4193.50% and manure management by 10.50%.

The third largest sector in Luxembourg with regard to 2018 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 88.39% since 1990. Compared to 2017, emissions from industrial processes and product use increased by 0.45% in 2018, which is mainly due to an increase in the category *2.C.1- Metal industry*.

In the **waste** sector, the main source of GHG was solid waste disposal on land (5A), but its weight decreased over the period 1990-2018 due to the combination of reduced amounts of landfilled waste and increased emissions arising from composting activities (5D). GHG emission reduction for solid waste disposal on land (-48.18% between 1990 and 2018) still drove a reduction for the overall waste sector despite rising emissions from composting. Wastewater handling emissions (5D) decreased by 47.19% over the same period.

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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 CO_2 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.

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

ES.3.2. KP-LULUCF activities

In 2018, Article 3.3 activities were a net sink in Luxembourg and net CO_2 removals amounted to 128 Gg CO_2e. Removals from afforestation/reforestation amounted to 164 Gg CO_2. About 2/3 of these gains were caused by the C stock increases in living biomass, 1/3 was due to increases in soil carbon and litter at the afforestation/reforestation (AR) areas. In the same year, emissions from deforestation amounted to 36 Gg CO_2. About 1/3 were due to biomass losses, and 2/3 due to C stock losses in litter and soil.

Under Article 3.4, CO2 removals from the activity forest management amounted to 94.94 Gg CO_2eq. By taking into account the FMRL of 418 Gg CO_2eq and a technical correction of 181.68 Gg CO_2eq, the activity forest management becomes a net source of 141.38 Gg CO_2eq. 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 SO_2

Some indirect GHG – NO_x, CO, NMVOCs – and SO_2 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: 1990-2018

Gg (1000 t.) CO_2eq	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
CO_2	11847.64	12465.79	12232.16	12372.81	11563.93	9170.30	9219.91	8573.11	7695.07	8147.98	8731.57	9226.37	10003.05	10476.02	11844.31	12105.45	11936.28	11333.58	11195.25	10647.82	11219.29	11114.55	10851.40	10303.87	9825.22	9333.17	9080.25	9250.40	9568.52
	92.99%	93.15%	93.04%	93.07%	92.74%	90.87%	90.79%	90.21%	89.25%	89.66%	90.30%	90.83%	91.48%	92.09%	92.77%	93.05%	92.98%	92.49%	92.26%	91.89%	92.20%	92.27%	92.17%	91.72%	91.17%	90.70%	90.34%	90.37%	90.72%
CH_4 (1)	581.65	594.13	578.37	583.07	570.56	586.38	595.28	590.00	587.62	592.55	585.41	590.72	590.20	579.59	576.28	575.20	571.39	580.19	590.50	591.86	591.66	567.31	559.25	563.56	576.50	582.38	586.33	593.66	587.66
	4.57%	4.44%	4.40%	4.39%	4.58%	5.81%	5.86%	6.21%	6.82%	6.52%	6.05%	5.82%	5.40%	5.09%	4.51%	4.42%	4.45%	4.73%	4.87%	5.11%	4.86%	4.71%	4.75%	5.02%	5.35%	5.66%	5.83%	5.80%	5.57%
N_2O (2)	310.50	321.49	329.31	323.07	318.17	318.23	320.79	317.84	314.37	318.99	318.68	299.88	296.54	274.77	299.73	282.69	281.30	286.24	292.53	289.51	297.15	300.09	295.55	296.08	299.36	297.59	308.34	312.14	313.13
	2.44%	2.40%	2.50%	2.43%	2.55%	3.15%	3.16%	3.34%	3.65%	3.51%	3.30%	2.95%	2.71%	2.42%	2.35%	2.17%	2.19%	2.34%	2.41%	2.50%	2.44%	2.49%	2.51%	2.64%	2.78%	2.89%	3.07%	3.05%	2.97%
HFCs (3)	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	40.47	43.37	47.76	50.25	51.40	53.67	56.55	58.91	62.45	66.86	67.60	66.04	69.58	67.64
	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%	0.56%	0.62%	0.66%	0.66%	0.68%	0.64%
PFCs (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
	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
SF_6 (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	8.91	9.37	9.72	9.90	10.20
	0.01%	0.01%	0.01%	0.01%	0.01%	0.02%	0.02%	0.02%	0.03%	0.02%	0.02%	0.03%	0.03%	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%
Total GHG excluding LULUCF	12741.06	13382.78	13146.80	13293.45	12468.53	10091.81	10155.26	9503.14	8622.18	9087.98	9669.11	10158.18	10934.88	11376.30	12766.97	13009.12	12838.07	12253.93	12135.10	11587.58	12169.06	12046.25	11773.25	11234.48	10776.85	10290.10	10050.69	10235.70	10547.15
	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

Notes:

(1) The methane emissions are converted in CO_2 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 CO_2 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 SF_6 expressed in CO_2 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: 1990-2018

Gg (1000 t.) CO_2eq	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
1. Energy	10300.98	11005.60	10845.78	11010.42	10294.83	8259.92	8367.77	7830.49	7110.58	7529.10	8088.16	8644.21	9416.09	9945.22	11262.92	11549.32	11332.65	10736.92	10657.78	10180.03	10738.32	10615.41	10416.93	9884.09	9394.03	8906.86	8628.29	8794.37	9112.19
	80.85%	82.24%	82.50%	82.83%	82.57%	81.85%	82.40%	82.40%	82.47%	82.85%	83.65%	85.10%	86.11%	87.42%	88.22%	88.78%	88.27%	87.62%	87.83%	87.85%	88.24%	88.12%	88.48%	87.98%	87.17%	86.56%	85.85%	85.92%	86.39%
2. Industrial Processes	1639.38	1560.83	1495.00	1479.75	1388.05	1028.74	974.78	867.65	710.23	750.63	781.18	730.88	752.16	697.18	755.23	726.08	780.12	776.03	721.51	650.91	675.77	692.07	632.81	616.00	632.61	625.11	650.69	659.63	662.58
	12.87%	11.66%	11.37%	11.13%	11.13%	10.19%	9.60%	9.13%	8.24%	8.26%	8.08%	7.19%	6.88%	6.13%	5.92%	5.58%	6.08%	6.33%	5.95%	5.62%	5.55%	5.75%	5.37%	5.48%	5.87%	6.07%	6.47%	6.44%	6.28%
3. Agriculture	695.57	709.26	698.39	694.27	684.74	702.11	709.78	699.76	694.48	702.12	694.56	678.47	661.50	624.67	644.51	628.90	620.26	634.52	648.34	650.46	659.90	647.80	634.42	644.89	659.58	672.75	688.16	697.69	690.44
	5.46%	5.30%	5.31%	5.22%	5.49%	6.96%	6.99%	7.36%	8.05%	7.73%	7.18%	6.68%	6.05%	5.49%	5.05%	4.83%	4.83%	5.18%	5.34%	5.61%	5.42%	5.38%	5.39%	5.74%	6.12%	6.54%	6.85%	6.82%	6.55%
4. Land use, land-use change and	101.25	-194.21	-544.60	-648.55	-448.90	-568.93	-615.05	-707.04	-589.97	-683.97	-717.53	-701.08	-699.25	-655.60	-676.95	-623.72	-529.11	-438.50	-450.22	-431.75	-119.48	-290.95	-381.75	-559.28	-472.30	-421.57	-509.36	-402.41	-213.28
	0.79%	-1.45%	-4.14%	-4.88%	-3.60%	-5.64%	-6.06%	-7.44%	-6.84%	-7.53%	-7.42%	-6.90%	-6.39%	-5.76%	-5.30%	-4.79%	-4.12%	-3.58%	-3.71%	-3.73%	-0.98%	-2.42%	-3.24%	-4.98%	-4.38%	-4.10%	-5.07%	-3.93%	-2.02%
5. Waste	105.14	107.09	107.62	109.02	100.92	101.03	102.92	105.24	106.88	106.13	105.21	104.63	105.13	109.24	104.32	104.82	105.04	106.46	107.47	106.17	95.07	90.97	89.10	89.50	90.64	85.38	83.55	84.00	81.93
	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
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
	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	12842.31	13188.57	12602.20	12644.90	12019.64	9522.87	9540.21	8796.10	8032.21	8404.01	8951.57	9457.10	10235.63	10720.70	12090.03	12385.40	12308.96	11815.43	11684.88	11155.83	12049.58	11755.30	11391.50	10675.20	10304.55	9868.52	9541.33	9833.28	10333.88
	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%
Total GHG excluding LULUCF	12741.06	13382.78	13146.80	13293.45	12468.53	10091.81	10155.26	9503.14	8622.18	9087.98	9669.11	10158.18	10934.88	11376.30	12766.97	13009.12	12838.07	12253.93	12135.10	11587.58	12169.06	12046.25	11773.25	11234.48	10776.85	10290.10	10050.69	10235.70	10547.15
	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%	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%

Source: Environment Agency

Notes: Percentages are relative to the total GHG emissions excluding LULUCF.

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 km^2) 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 (CO_2), methane (CH_4), nitrous oxide (N_2O) as well as hydrogenated fluorocarbons (HFCs), perfluorated halocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

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 As-signed 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 2016. 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 2019.[6] It is based on data submitted to the UNFCCC in the Common Reporting Format (*CRF*) on 15th April 2020: submission 2020v1.[7] Besides being a submission under the UNFCCC, submission 2020v1 is also a mandatory submission under the Kyoto Protocol.

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 2019 NIR have been as follows:

Executive Summary: Marc Schuman, Nora Becker, Nora Schintgen, Tim Mirgain

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6 Luxembourg's National Inventory Report dated 15 April 2017 (covering inventory years 1990 to 2015)

7 Submission 2019v1 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;
b) The UNFCCC web site: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/10566.php.

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

Chapter 1:	Marc Schuman, Nora Becker (key category analysis & uncertainties), Nora Schintgen
Chapter 2:	Nora Schintgen, Nora Becker, Marc Schuman
Chapter 3:	Marc Schuman, Nora Becker, Nora Schintgen
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, 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

The GHG inventory reviewed in the present NIR covers the period 1990-2018 and contains information on anthropogenic emissions by sources and removals by sinks for direct GHG (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3). With regard to indirect greenhouse gases (CO, NO_x, NMVOCs) and SO_2, 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-ECE CLRTAP). Consequently, indirect GHG and SO_2 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 website[10].

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

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.

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[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:
  - o 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);
  - o 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);
  - o 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;

o Decision 11/CP.4 – National communications from Parties included in Annex I to the Convention;

o 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).

o 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 SO_2, NOx, NMVOCs, NH_3, CO, TSP, PM_{10}, 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 SO_2, NOx, NMVOCs and NH_3;
- 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, CO_2 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. The system that this new Regulation defines will be applied for reporting from the 1st of January 2018 on. Consequently, submission 2020v1 has been partly realized under the new Regulation.

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]

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).

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.

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 example, indirect GHG and SO_2 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.

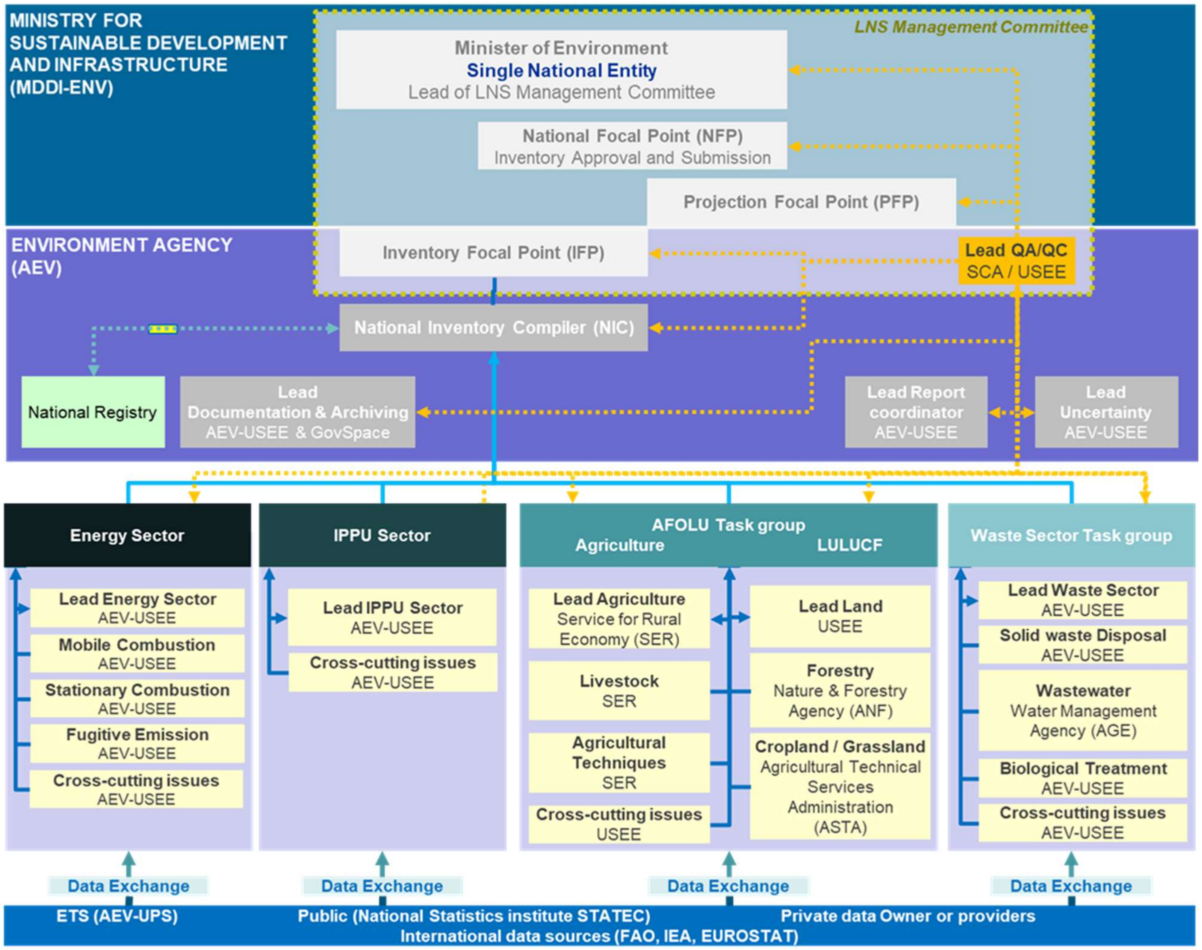
With regards to outputs from the *Unité surveillance et évaluation de l'environnement*, not only are they used for the various inventory reporting obligations (GHG, CLRTAP, NEC), but also for other reporting activities, such as those linked to Spatial Data Information (such as the EC INSPIRE Directive[13]) 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 manger 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 comiler; 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 2016 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 Inventories[15];
- the 2013 Revised Supplementary Methods and Good Practice Gudance 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.

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

1.3.2 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 2019
Energy – CRF 1 – mobile combustion	NEMO 5.0.1 and MS Excel 2019
Industrial Processes – CRF 2	MS Excel 2019
Agriculture – CRF 3	MS Excel 2019
LULUCF – CRF 4	MS Excel 2019
Waste – CRF 5	MS Excel 2019

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 (CO_2, CO, CH_4, NO_x, VOC, and PM) and several more (N_2O, NH_3, SO_2...). Data produced is then transformed 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.

1.3.3 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 0).

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

	CO_2			CH_4			N_2O		
CRF Sector	***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	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	NA	NA	NA	Tier 1 Tier 2	EJ NS	CS D OTH	Tier 1	EJ NS	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 Tier 2	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 developped 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 Questionnaires[16]), 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_2010[17];
- 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

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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 enrgey 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.

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.

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 — 2019[20] 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 CO_2, CH_4, N_2O, HFC, PFC and SF_6, and all IPCC categories.

The key category analysis was performed using the Tier 1 approach based on submission 2020v1. It comprises a level assessment for all years between 1990 and 2018, as well as a trend assessment for the trend of the year 2018 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 2018 are listed in Table 1-6 (excl. LULUCF) and Table 1-8 (incl. LULUCF). The 15 key categories without LULUCF comprise 10043.80 Gg CO_2e in 2018, which is a share of 95.23% of Luxembourg’s total GHG emissions, excluding LULUCF.

Table 1-6 – 2018 key categories (Tier 1, LA) excluding LULUCF based on emission data reported in submission 2020v1

IPCC category	Category name	Fuel	Gas	2018 emissions in Gg CO2e	Share in 2018 national total GHG emissions (excl. LULUCF)
1A1	Fuel combustion - Energy industries	gaseous	CO_2	118.41	1.12%
1A1	Fuel combustion - Energy industries	other	CO_2	95.79	0.91%
1A2	Fuel combustion - Manufacturing Industries and Construction	liquid	CO_2	225.01	2.13%
1A2	Fuel combustion - Manufacturing Industries and Construction	solid	CO_2	153.30	1.45%
1A2	Fuel combustion - Manufacturing Industries and Construction	gaseous	CO_2	686.39	6.51%
1A2	Fuel combustion - Manufacturing Industries and Construction	other	CO_2	88.14	0.84%
1A3b	Road Transportation	gasoline	CO_2	1000.23	9.48%
1A3b	Road Transportation	Diesel oil	CO_2	4933.10	46.77%
1A4	Fuel combustion – Other sectors	Liquid	CO_2	832.61	7.89%
1A4	Fuel combustion – Other sectors	gaseous	CO_2	813.63	7.71%
2A1	Cement production		CO_2	371.68	3.52%
2A3	Glass production		CO_2	62.65	0.59%
2C1	Iron & steel production		CO_2	112.14	1.06%
3A	Enteric fermentation		CH_4	403.44	3.83%
3D1	Direct N_2O emissions from managed soils		N_2O	147.30	1.40%
All	**Sum of all 2018 key categories**	**all**	**all**	**10043.80**	**95.23%**

Table 1-7 specifies for which years any source category has been identified as key category (LA) for from 1990 to 2018 (excl. LULUCF).

Table 1-7 – Key categories (Tier 1, LA) excluding LULUCF of submission 2020v1: 1990-2018

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
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
1A1	CO_2	other									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
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
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
1A2	CO_2	other																								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
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
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
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
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
2A3	CO_2									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
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
3B	CH_4										X	X	X	X																	
3D1	N_2O		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									

Table 1-8 indicates which source categories – including LULUCF - have been identified as key categories (LA) for 2018. The key categories comprise 10424.15 Gg CO_2e in the year 2018, which is a share of 95.22% of Luxembourg's 2018 total GHG emissions, including LULUCF.

Table 1-8 – 2018 key categories (Tier 1, LA) including LULUCF based on emission data recorded in submission 2020v1

IPCC	IPCC source category	Fuel	Gas	2018 emissions in Gg CO_2e	Share in 2018 national total GHG emissions (incl. LULUCF)
1A1	Fuel combustion - Energy industries	gaseous	CO_2	118.41	1.08%
1A1	Fuel combustion - Energy industries	other	CO_2	95.79	0.87%
1A2	Fuel combustion – Manufacturing industries and construction	liquid	CO_2	225.01	2.06%
1A2	Fuel combustion – Manufacturing industries and construction	solid	CO_2	153.30	1.40%
1A2	Fuel combustion – Manufacturing industries and construction	gaseous	CO_2	686.39	6.27%
1A2	Fuel combustion – Manufacturing industries and construction	other	CO_2	88.14	0.81%
1A3b	Fuel combustion – Transport - Road transportation	gasoline	CO_2	1000.23	9.14%
1A3b	Fuel combustion – Transport - Road transportation	diesel oil	CO_2	4933.10	45.06%
1A3b	Fuel combustion – Transport - Road transportation	diesel oil	N_2O	57.84	0.53%
1A4	Fuel combustion – Other sectors	liquid	CO_2	832.61	7.61%
1A4	Fuel combustion – Other sectors	gaseous	CO_2	813.63	7.43%
2A1	Cement production		CO_2	371.68	3.40%
2A3	Glass production		CO_2	62.65	0.57%
2C1	Iron and steel production		CO_2	112.14	1.02%
3A	Enteric fermentation		CH_4	403.44	3.69%
3B	Manure management		CH_4	59.93	0.55%
3D1	Direct N_2O emissions from managed soils		N_2O	147.30	1.35%
4A1	Forest Land remaining Forest Land		CO_2	202.51	1.85%
4E2	Land converted to settlements		CO_2, N_2O	60.06	0.55%
all	**Sum of all 2018 key categories**	**all**	**all**	**10424.15**	**95.22%**

Table 1-9 specifies for which years any source category has been identified as key category (LA) for from 1990 to 2018 (incl. LULUCF).

The key category with the highest contribution to the national total emissions in 2018 is *1A3b Road Transportation – diesel oil (CO_2)*. The contribution to the national total emissions in the base year was 9.96%, whereas in 2018 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 (CO_2)* is the most important category in terms of emission trends and, since 1990 emissions have increased by 289%.

The second most important source of greenhouse gas emissions in 2018 in Luxembourg is *1A3b Road Transportation – gasoline (CO_2)*. Its contribution to national total emissions is 9.48% for 2018 compared to 10.06% in the base year, followed by *1A4 – Other sectors – liquid fuels (CO_2)* with a contribution of 7.89% in 2018 (7.67% in 1990).

The key category with the highest contribution to national removals is *4.A.1 Forest land remaining forest land (CO_2)*. In the key category analysis including LULUCF it is the 9th largest category in the level assessment (1.85%) in 2018 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 2018.

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 2020v1: 1990-2018

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
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
1A1	CO_2	other									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
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
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
1A2	CO_2	other																								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
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
1A3b	N_2O	diesel oil																													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
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
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
2A3	CO_2									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
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
3B	CH_4										X	X	X	X														X	X	X	X
3D1	N_2O		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
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	
4B2	CO_2							X	X	X	X	X																			
4C2	CO2, N_2O												X	X	X	X						X	X	X							
4E2	CO_2, N_2O		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					

Table 1-10 –Key categories (excluding and including LULUCF) according to the trend assessment for 2018.

IPCC Category	Category Name	Fuel	GHG	TA excl. LULUCF	TA incl. LULUCF
1A1	Energy Industries	other	CO_2		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
2A1	Cement Production		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_2O		X

Source: 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-Protocol[22].

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 2020v1. It comprises a level assessment for all years between 1990 and 2018, as well as a trend assessment for the trend of the year 2018 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).

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

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.

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 2018[23]. 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.

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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

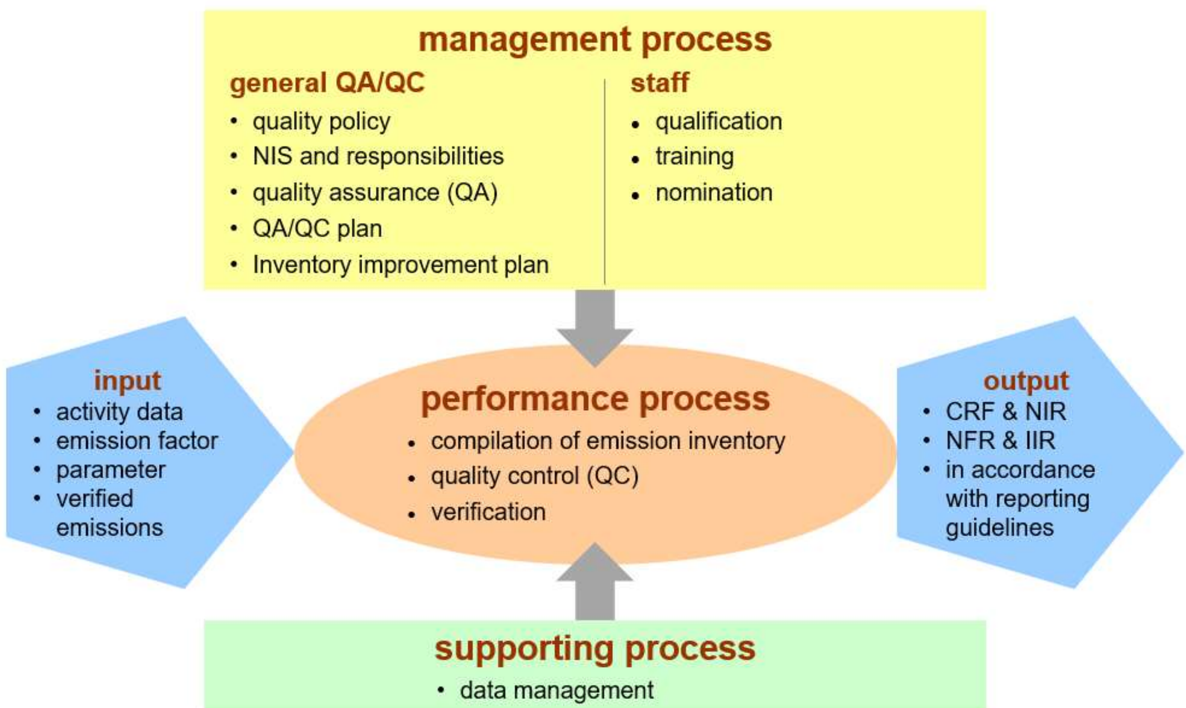
Luxembourg's Quality Management System (QMS) of the GHG Inventory is organised in three layers (Figure 1-2):

a) 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.

b) 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.

c) 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 the demands resulting from ● 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) -> 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) -> 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 ● AEV -> EIONET, ● MEV -> UNFCCC ● MEV oder AEV -> UNECE/LRTAP Inventory Focal Point (IFP/NIC) and Quality Manager (QM) -> check validity -> adjustment if necessary -> announcement	yearly before kick-off meeting
			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 -> adjustment if necessary -> announcement	yearly before kick-off meeting
	personnel		**nomination**	nominations of sector experts and data suppliers according RGD	nomination by minister of environment; IFP/NIC and quality manager check validity -> information of ministry if necessary -> nomination proposed by IFP/NIC	yearly before kick-off meeting or in case of staff changing the function/unit/devision, etc.
			personal file	proof of sector expert's qualification	sector experts complete their personal file	regular
	quality assurance	to support and complete quality control measures	**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 -> internal audit report -> QA/QC plan	yearly before kick-off meeting
		check of formal aspects	**internal audit report**	audited sectors, observations, proposed improvements	report prepared by quality manager and IFP/NIC -> generation of QA/QC plan	yearly before kick-off meeting
		check of applicability & comparisons	**external audit report**	audited sectors, observations, proposed improvements	report prepared by external persons or organisations -> 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
			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) -> informing of IFP/NIC and quality manager -> entry of proposals for improvement in QA/QC plan	yearly before kick-off meeting
	improvement plan	list of objectives and proposed actions in order to improve inventory's quality	**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 -> definition of deadlines -> check if objectives have been achieved during the following audits	regular
			Criteria for the priorizitation of the QAQC plan	criteria for the priorizitation of the QAQC plan	QAQC plan is set up according the criteria for the priorizitation;	yearly before kick-off meeting
performance processes	**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 -> adjustment if necessary -> announcement per mail	yearly before kick-off meeting
			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 -> 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 -> IFP/NIC generates CRF-tables and compiles NIR -> submission of crf-tables and NIR to EU and UNFCCC	regular according the deadlines
			IIR and NFR-tables	national air pollutant emission inventory	sector experts submit calculation sheets to IFP/NIC before deadline -> IFP/NIC generates NFR-tables and compiles IIR -> submission of NFR-tables and IIR to EU and UNECE/LRTAP	regular according 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 (1st party) performed throughout preparation of inventory	
TIER 1	**TIER 2**
Data validation, calculation sheet (check of formal aspects)	Preparation of NIR, comparision with Guidelines (check of applicability, comparisions)
QA procedures Quality manager (2nd or 3rd 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:

a) 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.

b) Checklists for data supplier that have to be completed by external suppliers of input data in order to assure the reliability of reported data.

c) 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												
	Activity data			check done			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 recordedand 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																		

	Uncertainties			check done		
Greenhouse gas	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:

- o 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)
- o 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)
- o 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)
- o Check of uncertainties (check of correct calculation and estimation of uncertainties in emissions and removals).

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

e) 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:
  - o 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
  - o whether data acquisition, calculation, referencing and archiving is handled according to the defined methods
  - o whether there are enough resources for inventory work
  - o whether relevant data are available and if the reliability of external data is guaranteed
  - o whether the QMS system needs improvement
  - o 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 planned during 2018

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 2020v1, 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 1-12. 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 4.12% and a trend uncertainty of 3.52%, and the TIER 1 approach excluding LULUCF suggests an overall level uncertainty of 3.85% and a trend uncertainty of 3.29%

(Table 1 12).

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25 2000 IPCC GPG – Chapter UNCERTAINTIES

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 CO_2 emission factors are much better understood (can be derived from material balances) than emission factors of CH_4 or N_2O. The fact that at the same time, in the total inventory, N_2O and CH_4 emissions are less important, leads to a structurally lower uncertainty.

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 N_2O from soils and the uptake/release of CO_2 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 N_2O emission factors. Such validation exercises might provide a closure of the error margins.

Table 1-12 – Input parameters and results of the Tier 1 uncertainty analysis (2020v1). KP-LULUCF inventory

IPCC category/Group	Gas	Base year emissions or removals	Year 2018 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	%	%								
1A - Stationary Combustion - Gaseous Fuels	CO2	1035.80	1618.43	2%	0.5%	0.0206	0.0000	0.0552	0.0890	0.0003	0.0025	6.41E-06	
1A - Stationary Combustion - Gaseous Fuels	CH4	1.04	2.17	2%	50%	0.5004	0.0000	0.0001	0.0001	0.0000	0.0000	1.84E-09	
1A - Stationary Combustion - Gaseous Fuels	N2O	0.53	0.86	2%	50%	0.5004	0.0000	0.0000	0.0000	0.0000	0.0000	2.23E-10	
1A - Stationary Combustion - Liquid Fuels	CO2	1166.05	862.23	2%	0.5%	0.0206	0.0000	0.0094	0.0474	0.0000	0.0013	1.80E-06	
1A - Stationary Combustion - Liquid Fuels	CH4	3.34	2.74	2%	50%	0.5004	0.0000	0.0000	0.0002	0.0000	0.0000	4.56E-10	
1A - Stationary Combustion - Liquid Fuels	N2O	2.68	2.03	2%	50%	0.5004	0.0000	0.0000	0.0001	0.0000	0.0000	1.62E-10	
1A - Stationary Combustion - Other Fuels	CO2	33.29	202.43	8%	20%	0.2154	0.0000	0.0100	0.0111	0.0020	0.0013	5.62E-06	
1A - Stationary Combustion - Other Fuels	CH4	0.25	1.64	8%	50%	0.5064	0.0000	0.0001	0.0001	0.0000	0.0000	1.78E-09	
1A - Stationary Combustion - Other Fuels	N2O	0.40	2.84	8%	50%	0.5064	0.0000	0.0001	0.0002	0.0001	0.0000	5.42E-09	
1A - Stationary Combustion - Biomass	CH4	5.50	10.45	7%	50%	0.5049	0.0000	0.0004	0.0006	0.0002	0.0001	4.24E-08	
1A - Stationary Combustion - Biomass	N2O	1.81	5.63	7%	60%	0.6041	0.0000	0.0003	0.0003	0.0002	0.0000	2.36E-08	
1A - Stationary Combustion - Solid Fuels	CO2	5317.44	154.27	1%	3%	0.0316	0.0000	0.1642	0.0085	0.0049	0.0001	2.43E-05	
1A - Stationary Combustion - Solid Fuels	CH4	5.40	0.48	1%	50%	0.5001	0.0000	0.0001	0.0000	0.0001	0.0000	5.59E-09	
1A - Stationary Combustion - Solid Fuels	N2O	5.94	0.73	1%	50%	0.5001	0.0000	0.0002	0.0000	0.0001	0.0000	5.88E-09	
1A3a - Transport - Civil Aviation	CO2	5317.44	0.56	10%	5%	0.1118	0.0000	0.1726	0.0000	0.0086	0.0000	7.45E-05	
1A3a - Transport - Civil Aviation	CH4	5.40	0.00	10%	100%	1.0050	0.0000	0.0002	0.0000	0.0002	0.0000	3.09E-08	
1A3a - Transport - Civil Aviation	N2O	5.94	0.00	10%	150%	1.5033	0.0000	0.0002	0.0000	0.0003	0.0000	8.38E-08	
1A3b - Road Transportation - Diesel Oil	CO2	1269.24	4933.10	2%	2%	0.0283	0.0002	0.2298	0.2713	0.0046	0.0077	8.00E-05	
1A3b - Road Transportation - Diesel Oil	CH4	0.68	2.16	2%	20%	0.2010	0.0000	0.0001	0.0001	0.0000	0.0000	3.84E-10	
1A3b - Road Transportation - Diesel Oil	N2O	2.53	57.84	2%	20%	0.2010	0.0000	0.0031	0.0032	0.0006	0.0001	3.92E-07	
1A3b - Road Transportation - Gasoline	CO2	1282.06	1000.23	2%	2%	0.0283	0.0000	0.0132	0.0550	0.0003	0.0016	2.49E-06	
1A3b - Road Transportation - Gasoline	CH4	11.67	1.10	2%	20%	0.2010	0.0000	0.0003	0.0001	0.0001	0.0000	4.09E-09	
1A3b - Road Transportation - Gasoline	N2O	12.79	1.64	2%	20%	0.2010	0.0000	0.0003	0.0001	0.0001	0.0000	4.26E-09	

IPCC category/Group	Gas	Base year emissions or removals	Year 2018 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	%	%								
1A3b - Road Transportation - LPG	CO2	11.34	1.01	2%	2%	0.0283	0.0000	0.0003	0.0001	0.0000	0.0000	4.19E-11	
1A3b - Road Transportation - LPG	CH4	0.10	0.00	2%	40%	0.4005	0.0000	0.0000	0.0000	0.0000	0.0000	1.53E-12	
1A3b - Road Transportation - LPG	N2O	0.13	0.00	2%	100%	1.0002	0.0000	0.0000	0.0000	0.0000	0.0000	1.61E-11	
1A3b - Road Transportation - biomass	CH4	0.00	0.18	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	3.93E-12	
1A3b - Road Transportation - biomass	N2O	0.00	4.05	2%	20%	0.2010	0.0000	0.0002	0.0002	0.0000	0.0000	2.02E-09	
1A3b - Road Transportation - other fossil fuels	CO2	0.00	18.40	20%	2%	0.2010	0.0000	0.0010	0.0010	0.0000	0.0003	8.23E-08	
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	2.39E-14	
1A3b - Road Transportation - other fossil fuels	N2O	0.00	0.22	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	1.72E-11	
1A3c - Railways - liquid fuels	CO2	24.82	6.98	2%	2%	0.0283	0.0000	0.0004	0.0004	0.0000	0.0000	1.90E-10	
1A3c - Railways - liquid fuels	CH4	0.05	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	6.96E-14	
1A3c - Railways - liquid fuels	N2O	0.04	0.01	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	2.43E-14	
1A3c - Railways - biomass	CH4	0.00	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	1.39E-17	
1A3c - Railways - biomass	N2O	0.00	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	3.10E-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	1.65E-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	1.27E-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	2.84E-19	
1A3d - Navigation - liquid fuels	CO2	1.30	1.12	2%	2%	0.0283	0.0000	0.0000	0.0001	0.0000	0.0000	3.18E-12	
1A3d - Navigation - liquid fuels	CH4	0.03	0.01	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	1.15E-14	
1A3d - Navigation - liquid fuels	N2O	0.10	0.07	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	2.27E-14	
1A3d - Navigation - biomass	CH4	0.00	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	1.00E-17	
1A3d - Navigation - biomass	N2O	0.00	0.00	2%	20%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	2.73E-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	3.65E-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	9.19E-20	
1A3d - Navigation - other fossil fuels	N2O	0.00	0.00	20%	20%	0.2828	0.0000	0.0000	0.0000	0.0000	0.0000	2.51E-17	

IPCC category/Group	Gas	Base year emissions or removals	Year 2018 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	%	%								
1A - other mobile machinery - liquid fuels	CO2	76.89	196.82	2%	2%	0.0283	0.0000	0.0083	0.0108	0.0002	0.0003	1.21E-07	1A2gvii, 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	3.44E-12	1A2gvii, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - liquid fuels	N2O	7.53	6.73	2%	20%	0.2010	0.0000	0.0001	0.0004	0.0000	0.0000	7.34E-10	1A2gvii, 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	5.00E-15	1A2gvii, 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	2.53E-11	1A2gvii, 1A4bii, 1A4cii, 1A5b
1A - other mobile machinery - other fossil fuels	CO2	0.00	0.71	20%	2%	0.2010	0.0000	0.0000	0.0000	0.0000	0.0000	1.24E-10	1A2gvii, 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	1.04E-18	1A2gvii, 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	2.31E-13	1A2gvii, 1A4cii, 1A5b
1B2b - Fugitive Emission from Natural Gas	CO2	0.03	0.04	2%	100%	1.0002	0.0000	0.0000	0.0000	0.0000	0.0000	1.98E-12	
1B2b - Fugitive Emission from Natural Gas	CH4	19.36	30.94	2%	100%	1.0002	0.0000	0.0011	0.0017	0.0011	0.0000	1.15E-06	
2A1 - Cement Production	CO2	569.88	371.68	1%	3%	0.0269	0.0000	0.0019	0.0204	0.0000	0.0003	8.57E-08	
2A3 - Glass Production	CO2	53.57	62.65	2%	10%	0.1020	0.0000	0.0017	0.0034	0.0002	0.0001	3.84E-08	
2C1 - Iron & Steel Production	CO2	984.91	112.14	5%	5%	0.0707	0.0000	0.0259	0.0062	0.0013	0.0004	1.87E-06	
2C7 - Other Metal Industry	CO2	0.00	2.25	0.4%	50%	0.5000	0.0000	0.0001	0.0001	0.0001	0.0000	3.82E-09	
2D1 - Lubricant use	CO2	6.20	5.38	5%	50%	0.5025	0.0000	0.0001	0.0003	0.0000	0.0000	2.65E-09	
2D2 - Paraffin wax use	CO2	0.21	2.24	5%	100%	1.0012	0.0000	0.0001	0.0001	0.0001	0.0000	1.37E-08	
2D3 - solvent use	CO2	14.13	10.87	50%	50%	0.7071	0.0000	0.0001	0.0006	0.0001	0.0004	1.83E-07	
2D3 - urea-based catalysts	CO2	0.00	13.09	20%	5%	0.2062	0.0000	0.0007	0.0007	0.0000	0.0002	4.27E-08	
2F - Product Uses as Substitutes for ODS	F-gases	15.15	63.08	30%	20%	0.3606	0.0000	0.0030	0.0035	0.0006	0.0015	2.52E-06	
2G - Other Product Manufacture and Use	F-gases	1.75	4.56	7%	0%	0.0660	0.0000	0.0002	0.0003	0.0000	0.0000	5.47E-10	
2G - Other Product Manufacture and Use	N2O	9.19	4.44	20%	20%	0.2828	0.0000	0.0001	0.0002	0.0000	0.0001	4.89E-09	
3A - Enteric fermentation	CH4	387.78	403.44	16%	0%	0.1570	0.0000	0.0096	0.0222	0.0000	0.0049	2.42E-05	total subcategory uncertainty
3Ba - Manure management	CH4	46.36	59.93	29%	0%	0.2900	0.0000	0.0018	0.0033	0.0000	0.0014	1.83E-06	total subcategory uncertainty
3Bb - Manure management	N2O	32.55	27.27	178%	0%	1.7759	0.0000	0.0004	0.0015	0.0000	0.0038	1.42E-05	total subcategory uncertainty
3D - Agricultural soils	N2O	228.62	188.82	198%	0%	1.9764	0.0012	0.0029	0.0104	0.0000	0.0290	8.42E-04	total subcategory uncertainty
3G - Liming	CO2	0.26	10.98	52%	0%	0.5188	0.0000	0.0006	0.0006	0.0000	0.0004	1.96E-07	total subcategory uncertainty

IPCC category/Group	Gas	Base year emissions or removals	Year 2018 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	%	%								
4 - Land Use, Land-Use Change and Forestry	CO2, N2O	101.25	213.28	74%	0%	0.7400	0.0002	0.0084	0.0117	0.0000	0.0123	1.51E-04	total sector uncertainty
5A - Solid Waste disposal on Land	CH4	92.18	47.77	8%	42%	0.4276	0.0000	0.0004	0.0026	0.0002	0.0003	1.13E-07	
5B - Biological treatment of solid waste	CH4	0.00	21.77	5%	50%	0.5025	0.0000	0.0012	0.0012	0.0006	0.0001	3.65E-07	
5B - Biological treatment of solid waste	N2O	0.00	5.55	5%	100%	1.0012	0.0000	0.0003	0.0003	0.0003	0.0000	9.36E-08	
5D - Wastewater treatment and discharge	CH4	7.30	2.69	10%	50%	0.5099	0.0000	0.0001	0.0001	0.0000	0.0000	2.47E-09	
5D - Wastewater treatment and discharge	N2O	5.65	4.15	10%	50%	0.5099	0.0000	0.0000	0.0002	0.0000	0.0000	1.54E-09	
Total Uncertainties including LULUCF						Uncertainty in total inventory %:	4.12%				Trend uncertainty %:	3.52%	
Total Uncertainties excluding LULUCF						Uncertainty in total inventory %:	3.85%				Trend uncertainty %:	3.29%	

Please refer to sections 1.5.2 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 2018. 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 2020v1. 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 1-13. 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 1-13 - Completeness overview for submission 2020v1.

GHG source & sink categories (CRF nomenclature)	CO_2	CH_4	N_2O	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 (2000-2018)	X (2000-2018)	X (2000-2018)				
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	NO	NO	NO				
d. other	NA	NA	NA				
C. CO_2 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_2O	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 (2016-2018)	NO	NO	NO	NO	NO	NO
D. non-energy products from fuels and solvent us	**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

GHG source & sink categories (CRF nomenclature)	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3
4. aerosols				X (1992-2018)	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**
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 (2013-2018)	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_2O 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_2O 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	**NE**						

GHG source & sink categories (CRF nomenclature)	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3
I. Other Carbon-containing Fertilisers	**NO**						
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**				
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 (1993-2018)	X (1993-2018)				
2. Anaerobic digestion at biogas facilities		X (1992-2018)	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**

GHG source & sink categories (CRF nomenclature)	CO_2	CH_4	N_2O	**HFCs**	**PFCs**	**SF_6**	**NF_3**
Memo Items	X	X	X				
International Bunkers	X	X	X				
aviation	X	X	X				
marine	X	X	X				
Multilateral Operations	NA	NA	NA				
CO_2 emissions from biomass	X						
CO_2 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 SO_2 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 1-14, transparency and completeness of submission 2020v1 is presented. The exercise focuses on the inventory year 2018 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 – (number of IE/number of estimates)] * 100
- Completeness (*CP*) [%] = [1 – (number of NE/number of estimates)] * 100

Table 1-14 - Transparency and completeness indexes for submission 2020v1.

CRF Sector	# 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	63	3	1	95%	98%
LULUCF – CRF 4	66	0	1	100%	98%
Waste – CRF 5 (*)	60	3	1	95%	98%
Total	**423**	**6**	**3**	**99%**	**99%**

(*) IE from Waste includes waste inc ineration 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 crossroad for international trade and related transport flows, the most dynamic source of its GHG emissions.

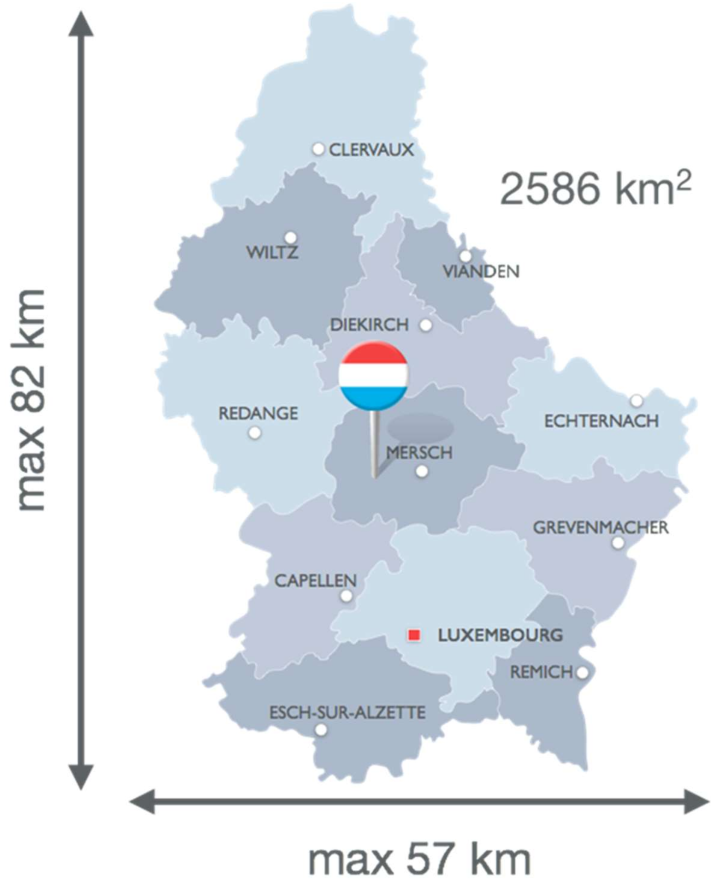
Luxembourg has a territory of 2 586 km². The maximum distance from North to South is some 82 km, from West to East about 57 km (Figure 2-2). In 2018, 85.2% of the total area of Luxembourg was agricultural land and land under forest – with around 51% for agriculture and 35% for forests. The built-up areas occupied 9.7% of the total surface and land covered by water and transport infrastructure about 4.5% (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



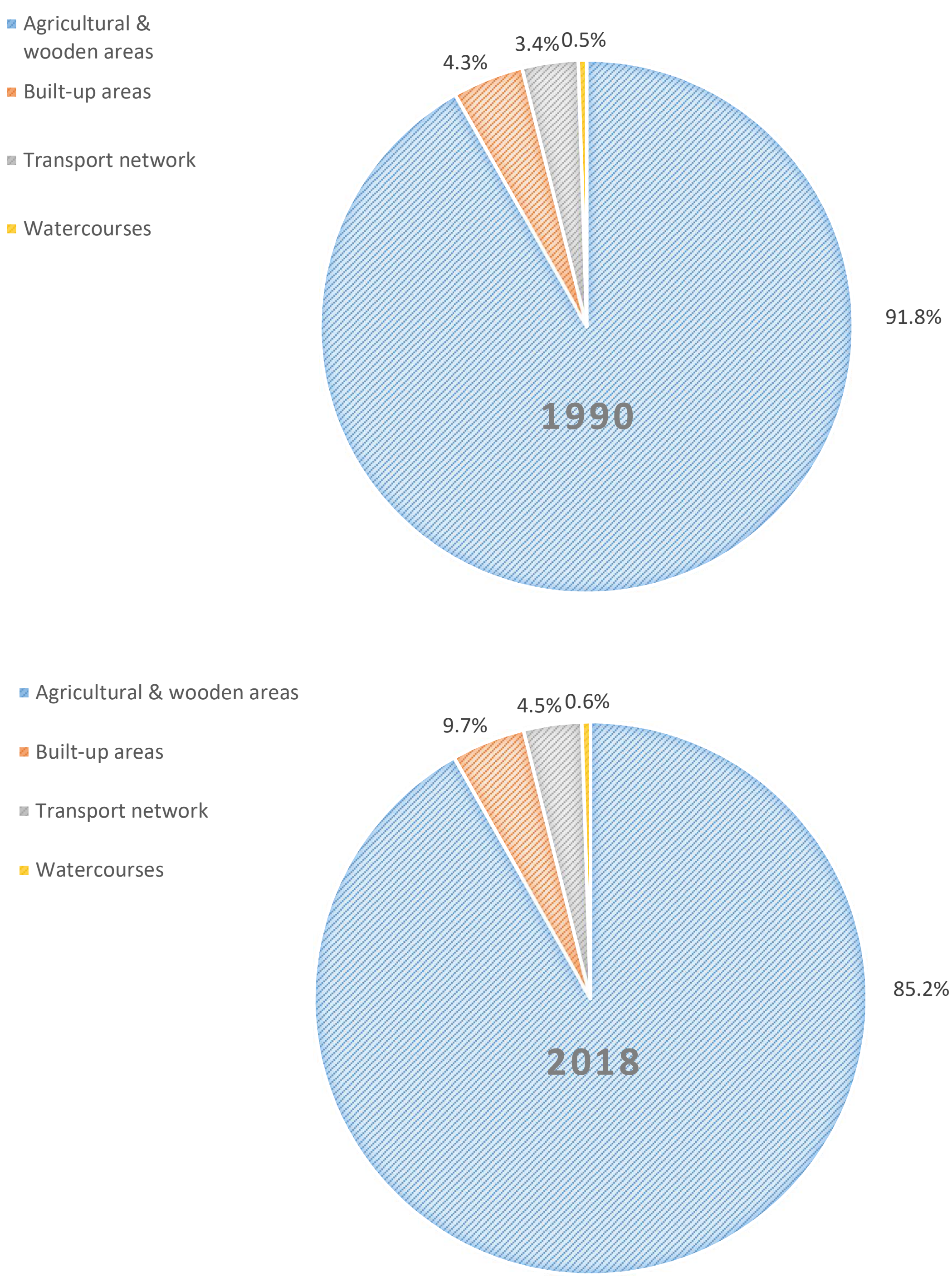
Source: Google Maps.

Table 2-1 – Land use in Luxembourg: 1972-2018

percentages	1972	1990	2000	2009	2010	2014	2016	2017	2018
Total land	100	100	100	100	100	100	100	100	100
Agricultural & wooden area	93.2	91.8	87.4	85.7	85.5	85.3	85.1	85.1	85.2
Built-up area	3.1	4.3	8.1	9.3	9.5	9.7	9.8	9.8	9.7
of which industrial area & other	n.a.	n.a.	2.7	3	3.1	3.1	3.1	3.1	3
Transport network & sheets of water	3.2	3.4	3.9	4.4	4.4	4.4	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

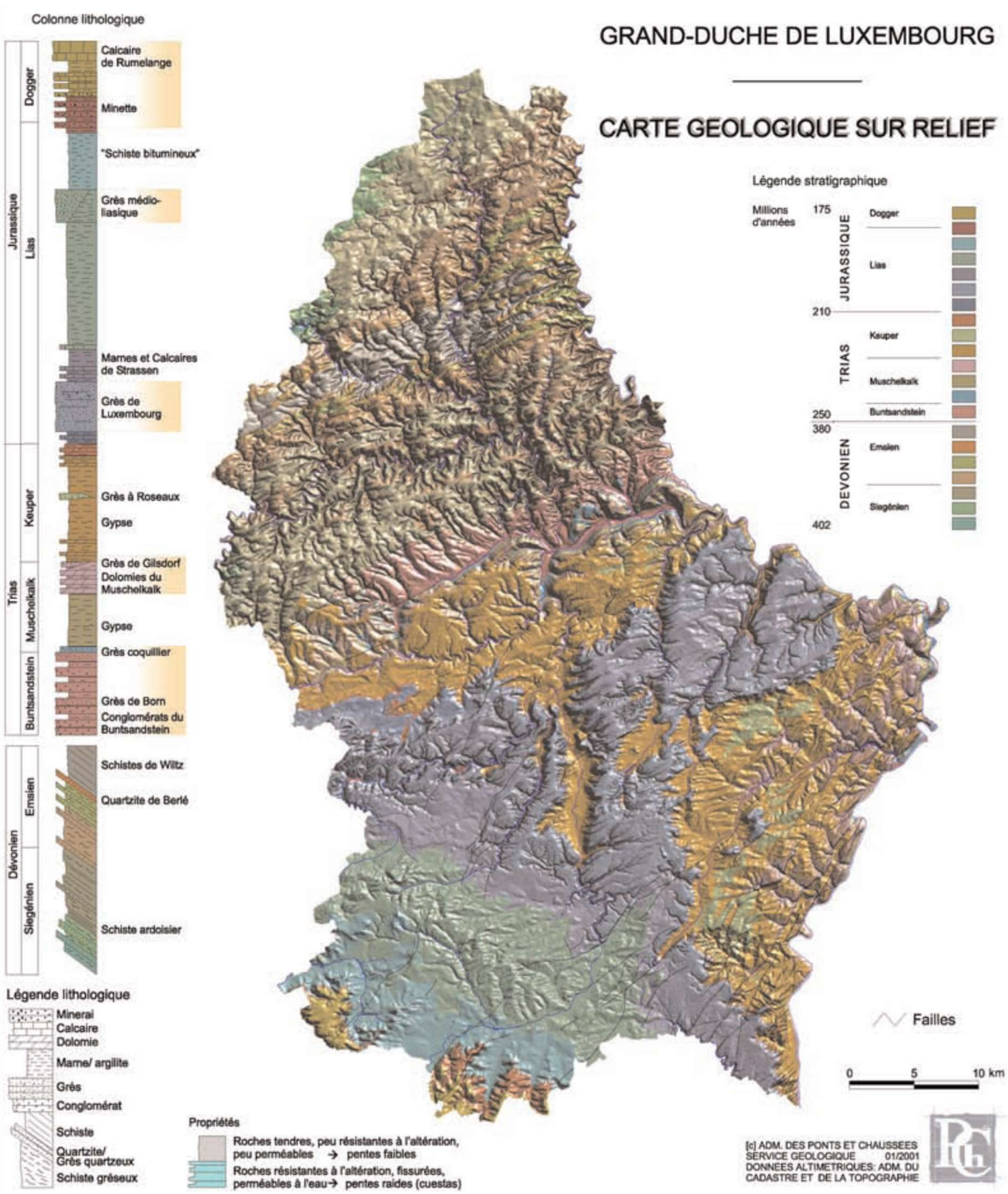
Source: STATEC, Statistical Yearbook, Table A.1101 (updated 11 March 2020): http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12695&IF_Language=fra&MainTheme=1&FldrName=1

Figure 2-3 – Land use: 1990 & 2018



Source: STATEC, Statistical Yearbook, Table A.1101 (updated 11 March 2020): 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	1.1	4.0	7.5	11.8	14.9	16.9	16.4	13.4	9.1	3.8	1.0	**8.3**
	0.8	1.6	5.2	8.7	13.0	15.9	18.2	17.7	13.9	9.5	4.7	1.8	**9.3**
Mean minimum air temperature [°C]	-2.3	-1.8	0.6	3.3	7.1	10.2	12.0	11.8	9.3	5.7	1.2	-1.3	**4.7**
	-1.6	-1.3	1.6	4.4	8.4	11.1	13.3	13.0	10.0	6.3	2.2	-0.5	**5.6**
Mean maximum air temperature [°C]	2.3	4.2	7.9	12.1	16.8	20.0	22.0	21.6	18.2	13.0	6.6	3.3	**12.3**
	3.1	4.7	9.1	13.3	17.8	20.7	23.2	22.8	18.4	13.1	7.3	3.9	**13.1**
Mean monthly precipitation sum [mm]	71.1	61.7	70.1	61.0	81.2	81.5	68.4	72.2	69.8	74.7	83.1	79.6	**874.4**
	76.6	62.5	69.1	58.2	78.5	79.9	71.0	75.4	76.3	86.8	76.0	86.7	**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).

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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 2-3: 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**

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).

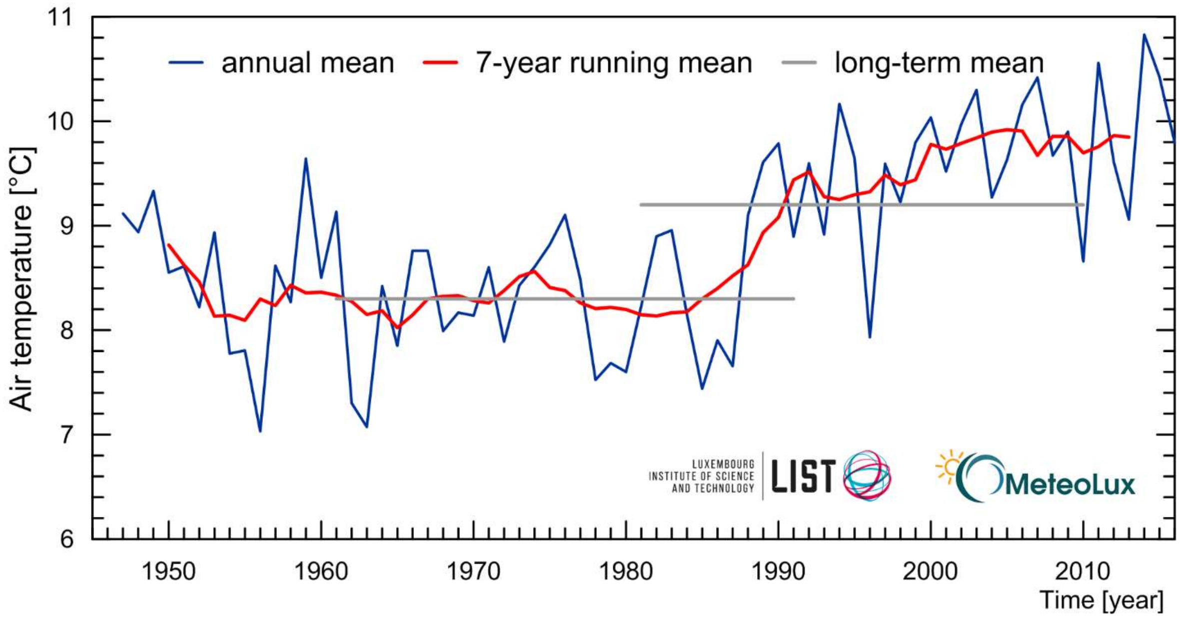
Further analysis of the data suggests that the average air temperature in Luxembourg has increased during the winter seasons, coupled with longer frost-free periods.

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

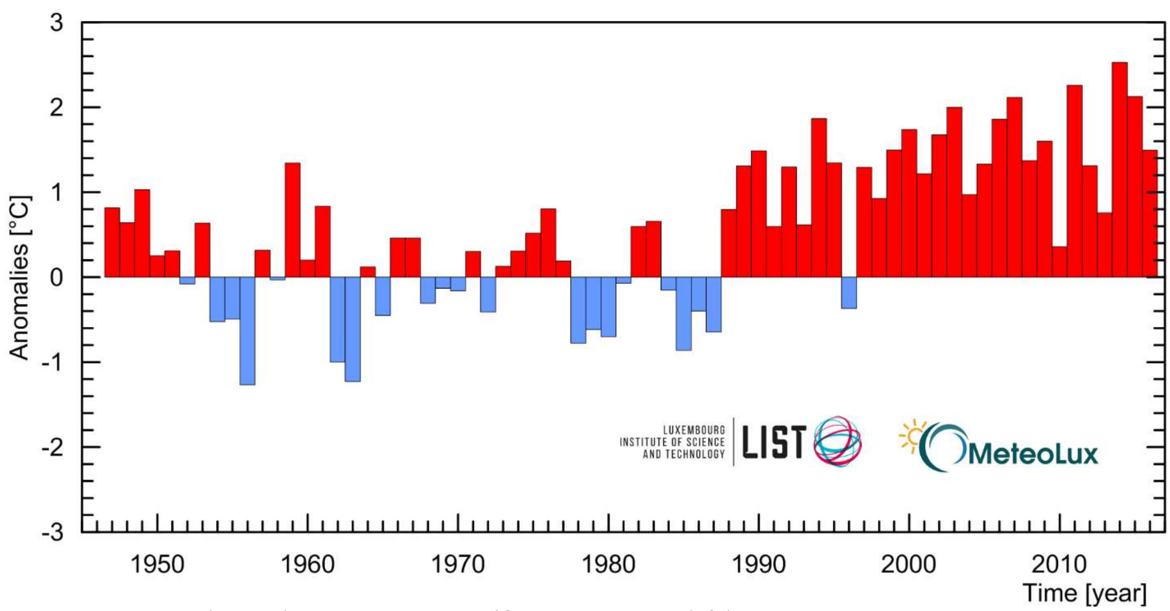
Sources: MeteoLux (http://meteolux.lu/filedownload/73/2016_Informations_sur_le_climat_au_Luxembourg_en_2016_Anglais.pdf)

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



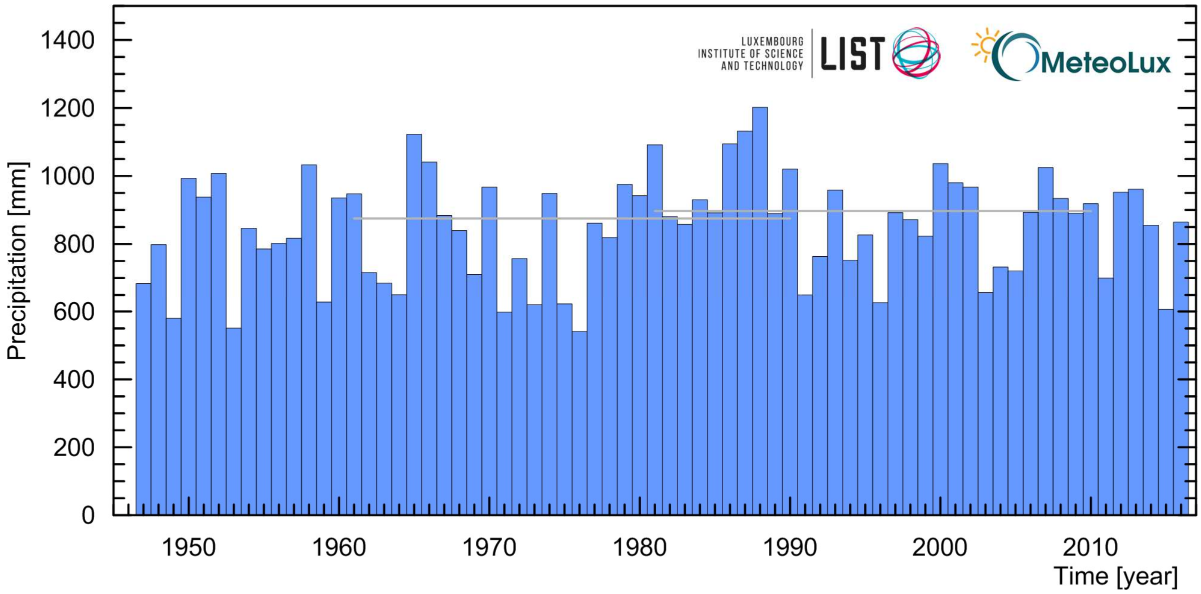
Sources: Findel-Airport station (MeteoLux) and Luxembourg Institute of Science and Technology (LIST). unpublished.

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



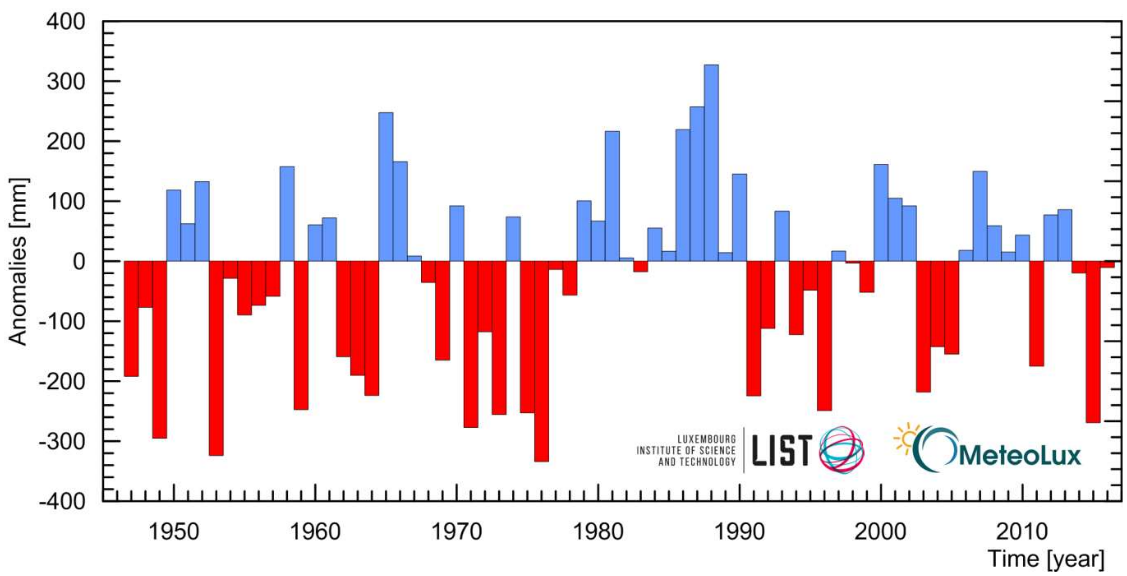
Sources: Findel-Airport station (MeteoLux) and Luxembourg Institute of Science and Technology (LIST). unpublished.
Note: anomalies from the reference period 1961 until 1990: long-term mean: 8.3°C.

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



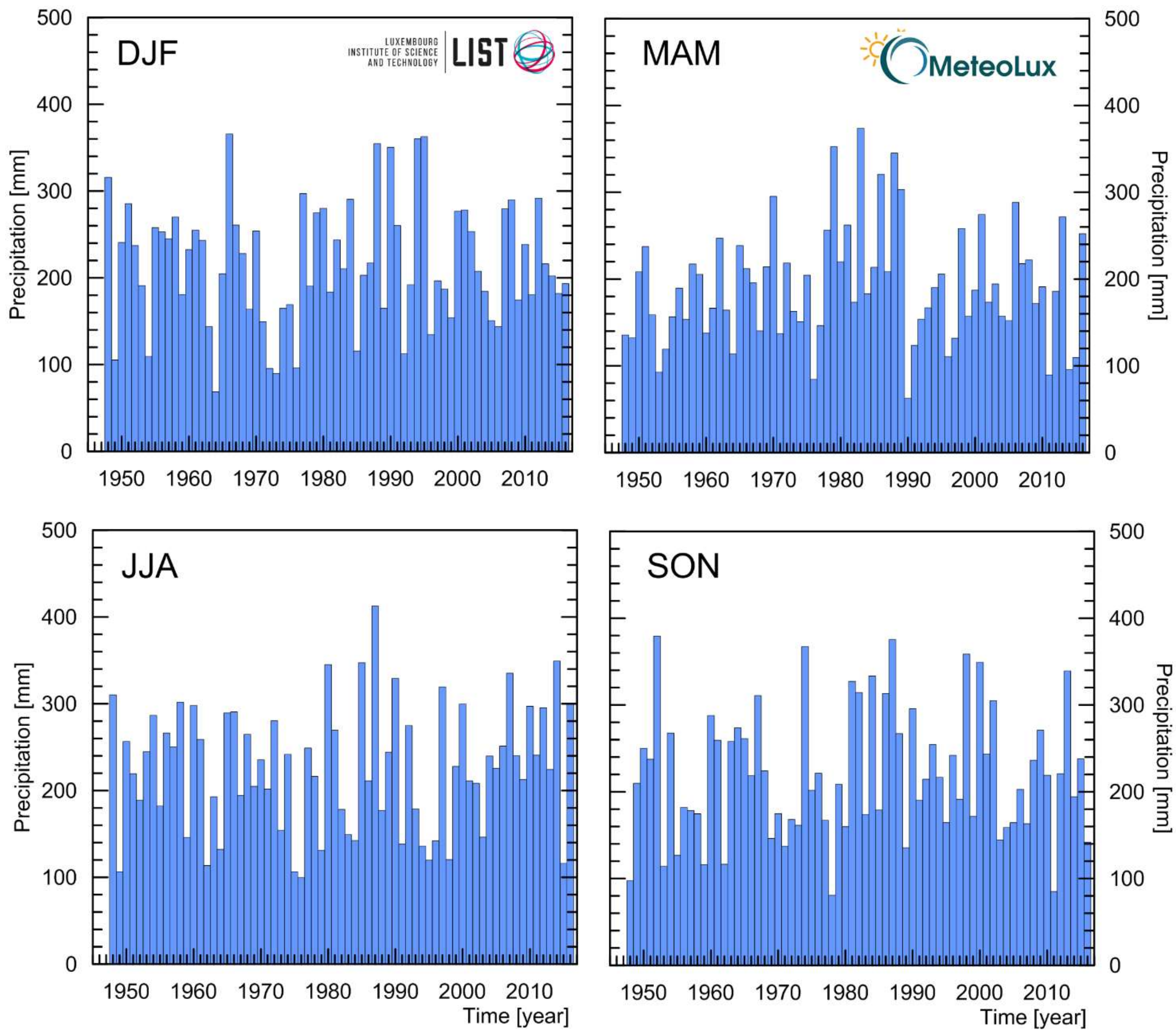
Sources: Findel-Airport station (MeteoLux) and Luxembourg Institute of Science and Technology (LIST). unpublished.
Note: anomalies from the reference period 1961 until 1990: long-term mean: 874 mm.

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

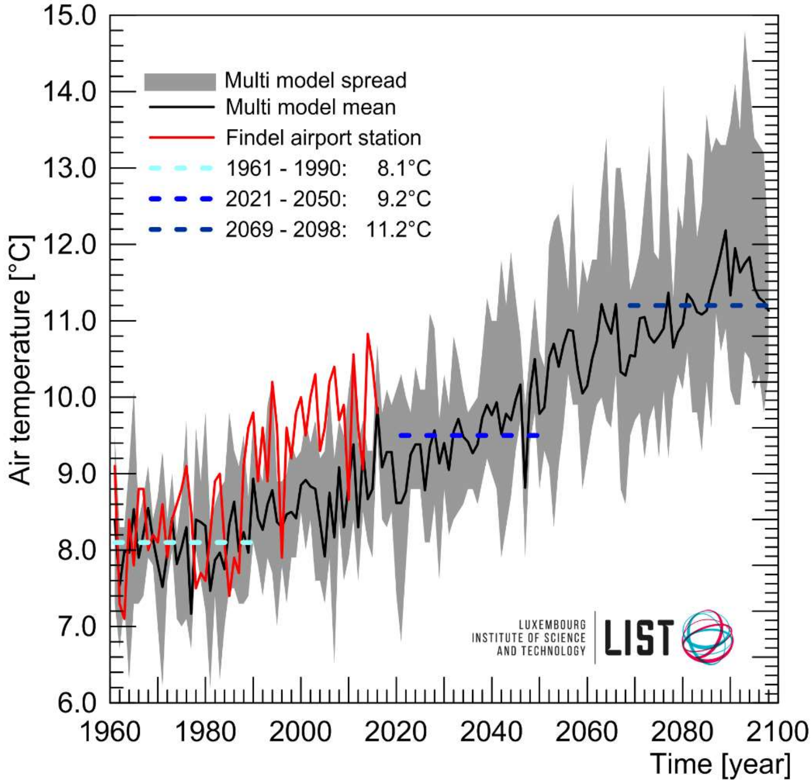


Sources: Findel-Airport station (MeteoLux) and Luxembourg Institute of Science and Technology (LIST). unpublished.

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 projections,[28] 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.

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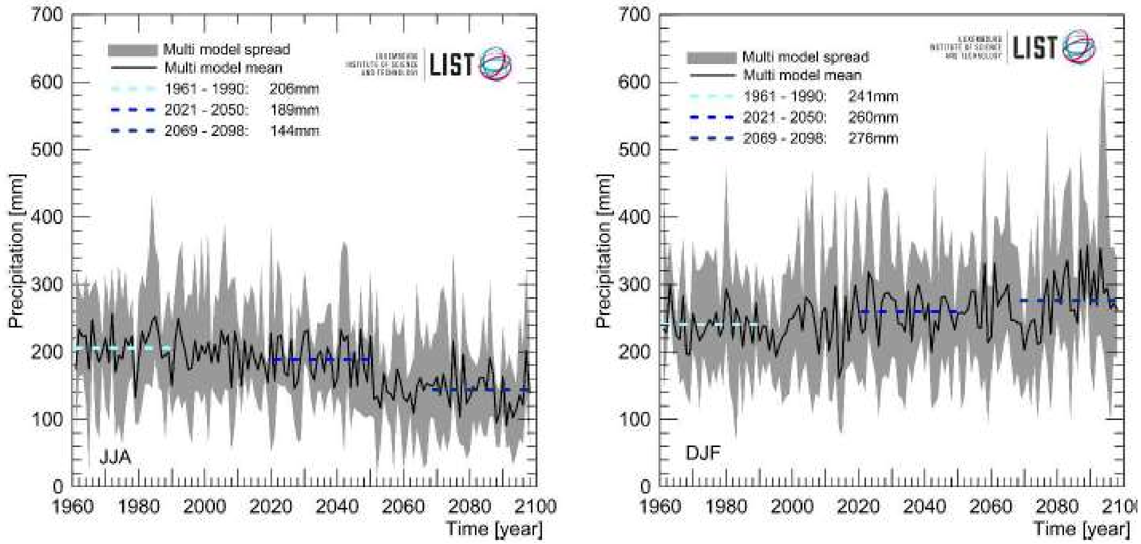
28 More details on ENSEMBLE are provided in Box VI.1-1 in Section V.1.1. see also http://ensembles-eu.metoffice.com.

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.

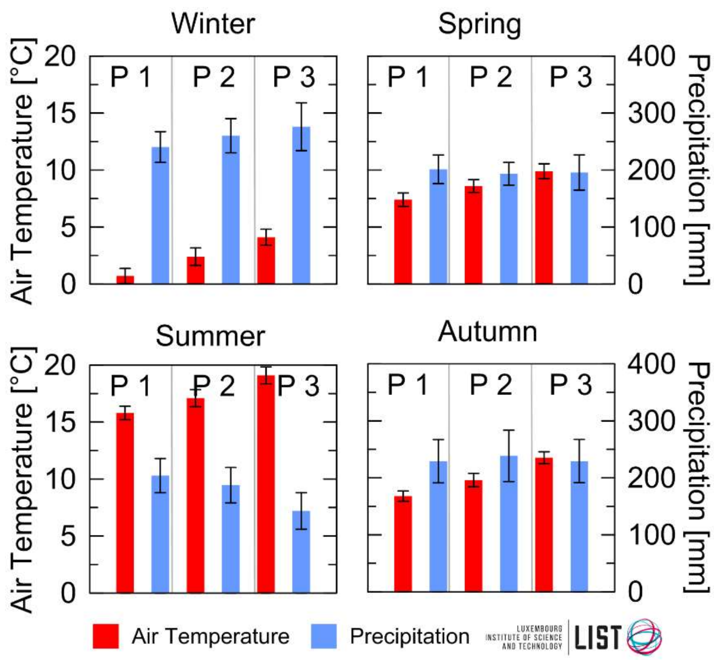


Source: Luxembourg Institute of Science and Technology (LIST). Unpublished.

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.

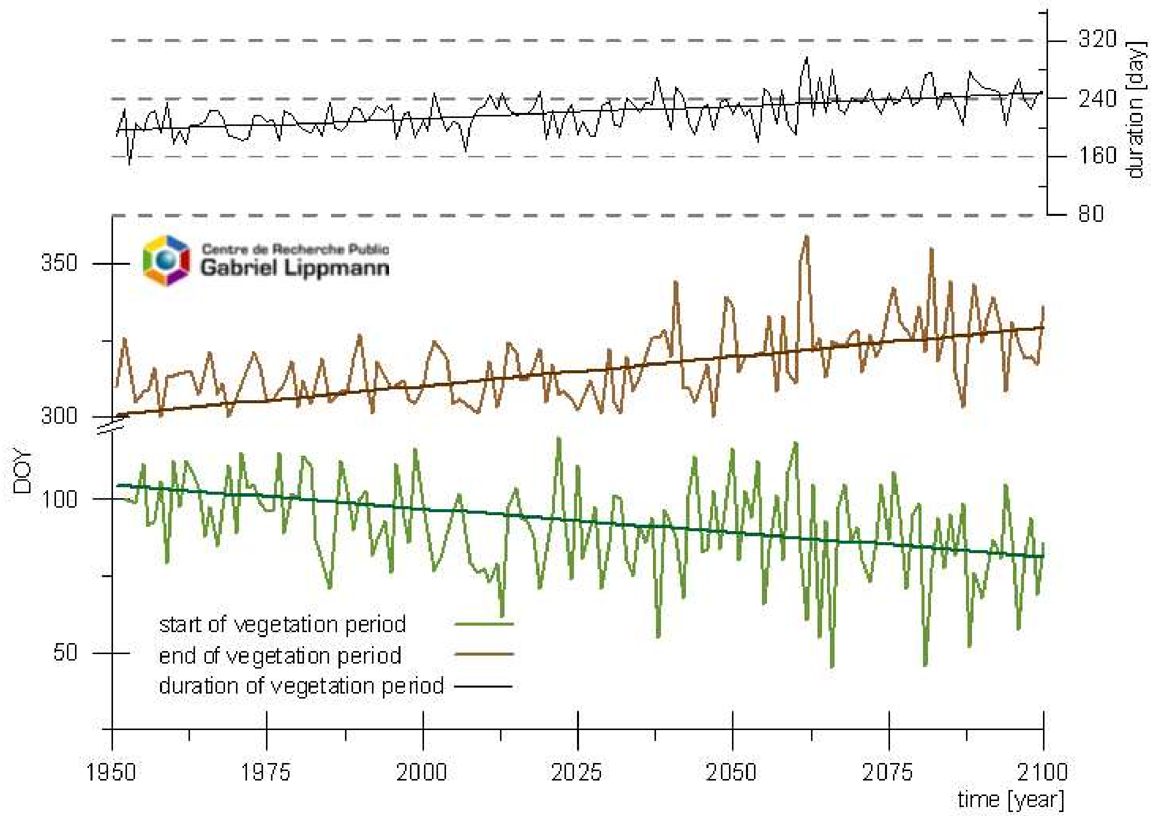
Two of these threats are of main concern for Luxembourg, **those relating to forests**. **Temperature extremes** and **summer precipitation** reduction are also causes for concern due to their impacts on human health, especially of the most fragile persons and the elderly (heat, air quality), and impacts 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, Georgen, 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 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 2018, 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 (1.59%) was about 4 times higher than its equivalent for the *Grande Région*.[32] It even reached 1.7% 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 2018, 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 2.1.4.

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 2010 forecast, under the "baseline" scenario, that almost 750 000 inhabitants could be living in Luxembourg by 2050 (Figure 2-15).[33] As it is the case for any forecasts, these predictions

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30 http://www.hydroclimato.lu.

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 (2012), *Projections socio-économiques 2010-2060*, Bulletin du STATEC N° 5/2010, Luxembourg, pages 262-272 (http://www.statistiques.public.lu/fr/publications/series/bulletin-statec/2010/05-10-Projpop/index.html). Other projections, which are a bit lower than STATEC's baseline scenario, are also produced in the framework of the European Commission Ageing

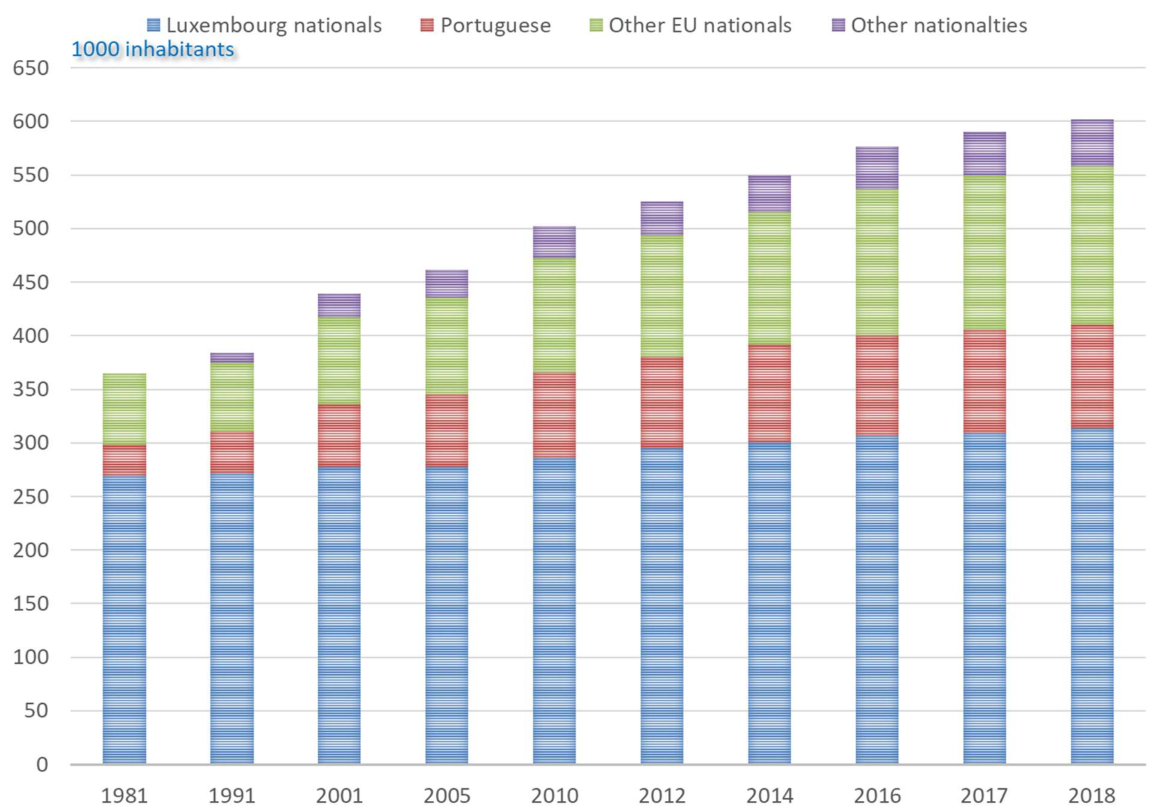
should be treated with caution because they cannot predict radical changes in the economic structure or demographics of a country, especially a small one whose economy relies heavily on a few economic sectors. However, since population growth is one of the key drivers for domestic energy use, mainly 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: 1960-2018

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

Source: STATEC, Statistical Yearbook, Table B.1100 (updated 30 March 2020): http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12856&IF_Language=fra&MainTheme=2&FldrName=1

Figure 2-14 – Population structure on 31st December: 1981-2018

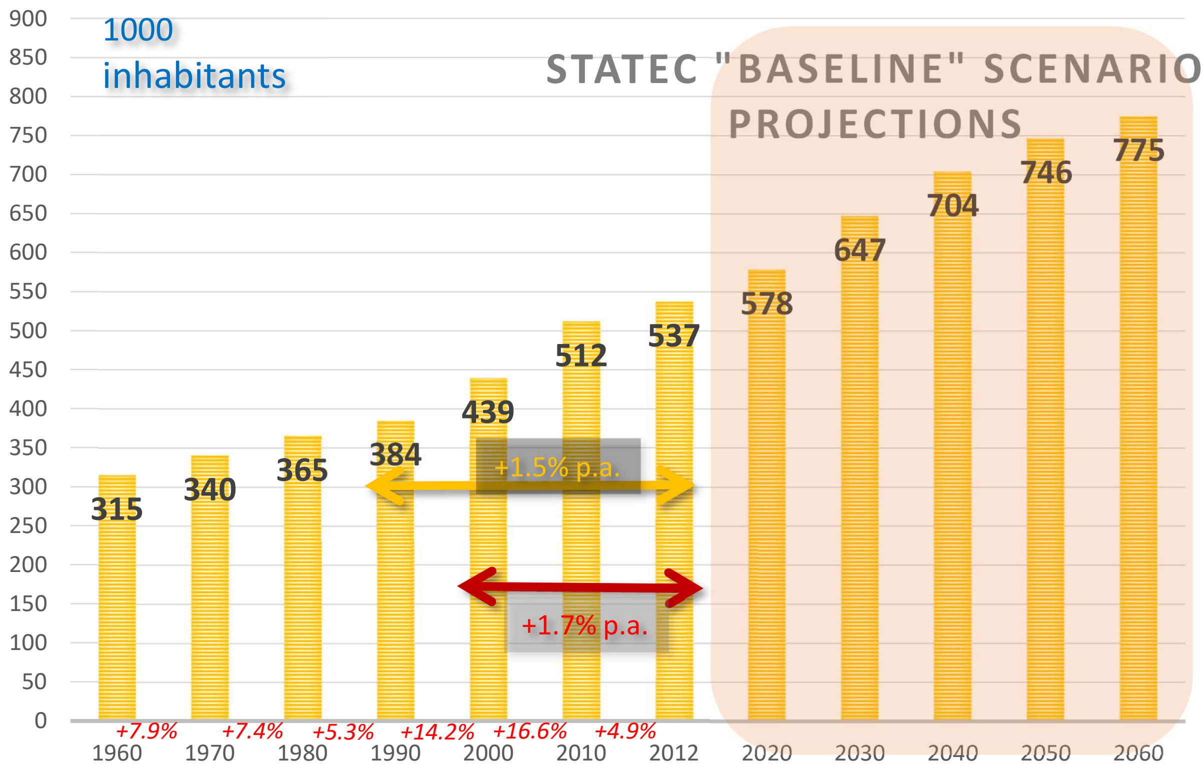


Source: STATEC, *Statistical Yearbook*, Table B.1101 (updated 30 March 2020): http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12856&IF_Language=fra&MainTheme=2&FldrName=1.

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

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 2-15 – Population growth on 31st December: 1960-2060



Sources: STATEC, *Statistical Yearbook*, Table B.1101 (updated 05.05.2017):
http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12856&IF_Language=fra&MainTheme=2&FldrName=1.
Eurostat, *Population projections*, Table proj_15npms (updated 19.06.2017):
http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=proj_15npms&lang=en.

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.

***Grande Région* entity**	**Population change** (1st January)	**Population annual average growth rate** (1st January)	**GDP at current price annual average growth rate**	**Total employment in 2015**
	% 1990-2015	*% 1990-2015*	*% 1990-2015*	*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 118 125 in 2018 - but, this was not enough. So the **cross-border commuters** came into play. Between 1995 and 2018, the number of cross-border workers increased from 56 900 to 192 100 (Figure 2-16).[34]

For 2018, among the commuters employed in Luxembourg, 51.1% came from France, 24.6% from Germany and 24.3% from Belgium. In total, the commuters accounted for 43% of the total workforce in Luxembourg and for 31% 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).

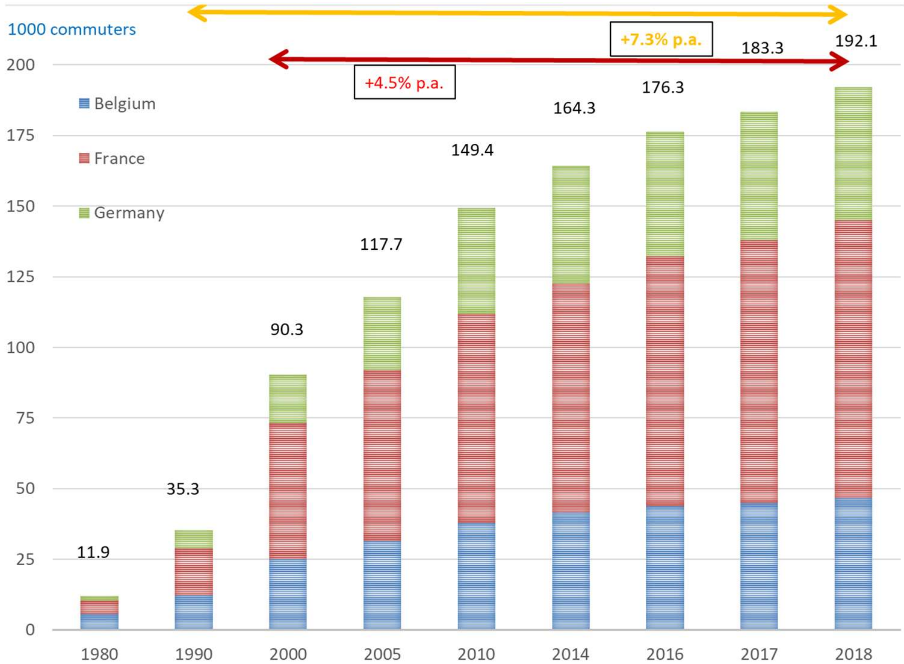
A vast majority of workers from abroad commute by car.[36] However, in order to alter the current modal split of home-work journeys, Luxembourg invests predominantly and jointly with the neighbouring regions into the public transport offer.

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

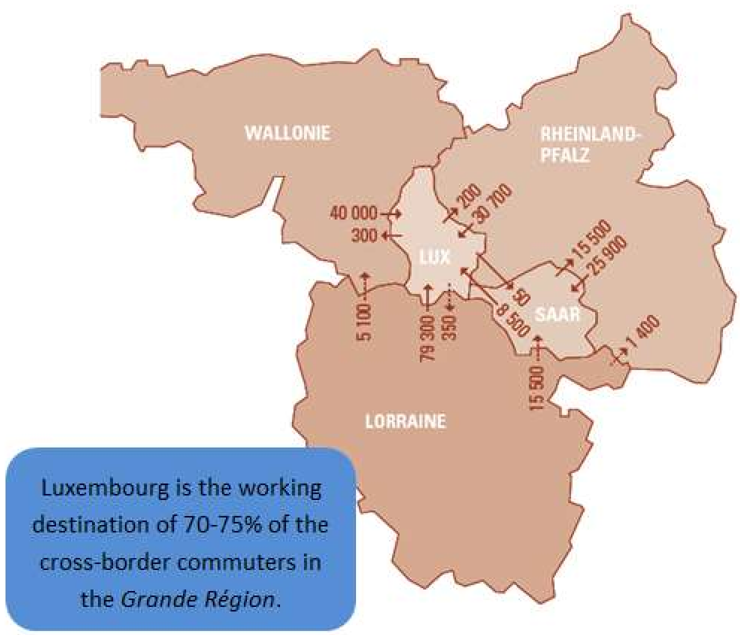
36 According to a recent study, for 2010, it was estimated that 86% of the cross-border commuters were only using their car for their home-work journeys. This percentage was 91% in 2007: http://www.ceps.lu/?type=module&id=104&tmp=1900.

Figure 2-16 – Cross-border commuters' growth: annual cumulative averages 1980-2018



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&RFPath=92

Figure 2-17 – Commuting flows 2015



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&RFPath=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 45.6% in 2018.[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 15% in 1995 to 7% in 2018. Other service activities ranged between a share of 18 to 24% and construction kept a rather constant share in total gross value added around 6%. 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.

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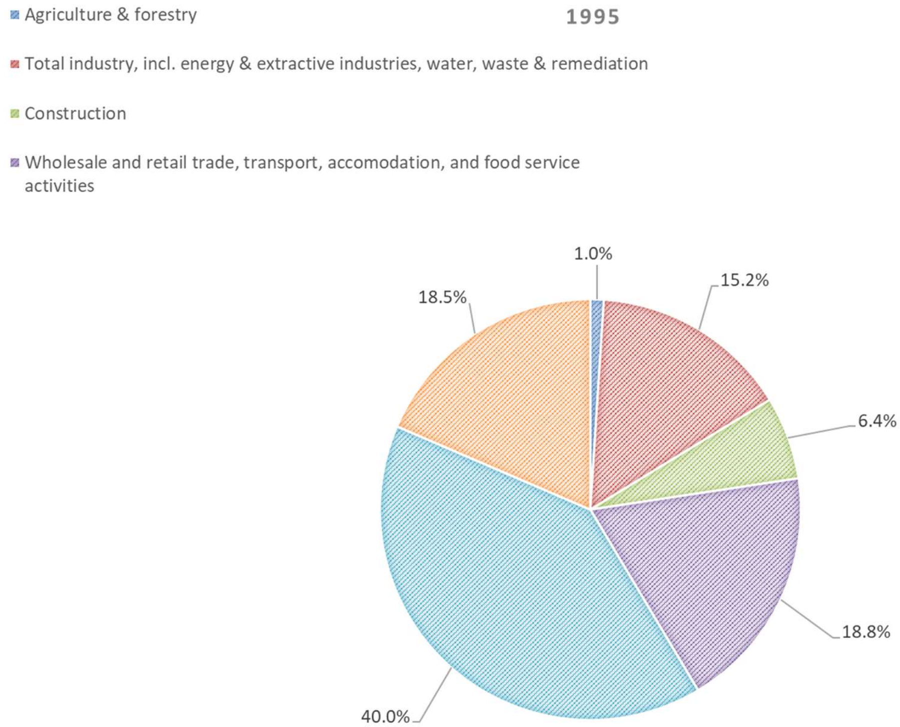
37 Data prior to 1995 are and will not be translated into the new European System of Accounts (ESA).

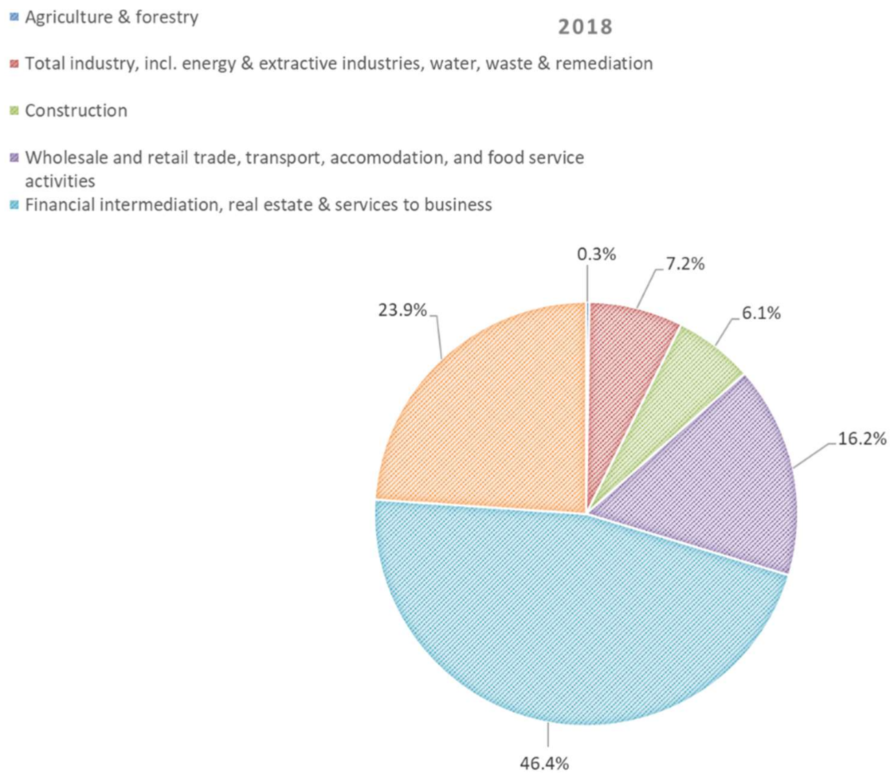
Table 2-9 – Sectoral gross value added at current prices: 1995-2018

mio. EUR		1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Agriculture, forestry & fishing (A)		144	144	107	115	152	119	94	99	109	159	129	145	118	117	139	136
	%	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%
Total industry, including extractive industries, energy production & distribution, water supply, sewerage, waste		2131	2594	2886	2948	3585	3185	2346	2661	2706	2673	2942	2729	3176	3656	3537	3830
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%
Construction (F)		892	1240	1527	1663	1943	1915	1914	1931	2124	2034	2129	2511	2571	2745	2851	3239
	%	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%
Wholesale and retail trade, transport,		2636	3599	4257	4738	4910	5835	5374	6145	7261	7017	7699	8111	7634	8228	8492	8657
accomodation	%	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%
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
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%
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
Oher 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%
Total: all NACE rev2 branches		**14270**	**20619**	**26668**	**30339**	**33276**	**34203**	**33135**	**36137**	**38739**	**39386**	**41527**	**44396**	**47057**	**49771**	**51599**	**54378**
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 30 March 2020): http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=13158&IF_Language=fra&MainTheme=5&FldrName=2&RFPath=21

Figure 2-18 – Sectoral gross value added at current prices: 1995 & 2018





Source: STATEC, *Statistical Yearbook*, Table E.2304 (updated 30 March 2020): http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=13157&IF_Language=fra&MainTheme=5&FldrName=2&RFPath=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 27.32% between 1990 and 2018. Whereas solid fuels and coal declined by 96.47% over the period, liquid fuels (incl. kerosene) and natural gas consumptions increased by 84.1% and 59.6% respectively (Table 2-10 & Figure 2-19).

Table 2-10 – Primary energy consumption: 1990-2018

TJ	1990 (base year)	1991	1992	1993	1994	1995	1996	1997	1998
Solid fuels & coal	49939.83	45812.91	43145.01	44770.76	38726.29	22010.21	20893.02	13306.17	4861.42
	33.23%	28.98%	27.20%	27.75%	24.76%	15.90%	14.78%	9.57%	3.57%
Liquid fuels (incl. kerosene)	66030.62	76910.67	79078.34	78994.97	78578.11	72455.60	74715.90	77882.37	82209.79
	43.94%	48.66%	49.86%	48.97%	50.24%	52.35%	52.85%	56.00%	60.30%
Natural gas (1)	19925.91	20717.94	21593.35	22427.07	22593.81	25819.65	28324.39	29023.46	29305.68
	13.26%	13.11%	13.61%	13.90%	14.45%	18.65%	20.03%	20.87%	21.50%
Electricity	13256.15	13464.58	13631.32	14006.50	15423.82	17083.75	16644.80	17889.96	18859.16
	8.82%	8.52%	8.59%	8.68%	9.86%	12.34%	11.77%	12.86%	13.83%
Heat	NO	NO	NO	NO	NO	NO	NO	NO	NO
	NA	NA	NA	NA	NA	NA	NA	NA	NA
Renewable energy sources & waste	1125.52	1167.21	1167.21	1125.52	1083.84	1042.15	808.71	964.61	1100.93
Incineration (with heat recovery) (2)	0.75%	0.74%	0.74%	0.70%	0.69%	0.75%	0.57%	0.69%	0.81%
Total	**150278.03**	**158073.31**	**158615.23**	**161324.82**	**156405.87**	**138411.36**	**141386.82**	**139066.58**	**136336.98**

TJ	1999	2000	2001	2002	2003	2004	2005	2006	2007
Solid fuels & coal	4814.73	4594.52	4957.84	3083.62	2369.15	3328.54	3248.87	3876.79	3280.32
	3.33%	2.96%	3.02%	1.79%	1.31%	1.65%	1.58%	1.91%	1.65%
Liquid fuels (incl. kerosene)	87715.26	96236.54	102063.69	104261.62	111789.85	126709.57	130884.49	124310.30	121227.03
	60.72%	61.99%	62.27%	60.42%	61.74%	62.91%	63.82%	61.24%	60.92%
Natural gas (1)	30397.85	31231.01	34718.00	49629.00	50238.00	55632.00	54720.18	57237.24	53426.14
	21.04%	20.12%	21.18%	28.76%	27.74%	27.62%	26.68%	28.20%	26.85%
Electricity	19580.75	21059.69	19649.82	12952.77	13931.02	12698.58	12323.47	13490.64	14981.85
	13.55%	13.56%	11.99%	7.51%	7.69%	6.30%	6.01%	6.65%	7.53%
Heat	NO	0.03	2.02	6.47	9.85	13.60	17.53	21.62	28.95
	NA	0.00%	0.00%	0.00%	0.01%	0.01%	0.01%	0.01%	0.01%
Renewable energy sources & waste	1946.32	2128.82	2520.68	2630.06	2736.22	3041.45	3883.23	4049.26	6063.63
Incineration (with heat recovery) (2)	1.35%	1.37%	1.54%	1.52%	1.51%	1.51%	1.89%	1.99%	3.05%
Total	**144454.91**	**155250.60**	**163912.04**	**172563.50**	**181074.05**	**201423.74**	**205077.57**	**202985.71**	**199007.74**

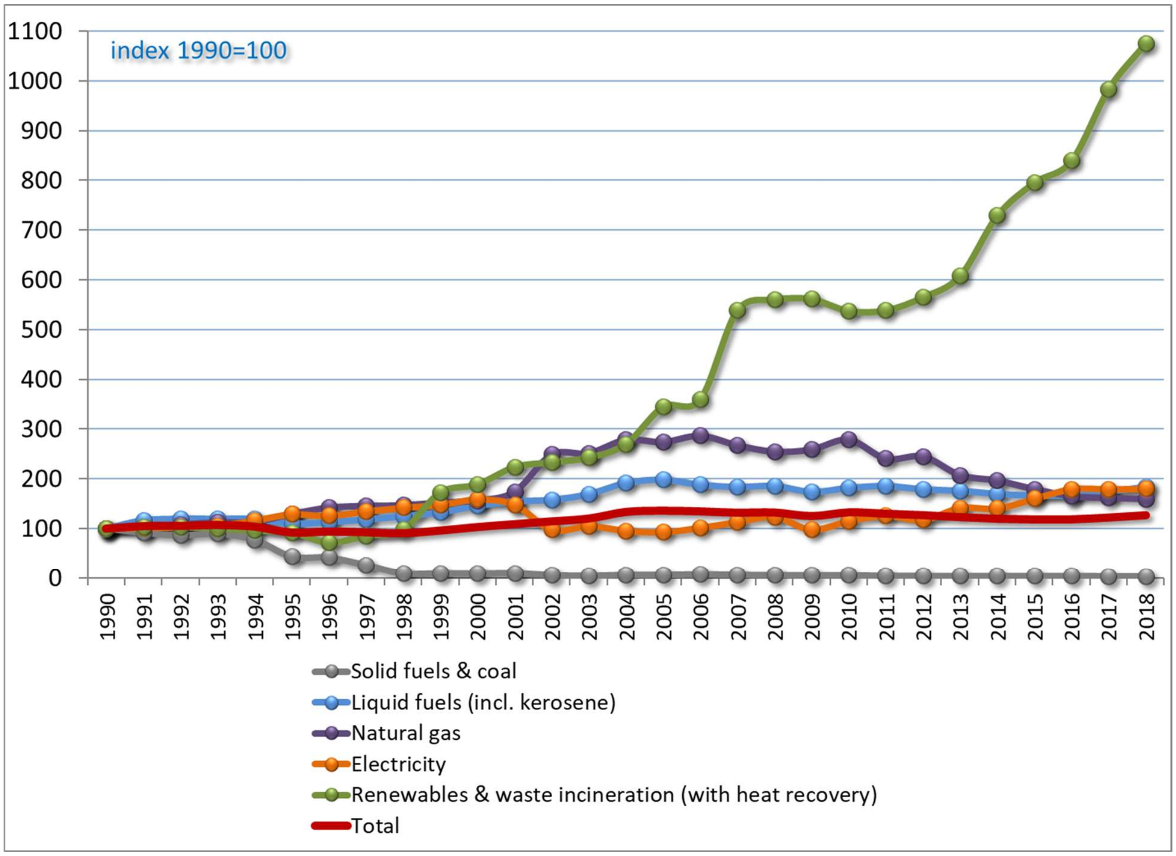
TJ	2008	2009	2010	2011	2012	2013	2014	2015	2016
Solid fuels & coal	3136.57	2801.27	2806.63	2443.45	2249.59	2005.86	2235.46	2057.27	2193.19
	1.57%	1.48%	1.40%	1.25%	1.17%	1.08%	1.24%	1.15%	1.23%
Liquid fuels (incl. kerosene)	122653.44	114781.92	120101.37	122553.58	118269.72	116297.53	112052.94	110128.94	109970.55
	61.51%	60.83%	60.05%	62.57%	61.77%	62.69%	62.07%	61.75%	61.55%
Natural gas (1)	50856.70	51751.75	55665.22	48021.10	48894.89	41398.28	39223.62	35770.96	32988.07
	25.50%	27.42%	27.83%	24.52%	25.54%	22.32%	21.73%	20.06%	18.46%
Electricity	16412.67	12987.43	15290.40	16677.00	15567.70	18791.88	18634.28	21238.39	23821.51
	8.23%	6.88%	7.65%	8.51%	8.13%	10.13%	10.32%	11.91%	13.33%
Heat	41.42	62.14	84.70	106.64	133.07	160.91	182.47	208.17	231.67
	0.02%	0.03%	0.04%	0.05%	0.07%	0.09%	0.10%	0.12%	0.13%
Renewable energy sources & waste	6310.98	6320.76	6052.85	6067.60	6363.53	6846.43	8208.17	8956.12	9453.53
Incineration (with heat recovery) (2)	3.16%	3.35%	3.03%	3.10%	3.32%	3.69%	4.55%	5.02%	5.29%
Total	**199411.78**	**188705.27**	**200001.16**	**195869.37**	**191478.51**	**185500.90**	**180536.93**	**178359.85**	**178658.51**

TJ	2017	2018
Solid fuels & coal	1897.95	1764.00
	1.03%	0.92%
Liquid fuels (incl. kerosene)	115043.66	121501.00
	62.35%	63.50%
Natural gas (1)	32244.57	31803.00
	17.48%	16.62%
Electricity	23785.11	23859.00
	12.89%	12.47%
Heat	257.20	289.00
	0.14%	0.15%
Renewable energy sources & waste	11075.00	12113.00
Incineration (with heat recovery) (2)	6.00%	6.33%
Total	**184502.85**	**191329.00**

Source: STATEC, *Statistical Yearbook*, Table A.4200 (updated 30 March 2020): http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12759&IF_Language=fra&MainTheme=1&FldrName=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: 1990-2018



Source: STATEC, *Statistical Yearbook*, Table A.4200 (updated 4 April 2020): http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12759&IF_Language=fra&MainTheme=1&FldrName=4&RFPath=54

Final energy consumption increased by 28.43% between 1990 and 2018. 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 1990-2018, 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 2018, 81.59% of the **final energy consumption** was covered by fossil fuels – 65.09% by liquid fuels including the important volume of road fuels as well as kerosene,[38] 15.55% by natural gas and 0.95% by coal. The remaining 18.41% of the consumption were either electricity (12.5%) and heat (1.67%) or renewable energy sources, including organic waste incineration with energy recovery, biogas, and biofuels (4.24%). 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). What happened?

- Regarding **solid fuels and coal**, the important decline (-94.47%) 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 (+72.08%) was driven by road fuel sales and kerosene, but with the former being 4 to 5 times higher in quantity than the latter. This is especially "road fuel sales to non-residents" that explains a great deal of the sharp increase (see Section 2.1.6);
- The 48.04% 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 2018 – and even first if "road fuel sales to non-residents" and kerosene are not considered.

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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: 1990-2018

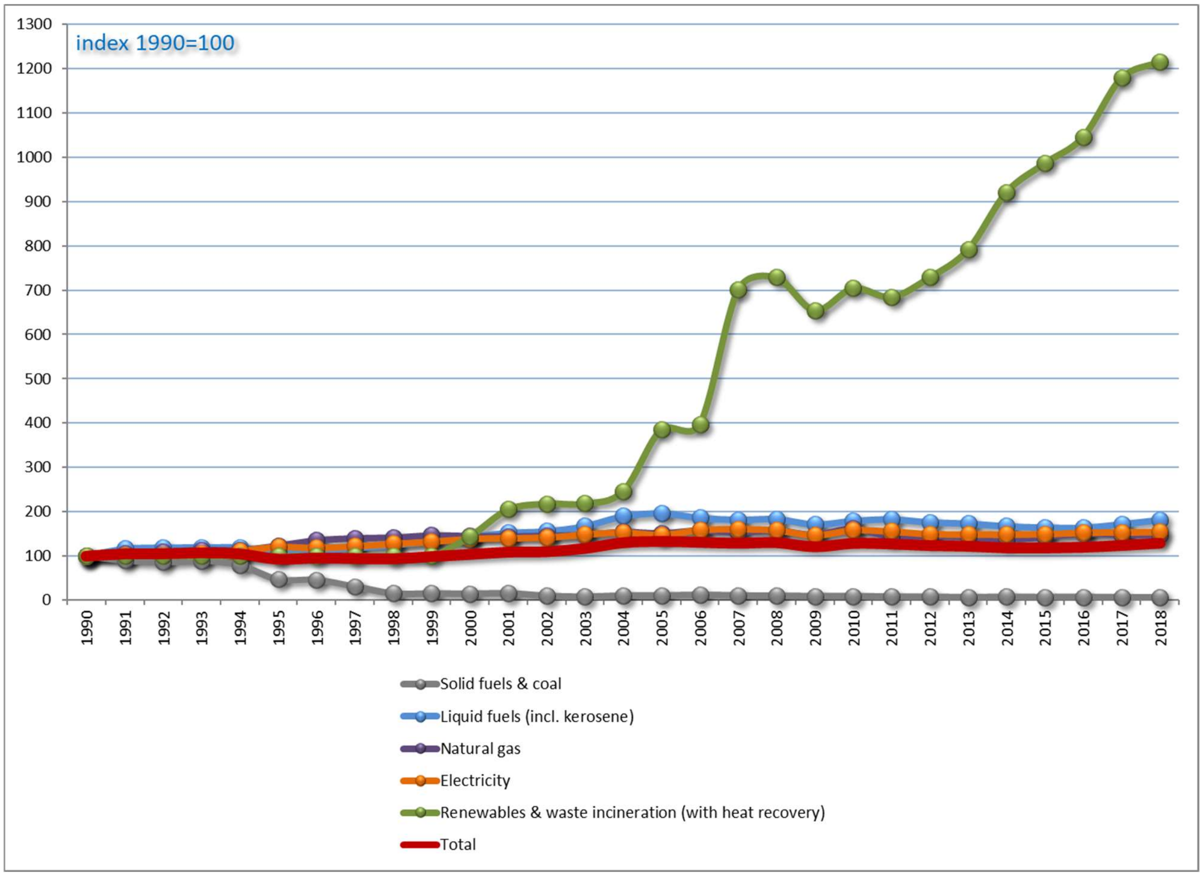
TJ	1990 (base year)	1991	1992	1993	1994	1995	1996	1997	1998
Solid fuels & coal	34331.76	30814.85	29475.07	30689.24	27268.21	16035.03	15670.77	10422.20	4882.65
	23.83%	20.38%	19.46%	19.85%	18.05%	11.91%	11.35%	7.64%	3.60%
Liquid fuels (incl. kerosene)	66193.31	76911.52	78669.97	78837.44	78753.71	72682.85	74734.38	78046.98	82554.07
	45.95%	50.87%	51.93%	51.00%	52.14%	53.99%	54.13%	57.20%	60.90%
Natural gas (1)	19426.75	20389.72	21227.08	22064.44	21989.91	23906.63	26251.24	27155.58	27436.94
	13.49%	13.49%	14.01%	14.27%	14.56%	17.76%	19.01%	19.90%	20.24%
Blast furnaces gas	8'457.34	7'234.79	6'196.46	6'514.24	5'503.55	2'731.89	2'511.66	1'347.31	NO
	5.87%	4.79%	4.09%	4.21%	3.64%	2.03%	1.82%	0.99%	NA
Electricity	14988.74	15198.08	15281.82	15826.10	16747.20	18045.11	17710.16	18254.45	19091.81
	10.41%	10.05%	10.09%	10.24%	11.09%	13.40%	12.83%	13.38%	14.08%
Heat (2)	NO	NO	NO	NO	125.60	586.15	547.21	563.54	949.98
	NA	NA	NA	NA	0.08%	0.44%	0.40%	0.41%	0.70%
Renewable energy sources & waste	644.77	644.77	644.77	644.77	644.77	644.77	644.77	644.77	644.77
Incineration (with heat recovery) (3)	0.45%	0.43%	0.43%	0.42%	0.43%	0.48%	0.47%	0.47%	0.48%
Total	**144043**	**151194**	**151495**	**154576**	**151033**	**134632**	**138070**	**136435**	**135560**

TJ	1999	2000	2001	2002	2003	2004	2005	2006	2007
Solid fuels & coal	4835.75	4594.52	4957.84	3083.62	2369.15	3328.54	3248.87	3876.79	3280.32
	3.39%	3.07%	3.16%	1.95%	1.41%	1.78%	1.71%	2.07%	1.77%
Liquid fuels (incl. kerosene)	88082.74	94644.90	100723.34	103120.21	110821.65	125715.23	130171.42	123605.43	120541.81
	61.67%	63.27%	64.29%	65.18%	65.83%	67.37%	68.35%	65.86%	65.21%
Natural gas (1)	28436.00	28125.74	27997.84	28258.28	28673.98	29942.32	29338.04	30622.60	29822.71
	19.91%	18.80%	17.87%	17.86%	17.03%	16.04%	15.40%	16.32%	16.13%
Blast furnaces gas	NO	NO	NO	NO	NO	NO	NO	NO	NO
	NA	NA	NA	NA	NA	NA	NA	NA	NA
Electricity	19836.00	20790.21	21033.19	21260.54	22252.42	23007.38	22149.43	23806.48	24097.50
	13.89%	13.90%	13.43%	13.44%	13.22%	12.33%	11.63%	12.68%	13.04%
Heat (2)	986.41	503.93	624.35	1086.98	2818.44	3036.13	3055.77	3210.55	2581.94
	0.69%	0.34%	0.40%	0.69%	1.67%	1.63%	1.60%	1.71%	1.40%
Renewable energy sources & waste	644.77	929.70	1321.31	1405.98	1406.76	1586.77	2489.86	2562.50	4518.54
Incineration (with heat recovery) (3)	0.45%	0.62%	0.84%	0.89%	0.84%	0.85%	1.31%	1.37%	2.44%
Total	**142821**	**149589**	**156659**	**158216**	**168342**	**186616**	**190453**	**187684**	**184843**

TJ	2008	2009	2010	2011	2012	2013	2014	2015	2016
Solid fuels & coal	3136.57	2801.27	2806.63	2443.45	2249.59	2005.86	2235.46	2057.27	2193.19
	1.68%	1.61%	1.52%	1.34%	1.27%	1.14%	1.31%	1.21%	1.27%
Liquid fuels (incl. kerosene)	121613.03	113535.87	118859.54	121270.87	116787.74	114974.13	110826.74	108956.97	108684.56
	65.13%	65.36%	64.46%	66.45%	65.80%	65.54%	65.08%	64.12%	63.11%
Natural gas (1)	30616.00	28658.82	31411.99	27916.40	28262.17	27789.82	26536.40	27791.20	29226.32
	16.40%	16.50%	17.04%	15.30%	15.92%	15.84%	15.58%	16.35%	16.97%
Blast furnaces gas	NO	NO	NO	NO	NO	NO	NO	NO	NO
	NA	NA	NA	NA	NA	NA	NA	NA	NA
Electricity	23750.44	22004.89	23734.71	23343.11	22449.55	22315.52	22256.43	22406.96	22922.20
	12.72%	12.67%	12.87%	12.79%	12.65%	12.72%	13.07%	13.19%	13.31%
Heat (2)	2922.39	2483.81	3036.59	3102.44	3045.38	3230.12	2511.90	2355.44	2432.74
	1.56%	1.43%	1.65%	1.70%	1.72%	1.84%	1.47%	1.39%	1.41%
Renewable energy sources & waste	4697.03	4219.33	4540.66	4414.70	4700.15	5103.19	5938.32	6360.30	6742.58
Incineration (with heat recovery) (3)	2.52%	2.43%	2.46%	2.42%	2.65%	2.91%	3.49%	3.74%	3.92%
Total	**186735**	**173704**	**184390**	**182491**	**177495**	**175419**	**170305**	**169928**	**172202**

TJ	2017	2018
Solid fuels & coal	1897.95	1764.00
	1.07%	0.95%
Liquid fuels (incl. kerosene)	113906.00	120411.00
	63.96%	65.09%
Natural gas (1)	28760.25	28762.00
	16.15%	15.55%
Blast furnaces gas	NO	NO
	NA	NA
Electricity	23015.53	23120.00
	12.92%	12.50%
Heat (2)	2782.06	3094.00
	1.56%	1.67%
Renewable energy sources & waste	7599.00	7837.00
	4.27%	4.24%
Total	**178102**	**184988**

Figure 2-20 – Final energy consumption: 1990-2018



Source: STATEC, *Statistical Yearbook*, Table A.4300 (updated 30 March 2020): http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12771&IF_Language=fra&MainTheme=1&FldrName=4&RFPath=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).

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 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, an energy balance for electric power is provided (Table 2-12 & Figure 2-21).

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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 2-12 – Energy balance for electric power: 1990-2016

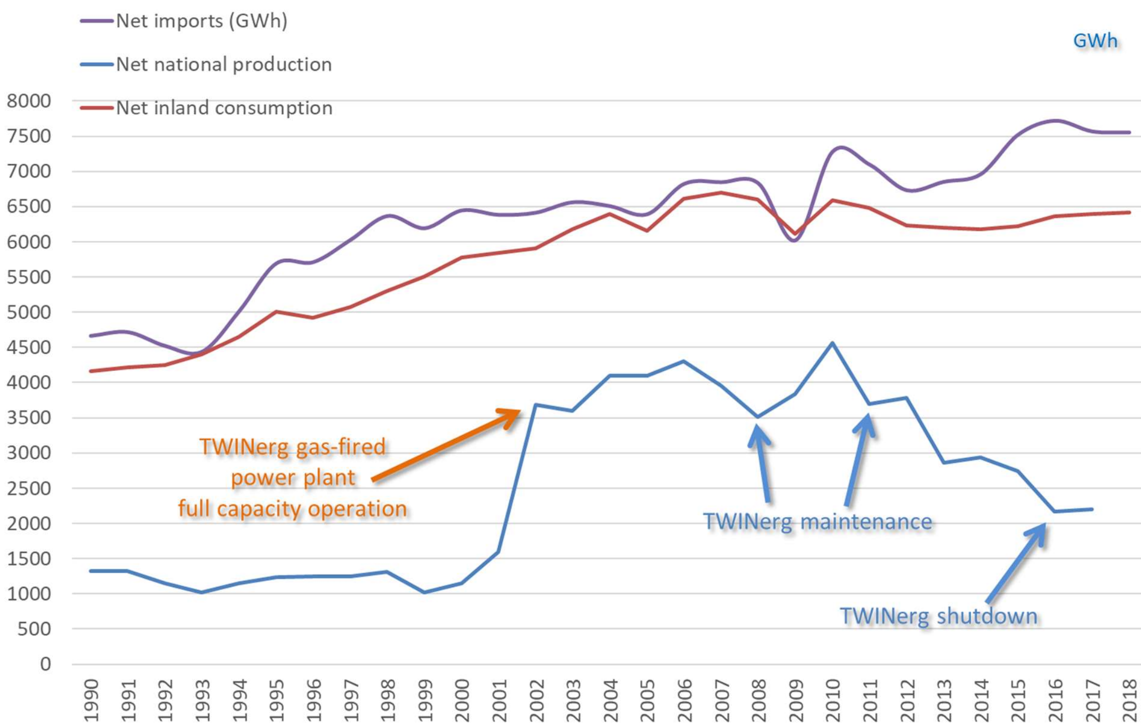
GWh	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Imports	**4665.46**	**4718.45**	**4523.56**	**4440.97**	**5015.24**	**5693.47**	**5712.33**	**6026.52**	**6366.60**	**6193.53**	**6445.38**	**6383.25**	**6413.64**
National production	**1322.04**	**1327.54**	**1144.30**	**1019.29**	**1150.11**	**1236.06**	**1251.78**	**1243.99**	**1311.39**	**1022.59**	**1148.34**	**1591.96**	**3687.51**
cogeneration	NO	NO	NO	NO	33.00	102.00	114.00	118.00	195.00	205.00	219.38	269.00	351.99
thermic power stations	558.72	622.11	594.14	607.83	538.96	448.53	420.24	331.96	299.76	256.62	270.88	726.25	2685.30
of which, TWINerg (2)	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*
hydro-electricity	804.24	751.85	593.24	454.16	648.62	821.85	858.42	932.62	1022.16	765.80	872.99	857.97	977.93
wind	NO	NO	NO	NO	NO	NO	NO	3.00	11.00	17.00	25.00	24.00	24.00
biomass & biogas	554.00	617.00	590.00	604.00	491.00	399.00	380.00	320.00	240.00	257.00	271.00	725.00	2685.00
gas from WWTPs	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
gas from landfill sites	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
photovoltaic	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total	**5987.50**	**6045.99**	**5667.85**	**5460.26**	**6165.36**	**6929.53**	**6964.11**	**7270.50**	**7678.00**	**7216.12**	**7593.72**	**7975.21**	**10101.15**
Exports	**0.75**	**0.72**	**0.54**	**0.39**	**0.57**	**0.74**	**0.81**	**0.85**	**0.92**	**0.65**	**0.74**	**1.07**	**2.94**
Conversion uses and losses	**389.32**	**395.43**	**334.28**	**318.06**	**364.83**	**434.15**	**431.95**	**418.98**	**428.05**	**340.97**	**359.49**	**414.82**	**450.53**
Net inland consumption	**4149.00**	**4211.00**	**4231.00**	**4385.00**	**4644.00**	**4996.00**	**4907.00**	**5057.00**	**5292.00**	**5495.00**	**5775.00**	**5843.00**	**5904.00**
Total	**4539.08**	**4601.04**	**4620.87**	**4774.72**	**5033.89**	**5386.07**	**5297.13**	**5447.17**	**5682.25**	**5884.98**	**6165.06**	**6233.39**	**6296.26**

Summary in GWh	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Net imports	**4665.46**	**4718.45**	**4523.56**	**4440.97**	**5015.24**	**5693.47**	**5712.33**	**6026.52**	**6366.60**	**6193.53**	**6445.38**	**6383.25**	**6413.64**
Net national production (1)	**1322.04**	**1327.54**	**1144.30**	**1019.29**	**1150.11**	**1236.06**	**1251.78**	**1243.99**	**1311.39**	**1022.59**	**1148.34**	**1591.96**	**3687.51**
Net inland consumption	**4149.00**	**4211.00**	**4231.00**	**4385.00**	**4644.00**	**4996.00**	**4907.00**	**5057.00**	**5292.00**	**5495.00**	**5775.00**	**5843.00**	**5904.00**
Net inland consumption in Mio. MJ (3)	14936.40	15159.60	15231.60	15786.00	16718.40	17985.60	17665.20	18205.20	19051.20	19782.00	20790.00	21034.80	21254.40
Net inland consumption in 1000 toe	356.75	362.08	363.80	377.04	399.31	429.58	421.93	434.82	455.03	472.48	496.56	502.41	507.65

GWh	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Imports	**6562.18**	**6506.31**	**6391.61**	**6823.54**	**6846.58**	**6829.87**	**6022.47**	**7279.51**	**7096.34**	**6732.10**	**6851.52**	**6961.18**	**7518.76**	**7718.39**
National production	**3597.10**	**4102.05**	**4104.41**	**4301.32**	**3959.54**	**3516.43**	**3835.95**	**4560.28**	**3693.17**	**3786.31**	**2859.81**	**2937.81**	**2938.81**	**2939.81**
cogeneration	397.41	441.91	445.15	470.69	398.98	422.18	390.45	439.66	447.05	437.88	417.32	381.36	349.89	355.05
thermic power stations	2682.89	3229.29	3181.75	3337.18	2997.85	2511.43	2961.88	3047.06	2495.80	2541.81	1574.22	1622.00	1029.80	467.66
of which, TWINerg (2)	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*	*NO*
hydro-electricity	902.91	842.98	867.65	906.31	906.12	951.92	820.53	1457.23	1124.76	1146.81	1145.22	1157.88	1158.88	1159.88
wind	26.00	39.00	52.00	58.00	64.00	61.00	63.00	55.00	64.00	77.00	83.00	80.00	102.00	101.00
biomass & biogas	2683.00	3230.00	3184.00	3339.00	2999.00	2513.00	2963.00	3046.00	2498.00	2543.00	1573.00	1622.00	1030.00	467.00
gas from WWTPs	NO	NO	NO	NO	NO	5.32	5.85	5.14	6.00	6.00	6.00	6.00	6.00	6.00
gas from landfill sites	NO	NO	NO	NO	NO	NO	0.26	0.41	0.00	1.00	1.00	1.00	1.00	1.00
photovoltaic	1.00	9.00	18.00	21.00	21.00	20.00	20.00	21.00	26.00	38.00	74.00	95.00	104.00	100.00
Total	**10159.28**	**10608.36**	**10496.01**	**11124.85**	**10806.12**	**10346.30**	**9858.42**	**11839.79**	**10789.51**	**10518.41**	**9711.33**	**9898.99**	**10457.57**	**10658.21**
Exports	**2.80**	**3.13**	**3.13**	**3.27**	**2.89**	**2.48**	**2.60**	**3.22**	**2.61**	**2.62**	**1.91**	**2.07**	**1.92**	**1.42**
Conversion uses and losses	**475.68**	**366.33**	**453.13**	**472.35**	**466.47**	**474.25**	**423.09**	**674.15**	**608.00**	**593.24**	**593.24**	**593.24**	**594.24**	**595.24**
Net inland consumption	**6182.00**	**6393.00**	**6150.00**	**6614.00**	**6695.00**	**6598.00**	**6114.00**	**6593.00**	**6485.00**	**6236.00**	**6201.00**	**6181.00**	**6225.00**	**6367.00**
Total	**6574.12**	**6785.46**	**6542.46**	**7006.59**	**7087.21**	**6989.81**	**6505.93**	**6985.54**	**6876.94**	**6627.95**	**6592.23**	**6572.39**	**6617.24**	**6759.74**

Summary in GWh	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Net imports	**6562.18**	**6506.31**	**6391.61**	**6823.54**	**6846.58**	**6829.87**	**6022.47**	**7279.51**	**7096.34**	**6732.10**	**6851.52**	**6961.18**	**7518.76**	**7718.39**
Net national production (1)	**3597.10**	**4102.05**	**4104.41**	**4301.32**	**3959.54**	**3516.43**	**3835.95**	**4560.28**	**3693.17**	**3786.31**	**2859.81**	**2937.81**	**2938.81**	**2939.81**
Net inland consumption	**6182.00**	**6393.00**	**6150.00**	**6614.00**	**6695.00**	**6598.00**	**6114.00**	**6593.00**	**6485.00**	**6236.00**	**6201.00**	**6181.00**	**6225.00**	**6367.00**
Net inland consumption in Mio. MJ (3)	22255.20	23014.80	22140.00	23810.40	24102.00	23752.80	22010.40	23734.80	23346.00	22449.60	22323.60	22251.60	22410.00	22921.20
Net inland consumption in 1000 toe	531.56	549.70	528.80	568.70	575.67	567.33	525.71	566.90	557.61	536.20	533.19	531.47	535.25	547.46

Figure 2-21 –Energy balance for electric power: 1990-2018



Sources: Compiled by the Environment Agency on 31 March 2020 using data published by the Ministry of the Economy – Energy Department, the *Institut Luxembourgeois de Régulation* and STATEC (Table A.4203). Net national production data for 2018 were not yet available at this date.

Notes: (1) The net national production is the difference between the national production and the conversion process uses and losses.
(2) Net inland consumption expressed in TJ (Mio. MJ) differs slightly from the corresponding figures in Table II.6-2 – less than 2% – because data sources, units and calculations are not exactly the same.

2.1.6 Road transportation

2.1.6.1 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 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, in first instance, 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 well using the NEMO model. Details are provided in Section 3.2.8.3.2.2 of this National Inventory 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, whose an important share fills up in Luxembourg because of lower fuel prices;
2. Cross-border commuters who are also benefiting of the cheaper fuel prices;
3. "Fuel tourism", known as "*Tanktourismus*" in Luxembourg: people driving especially to Luxembourg for benefiting of 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%).

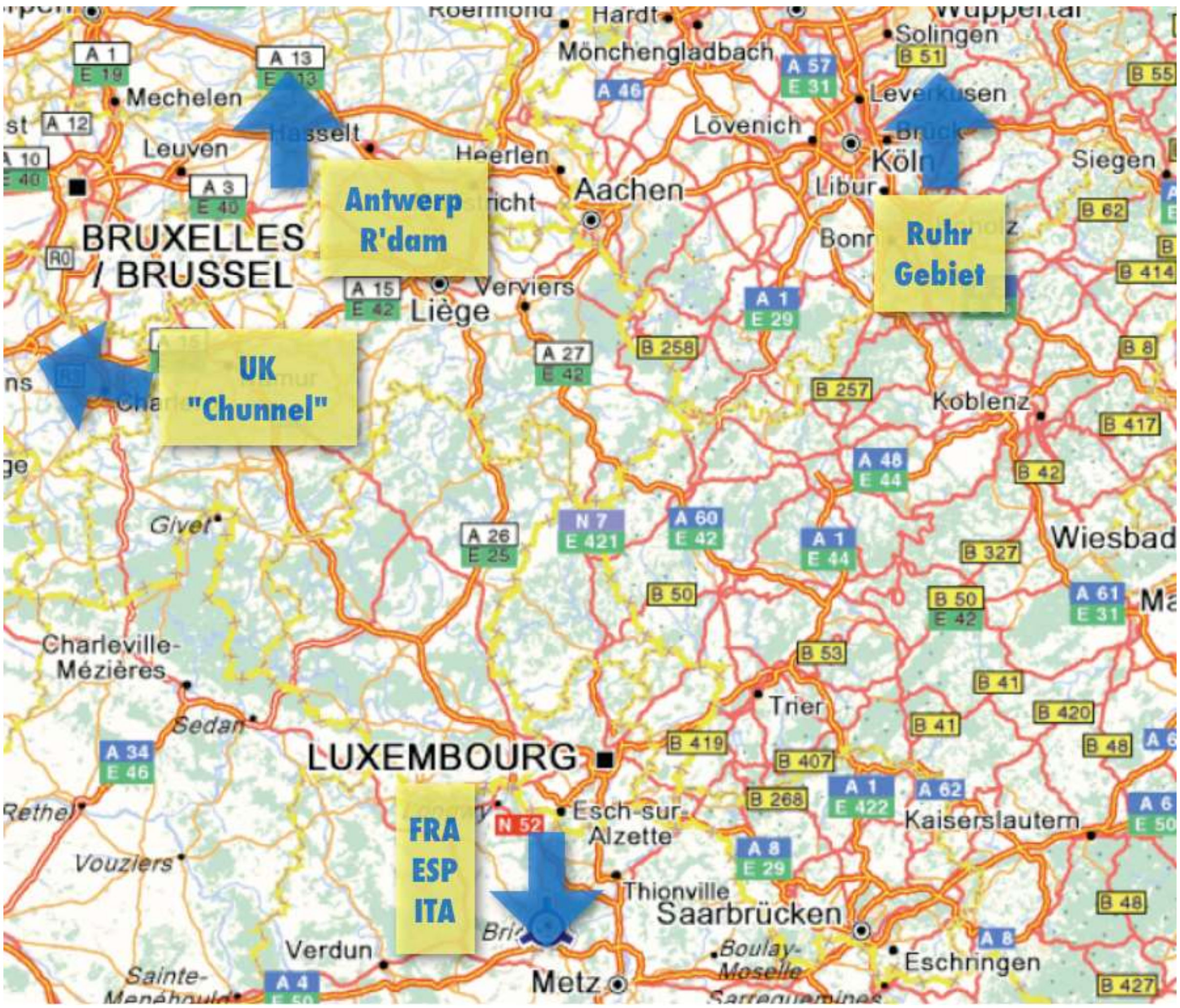
In the subsequent chapters & sections of this NIR, "road fuel sales to non-residents" is sometimes referred to as "(road) fuel exports".

2.1.6.2 Effects on GHG emissions: an untypical situation

Combining the size of the country and of its economy, on the one side, and lower road fuel prices that implies 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 emissions balance. In 2018, 6.02 Mio. t CO_2eq were produced by the road transportation sector and out of these, 4.26 Mio. t CO_2eq, corresponding to 71%, was the result of road fuels emitted abroad by commuting and transiting vehicles. That last amount represented around 40.4% of the total 2018 GHG emissions for Luxembourg (excluding LULUCF) while the whole CRF sub-category 1A3b accounted for 57% of the total 2018 GHG emissions for Luxembourg (excluding LULUCF) (Figure 2-22).

Both emissions generated by the national vehicles fleet and by the non-residents – "road fuel sales to non-residents" – showed dramatic increases over the period: +98% and +149%, respectively.[41] For the national fleet, the evolution is correlated with both the population and economic activity growth. It is also explained by an increasing rate for passenger cars per inhabitants (from 499 to 670 passenger cars per 1000 inhabitants between 1990 and 2017, *i.e.* the highest rate within the EU[42]). 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.

Figure 2-22 – MAIN ROAD FREIGHT AXES CROSSING LUXEMBOURG

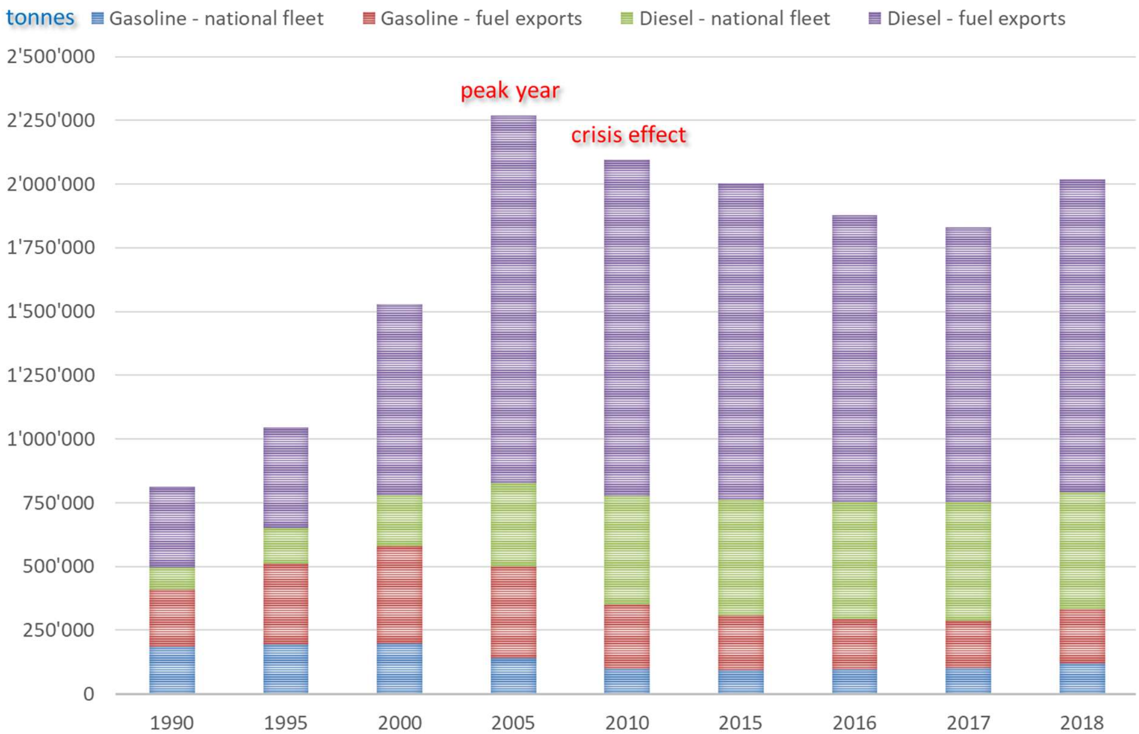


Source: ViaMichelin.

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 3-52 since the latter includes CO_2 emissions from biomass which is not counted here.

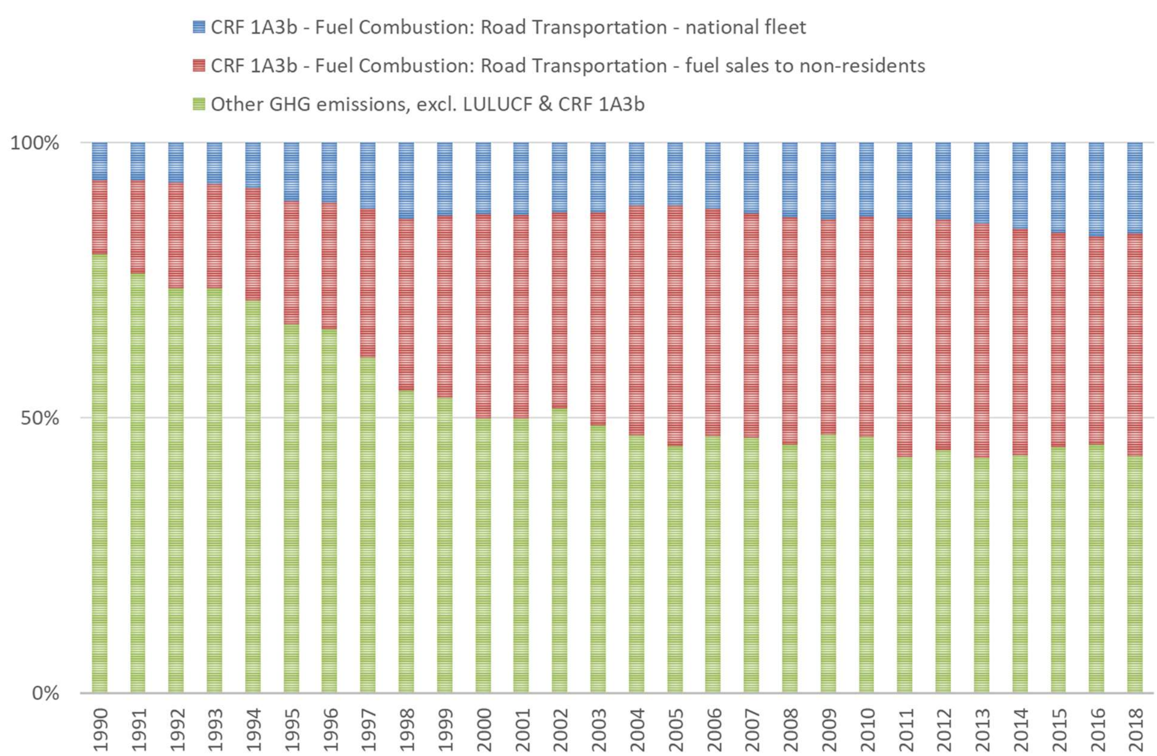
42 Data extracted from https://ec.europa.eu on 2 April 2020

Figure 2-23 – Road blended fuel sales: 1990-2018 in tonnes



Source: based on Table 3-51 in Section 3.2.8.3.

Figure 2-24 – GHG emissions for road transportation (CRF sub-category 1A3b): 1990-2018



Source: Submission 2020v1.
Note: CO_2 emissions from biofuels are excluded, and reported as "memo item".

2.1.7 UNFCCC and Kyoto Protocol: a demanding challenge for Luxembourg

2.1.7.1 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 CO_2 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 terms[44]. 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-

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[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

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.

2.1.7.2 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 have so far any substantial electricity generating capacity, saw, at once, its GHG emissions increasing by 0.9 to 1 Mio. t CO_2e 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.

2.1.7.3 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 CO_2e in 2018 – about 19% of total GHG emissions (excluding LULUCF) – coming from slightly more than 7.9 Mio. t CO_2e 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 additional amount of up to 1.2 Mio. t CO_2e 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 CO_2 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.

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

For the period 2002-2012, 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 would a "consumer" or "polluter pays" approach 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 2002-2012 (the period during which the TWINerg power plant was fully operational), but about 1.6 Mio. t CO_2e lower for 2015

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

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

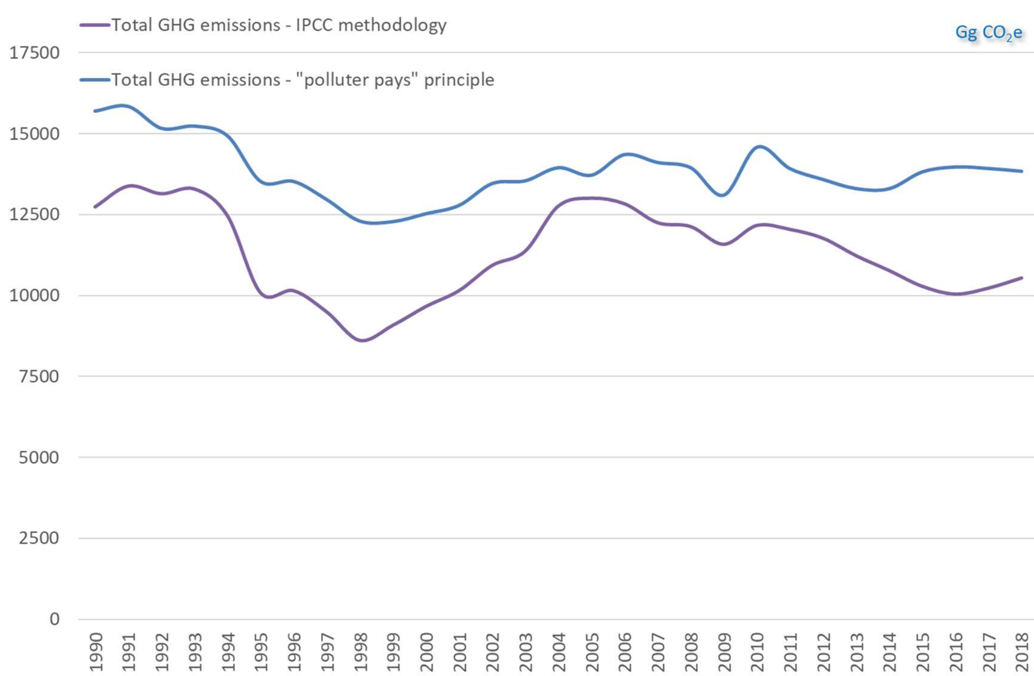
47 Max. 1 Mio. t CO_2e for the TWINerg and about 0.2 Mio. t CO_2e for CHP installations.

48 See the second *Action Plan for Reducing CO_2 Emissions* (http://www.environnement.public.lu/actualites/2013/05/plan_action_climat/index.html).

(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.

Thus, 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 upon renewable energies and, for 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 CO_2 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 CO_2 per GWh).

Figure 2-25 – Total GHG emissions, excluding LULUCF – two approaches: 1990-2018



Sources: Environment Agency and MDDI-DEV.

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

49 After having reached a "surplus" of 1.8 Mio. t CO_2e in 2005.

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

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.

2.1.8 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 go on once the financial and economic crisis will be over;
- **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: 1990-2018

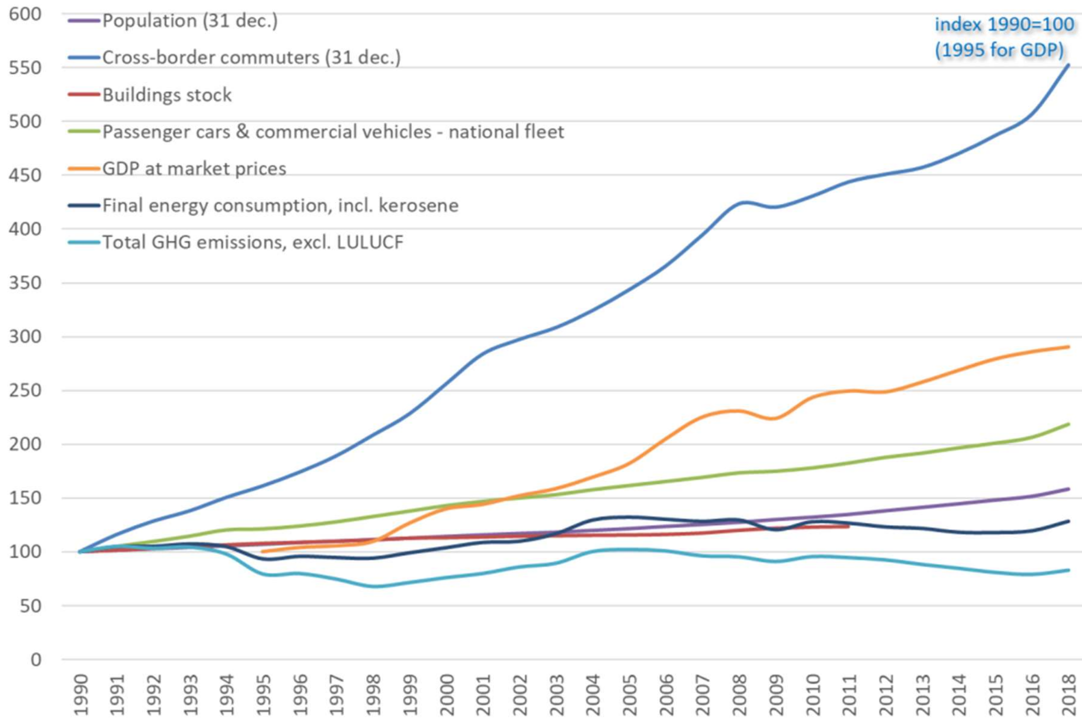


Figure 2-27 – Key variables trends – 1: 1990-2018 (excl. cross-border commuters)

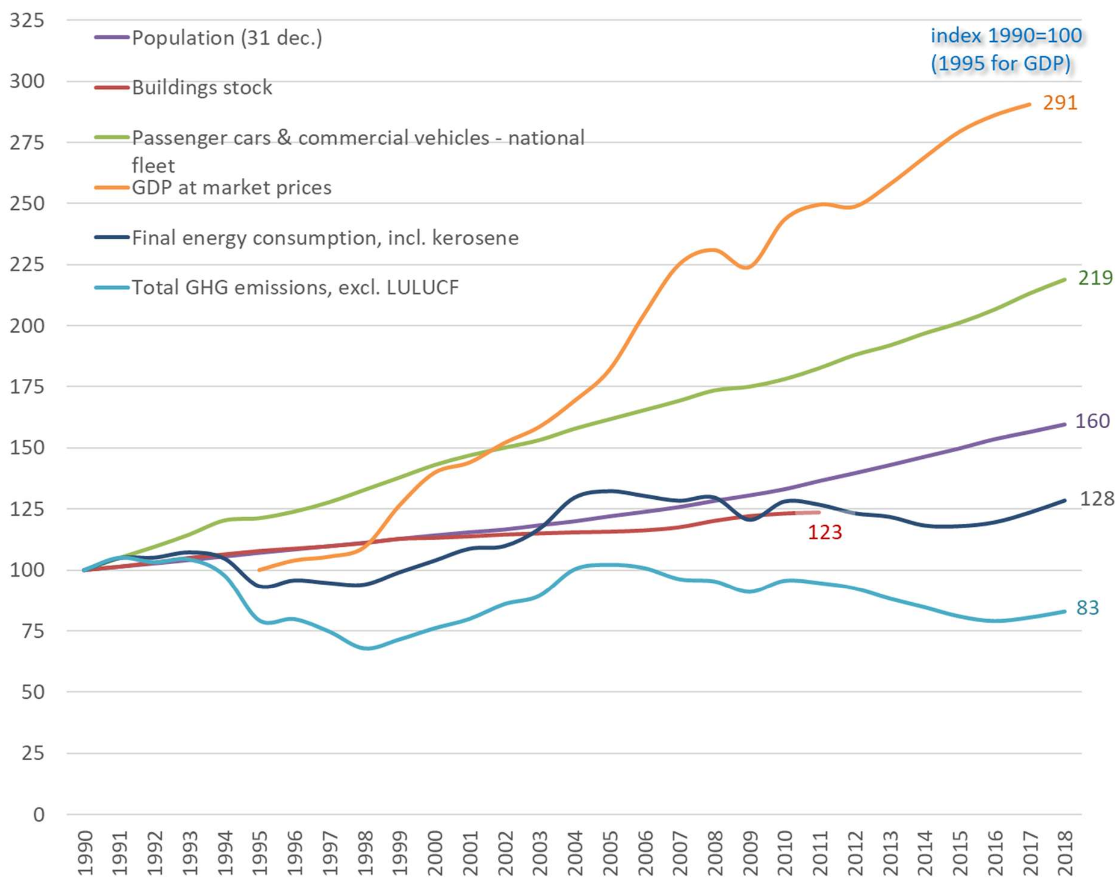
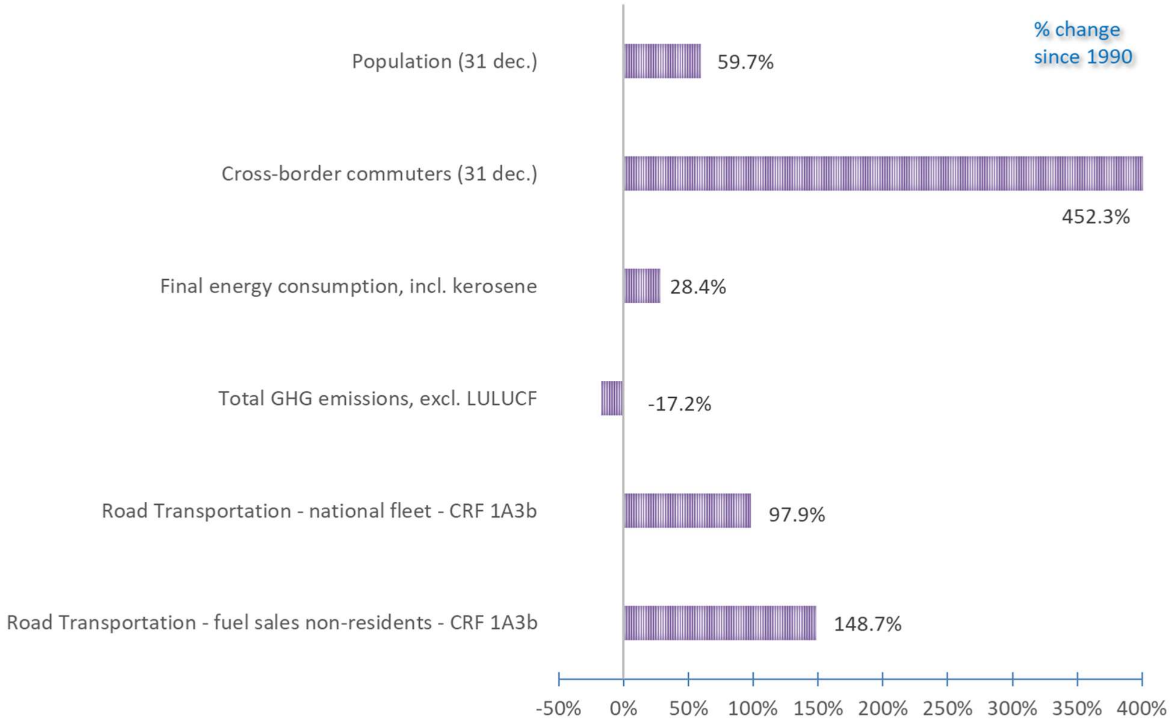


Figure 2-28 – Key variables trends – 2: 1990 & 2018



Sources: Population: STATEC, *Statistical Yearbook*, Table B.1100 (updated 4 April 2020).
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 April 2020).
http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12928&IF_Language=fra&MainTheme=2&FldrName=3&RFPath=92
Buildings stock: MDDI-DEV 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 April 2020).
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 April 2020).
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 April 2020).
http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12771&IF_Language=fra&MainTheme=1&FldrName=4&RFPath=51
GHG: Environment Agency and MDDI-DEV – Submission 2020v1.

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 2018, carbon dioxide was the main source of GHG in Luxembourg. This source counted for 90.72% of the total GHG emissions calculated in CO_2e – total excluding LULUCF.[51] The second source of GHG was methane with 5.57% of the total GHG emissions. Nitrous oxide was the third source with 2.97%. Fluorinated gases only accounted for 0.74% of the total GHG emissions, with hydrofluorocarbons representing 0.64% of the total GHG emissions and sulphur hexafluoride representing 0.10% of the total GHG emissions.

In 2018, total GHG emissions amounted to 10.547 Mio. t CO_2e, 17.2% below their level in 1990 and 17.3% below the level retained for the base year under the Kyoto Protocol.[52] As Figure 2-27 shows, several phases can clearly be distinguished over the period 1990 to 2018:

- 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 CO_2e is observed;
- a decrease occurred between 2006 and 2007 followed by a period of two years impacted by the financial and economic crisis.

The evolution during those 28 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.

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51 In Section 2.2, "total (GHG) emissions" mean "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 12.756 Mio. t CO_2e. The base year for CO_2, CH_4 and N_2O 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: 1990-2018

Gg (1000 t) CO_2 equivalent	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
CO_2 emissions, incl. net CO_2	**11927.56**	**12250.26**	**11666.24**	**11702.93**	**11093.71**	**8580.04**	**8583.54**	**7844.74**	**7083.78**	**7442.69**	**7993.03**	**8504.60**	**9283.43**	**9800.36**	**11147.62**
from LULUCF (1)	92.88%	92.89%	92.57%	92.55%	92.30%	90.10%	89.97%	89.18%	88.19%	88.56%	89.29%	89.93%	90.70%	91.42%	92.21%
CO_2 emissions, excl. net CO_2	**11847.64**	**12465.79**	**12232.16**	**12372.81**	**11563.93**	**9170.30**	**9219.91**	**8573.11**	**7695.07**	**8147.98**	**8731.57**	**9226.37**	**10003.05**	**10476.02**	**11844.31**
from LULUCF	92.99%	93.15%	93.04%	93.07%	92.74%	90.87%	90.79%	90.21%	89.25%	89.66%	90.30%	90.83%	91.48%	92.09%	92.77%
CH_4 (2) emissions, incl. net CH_4	**581.65**	**594.13**	**578.37**	**583.07**	**570.56**	**586.38**	**595.28**	**590.00**	**587.62**	**592.55**	**585.41**	**590.72**	**590.20**	**579.59**	**576.28**
from LULUCF (1)	4.53%	4.50%	4.59%	4.61%	4.75%	6.16%	6.24%	6.71%	7.32%	7.05%	6.54%	6.25%	5.77%	5.41%	4.77%
CH_4 (2) emissions, excl. net CH_4	**581.65**	**594.13**	**578.37**	**583.07**	**570.56**	**586.38**	**595.28**	**590.00**	**587.62**	**592.55**	**585.41**	**590.72**	**590.20**	**579.59**	**576.28**
from LULUCF	4.57%	4.44%	4.40%	4.39%	4.58%	5.81%	5.86%	6.21%	6.82%	6.52%	6.05%	5.82%	5.40%	5.09%	4.51%
N_2O (3) emissions, incl. net N_2O	**331.82**	**342.81**	**350.63**	**344.39**	**339.49**	**339.55**	**342.12**	**339.16**	**335.70**	**340.32**	**339.69**	**320.56**	**316.91**	**294.82**	**319.47**
from LULUCF (1)	2.58%	2.60%	2.78%	2.72%	2.82%	3.57%	3.59%	3.86%	4.18%	4.05%	3.79%	3.39%	3.10%	2.75%	2.64%
N_2O (3) emissions, excl. net N_2O	**310.50**	**321.49**	**329.31**	**323.07**	**318.17**	**318.23**	**320.79**	**317.84**	**314.37**	**318.99**	**318.68**	**299.88**	**296.54**	**274.77**	**299.73**
from LULUCF	2.44%	2.40%	2.50%	2.43%	2.55%	3.15%	3.16%	3.34%	3.65%	3.51%	3.30%	2.95%	2.71%	2.42%	2.35%
HFCs (4)	**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**
	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%
PFCs (4)	**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
SF_6 (4)	**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**
	0.01%	0.01%	0.01%	0.01%	0.01%	0.02%	0.02%	0.02%	0.03%	0.02%	0.02%	0.03%	0.03%	0.04%	0.04%
1. Energy	**10300.98**	**11005.60**	**10845.78**	**11010.42**	**10294.83**	**8259.92**	**8367.77**	**7830.49**	**7110.58**	**7529.10**	**8088.16**	**8644.21**	**9416.09**	**9945.22**	**11262.92**
	80.85%	82.24%	82.50%	82.83%	82.57%	81.85%	82.40%	82.40%	82.47%	82.85%	83.65%	85.10%	86.11%	87.42%	88.22%
2. Industrial Processes	**1639.38**	**1560.83**	**1495.00**	**1479.75**	**1388.05**	**1028.74**	**974.78**	**867.65**	**710.23**	**750.63**	**781.18**	**730.88**	**752.16**	**697.18**	**755.23**
	12.86%	11.65%	11.39%	11.14%	11.13%	10.19%	9.60%	9.13%	8.23%	8.25%	8.07%	7.19%	6.87%	6.13%	5.91%
3. Agriculture	**695.57**	**709.26**	**698.39**	**694.27**	**684.74**	**702.11**	**709.78**	**699.76**	**694.48**	**702.12**	**694.56**	**678.47**	**661.50**	**624.67**	**644.51**
	5.46%	5.30%	5.31%	5.22%	5.49%	6.96%	6.99%	7.36%	8.05%	7.73%	7.18%	6.68%	6.05%	5.49%	5.05%
4. LULUCF	**101.25**	**-194.21**	**-544.60**	**-648.55**	**-448.90**	**-568.93**	**-615.05**	**-707.04**	**-589.97**	**-683.97**	**-717.53**	**-701.08**	**-699.25**	**-655.60**	**-676.95**
	0.79%	-1.47%	-4.32%	-5.13%	-3.73%	-5.97%	-6.45%	-8.04%	-7.35%	-8.14%	-8.02%	-7.41%	-6.83%	-6.12%	-5.60%
5. Waste	**105.14**	**107.09**	**107.62**	**109.02**	**100.92**	**101.03**	**102.92**	**105.24**	**106.88**	**106.13**	**105.21**	**104.63**	**105.13**	**109.24**	**104.32**
	0.83%	0.80%	0.82%	0.82%	0.81%	1.00%	1.01%	1.11%	1.24%	1.17%	1.09%	1.03%	0.96%	0.96%	0.82%
6. Other	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
	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	**12842.31**	**13188.57**	**12602.20**	**12644.90**	**12019.64**	**9522.87**	**9540.21**	**8796.10**	**8032.21**	**8404.01**	**8951.57**	**9457.10**	**10235.63**	**10720.70**	**12090.03**
	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%
Total GHG excluding LULUCF	**12741.06**	**13382.78**	**13146.80**	**13293.45**	**12468.53**	**10091.81**	**10155.26**	**9503.14**	**8622.18**	**9087.98**	**9669.11**	**10158.18**	**10934.88**	**11376.30**	**12766.97**

Gg (1000 t) CO_2 equivalent	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
CO_2 emissions, incl. net CO_2	**11462.30**	**11388.07**	**10876.29**	**10726.95**	**10198.70**	**11083.11**	**10807.59**	**10454.33**	**9730.01**	**9339.10**	**8898.56**	**8558.65**	**8836.47**	**9344.44**
from LULUCF (1)	92.55%	92.52%	92.05%	91.80%	91.42%	91.98%	91.94%	91.77%	91.15%	90.63%	90.17%	89.70%	89.86%	90.43%
CO_2 emissions, excl. net CO_2	**12105.45**	**11936.28**	**11333.58**	**11195.25**	**10647.82**	**11219.29**	**11114.55**	**10851.40**	**10303.87**	**9825.22**	**9333.17**	**9080.25**	**9250.40**	**9568.52**
from LULUCF	93.05%	92.98%	92.49%	92.26%	91.89%	92.20%	92.27%	92.17%	91.72%	91.17%	90.70%	90.34%	90.37%	90.72%
CH_4 (2) emissions, incl. net CH_4	**575.20**	**571.39**	**580.19**	**590.50**	**591.86**	**591.66**	**567.31**	**559.25**	**563.56**	**576.50**	**582.38**	**586.33**	**593.66**	**587.66**
from LULUCF (1)	4.64%	4.64%	4.91%	5.05%	5.31%	4.91%	4.83%	4.91%	5.28%	5.59%	5.90%	6.15%	6.04%	5.69%
CH_4 (2) emissions, excl. net CH_4	**575.20**	**571.39**	**580.19**	**590.50**	**591.86**	**591.66**	**567.31**	**559.25**	**563.56**	**576.50**	**582.38**	**586.33**	**593.66**	**587.66**
from LULUCF	4.42%	4.45%	4.73%	4.87%	5.11%	4.86%	4.71%	4.75%	5.02%	5.35%	5.66%	5.83%	5.80%	5.57%
N_2O (3) emissions, incl. net N_2O	**302.11**	**300.41**	**305.03**	**310.61**	**306.87**	**313.85**	**316.10**	**310.87**	**310.66**	**313.17**	**310.62**	**320.58**	**323.66**	**323.93**
from LULUCF (1)	2.44%	2.44%	2.58%	2.66%	2.75%	2.60%	2.69%	2.73%	2.91%	3.04%	3.15%	3.36%	3.29%	3.13%
N_2O (3) emissions, excl. net N_2O	**282.69**	**281.30**	**286.24**	**292.53**	**289.51**	**297.15**	**300.09**	**295.55**	**296.08**	**299.36**	**297.59**	**308.34**	**312.14**	**313.13**
	2.17%	2.19%	2.34%	2.41%	2.50%	2.44%	2.49%	2.51%	2.64%	2.78%	2.89%	3.07%	3.05%	2.97%
HFCs (4)	**40.47**	**43.37**	**47.76**	**50.25**	**51.40**	**53.67**	**56.55**	**58.91**	**62.45**	**66.86**	**67.60**	**66.04**	**69.58**	**67.64**
	0.31%	0.34%	0.39%	0.41%	0.44%	0.44%	0.47%	0.50%	0.56%	0.62%	0.66%	0.66%	0.68%	0.64%
PFCs (4)	**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
SF_6 (4)	**5.31**	**5.73**	**6.17**	**6.58**	**6.99**	**7.29**	**7.75**	**8.14**	**8.51**	**8.91**	**9.37**	**9.72**	**9.90**	**10.20**
	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%
1. Energy	**11549.32**	**11332.65**	**10736.92**	**10657.78**	**10180.03**	**10738.32**	**10615.41**	**10416.93**	**9884.09**	**9394.03**	**8906.86**	**8628.29**	**8794.37**	**9112.19**
	88.78%	88.27%	87.62%	87.83%	87.85%	88.24%	88.12%	88.48%	87.98%	87.17%	86.56%	85.85%	85.92%	86.39%
2. Industrial Processes	**726.08**	**780.12**	**776.03**	**721.51**	**650.91**	**675.77**	**692.07**	**632.81**	**616.00**	**632.61**	**625.11**	**650.69**	**659.63**	**662.58**
	5.58%	6.07%	6.33%	5.94%	5.61%	5.55%	5.74%	5.37%	5.49%	5.87%	6.08%	6.47%	6.47%	106.47%
3. Agriculture	**628.90**	**620.26**	**634.52**	**648.34**	**650.46**	**659.90**	**647.80**	**634.42**	**644.89**	**659.58**	**672.75**	**688.16**	**697.69**	**690.44**
	4.83%	4.83%	5.18%	5.34%	5.61%	5.42%	5.38%	5.39%	5.74%	6.12%	6.54%	6.85%	6.82%	6.55%
4. LULUCF	**-623.72**	**-529.11**	**-438.50**	**-450.22**	**-431.75**	**-119.48**	**-290.95**	**-381.75**	**-559.28**	**-472.30**	**-421.57**	**-509.36**	**-402.41**	**-213.28**
	-5.04%	-4.30%	-3.71%	-3.85%	-3.87%	-0.99%	-2.48%	-3.35%	-5.24%	-4.58%	-4.27%	-5.34%	-4.09%	-2.06%
5. Waste	**104.82**	**105.04**	**106.46**	**107.47**	**106.17**	**95.07**	**90.97**	**89.10**	**89.50**	**90.64**	**85.38**	**83.55**	**84.00**	**81.93**
	0.81%	0.82%	0.87%	0.89%	0.92%	0.78%	0.76%	0.76%	0.80%	0.84%	0.83%	0.83%	0.82%	0.78%
6. Other	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
	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%	100.00%
Total GHG including LULUCF	**12385.40**	**12308.96**	**11815.43**	**11684.88**	**11155.83**	**12049.58**	**11755.30**	**11391.50**	**10675.20**	**10304.55**	**9868.52**	**9541.33**	**9833.28**	**10333.88**
	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%
Total GHG excluding LULUCF	**13009.12**	**12838.07**	**12253.93**	**12135.10**	**11587.58**	**12169.06**	**12046.25**	**11773.25**	**11234.48**	**10776.85**	**10290.10**	**10050.69**	**10235.70**	**10547.15**
	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%

Source: Environment Agency and MDDI-DEV.

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

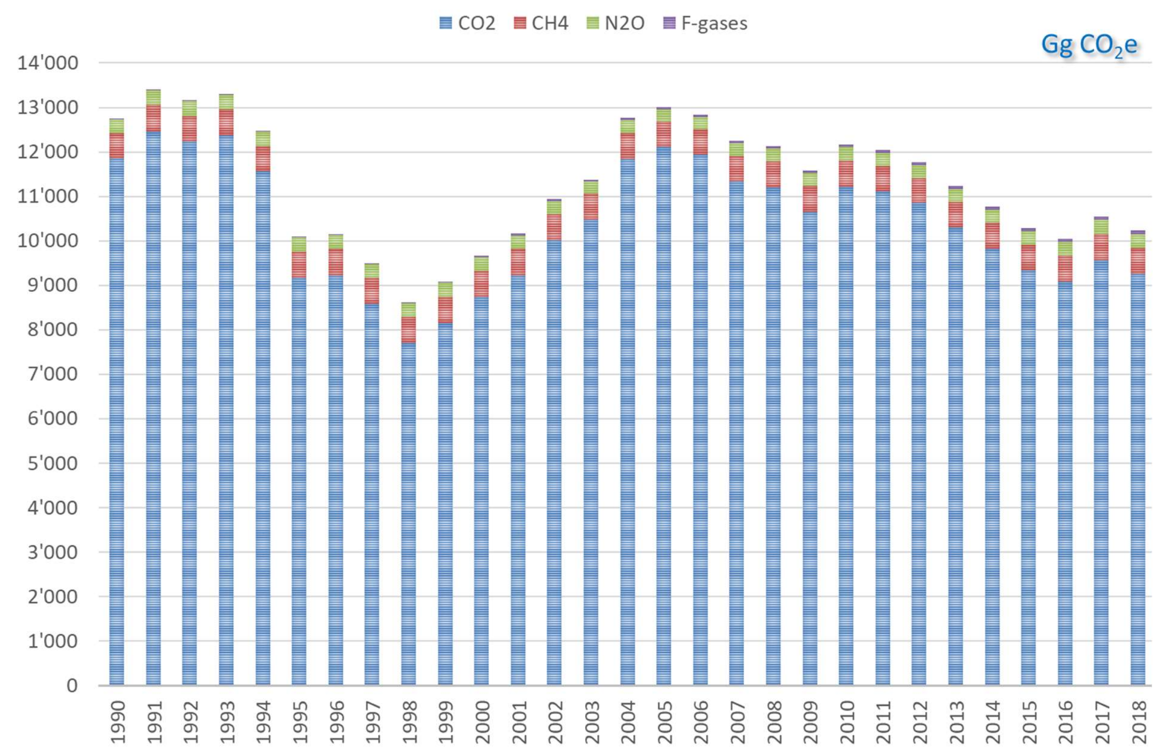
(2) The methane emissions are converted in CO_2 equivalents by multiplying the emissions by 25, *i.e.* the global warming potential (GWP) value for methane based on the effects of GHG over a 100-year time horizon.

(3) The nitrous oxide emissions are converted in CO_2 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.

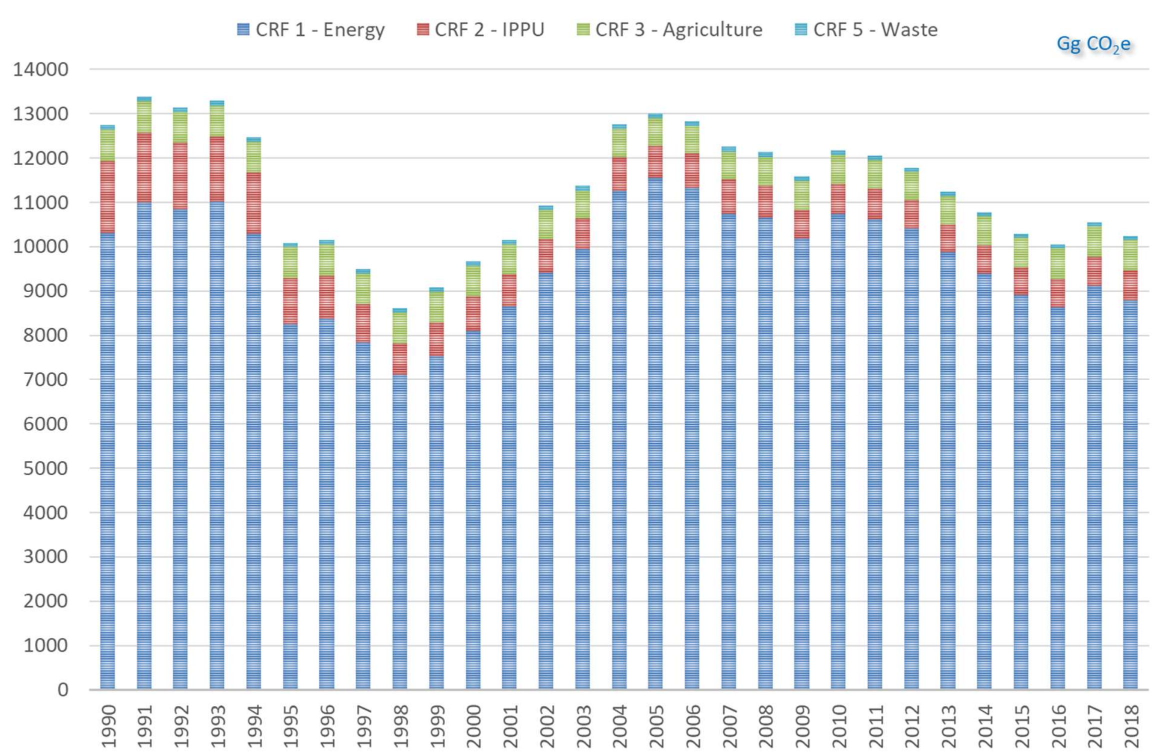
(4) The F-gases are those not covered by the Montreal Protocol, *i.e.* the HFCs, PFCs and SF_6 expressed in CO_2 equivalents using the global warming potential (GWP) values based on the effects of GHG over a 100-year time horizon.

Figure 2-29 – Luxembourg's GHG emissions (excl. LULUCF) – absolute values: 1990-2018

GHG



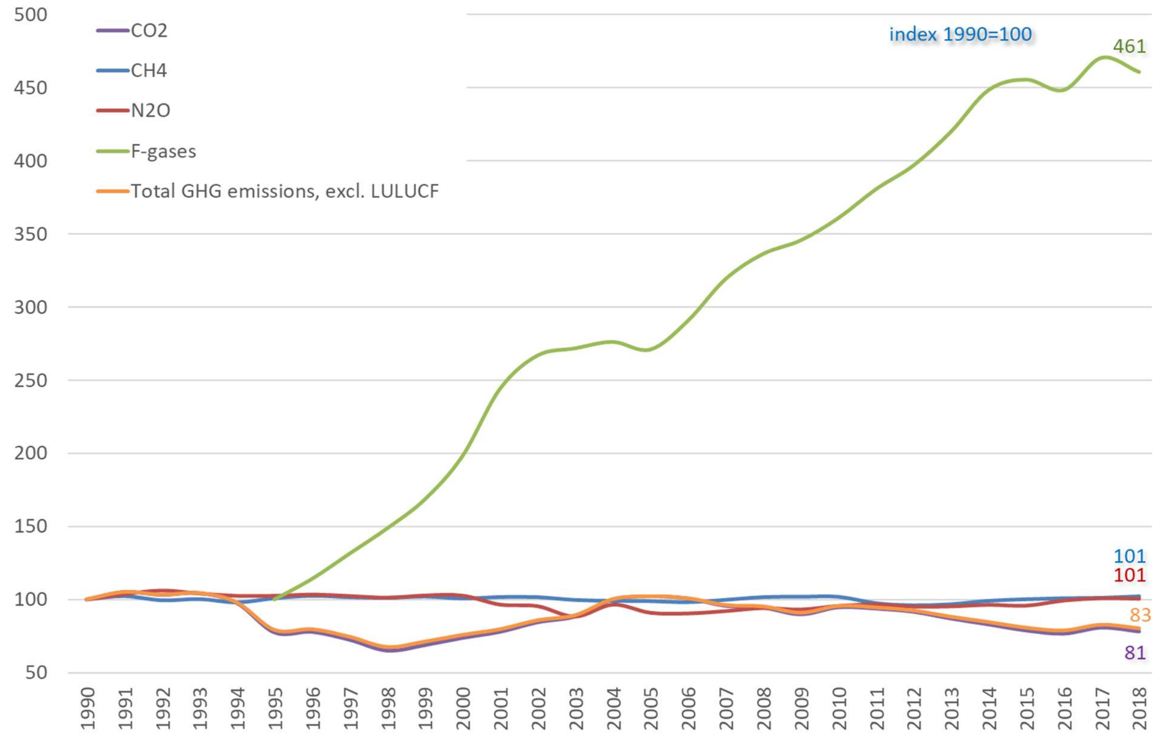
CRF Sectors



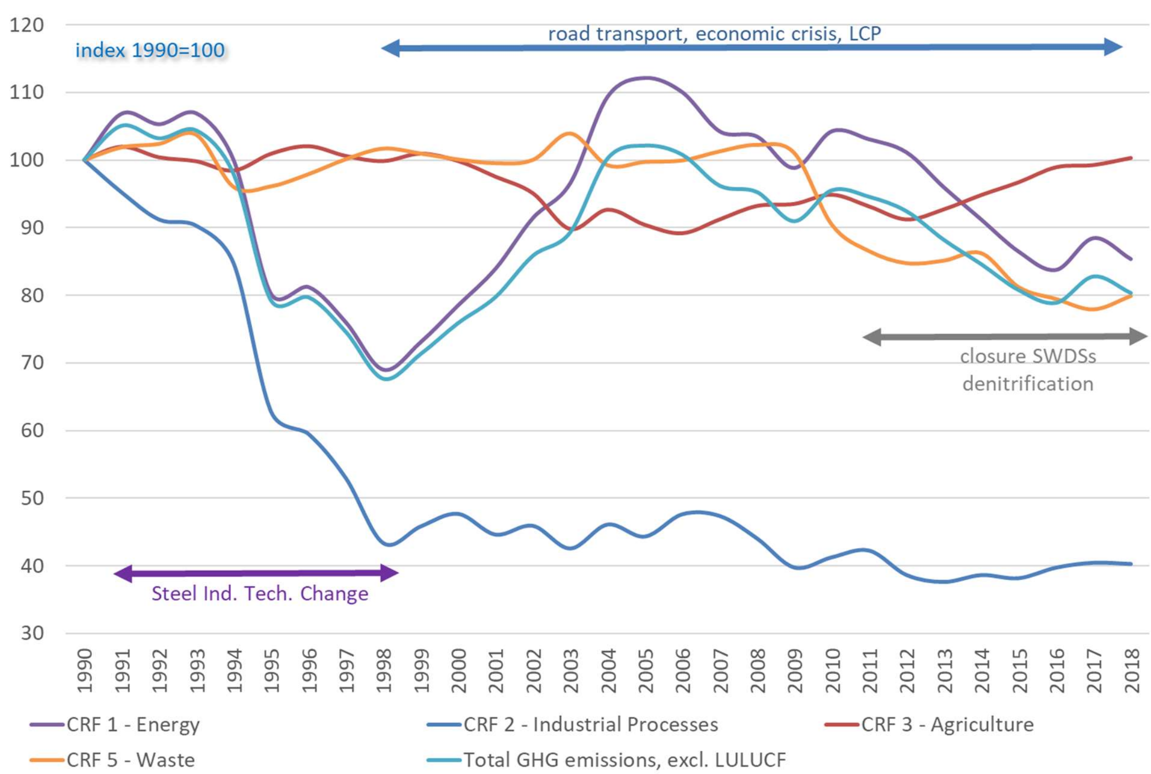
Sources: Environment Agency and MDDI-DEV.

Figure 2-30 – Luxembourg's GHG emissions (excl. LULUCF) – indexes: 1990-2018

GHG



CRF Sectors



Sources: Environment Agency and MDDI-DEV.

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 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 transport sector, on the other hand, is a clear example on **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 diminution of GHG emissions from the power generation sector, the latter being exceptionally important for the years 2008 and 2011-2016 when the main power plant of the country experienced maintenance or reduced activities which resulted in several months without substantial production.

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, CO_2e 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 building of the TWINerg power plant. This plant started its operation in mid-2002 and, by 2010, was responsible of about 0.96 Mio. t CO_2, *i.e.* around 8% of the total GHG emissions. In the last few years, 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 1990-2018 (and 2017-2018) were as follows:

- CO_2: .... -19.24% (+3.44%)
- CH_4: .... +1.03% (-1.01%)
- N_2O: ....+0.85% (+0.32%)
- F-gases: ....+360.55% (-2.07%)

For carbon dioxide, the development between 1990 and 2018 hides a U-shape evolution over the period as well as important changes in the sources of CO_2 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 1990-2018. In 2018, reduced methane emissions were observed in waste management (-27.4%) as compared to 1990, and increasing emissions in agriculture (+6.73%) and in energy use (+8.42%), the latter being mainly due to an upward trend for fugitive emissions from natural gas distribution and use, and to a lesser extent in energy production industries and in the commercial and residential sector.

Nitrous oxide emissions development between 1990 and 2018 is closely linked to an increase of liquid fuels related emissions from combustion activities (+140.34% in the Energy sector) and to emissions from the waste sector (+71.79%) that could not be balanced by declining emissions from the agriculture (-17.26%) and industrial products and product use sectors (-51.68%). Total N_2O emissions (excl. LULUCF) have increased by 0.85 % since 1990.

With regard to F-gases, HFCs emissions increased by 346% in 2018 compared to the base year (1995), whereas SF_6 emissions showed a 483% increase between 1995 and 2018. These evolutions can be visualized in Table 2-14, which distributes, for each GHG, emissions amongst the main source categories, as well as in the associated Figure 2-31 and Figure 2-32. These table and figures offer the opportunity to further analyse emission trends for each 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 10333.88 million tonnes CO_2 eq (incl. LULUCF) in 2018. Net removals from the LULUCF sector amounted to 213.28 Gg CO_2 eq. Since 1990, net emissions have decreased by 310.65% per cent (the sector was a source of net emissions in 1990 (101.25 Gg CO_2 eq) and a source of net removals in 1991-2018).

Table 2-14 – Luxembourg's GHG emissions (excl. LULUCF) –sector-based breakdown: 1990-2018

Gg (1000 t.) CO_2 equivalent	CRF Categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Public Electricity & Heat Production	**1A1a**	**35.64**	**37.29**	**37.19**	**35.38**	**34.61**	**93.54**	**82.36**	**89.73**	**155.94**	**173.47**	**120.20**	**282.30**	**1029.35**	**1036.73**
(excl. waste incineration)		NA	NA	NA	NA	NA	0.92%	0.80%	0.93%	1.78%	1.87%	1.23%	2.74%	9.27%	8.99%
Iron & Steel	**1A2a + 2C1**	**6396.29**	**6090.21**	**5608.07**	**5844.00**	**4837.99**	**2781.92**	**2518.25**	**1629.12**	**451.44**	**493.16**	**478.70**	**548.43**	**530.66**	**512.54**
(fuel combustion & processes)		49.87%	45.24%	42.29%	43.63%	38.53%	27.33%	24.58%	16.95%	5.14%	5.31%	4.88%	5.32%	4.78%	4.44%
Other Manufacturing Industries &	**1A2b/c/d/e/f + 2A**	**1509.34**	**1579.50**	**1660.83**	**1539.02**	**1740.69**	**1582.17**	**1638.25**	**1656.02**	**1634.15**	**1821.30**	**1697.28**	**1666.68**	**1590.81**	**1493.65**
Construction (fuel combustion & processes)		11.77%	11.73%	12.52%	11.49%	13.86%	15.54%	15.99%	17.23%	18.62%	19.62%	17.30%	16.15%	14.33%	12.95%
Road Transportation - national fleet	**1A3b**	**862.85**	**903.28**	**939.50**	**987.54**	**989.70**	**1045.77**	**1071.21**	**1114.49**	**1165.17**	**1177.46**	**1225.36**	**1294.36**	**1351.97**	**1380.06**
		6.73%	6.71%	7.08%	7.37%	7.88%	10.27%	10.46%	11.59%	13.27%	12.68%	12.49%	12.55%	12.18%	11.97%
Road Transportation - fuel export	**1A3b**	**1692.86**	**2239.97**	**2479.70**	**2481.06**	**2535.18**	**2244.16**	**2325.65**	**2543.01**	**2670.22**	**2980.76**	**3566.96**	**3741.23**	**3873.86**	**4397.94**
		13.20%	16.64%	18.70%	18.52%	20.19%	22.05%	22.70%	26.46%	30.42%	32.11%	36.37%	36.26%	34.89%	38.13%
Residential Fuel Combustion	**1A4b**	**678.85**	**813.59**	**747.72**	**741.78**	**706.14**	**716.08**	**785.96**	**761.62**	**792.10**	**711.22**	**1077.55**	**1169.82**	**1113.50**	**1156.69**
		5.29%	6.04%	5.64%	5.54%	5.62%	7.03%	7.67%	7.92%	9.02%	7.66%	10.99%	11.34%	10.03%	10.03%
Commercial & Institutional Fuel	**1A4a**	**640.16**	**770.15**	**710.60**	**702.46**	**676.83**	**682.30**	**761.54**	**738.29**	**772.36**	**692.13**	**548.23**	**498.40**	**500.43**	**497.13**
Combustion		4.99%	5.72%	5.36%	5.24%	5.39%	6.70%	7.43%	7.68%	8.80%	7.46%	5.59%	4.83%	4.51%	4.31%
Agriculture (fuel combustion,	**1A4c+4**	**810.15**	**821.29**	**795.03**	**785.37**	**768.20**	**785.48**	**793.86**	**791.08**	**789.87**	**814.08**	**776.39**	**759.22**	**745.80**	**707.94**
livestock, crops, soils)		6.32%	6.10%	6.00%	5.86%	6.12%	7.72%	7.75%	8.23%	9.00%	8.77%	7.92%	7.36%	6.72%	6.14%
Municipal Waste Incineration	**1A1a (5C)**	**33.94**	**35.51**	**35.41**	**33.69**	**32.96**	**31.47**	**24.35**	**30.19**	**59.58**	**68.71**	**65.98**	**66.07**	**66.71**	**67.00**
(with energy & heat recovery)		0.26%	0.26%	0.27%	0.25%	0.26%	0.31%	0.24%	0.31%	0.68%	0.74%	0.67%	0.64%	0.60%	0.58%
Other Transport	**1A3a/c/d**	**28.96**	**29.20**	**29.27**	**29.47**	**28.71**	**23.52**	**26.09**	**25.73**	**25.60**	**25.76**	**25.31**	**27.29**	**24.43**	**21.73**
		0.23%	0.22%	0.22%	0.22%	0.23%	0.23%	0.25%	0.27%	0.29%	0.28%	0.26%	0.26%	0.22%	0.19%
Other Energy Sources	**1A5 + 1B2b**	**22.51**	**23.24**	**47.79**	**45.42**	**43.99**	**35.79**	**45.89**	**51.01**	**62.31**	**92.27**	**42.19**	**57.55**	**61.26**	**51.63**
(incl. lubricants reported under 1A3b)		0.18%	0.17%	0.36%	0.34%	0.35%	0.35%	0.45%	0.53%	0.71%	0.99%	0.43%	0.56%	0.55%	0.45%
F-gases	**2F**	**0.00**	**0.00**	**13.68**	**14.70**	**15.98**	**18.31**	**20.06**	**22.54**	**24.98**	**26.78**	**29.58**	**33.49**	**36.38**	**38.70**
		0.00%	0.00%	0.10%	0.11%	0.13%	0.18%	0.20%	0.23%	0.28%	0.29%	0.30%	0.32%	0.33%	0.34%
Municipal Waste Disposal on Land	**5A**	**22.51**	**23.24**	**47.79**	**45.42**	**43.99**	**35.79**	**45.89**	**51.01**	**62.31**	**92.27**	**42.19**	**57.55**	**61.26**	**51.63**
		0.18%	0.17%	0.36%	0.34%	0.35%	0.35%	0.45%	0.53%	0.71%	0.99%	0.43%	0.56%	0.55%	0.45%
Waste Water Handling	**5B**	**0.00**	**0.00**	**13.68**	**14.70**	**15.98**	**18.31**	**20.06**	**22.54**	**24.98**	**26.78**	**29.58**	**33.49**	**36.38**	**38.70**
		0.00%	0.00%	0.10%	0.11%	0.13%	0.18%	0.20%	0.23%	0.28%	0.29%	0.30%	0.32%	0.33%	0.34%
Composting	**5D**	**92.18**	**94.22**	**94.59**	**93.32**	**84.56**	**84.29**	**84.22**	**86.19**	**86.31**	**86.34**	**82.73**	**81.78**	**81.38**	**81.58**
		NA	NA	NA	0.70%	0.67%	0.83%	0.82%	0.90%	0.98%	0.93%	0.84%	0.79%	0.73%	0.71%
Total GHG excluding LULUCF		**12826.26**	**13460.69**	**13260.86**	**13393.31**	**12555.50**	**10178.89**	**10243.65**	**9612.58**	**8777.31**	**9282.50**	**9808.22**	**10317.67**	**11104.19**	**11533.67**
		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%
International Bunkers - Aviation		**389.45**	**407.06**	**393.54**	**389.21**	**493.77**	**559.71**	**608.18**	**727.59**	**882.03**	**995.17**	**948.48**	**1025.85**	**1111.46**	**1157.87**
		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
International Bunkers - Marine		**0.09**	**0.09**	**0.09**	**0.12**	**0.10**	**0.10**	**0.10**	**0.09**	**0.09**	**0.10**	**0.11**	**0.11**	**0.12**	**0.12**
		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CO_2 Emissions from Biomass		**159.05**	**163.07**	**163.73**	**159.33**	**157.46**	**153.78**	**135.56**	**146.84**	**139.67**	**148.82**	**150.04**	**164.85**	**166.20**	**182.13**
		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Gg (1000 t.) CO_2 equivalent	CRF Categories	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Public Electricity & Heat Production	**1A1a**	**1257.43**	**1243.21**	**1305.29**	**1181.73**	**996.03**	**1190.81**	**1205.98**	**1004.17**	**1042.73**	**685.99**	**669.04**	**457.60**	**252.39**
(excl. waste incineration)		9.72%	9.44%	10.03%	9.51%	8.09%	10.11%	9.76%	8.20%	8.71%	6.01%	6.10%	4.36%	2.46%
Iron & Steel	**1A2a + 2C1**	**558.40**	**532.45**	**652.22**	**626.31**	**572.31**	**458.02**	**512.64**	**458.20**	**399.34**	**377.89**	**375.62**	**397.33**	**388.81**
(fuel combustion & processes)		4.32%	4.04%	5.01%	5.04%	4.65%	3.89%	4.15%	3.74%	3.34%	3.31%	3.42%	3.79%	3.79%
Other Manufacturing Industries &	**1A2b/c/d/e/f + 2A**	**1603.90**	**1598.22**	**1604.99**	**1530.07**	**1470.16**	**1376.61**	**1425.99**	**1473.70**	**1416.69**	**1371.79**	**1401.57**	**1327.28**	**1388.68**
Construction (fuel combustion & processes)		12.40%	12.13%	12.33%	12.31%	11.94%	11.69%	11.54%	12.04%	11.84%	12.01%	12.77%	12.65%	13.55%
Road Transportation - national fleet	**1A3b**	**1422.58**	**1442.72**	**1501.86**	**1523.67**	**1596.76**	**1591.62**	**1603.02**	**1632.73**	**1629.19**	**1623.60**	**1689.81**	**1701.17**	**1724.51**
		11.00%	10.95%	11.54%	12.26%	12.96%	13.52%	12.98%	13.34%	13.61%	14.22%	15.40%	16.22%	16.83%
Road Transportation - fuel export	**1A3b**	**5315.30**	**5677.89**	**5302.28**	**4986.22**	**5018.26**	**4501.67**	**4846.23**	**5190.14**	**4887.36**	**4756.11**	**4381.78**	**3938.62**	**3744.67**
		41.09%	43.10%	40.74%	40.11%	40.74%	38.23%	39.23%	42.40%	40.84%	41.65%	39.93%	37.55%	36.55%
Residential Fuel Combustion	**1A4b**	**1237.43**	**1211.99**	**1199.93**	**1160.13**	**1193.13**	**1179.65**	**1158.08**	**1061.21**	**1079.90**	**1072.60**	**970.55**	**1082.61**	**1050.99**
		9.56%	9.20%	9.22%	9.33%	9.69%	10.02%	9.38%	8.67%	9.02%	9.39%	8.84%	10.32%	10.26%
Commercial & Institutional Fuel	**1A4a**	**462.90**	**418.25**	**395.34**	**348.55**	**376.96**	**380.70**	**498.87**	**332.93**	**439.55**	**461.44**	**388.76**	**476.32**	**573.90**
Combustion		3.58%	3.17%	3.04%	2.80%	3.06%	3.23%	4.04%	2.72%	3.67%	4.04%	3.54%	4.54%	5.60%
Agriculture (fuel combustion,	**1A4c+4**	**722.64**	**710.61**	**702.32**	**717.22**	**734.05**	**738.19**	**748.39**	**740.04**	**719.74**	**732.22**	**742.24**	**760.25**	**776.11**
livestock, crops, soils)		5.59%	5.39%	5.40%	5.77%	5.96%	6.27%	6.06%	6.05%	6.01%	6.41%	6.76%	7.25%	7.57%
Municipal Waste Incineration	**1A1a (5C)**	**73.20**	**67.22**	**71.23**	**72.51**	**74.72**	**71.10**	**64.09**	**68.77**	**69.11**	**67.37**	**76.24**	**81.94**	**94.64**
(with energy & heat recovery)		0.57%	0.51%	0.55%	0.58%	0.61%	0.60%	0.52%	0.56%	0.58%	0.59%	0.69%	0.78%	0.92%
Other Transport	**1A3a/c/d**	**17.54**	**11.96**	**9.24**	**12.84**	**14.58**	**13.88**	**14.89**	**14.94**	**13.87**	**12.38**	**14.15**	**11.07**	**10.57**
		0.14%	0.09%	0.07%	0.10%	0.12%	0.12%	0.12%	0.12%	0.12%	0.11%	0.13%	0.11%	0.10%
Other Energy Sources	**1A5 + 1B2b**	**53.81**	**53.00**	**55.61**	**52.03**	**49.76**	**50.30**	**54.09**	**46.90**	**47.98**	**40.87**	**38.60**	**34.72**	**31.91**
(incl. lubricants reported under 1A3b)		0.42%	0.40%	0.43%	0.42%	0.40%	0.43%	0.44%	0.38%	0.40%	0.36%	0.35%	0.33%	0.31%
F-gases	**2F**	**40.78**	**39.79**	**42.77**	**47.37**	**49.77**	**51.16**	**53.46**	**56.34**	**58.73**	**59.80**	**65.42**	**65.44**	**63.75**
		0.32%	0.30%	0.33%	0.38%	0.40%	0.43%	0.43%	0.46%	0.49%	0.52%	0.60%	0.62%	0.62%
Municipal Waste Disposal on Land	**5A**	**53.81**	**53.00**	**55.61**	**52.03**	**49.76**	**50.30**	**54.09**	**46.90**	**47.98**	**40.87**	**38.60**	**34.72**	**31.91**
		0.42%	0.40%	0.43%	0.42%	0.40%	0.43%	0.44%	0.38%	0.40%	0.36%	0.35%	0.33%	0.31%
Waste Water Handling	**5B**	**40.78**	**39.79**	**42.77**	**47.37**	**49.77**	**51.16**	**53.46**	**56.34**	**58.73**	**59.80**	**65.42**	**65.44**	**63.75**
		0.32%	0.30%	0.33%	0.38%	0.40%	0.43%	0.43%	0.46%	0.49%	0.52%	0.60%	0.62%	0.62%
Composting	**5D**	**76.70**	**74.65**	**73.45**	**72.97**	**71.30**	**70.31**	**58.78**	**58.94**	**56.11**	**57.31**	**56.66**	**54.33**	**49.65**
		0.59%	0.57%	0.56%	0.59%	0.58%	0.60%	0.48%	0.48%	0.47%	0.50%	0.52%	0.52%	0.48%
Total GHG excluding LULUCF		**12937.20**	**13174.76**	**13014.93**	**12431.00**	**12317.32**	**11775.51**	**12352.04**	**12242.25**	**11967.01**	**11420.03**	**10974.44**	**10488.82**	**10246.23**
		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%
International Bunkers - Aviation		**1259.86**	**1280.10**	**1197.98**	**1287.69**	**1296.20**	**1241.81**	**1269.69**	**1192.33**	**1100.10**	**1105.61**	**1200.12**	**1352.88**	**1503.59**
		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
International Bunkers - Marine		**0.12**	**0.16**	**0.17**	**0.13**	**0.14**	**0.12**	**0.11**	**0.14**	**0.13**	**0.11**	**0.12**	**0.12**	**0.14**
		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CO_2 Emissions from Biomass		**196.05**	**294.35**	**297.87**	**451.15**	**463.57**	**433.42**	**451.11**	**440.09**	**453.22**	**491.00**	**622.98**	**677.98**	**721.26**
		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Sources: Environment Agency and MDDI-DEV.

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

(2) The methane emissions are converted in CO_2 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 CO_2 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 SF_6 expressed in CO_2 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: 1990-2018

Gg (1000 t.) CO_2 equivalent	1990 (base year)	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
CO_2	**11847.64**	**12465.79**	**12232.16**	**12372.81**	**11563.93**	**9170.30**	**9219.91**	**8573.11**	**7695.07**	**8147.98**	**8731.57**	**9226.37**	**10003.05**	**10476.02**	**11844.31**
of which	92.99%	93.15%	93.04%	93.07%	92.74%	90.87%	90.79%	90.21%	89.25%	89.66%	90.30%	90.83%	91.48%	92.09%	92.77%
CRF 1 - Energy	10218.47	10914.73	10751.97	10914.74	10198.16	8164.83	8270.59	7733.00	7014.38	7430.86	7987.70	8539.78	9298.42	9827.13	11138.05
	80.20%	81.56%	81.78%	82.11%	81.79%	80.91%	81.44%	81.37%	81.35%	81.77%	82.61%	84.07%	85.03%	86.38%	87.24%
CRF 1A1 - Fuel Combustion from	33.29	34.83	34.73	33.04	32.32	91.29	80.61	87.67	153.39	170.55	116.23	277.55	1024.24	1031.72	1251.79
Energy Industries	0.26%	0.26%	0.26%	0.25%	0.26%	0.90%	0.79%	0.92%	1.78%	1.88%	1.20%	2.73%	9.37%	9.07%	9.80%
CRF 1A2 - Fuel Combustion from	6250.32	6092.59	5749.24	5885.35	5172.77	3319.14	3166.10	2402.85	1362.31	1551.31	1383.48	1475.12	1360.71	1299.11	1395.76
Manuf. Industries & Construction	49.06%	45.53%	43.73%	44.27%	41.49%	32.89%	31.18%	25.28%	15.80%	17.07%	14.31%	14.52%	12.44%	11.42%	10.93%
CRF 1A3 - Fuel Combustion from	2588.98	3177.07	3461.12	3507.79	3563.61	3322.74	3433.69	3693.95	3874.00	4198.83	4833.72	5081.48	5270.90	5824.37	6774.98
Transport	20.32%	23.74%	26.33%	26.39%	28.58%	32.93%	33.81%	38.87%	44.93%	46.20%	49.99%	50.02%	48.20%	51.20%	53.07%
of which, "road fuel export" **(1)**	1692.86	2239.97	2479.70	2481.06	2535.18	2244.16	2325.65	2543.01	2670.22	2980.76	3566.96	3741.23	3873.86	4397.94	5315.30
	13.29%	16.74%	18.86%	18.66%	20.33%	22.24%	22.90%	26.76%	30.97%	32.80%	36.89%	36.83%	35.43%	38.66%	41.63%
CRF 1A4 - Fuel Combustion from	1342.76	1607.11	1480.15	1464.96	1407.42	1420.87	1571.67	1525.53	1590.61	1447.19	1642.07	1681.43	1629.01	1668.63	1715.34
Other Sectors	10.54%	12.01%	11.26%	11.02%	11.29%	14.08%	15.48%	16.05%	18.45%	15.92%	16.98%	16.55%	14.90%	14.67%	13.44%
CRF 1A5 & 1B2b - Other Energy	3.10	3.10	26.72	23.58	22.01	10.75	18.49	22.98	34.03	62.95	12.17	24.16	13.49	3.25	0.12
Sources	0.02%	0.02%	0.20%	0.18%	0.18%	0.11%	0.18%	0.24%	0.39%	0.69%	0.13%	0.24%	0.12%	0.03%	0.00%
CRF 2 - Industrial Processes	1628.91	1550.60	1479.53	1457.04	1364.28	1004.26	948.24	838.52	678.51	715.90	741.82	684.11	701.48	645.84	703.63
	12.78%	11.59%	11.25%	10.96%	10.94%	9.95%	9.34%	8.82%	7.87%	7.88%	7.67%	6.73%	6.42%	5.68%	5.51%
Other Sources **(2)**	20.54	20.09	19.08	18.81	18.09	19.76	19.52	18.45	17.52	16.86	16.04	16.23	17.76	15.24	17.81
	0.16%	0.15%	0.15%	0.14%	0.15%	0.20%	0.19%	0.19%	0.20%	0.19%	0.17%	0.16%	0.16%	0.13%	0.14%
CH_4 (3)	**581.65**	**594.13**	**578.37**	**583.07**	**570.56**	**586.38**	**595.28**	**590.00**	**587.62**	**592.55**	**585.41**	**590.72**	**590.20**	**579.59**	**576.28**
	4.57%	4.44%	4.40%	4.39%	4.58%	5.81%	5.86%	6.21%	6.82%	6.52%	6.05%	5.82%	5.40%	5.09%	4.51%
of which	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 1 - Energy	48.02	50.88	49.85	48.97	46.91	47.39	48.75	48.41	47.75	48.33	48.96	52.85	66.47	66.91	72.74
	0.38%	0.38%	0.38%	0.37%	0.38%	0.47%	0.48%	0.51%	0.55%	0.53%	0.51%	0.52%	0.61%	0.59%	0.57%
CRF 3A+3B - Enteric Fermentation and	434.14	441.90	426.73	432.23	430.29	445.69	452.10	445.16	442.61	447.63	441.88	443.96	429.44	415.77	411.37
Manure Management	3.41%	3.30%	3.25%	3.25%	3.45%	4.42%	4.45%	4.68%	5.13%	4.93%	4.57%	4.37%	3.93%	3.65%	3.22%
Other Sources **(4)**	99.49	101.34	101.78	101.87	93.36	93.31	94.43	96.43	97.25	96.59	94.57	93.90	94.29	96.91	92.16
	0.78%	0.76%	0.77%	0.77%	0.75%	0.92%	0.93%	1.01%	1.13%	1.06%	0.98%	0.92%	0.86%	0.85%	0.72%
N_2O (5)	**310.50**	**321.49**	**329.31**	**323.07**	**318.17**	**318.23**	**320.79**	**317.84**	**314.37**	**318.99**	**318.68**	**299.88**	**296.54**	**274.77**	**299.73**
	2.44%	2.40%	2.50%	2.43%	2.55%	3.15%	3.16%	3.34%	3.65%	3.51%	3.30%	2.95%	2.71%	2.42%	2.35%
of which	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 1 - Energy	34.49	39.99	43.96	46.71	49.76	47.71	48.43	49.08	48.46	49.91	51.50	51.58	51.20	51.17	52.12
	0.27%	0.30%	0.33%	0.35%	0.40%	0.47%	0.48%	0.52%	0.56%	0.55%	0.53%	0.51%	0.47%	0.45%	0.41%
CRF 3D - Agricultural Soils	228.62	235.73	241.71	231.67	224.22	225.79	226.83	223.91	221.09	225.71	223.72	205.32	203.21	180.56	204.99
	1.79%	1.76%	1.84%	1.74%	1.80%	2.24%	2.23%	2.36%	2.56%	2.48%	2.31%	2.02%	1.86%	1.59%	1.61%
Other Sources **(6)**	47.39	45.78	43.65	44.68	44.19	44.73	45.53	44.85	44.83	43.37	43.46	42.98	42.13	43.03	42.62
	0.37%	0.34%	0.33%	0.34%	0.35%	0.44%	0.45%	0.47%	0.52%	0.48%	0.45%	0.42%	0.39%	0.38%	0.33%
F-gases (7)	**1.28**	**1.37**	**6.96**	**14.51**	**15.87**	**16.90**	**19.27**	**22.19**	**25.11**	**28.45**	**33.45**	**41.23**	**45.09**	**45.92**	**46.66**
	0.01%	0.01%	0.05%	0.11%	0.13%	0.17%	0.19%	0.23%	0.29%	0.31%	0.35%	0.41%	0.41%	0.40%	0.37%
Total GHG excluding LULUCF	**12741.06**	**13382.78**	**13146.80**	**13293.45**	**12468.53**	**10091.81**	**10155.26**	**9503.14**	**8622.18**	**9087.98**	**9669.11**	**10158.18**	**10934.88**	**11376.30**	**12766.97**
	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	**101.25**	**-194.21**	**-544.60**	**-648.55**	**-448.90**	**-568.93**	**-615.05**	**-707.04**	**-589.97**	**-683.97**	**-717.53**	**-701.08**	**-699.25**	**-655.60**	**-676.95**

Gg (1000 t.) CO_2 equivalent	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
CO_2	**12105.45**	**11936.28**	**11333.58**	**11195.25**	**10647.82**	**11219.29**	**11114.55**	**10851.40**	**10303.87**	**9825.22**	**9333.17**	**9080.25**	**9250.40**	**9568.52**
of which	93.05%	92.98%	92.49%	92.26%	91.89%	92.20%	92.27%	92.17%	91.72%	91.17%	90.70%	90.34%	89.25%	93.15%
CRF 1 - Energy	11425.52	11206.87	10613.38	10533.16	10055.94	10604.63	10485.29	10283.83	9755.90	9265.00	8781.14	8502.47	8665.70	8977.24
	87.83%	87.29%	86.61%	86.80%	86.78%	87.14%	87.04%	87.35%	86.84%	85.97%	85.34%	84.60%	84.66%	85.12%
CRF 1A1 - Fuel Combustion from	1237.79	1299.99	1176.38	990.75	1185.90	1201.05	999.08	1038.05	681.79	663.72	452.20	246.72	236.39	215.52
Energy Industries	9.51%	10.13%	9.60%	8.16%	10.23%	9.87%	8.29%	8.82%	6.07%	6.16%	4.39%	2.45%	2.31%	2.04%
CRF 1A2 - Fuel Combustion from	1390.95	1465.38	1369.62	1316.41	1177.18	1254.69	1231.01	1173.52	1133.04	1136.30	1101.71	1144.28	1132.79	1152.84
Manuf. Industries & Construction	10.69%	11.41%	11.18%	10.85%	10.16%	10.31%	10.22%	9.97%	10.09%	10.54%	10.71%	11.39%	11.07%	10.93%
CRF 1A3 - Fuel Combustion from	7151.73	6830.68	6543.17	6638.84	6115.41	6473.00	6842.11	6537.83	6395.35	6086.49	5645.84	5475.21	5585.85	5961.44
Transport	54.97%	53.21%	53.40%	54.71%	52.78%	53.19%	56.80%	55.53%	56.93%	56.48%	54.87%	54.48%	54.57%	56.52%
of which, "road fuel export" **(1)**	5677.89	5302.28	4986.22	5018.26	4501.67	4846.23	5190.14	4887.36	4756.11	4381.78	3938.62	3744.67	0.00	0.00
	43.65%	41.30%	40.69%	41.35%	38.85%	39.82%	43.09%	41.51%	42.33%	40.66%	38.28%	37.26%	0.00%	0.00%
CRF 1A4 - Fuel Combustion from	1644.87	1610.63	1524.03	1586.98	1577.27	1675.70	1412.91	1534.26	1545.56	1378.33	1581.23	1636.10	1710.51	1647.29
Other Sectors	12.64%	12.55%	12.44%	13.08%	13.61%	13.77%	11.73%	13.03%	13.76%	12.79%	15.37%	16.28%	16.71%	15.62%
CRF 1A5 & 1B2b - Other Energy	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.11	0.11
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%
CRF 2 - Industrial Processes	675.69	726.11	716.87	658.99	587.47	610.85	623.98	562.09	541.68	553.26	544.67	570.80	575.91	580.30
	5.19%	5.66%	5.85%	5.43%	5.07%	5.02%	5.18%	4.77%	4.82%	5.13%	5.29%	5.68%	5.63%	5.50%
Other Sources **(2)**	18.97	17.24	17.42	23.67	21.72	23.67	28.18	28.55	30.92	27.81	27.34	29.02	30.03	31.59
	0.15%	0.13%	0.14%	0.20%	0.19%	0.19%	0.23%	0.24%	0.28%	0.26%	0.27%	0.29%	0.29%	0.30%
CH_4 (3)	**575.20**	**571.39**	**580.19**	**590.50**	**591.86**	**591.66**	**567.31**	**559.25**	**563.56**	**576.50**	**582.38**	**586.33**	**593.66**	**587.66**
	4.42%	4.45%	4.73%	4.87%	5.11%	4.86%	4.71%	4.75%	5.02%	5.35%	5.66%	5.83%	5.80%	5.57%
of which	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 1 - Energy	71.55	73.53	68.65	66.50	66.85	71.01	61.78	64.11	57.48	56.05	53.19	51.96	51.29	52.06
	0.55%	0.57%	0.56%	0.55%	0.58%	0.58%	0.51%	0.54%	0.51%	0.52%	0.52%	0.52%	0.50%	0.49%
CRF 3A+3B - Enteric Fermentation and	411.82	406.24	419.17	431.23	433.06	439.81	426.67	416.69	427.03	440.81	453.31	461.04	467.98	463.37
Manure Management	3.17%	3.16%	3.42%	3.55%	3.74%	3.61%	3.54%	3.54%	3.80%	4.09%	4.41%	4.59%	4.57%	4.39%
Other Sources **(4)**	91.83	91.61	92.36	92.76	91.96	80.84	78.86	78.45	79.05	79.64	75.88	73.33	74.39	72.23
	0.71%	0.71%	0.75%	0.76%	0.79%	0.66%	0.65%	0.67%	0.70%	0.74%	0.74%	0.73%	0.73%	0.68%
N_2O (5)	**282.69**	**281.30**	**286.24**	**292.53**	**289.51**	**297.15**	**300.09**	**295.55**	**296.08**	**299.36**	**297.59**	**308.34**	**312.14**	**313.13**
	2.17%	2.19%	2.34%	2.41%	2.50%	2.44%	2.49%	2.51%	2.64%	2.78%	2.89%	3.07%	3.05%	2.97%
of which	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 1 - Energy	52.25	52.25	54.89	58.12	57.24	62.68	68.35	68.99	70.71	72.97	72.53	73.86	77.38	82.90
	0.40%	0.41%	0.45%	0.48%	0.49%	0.52%	0.57%	0.59%	0.63%	0.68%	0.70%	0.73%	0.76%	0.79%
CRF 3D - Agricultural Soils	187.65	185.82	186.21	187.65	186.83	189.60	189.95	187.05	185.87	185.42	185.37	193.03	193.23	188.82
	1.44%	1.45%	1.52%	1.55%	1.61%	1.56%	1.58%	1.59%	1.65%	1.72%	1.80%	1.92%	1.89%	1.79%
Other Sources **(6)**	42.80	43.23	45.13	46.75	45.43	44.86	41.80	39.51	39.50	40.97	39.68	41.44	41.53	41.41
	0.33%	0.34%	0.37%	0.39%	0.39%	0.37%	0.35%	0.34%	0.35%	0.38%	0.39%	0.41%	0.41%	0.39%
F-gases (7)	**45.78**	**49.10**	**53.92**	**56.83**	**58.39**	**60.97**	**64.30**	**67.05**	**70.97**	**75.77**	**76.96**	**75.77**	**79.49**	**77.84**
	0.35%	0.38%	0.44%	0.47%	0.50%	0.50%	0.53%	0.57%	0.63%	0.70%	0.75%	0.75%	0.78%	0.74%
Total GHG excluding LULUCF	**13009.12**	**12838.07**	**12253.93**	**12135.10**	**11587.58**	**12169.06**	**12046.25**	**11773.25**	**11234.48**	**10776.85**	**10290.10**	**10050.69**	**10235.70**	**10547.15**
	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	**-623.72**	**-529.11**	**-438.50**	**-450.22**	**-431.75**	**-119.48**	**-290.95**	**-381.75**	**-559.28**	**-472.30**	**-421.57**	**-509.36**	**-402.41**	**-213.28**

Sources: Environment Agency and MDDI-DEV.

Notes: (1) The methane emissions are converted in CO_2 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.

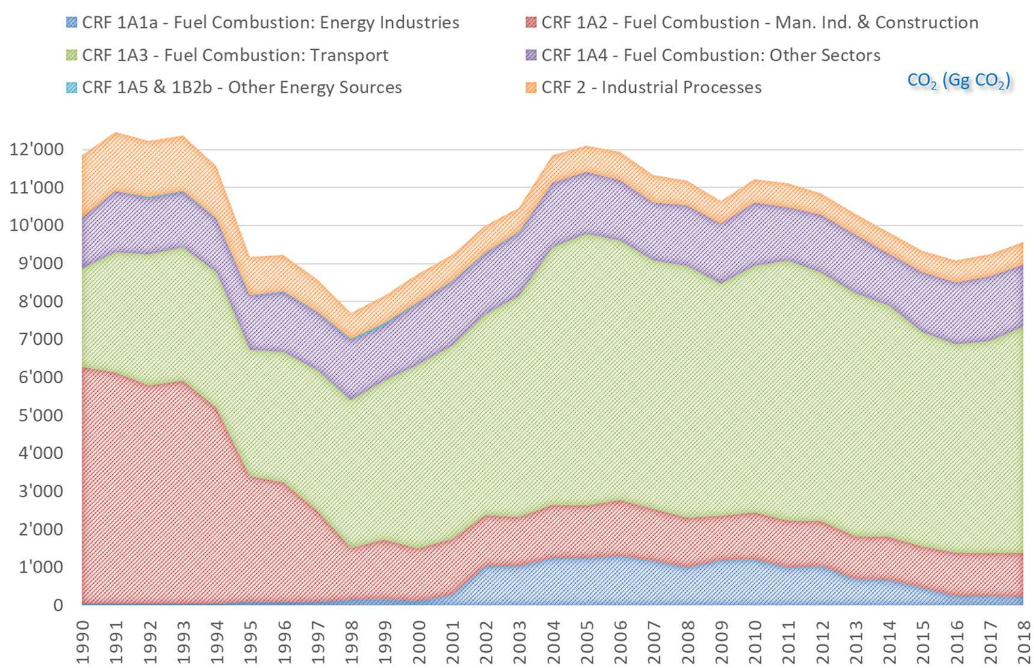
(2) The nitrous oxide emissions are converted in CO_2 equivalents by multiplying the emissions by 298, *i.e.* the global warming potential (GWP) value for nitrous oxide based on the effects of GHG over a 100-year time horizon.

(3) The F-gases are those not covered by the Montreal Protocol, *i.e.* the HFCs, PFCs and SF_6 expressed in CO_2 equivalents using the global warming potential (GWP) values based on the effects of GHG over a 100-year time horizon.

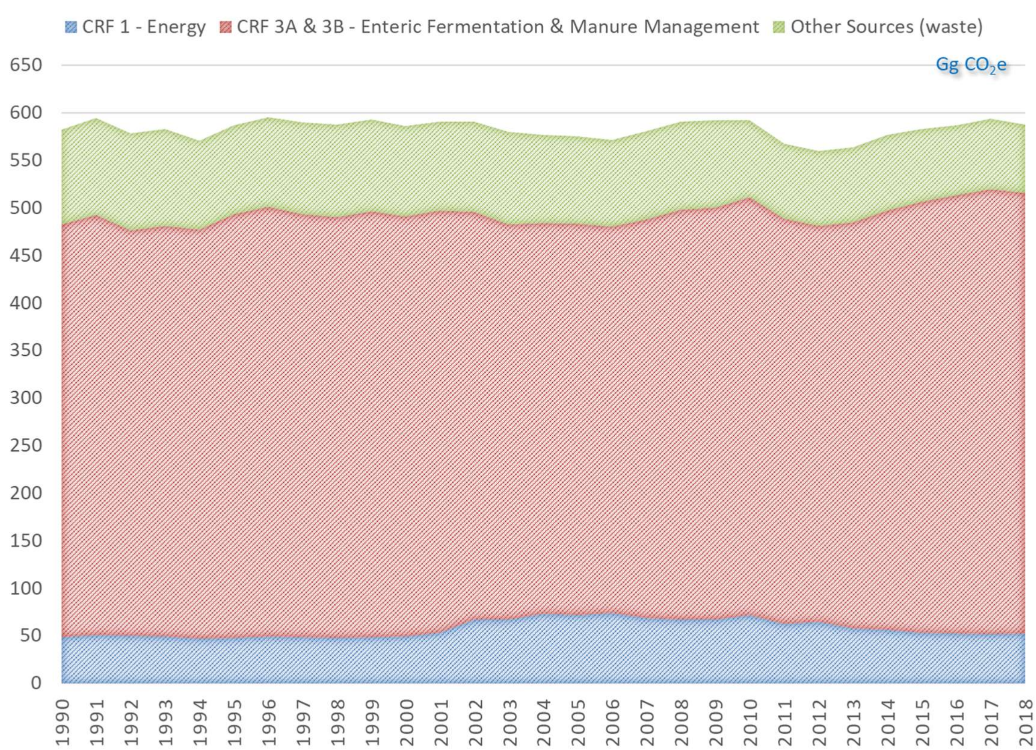
(4) CRF 1A4a&b: there are breaks in time series between 1999 & 2000: the two CRF 1A4 sub-categories had a very similar level because national energy statistics does not allow for distinguishing these two sub-categories before 2000. Hence, a 50-50 distribution was carried out in the inventories.

Figure 2-31 – Luxembourg's GHG emissions (excl. F-gases & LULUCF) – details by main gases: 1990-2018

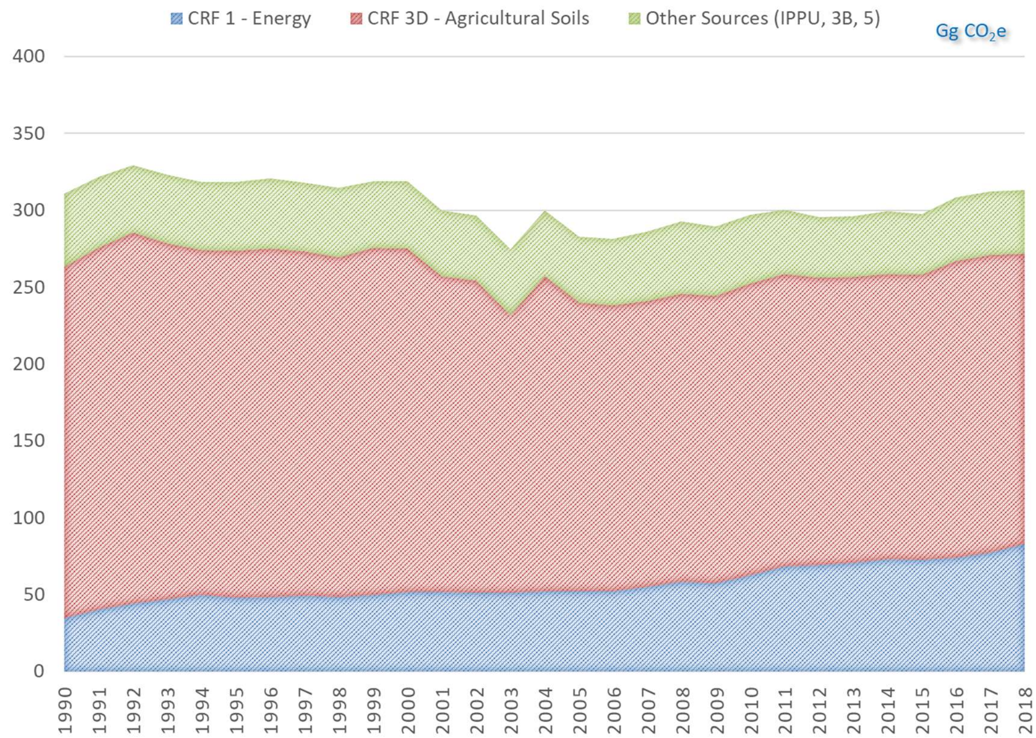
$\underline{CO_2}$



$\underline{CH_4}$



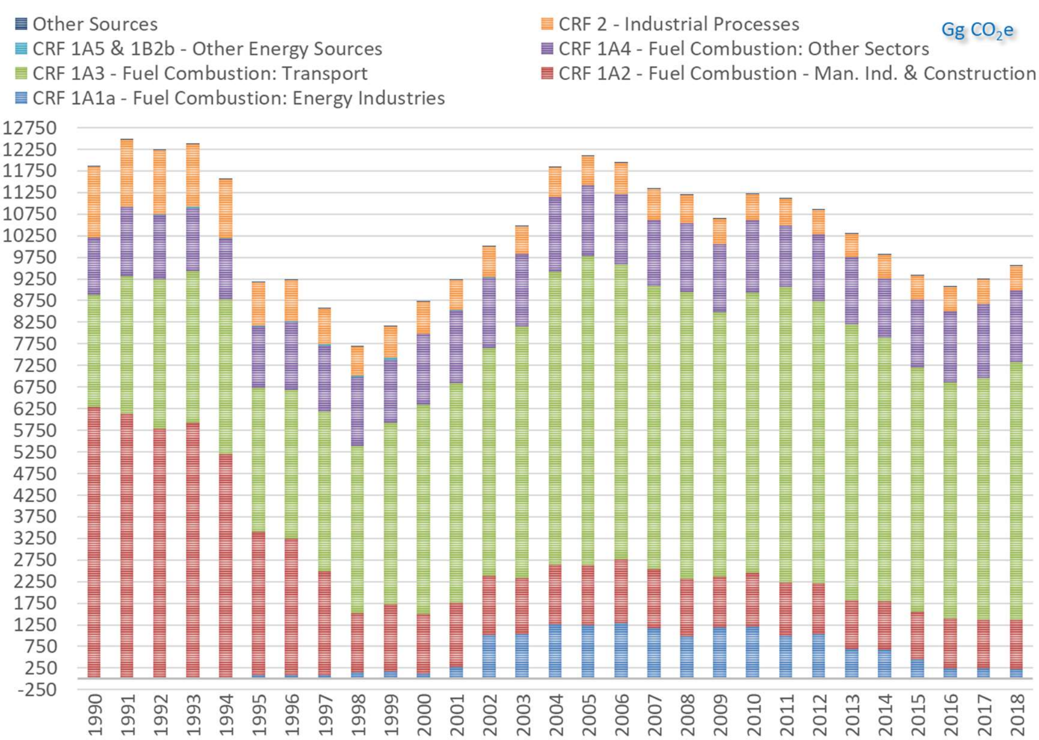
N_2O



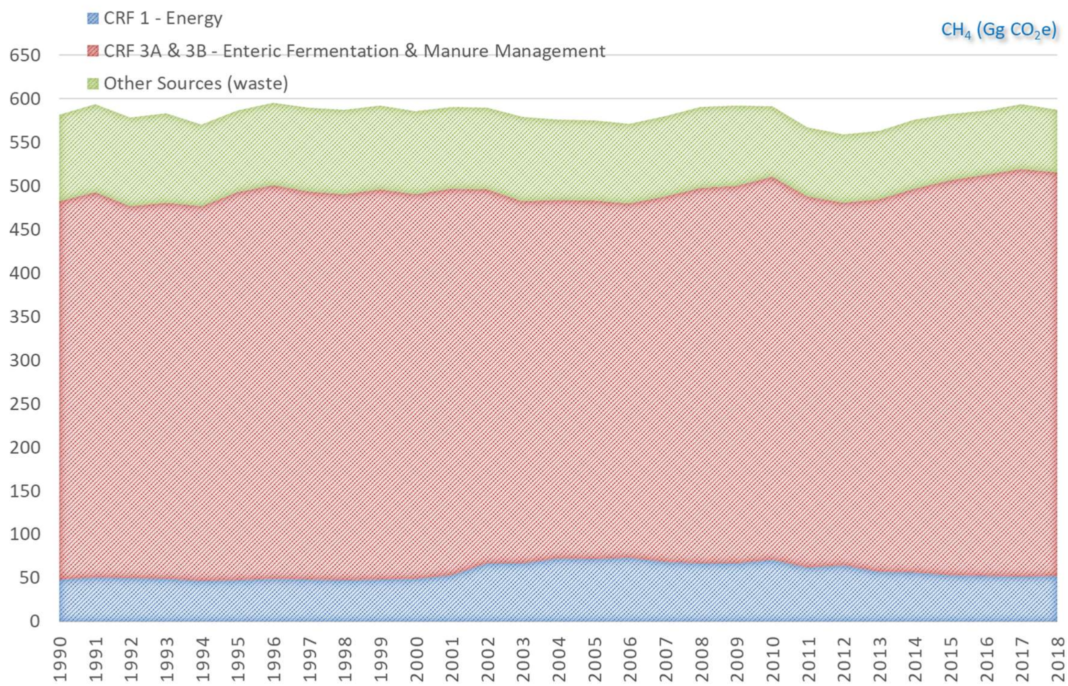
Sources: Environment Agency and MDDI-DEV.

Figure 2-32 – Luxembourg's GHG emission trends in % (excl. LULUCF) – details by main gases: 1990-2018

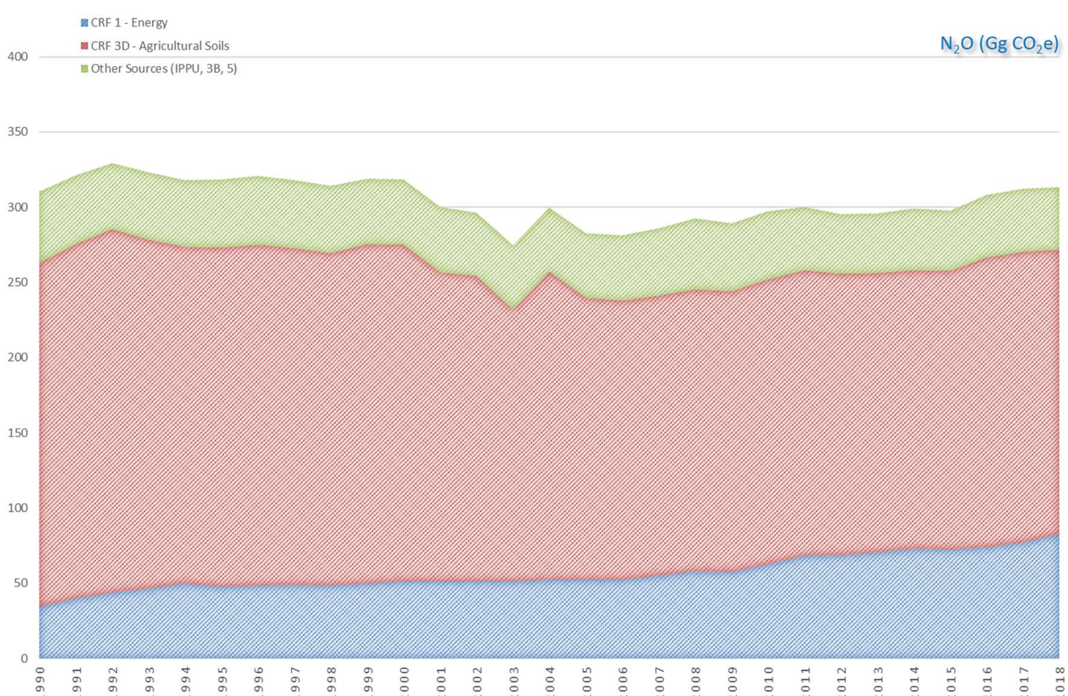
CO_2



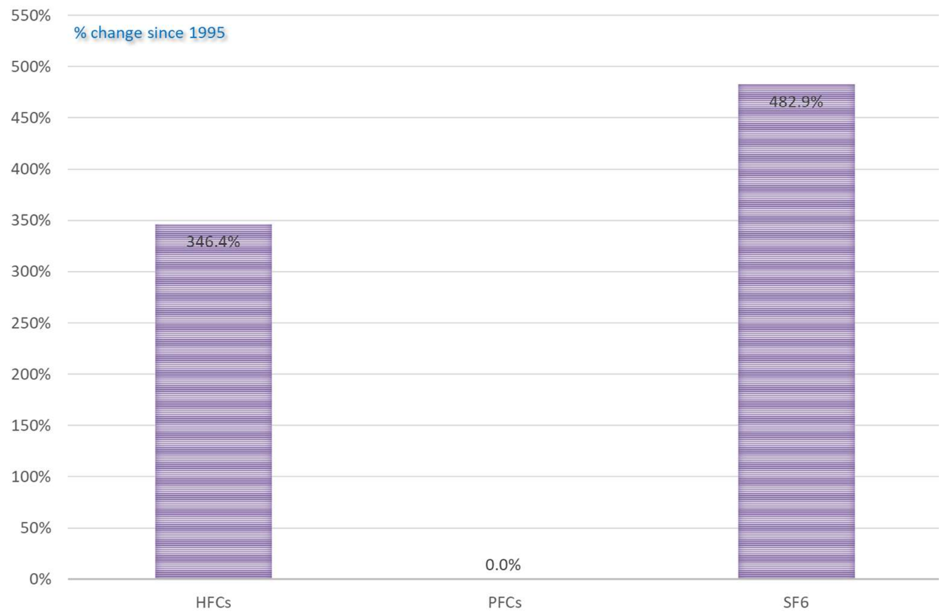
CH_4


CRF 1 - Energy
CRF 3A & 3B - Enteric Fermentation & Manure Management
Other Sources (waste)
CH4 (Gg CO2e)
650
600
550
500
450
400
350
300
250
200
150
100
50
0
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

N_2O


CRF 1 - Energy
CRF 3D - Agricultural Soils
Other Sources (IPPU, 3B, 5)
N2O (Gg CO2e)
400
350
300
250
200
150
100
50
0
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

F-gases



Sources: Environment Agency and MDDI-DEV.

2.3.1 Carbon dioxide – CO_2

CRF (sub-) categories covered	1 (1A1, 1A2, 1A3, 1A4, 1A5, 1B2b), 2, 3, 4	
Share in total GHG emissions, excl. LULUCF	***1990***	92.99% = 11 847.64 Gg CO_2e
	2018	90.72% = 9 568.52 Gg CO_2e

Throughout the period 1990-2018, the main GHG has remained carbon dioxide, which accounted for between 89% and 93% of the total GHG emissions. However, the structure of CO_2 emissions has evolved with an increase in fuel combustion, which accounted for 80.20% of total GHG emissions for the base year (1990) and climbed up to 93.82% in 2018.

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% of total GHG emissions. Then, with 5.96 Mio. t CO_2, this percentage reached 52.96% in 2018.[53] CO_2 emissions due solely to "road fuel sales to non-residents" amounted to about 1.7 Mio. t in 1990 and reached 4.2 Mio. t in 2018,[54] *i.e.* a 147% increase (the same comparison shows "only" a 98% increase for road fuel consumed by the national vehicle fleet). In 2018, "road fuel sales to non-residents" represented 71% of CO_2 emissions of the transport sector and 44% of the total CO_2 emissions. In 1990, these percentages were 66% and 14%, respectively.

53 The highest amount of emissions was recorded for the year 2005: 7.15 Mio. t CO_2 but "only" 55% of total GHG emissions

54 5.7 Mio. t in 2005.

Another important source of CO_2 in Luxembourg is **industrial processes**, mainly carbon oxidizing of pig iron from steel industry (basic oxygen furnace steel production) and decarbonisation of mineral input in clinker and glass industry. The steel production process change described above was the main driver behind declining emissions for this sector.

2.3.2 Methane – CH_4

CRF (sub-) categories covered	1, 3A, 3B, 5A, 5B, 5D		
Share in total GHG emissions, excl. LULUCF	***1990***	0.18% =	23.27 Gg CO_2e
	2018	0.22% =	23.51 Gg CO_2e

Methane emissions originate above all from the agricultural sector, and more precisely from **enteric fermentation** and from **manure production and management**: around 71-79% of methane emissions over the period 1990-2018. 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 (-27.4%) and growing emissions in **energy use** (+8.42%). 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.

2.3.3 Nitrous oxide – N_2O

CRF (sub-) categories covered	1, 2G, 3B, 3D, 5B and 5D		
Share in total GHG emissions, excl. LULUCF	***1990***	0.01% =	1.04 Gg CO_2e
	2018	0.01% =	1.05 Gg CO_2e

The major part of nitrous oxide emissions is caused by **agricultural soils.** Total emissipons of this gas over the period 1990-2018 are rather stable and fluctuate between 0.92 Gg and 1.11 Gg excl. N_2O from LULUCF, and between 0.99 Gg and 1.18 Gg incl. N_2O from LULUCF. Another important source that has been generating increasing N_2O emissions since 1990 is **road transportation**, where incomplete NO_X reduction in catalytic converters of diesel oil motor vehicles leads to N_2O emissions that were multiplied by a factor 4 over the period, following the increasing share of diesel vehicles on the roads. The increase in N_2O emissions from 1990-2018 (+0.16 Gg or +140%) observed for the **Energy sector** is counterbalanced by diminishing nitrous oxide emissions from the **Agriculture sector** (-0.15 Gg or -17%).

2.3.4 Hydrofluorocarbons – HFCs, perfluorocarbons - PFCs and sulphur hexafluoride – SF_6

CRF (sub-) categories covered	2D, 2F, 2G		
Share in total GHG emissions, excl. LULUCF	***1990***	0.01% =	1.28 Gg CO_2e
	2018	0.10% =	77.84 Gg CO_2e

The increase in **HFCs** emissions between 1990 and 2018 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.

SF_6 emissions increased from 1990 onwards following a raising 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 2018, the energy sector accounted for almost 86.39% of the total GHG emissions, excluding LULUCF. Two sectors represent around 6% of the total emissions, excluding LULUCF: industrial processes (6.28%) and agriculture (6.55%). The remaining sector[55] (waste[56] (0.78%) was not even reaching 1% of the total GHG emitted in Luxembourg: see Table 2-10 and Figure 2-27 and Figure 2-28.

For the different sectors, trends over the period 1990-2018 (and 2017-2018) were as follows:

- Energy: ....-11.54% (+3.61%)
- Industrial Processes: ....-59.58% (+0.45%)
- Agriculture: ....-0.74% (-1.04%)
- LULUCF: ………………………………........-310.65% (-47.00%)
- Waste: ....-22.07% (-2.46%)

2.4.1 CRF 1 – Energy

GHG covered	CO_2, CH_4 & N_2O	
Share in total GHG emissions, excl. LULUCF	***1990***	80.85% = 10 300.98 Gg CO_2e
	2018	86.39% = 9112.19 Gg CO_2e

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).

Energy production and consumption related GHG emissions have decreased by 11.54% between 1990 and 2018 - from 10.3 Mio. t CO_2e in 1990 to 9.1 Mio. t CO_2e in 2018. For carbon dioxide, methane and nitrous oxide, the changes over the period 1990-2018 were -12.15%, +8.42% and +140.34%, 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): +527.33% and +130.36%, respectively between 1990 and 2018. For the other sub-sectors, the observed trends between 1990 and 2018 are -81.42% for **manufacturing industries and construction** (1A2), +22.39% for the **other sectors** (1A4), and +59.77% 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 large impact on the national total of GHG emissions. The TWINerg power plant (2001-2016), and to a lesser extent several cogeneration (CHP) plants, also had an impact on the energy related GHG emissions, as already stressed in previous paragraphs. 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, have also a very important impact on the total GHG emissions.

In the iron and steel industry, the passage from blast furnaces to electric arc furnaces allowed to significantly reducing GHG emissions between 1994 and 1998. Due to the importance of 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 these 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).

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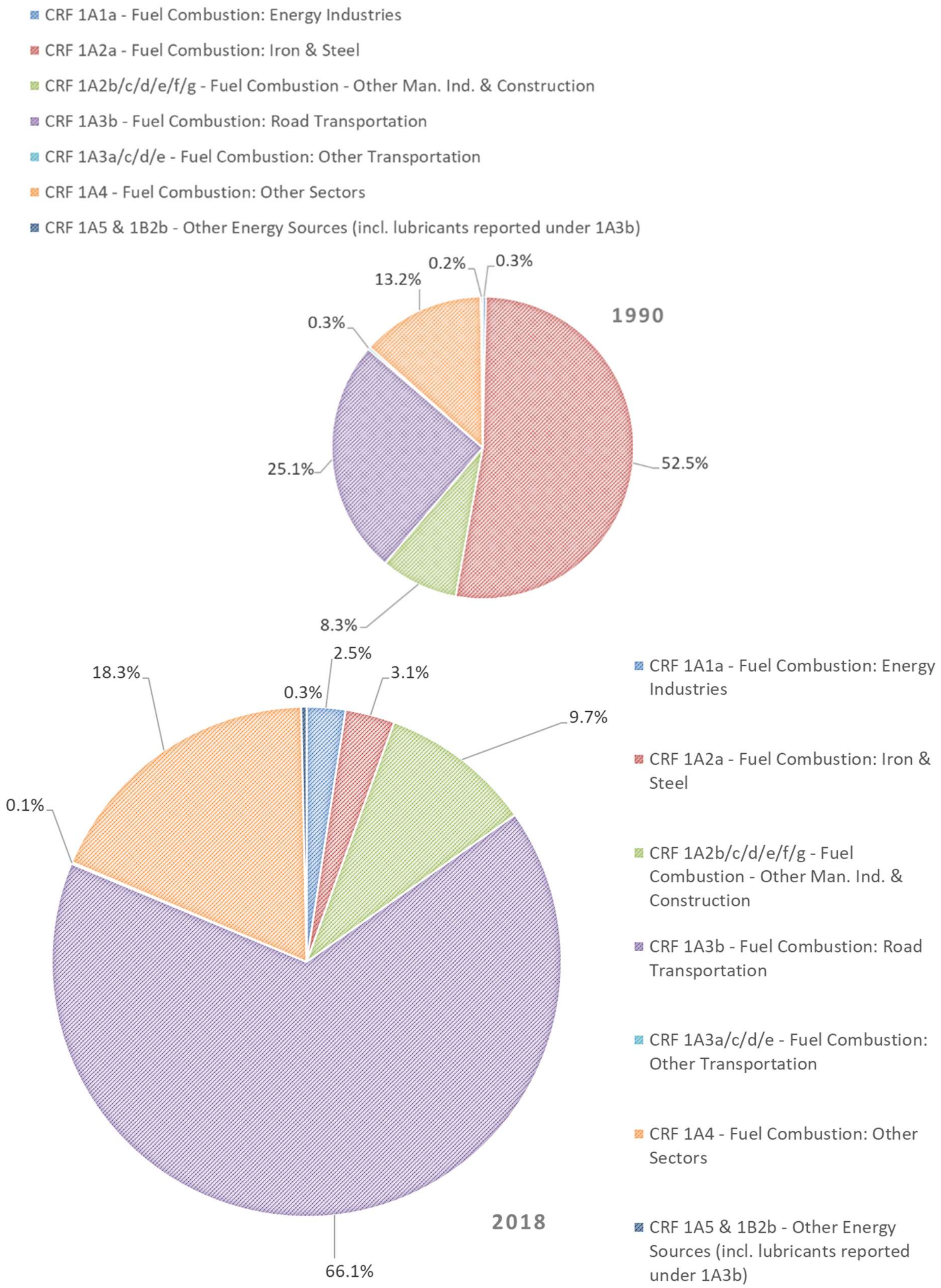
57 Fugitive emission growth is closely linked to natural gas use in Luxembourg.

Figure 2-33 – CRF sub-categories share in GHG emissions for CRF 1 – Energy: 1990 & 2018



<u>Sources:</u> Environment Agency and MDDI-DEV.

2.4.2 CRF 2 – Industrial Processes

GHG covered	CO_2, N_2O, F-gases		
Share in total GHG emissions, excl. LULUCF	***1990***	12.78% =	1 639.38 Gg CO_2e
	2018	6.28% =	662.58 Gg CO_2e

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 SF_6 (the fluorinated gases or F-gases). In Luxembourg, when leaving F-gases out, only 3 companies and their various production installations are part of CRF sector 2:

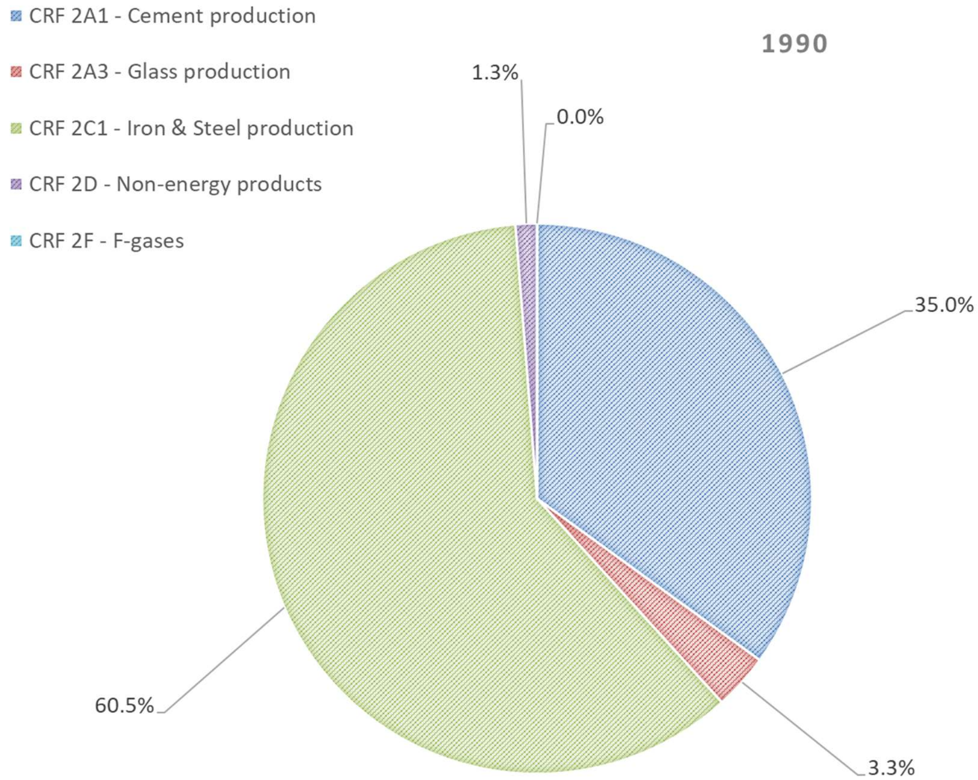
- CRF sub-categories 2A1 & 2A3: one cement works unit and one flat glass manufacturing company;
- CRF sub-category 2C1: the iron and steel manufacturing company ArcelorMittal.

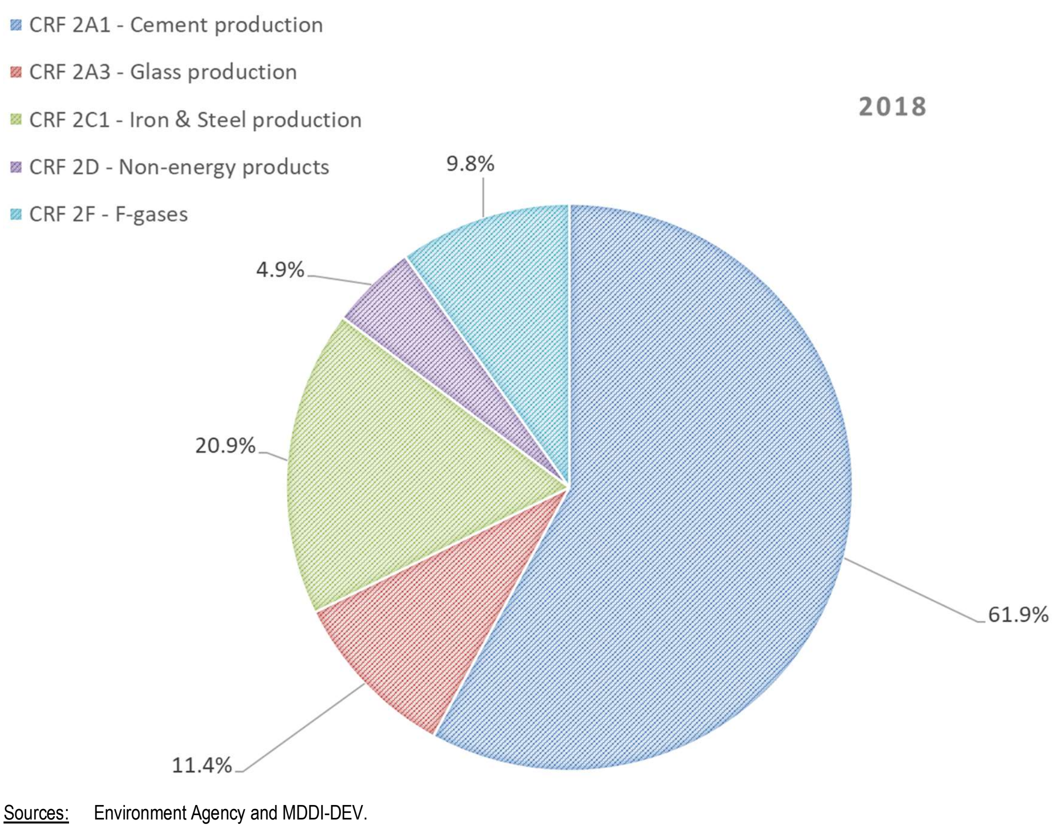
Emissions from industrial processes show a declining trend between 1990 and 1998, then a relative stabilisation. This evolution was mainly driven by **process changes that occurred in the iron & steel industry**. As indicated above, this industry moved from blast to electric arc furnaces between 1994 and 1998. As a consequence, steel industry process emissions in CO_2e decreased by 88.39% over the period 1990-2018. Overall sector emissions in CO_2e fell by about 59.58% between 1990 and 2018, reducing the weight of this sector in total GHG emissions from 12.87% to 6.28% over the period. By gas, however, the picture is different. For carbon dioxide, the decrease over the period 1990-2018 was -64.37%. F-gases emissions, on the contrary, increased regularly: +361% over the period 1995-2018, 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 supposedly growing use in the country, notably due to an increasing use of air conditioning and noise reduction windows (see Section 4.7).

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 & 2018





Sources: Environment Agency and MDDI-DEV.

2.4.3 CRF 3 – Agriculture

GHG covered	CO_2, CH_4, N_2O		
Share in total GHG emissions, excl. LULUCF	***1990***	5.46% =	695.57 Gg CO_2e
	2018	6.55% =	690.44 Gg CO_2e

Trends in agriculture were quite stable between 1990 and 2018: in general GHG related to agricultural activities have decreased by 0.74% (+4193% for CO_2, +6.7% for methane and -17.3% for nitrous oxide). Enteric Fermentation (3A) saw its emissions increasing by 4.0%, whereas for agricultural soils (3D), the decrease reaches 17.4%. For manure management (3B), emissions increased by 10.5% between 1990 and 2018, though opposite variations are observed for the two GHG emitted by this activity: methane increased by 29.3% and nitrous oxide decreased by 16.2%.

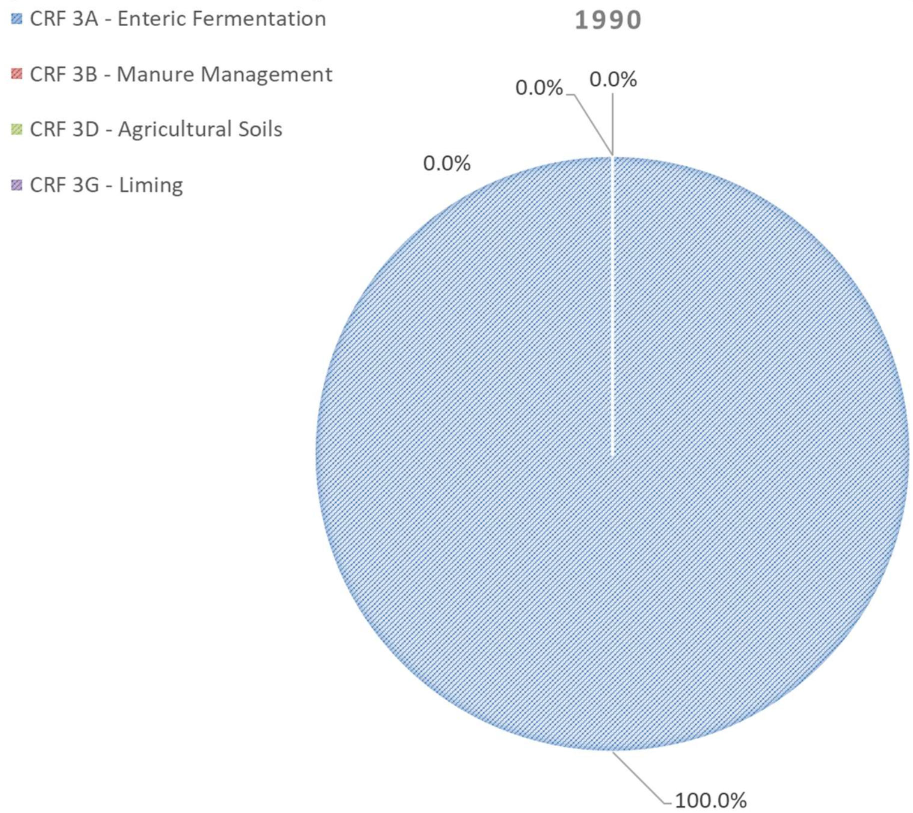
However, the evolution of nitrous oxide emissions stemming from agricultural soils (3D) shapes the overall agriculture emission pattern. Indeed, for both the years 1990 and 2018, CRF category 3D is the biggest contributor to agriculture related emissions, though it is also, as for other Annex I Parties, 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.

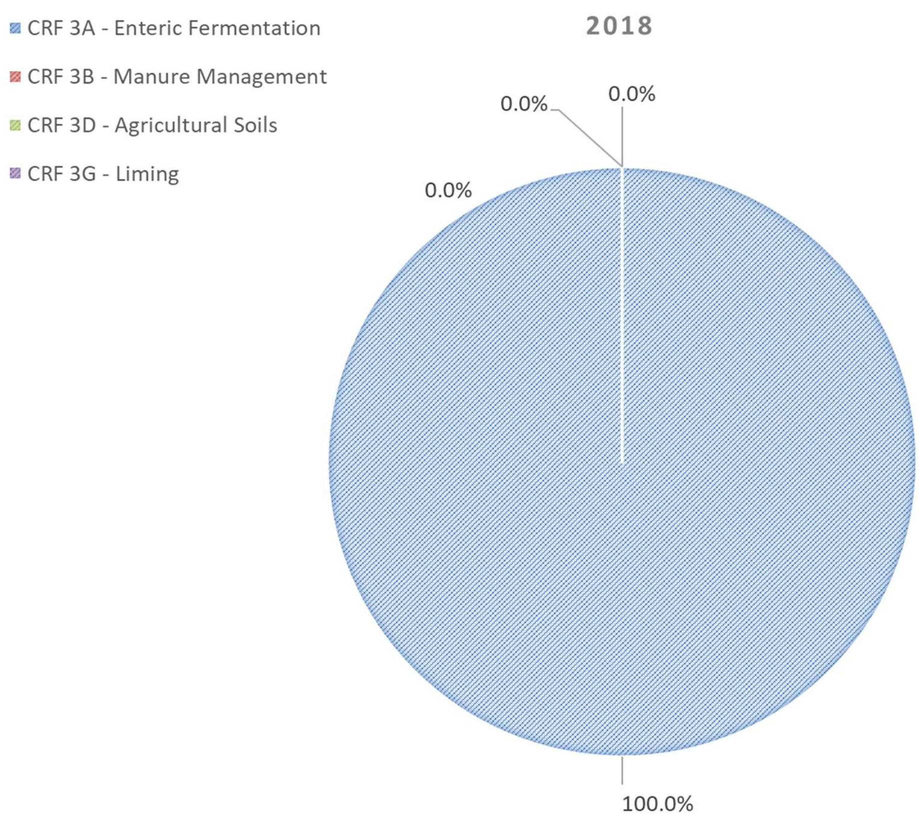
Looking at **methane** emissions from **manure management**, an increase by 29.3% can be observed for the period 1990-2018. Animals who contributed the most to these emissions were cattle and swine. As far as **nitrous oxide** emissions from **manure management** are concerned, a decrease of 16.2% is observed for the period 1990-2018. 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 & 2018





Source: MDDI-DEV.

2.4.4 CRF 5 – Waste

GHG covered	CH_4 & N_2O		
Share in total GHG emissions, excl. LULUCF	***1990***	0.83% =	105.14 Gg CO_2e
	2018	0.78% =	81.93 Gg CO_2e

In the waste sector, the main source of GHG was solid waste disposal on land (5A), but its weight decreased over the period 1990-2018 due to the combination of reduced amounts of waste disposed in landfills and of increased emissions arising from composting activities (5D). However, GHG emission reduction for solid waste disposal on land between 1990 and 2018 (-48.2%) still drove a reduction for the overall waste sector despite rising emissions from composting. Wastewater handling emissions (5D) experienced a 47.2% decline in emissions between 1990 and 2018. 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.

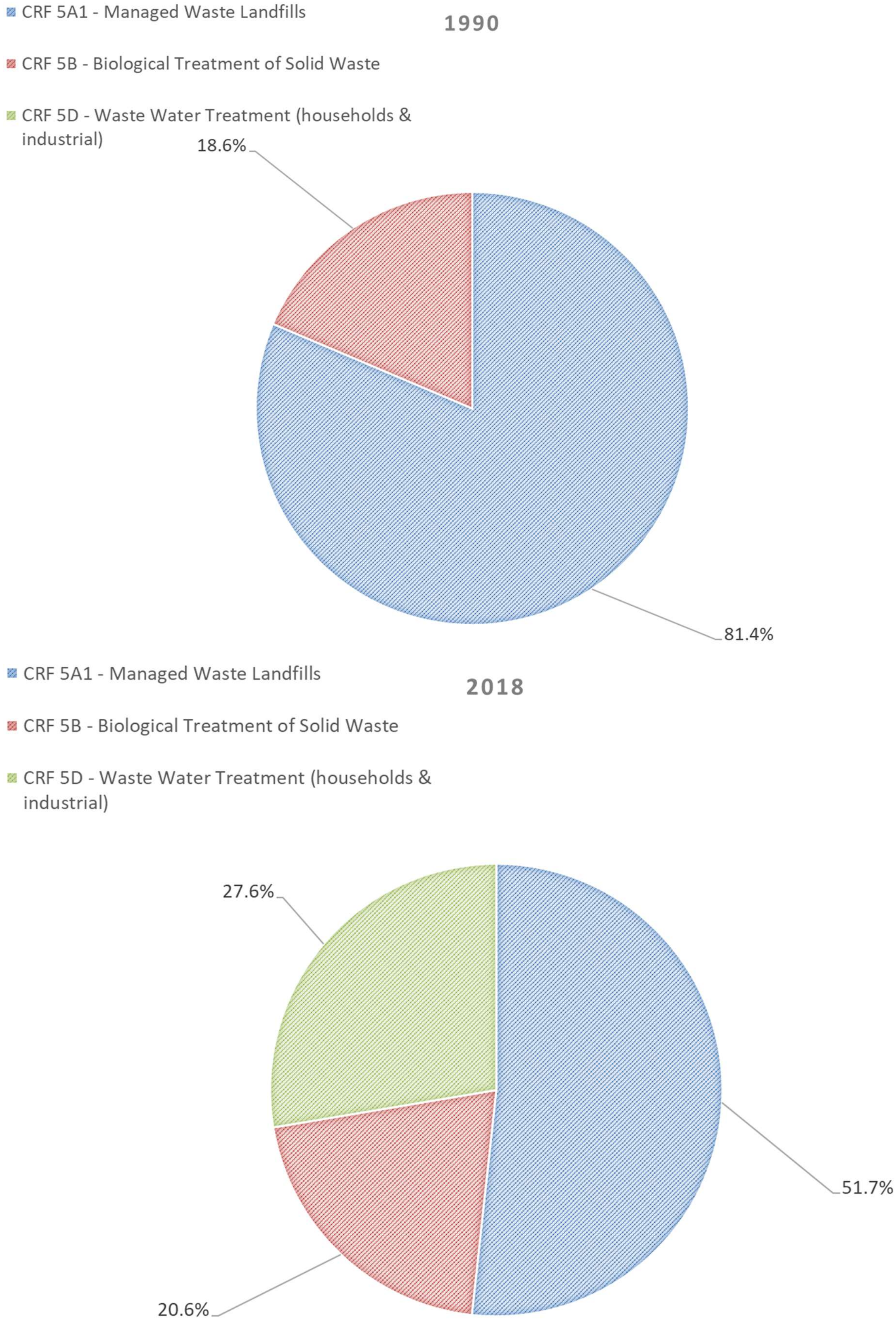
Wastewater treatment plant (WWTP) capacities expressed in population-equivalents have steadily grown since 1990. However, methane and nitrous oxide emissions decreased since 1990. Therefore, technical changes, with regard to wastewater treatment, have had an undeniable role too.

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 & 2018



Sources: Environment Agency, Water Agency and MDDI-DEV.

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 SO_2

Indirect GHG – NO_x, CO, NMVOCs – and SO_2 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 CO_2, whereas other categories and sub-categories reported in the inventory are generally sources of emissions (both CO_2 and N_2O).

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 130.63 Gg of CO_2e.[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 2018, CO_2 removals from **afforestation and reforestation** (AR) in Luxembourg amounted to -164.33 Gg CO_2. Emissions from **deforestation** (D) activities amounted in 2018 to 35.92 Gg CO_2eq.

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.

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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: (-1032.36+248.59)/6 = -130.63 Gg CO_2e. 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 0 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 2018.

GHG emissions from fossil fuel combustion are the main source of greenhouse gas emissions in the Grand-Duchy of Luxembourg. In 2018, about 86.1% 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 0.29% 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 2018 for each of the IPCC categories under CRF Sector *1 - Energy*, for which GHG emissions are reported. These are expressed in CO_2 equivalents and include CH_4 and N_2O emissions from biomass, but exclude CO_2 emissions from biomass combustion. CO_2 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 11.68% between 1990 and 2018 from 10.28 million tonnes CO_2 equivalents in 1990 to 9.08 million tonnes CO_2 equivalents in 2018. Carbon dioxide emissions decreased by 12.15% in 2018 compared to the base year. Methane emissions decreased by 26.3%, whereas nitrous oxide emissions increased by 140%, for the same period.

Figure 3-1 – GHG emission trends for CRF Sector 1-Energy: 1990-2018

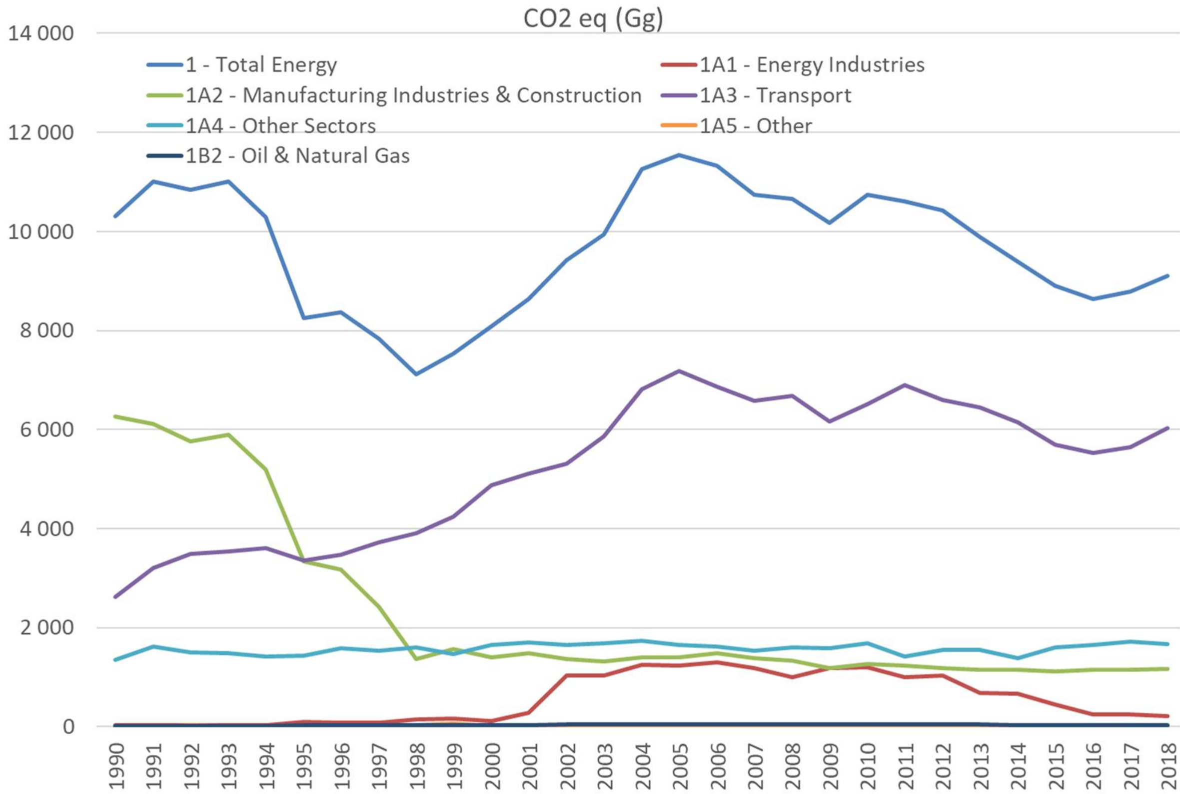

Figure 3-2 illustrates that the overall trend observed at sector level hides very different developments at the sub-category level. Indeed, between 1990 and 2018, GHG emissions have been strongly influenced by varying fuel consumption levels in industry, in particular in the iron and steel industry, 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 sales[61], have a very important weight in the national energy balance, and, consequently, have also a very important impact on the total GHG emissions.

61 See Section 2.2.

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 2018 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.

Table 3-1 – GHG emission trends in CO_2eq for CRF Sector 1 – Energy: 1990-2018

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_2O (incl. biomass)	Total $CO_{2\,eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	Total $CO_{2\,eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)
1990	3.12	3.10	0.000	0.000	19.39	0.03	0.77	NA, NO	10 300.97	10 218.47	1.92	0.12
1991	3.12	3.10	0.000	0.000	20.11	0.03	0.80	NA, NO	11 005.59	10 914.72	2.04	0.13
1992	26.87	26.72	0.003	0.000	20.99	0.03	0.84	NA, NO	10 845.77	10 751.96	1.99	0.15
1993	23.72	23.58	0.003	0.000	21.79	0.03	0.87	NA, NO	11 010.41	10 914.73	1.96	0.16
1994	22.14	22.01	0.003	0.000	21.94	0.03	0.88	NA, NO	10 294.83	10 198.16	1.88	0.17
1995	10.82	10.75	0.001	0.000	25.01	0.03	1.00	NA, NO	8 259.92	8 164.82	1.90	0.16
1996	18.61	18.49	0.002	0.000	27.36	0.04	1.09	NA, NO	8 367.77	8 270.58	1.95	0.16
1997	23.10	22.98	0.003	0.000	27.98	0.04	1.12	NA, NO	7 830.48	7 732.99	1.94	0.16
1998	34.21	34.03	0.004	0.000	28.20	0.04	1.13	NA, NO	7 110.57	7 014.36	1.91	0.16
1999	63.29	62.95	0.008	0.000	29.20	0.04	1.17	NA, NO	7 529.08	7 430.84	1.93	0.17
2000	12.21	12.17	0.001	0.000	29.98	0.04	1.20	NA, NO	8 088.16	7 987.70	1.96	0.17
2001	24.24	24.16	0.002	0.000	33.32	0.04	1.33	NA, NO	8 644.21	8 539.78	2.11	0.17
2002	13.54	13.49	0.001	0.000	47.72	0.06	1.91	NA, NO	9 416.09	9 298.42	2.66	0.17
2003	3.27	3.25	0.000	0.000	48.36	0.06	1.93	NA, NO	9 945.22	9 827.13	2.68	0.17
2004	0.13	0.12	0.000	0.000	53.67	0.07	2.14	NA, NO	11 262.92	11 138.05	2.91	0.17
2005	0.13	0.12	0.000	0.000	52.87	0.07	2.11	NA, NO	11 549.32	11 425.52	2.86	0.18
2006	0.13	0.12	0.000	0.000	55.48	0.07	2.22	NA, NO	11 332.65	11 206.87	2.94	0.18
2007	0.13	0.12	0.000	0.000	51.91	0.07	2.07	NA, NO	10 736.92	10 613.38	2.75	0.18
2008	0.13	0.12	0.000	0.000	49.64	0.07	1.98	NA, NO	10 657.78	10 533.16	2.66	0.20
2009	0.13	0.12	0.000	0.000	50.18	0.07	2.00	NA, NO	10 180.03	10 055.94	2.67	0.19
2010	0.13	0.12	0.000	0.000	53.96	0.07	2.16	NA, NO	10 738.32	10 604.63	2.84	0.21
2011	0.12	0.12	0.000	0.000	46.78	0.06	1.87	NA, NO	10 615.41	10 485.29	2.47	0.23
2012	0.12	0.12	0.000	0.000	47.85	0.06	1.91	NA, NO	10 416.93	10 283.83	2.56	0.23
2013	0.12	0.12	0.000	0.000	40.74	0.05	1.63	NA, NO	9 884.09	9 755.90	2.30	0.24
2014	0.12	0.12	0.000	0.000	38.47	0.05	1.54	NA, NO	9 394.03	9 265.00	2.24	0.24
2015	0.12	0.12	0.000	0.000	34.60	0.05	1.38	NA, NO	8 906.86	8 781.14	2.13	0.24
2016	0.12	0.12	0.000	0.000	31.80	0.04	1.27	NA, NO	8 628.29	8 502.47	2.08	0.25
2017	0.12	0.11	0.000	0.000	31.32	0.04	1.25	NA, NO	8 794.37	8 665.70	2.05	0.26
2018	0.12	0.11	0.000	0.000	30.98	0.04	1.24	NA, NO	9 112.19	8 977.24	2.08	0.28
Trend 1990-2018	-96.23%	-96.34%	-99.58%	-70.47%	59.77%	59.77%	59.77%	NA	-11.54%	-12.15%	8.42%	140.34%
Trend 2017-2018	-0.11%	0.02%	-9.06%	-3.17%	-1.09%	-1.09%	-1.09%	NA	3.61%	3.60%	1.49%	7.13%

Source: Environment Agency.

Notes: CH_4 emissions are converted in CO_2eq 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.

N_2O emissions are converted in CO_2eq 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: 1990-2018

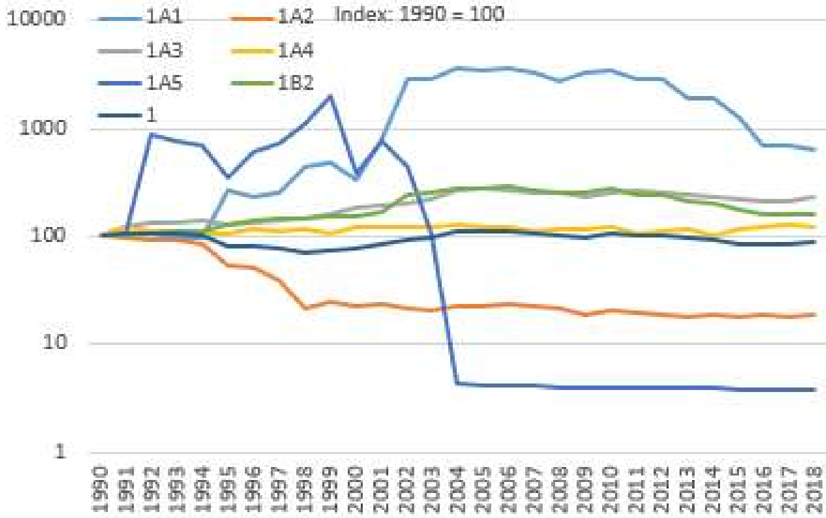

Figure 3-3 – IPCC sub-categories share in GHG emissions for CRF Sector 1 – Energy: 1990 and 2018

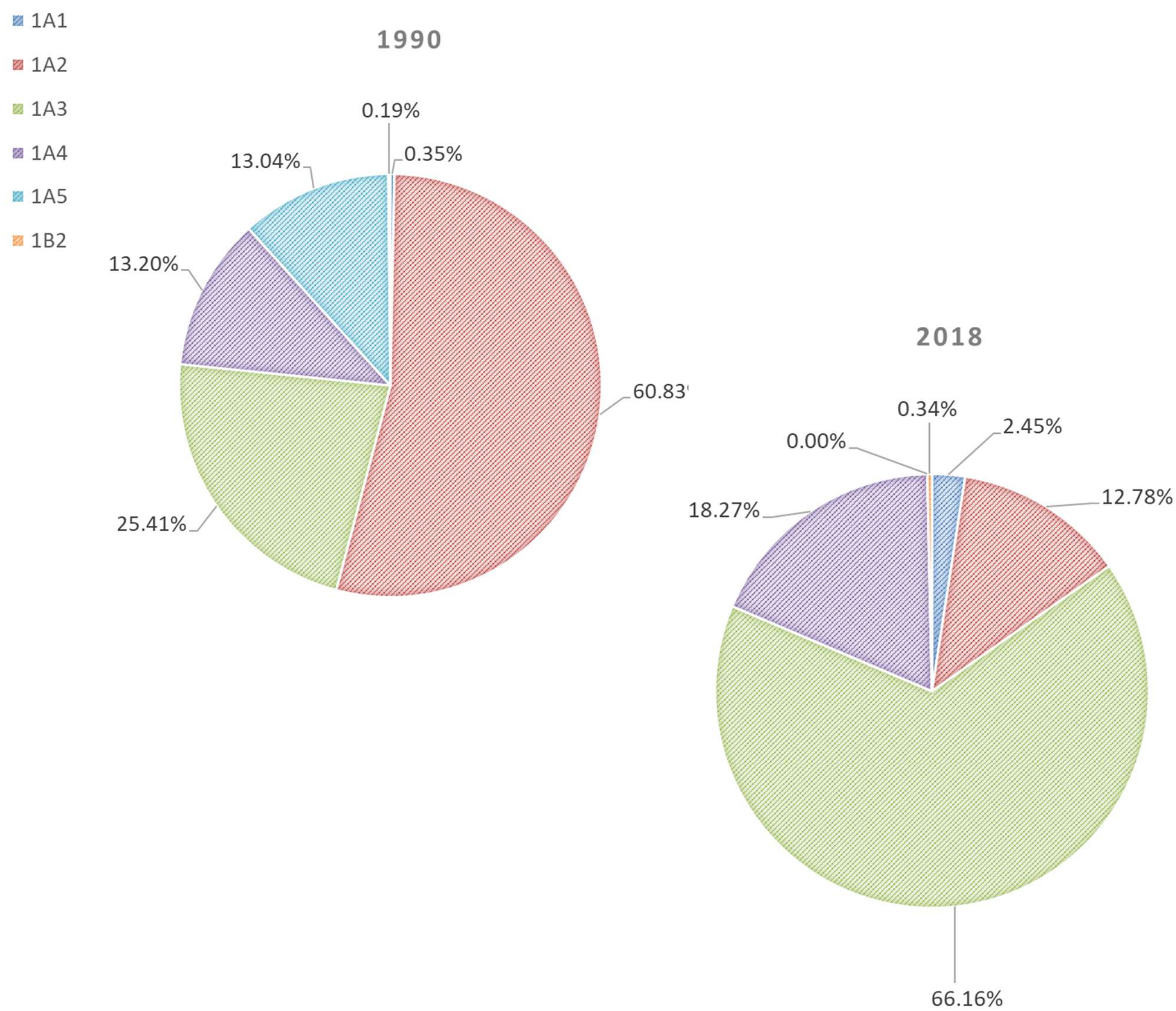

Table 3-2– Final energy consumption trends: 1990-2018

Year	Total	Coal	Blast furnace gas	Natural gas (1)	Electricity	Heat (2)	Liquid fuels (3)	Wood & biomass
	TJ							
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	156 683	4'958	-	27'998	21'033	624	100'748	1'321
2002	158 235	3'084	-	28'258	21'261	1'087	103'139	1'406
2003	168 359	2'369	-	28'674	22'252	2'818	110'838	1'407
2004	186 636	3'329	-	29'942	23'007	3'036	125'735	1'587
2005	190 472	3'249	-	29'338	22'149	3'056	130'190	2'490
2006	187 699	3'877	-	30'623	23'806	3'211	123'620	2'562
2007	184 859	3'280	-	29'823	24'098	2'582	120'558	4'519
2008	186 752	3'137	-	30'616	23'750	2'922	121'629	4'697
2009	173 715	2'801	-	28'659	22'005	2'484	113'546	4'219
2010	184 404	2'807	-	31'412	23'735	3'037	118'873	4'541
2011	182 506	2'443	-	27'916	23'343	3'102	121'286	4'415
2012	177 504	2'250	-	28'262	22'450	3'045	116'797	4'700
2013	175 426	2'006	-	27'790	22'316	3'230	114'981	5'103
2014	170 311	2'235	-	26'536	22'256	2'512	110'833	5'938
2015	169 931	2'057	-	27'791	22'407	2'355	108'960	6'360
2016	172 206	2'193	-	29'226	22'922	2'433	108'689	6'743
2017	177 905	1'898	-	28'760	23'016	2'725	113'906	7'599
2018	184 988	1'764	-	28'762	23'120	3'094	120'411	7'837
Trend 1990-2018	28.43%	-94.86%	NA	48.05%	54.25%	NA	81.91%	1115.54%
Share 1990	100.00%	23.83%	5.87%	13.49%	10.41%	NA	45.95%	0.45%
Share 2018	100.00%	0.95%	NA	15.55%	12.50%	1.67%	65.09%	4.24%

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 28th February 2019 (subject to change since that date)

Final energy consumption increased by 28.4% between 1990 and 2018 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 2018, 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 2018, with 65.1% 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 2018, 71% of road fuels sold on Luxembourg's territory are exported inside vehicle tanks and combusted abroad (see Table 3-61 in Section 3.2.8.3).

The importance of natural gas has increased constantly and significantly since 1990. In 2018, 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 capacity[62]. 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 developement 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 (no data for 2018 have been published by Statec as of 7 April 2020).

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

Table 3-3 – Electricity production trends: 1990-2017

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
Trend 1990-2017	49.52%	-77.78%	590.88%	NA
Share 1990	100.00%	89.22%	10.78%	NA
Share 2017	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 Feb 28 2019 (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 CO_2, CH_4 and N_2O

GHG source & sink category	Description	Status		
		CO_2	CH_4	N_2O
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 (2000-2018)	X (2000-2018)	X (2000-2018)
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	NO	NO	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	CO2 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 2018, GHG emissions of category *1A - Fuel Combustion* amounted to a total of 9.08 million tonnes CO_2eq (see Table 3-5). The transport sector (*1A3 - Transport*) represented the most important source, with a share of 66.39% of the GHG emissions within category *1A* (57.16% 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 18.33% of the GHG emissions within category *1A* (15.78% of national total excl. LULUCF), followed by the industrial sector (*1A2 - Manufacturing Industries and Construction*) and the energy sector (*1A1 - Energy*) with shares of 12.82% and 2.46%, respectively (11.04% and 2.12% 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 2018.

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 ($CO_{2\ eq}$ Gg)

Year	1A1 Energy Industries	1A2 Manufacturing Industries & Construction	1A3 Transportation	1A4 Other Sectors	1A5 Other	1A Fuel Combustion
1990	35.6	6 265.7	2 617.1	1 360.0	3.1	10 281.6
1991	37.3	6 108.5	3 210.6	1 626.0	3.1	10 985.5
1992	37.2	5 765.3	3 497.7	1 497.7	26.9	10 824.8
1993	35.4	5 902.0	3 545.1	1 482.4	23.7	10 988.6
1994	34.6	5 189.5	3 602.6	1 424.0	22.1	10 272.9
1995	93.5	3 333.1	3 359.8	1 437.7	10.8	8 234.9
1996	82.4	3 179.9	3 471.0	1 588.6	18.6	8 340.4
1997	89.7	2 415.8	3 731.6	1 542.3	23.1	7 802.5
1998	155.9	1 374.2	3 910.5	1 607.5	34.2	7 082.4
1999	173.5	1 564.7	4 235.2	1 463.2	63.3	7 499.9
2000	119.0	1 397.4	4 871.1	1 658.4	12.2	8 058.2
2001	280.5	1 490.1	5 117.8	1 698.3	24.2	8 610.9
2002	1 027.9	1 375.8	5 305.9	1 645.2	13.5	9 368.4
2003	1 035.5	1 313.7	5 859.6	1 684.8	3.3	9 896.9
2004	1 255.9	1 410.5	6 810.6	1 732.0	0.1	11 209.2
2005	1 241.8	1 406.7	7 187.1	1 660.7	0.1	11 496.5
2006	1 304.2	1 481.2	6 865.6	1 626.1	0.1	11 277.2
2007	1 180.6	1 385.1	6 580.9	1 538.4	0.1	10 685.0
2008	994.8	1 330.1	6 681.2	1 602.0	0.1	10 608.1
2009	1 190.0	1 189.4	6 157.5	1 592.8	0.1	10 129.9
2010	1 205.0	1 267.3	6 520.5	1 691.5	0.1	10 684.4
2011	1 003.0	1 243.0	6 896.5	1 426.0	0.1	10 568.6
2012	1 042.0	1 184.6	6 593.2	1 549.1	0.1	10 369.1
2013	685.5	1 144.4	6 452.5	1 560.9	0.1	9 843.3
2014	668.6	1 148.2	6 145.0	1 393.6	0.1	9 355.6
2015	457.4	1 113.2	5 703.8	1 597.8	0.1	8 872.3
2016	252.1	1 156.3	5 534.2	1 653.9	0.1	8 596.5
2017	242.8	1 144.6	5 648.2	1 727.4	0.1	8 763.1
2018	223.6	1 164.3	6 028.7	1 664.5	0.1	9 081.2
Trend 1990-2018	527.33%	-81.42%	130.36%	22.39%	-96.23%	-11.67%
Share 1990	0.35%	60.94%	25.45%	13.23%	0.03%	100.00%
Share 2018	2.46%	12.82%	66.39%	18.33%	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 (1990-2018)*

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	95,98-99,01-18	95, 98-99,01-18		
1A1	Energy Industries	other	CO_2	98, 02, 11-18	98, 02, 07-18		X
1A2	Manufacturing Industries and Construction	gaseous	CO_2	90-18	90-18	X	X
1A2	Manufacturing Industries and Construction	liquid	CO_2	90-18	90-18		
1A2	Manufacturing Industries and Construction	solid	CO_2	90-18	90-18	X	X
1A2	Manufacturing Industries and Construction	other	CO_2	13, 16-18	13, 16-18		
1A3b	Road Transportation	diesel oil	CO_2	90-18	90-18	X	X
1A3b	Road Transportation	gasoline	CO_2	90-18	90-18		
1A3b	Road Transportation	diesel oil	N_2O		18		
1A4	Other Sectors	gaseous	CO_2	90-18	90-18	X	X
1A4	Other Sectors	liquid	CO_2	90-18	90-18		
1A5	Other	liquid	CO_2	99	99		

Source: Environment Agency
Notes: LA= Level Assessment (Tier 1) including respectively excluding LULUCF
TA= Trend Assessment 2018 (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 CO_2 emissions obtained by the sectoral and the reference approaches. The difference for total CO_2 emissions from fuel combustion varies between -0.69% and +2.04% throughout the time-series.

Figure 3-4 - CO_2 emissions obtained with Reference and Sectoral Approach for 1990-2018

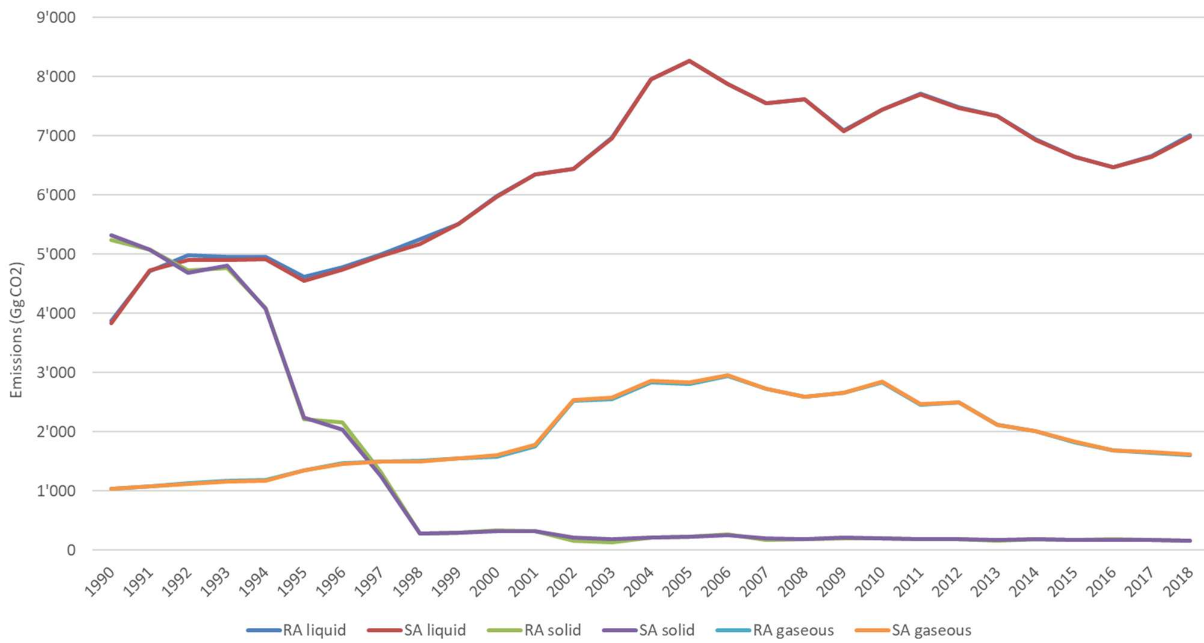

Table 3-7 – CO_2 emissions obtained with Reference and Sectoral Approach (1990-2018)

Year	Reference Approach					Sectoral Approach				
	Liquid	Solid	Gaseous	Other	Total	Liquid	Solid	Gaseous	Other	Total
	[Gg CO_2]	[Gg CO_2]	[Gg CO_2]	[Gg CO_2]	[Gg CO_2]	[Gg CO_2]	[Gg CO_2]	[Gg CO_2]	[Gg CO_2]	[Gg CO_2]
1990	5'241	3'881	1'039	33	**10'194**	5'317	3'832	1'036	33	**10'218**
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	4'910	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	32	**10'270**	4'073	4'919	1'174	32	**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	65	**7'104**	280	5'174	1'495	65	**7'014**
1999	287	5'514	1'552	73	**7'426**	296	5'515	1'546	73	**7'431**
2000	328	5'983	1'580	77	**7'969**	325	5'976	1'609	77	**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	**9'234**	215	6'438	2'540	105	**9'298**
2003	133	6'969	2'556	102	**9'760**	187	6'962	2'576	102	**9'827**
2004	218	7'960	2'837	112	**11'127**	213	7'954	2'859	112	**11'138**
2005	228	8'270	2'803	108	**11'409**	224	8'264	2'829	108	**11'425**
2006	264	7'876	2'937	116	**11'193**	260	7'873	2'958	116	**11'207**
2007	178	7'554	2'731	118	**10'581**	204	7'553	2'731	126	**10'613**
2008	189	7'625	2'594	126	**10'533**	186	7'620	2'594	133	**10'533**
2009	199	7'086	2'657	106	**10'048**	211	7'074	2'658	113	**10'056**
2010	202	7'448	2'841	116	**10'607**	199	7'441	2'842	123	**10'605**
2011	191	7'712	2'463	118	**10'483**	191	7'706	2'464	124	**10'485**
2012	184	7'478	2'499	119	**10'280**	185	7'473	2'500	126	**10'284**
2013	160	7'342	2'112	126	**9'740**	173	7'336	2'113	134	**9'756**
2014	183	6'939	2'004	129	**9'255**	186	6'935	2'004	139	**9'265**
2015	168	6'645	1'827	134	**8'774**	165	6'640	1'828	147	**8'781**
2016	181	6'472	1'679	165	**8'497**	178	6'466	1'680	179	**8'502**
2017	168	6'654	1'642	169	**8'633**	173	6'648	1'658	187	**8'666**
2018	155	7'008	1'609	183	**8'956**	154	6'980	1'618	202	**8'955**

Table 3-8 presents the relative difference of CO_2 emissions between reference and sectoral approach.

Table 3-8 – Difference of CO_2 emissions by type of fuel

Difference of CO_2 emissions between sectoral and reference [%]					
Year	Solid	Liquid	Gaseous	Other	Total
1990	- 1.44	1.28	0.27	0.00	- 0.24
1991	0.08	- 0.20	0.57	0.00	0.00
1992	1.01	1.43	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	- 6.12	- 0.31
2008	1.43	0.06	- 0.01	- 5.77	0.00
2009	- 5.63	0.17	- 0.03	- 6.39	- 0.08
2010	1.54	0.09	- 0.02	- 5.60	0.02
2011	- 0.15	0.07	- 0.04	- 5.24	- 0.02
2012	- 0.83	0.07	- 0.02	- 5.47	- 0.04
2013	- 7.27	0.08	- 0.07	- 5.86	- 0.17
2014	- 1.35	0.05	- 0.04	- 7.39	- 0.11
2015	1.56	0.07	- 0.06	- 8.74	- 0.08
2016	1.48	0.09	- 0.03	- 7.52	- 0.06
2017	- 2.67	0.08	- 0.95	- 9.66	- 0.38
2018	0.75	0.41	- 0.59	- 9.46	0.01

Source: Environment Agency
Note: Positive numbers indicate that CO_2 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, CO_2 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 CO_2 emissions between the two approaches is about +0.41% in 2018 and lies below the 2% significance threshold for the entire timeseries.
- Solid fuels: difference in CO_2 emissions between the two approaches is about 0.75% for 2018. For some years there is a significant difference between both approaches (up to 28.8% 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).
- Gaseous fuels: difference in CO_2 emissions between the two approaches is about -0.59% in 2018 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 CO_2 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 260 for details). As a consequence, the difference between the sectoral and the reference approach for other fossil fuels is 9.5% in 2018. This results from the fact that the national energy balance considers biodiesel to be 100% biomass.

3.2.1.3 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 2019v1 ➔ 2020v1	Type of revision
All fuels	AD was revised according to the revised energy balance and IEA Questionnaires as provided by STATEC	updated AD

3.2.1.4 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
	No planned improvements

3.2.2 International Bunker Fuels

In 2018, GHG emissions from International Bunkers amounted to 1800.53 Gg CO_2e (see Table 3-11), an increase of approximately 362% 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 $CO_{2\,eq}$
	Activity (GJ)	Total CO_2 eq	CO_2	CH_4	N_2O	Activity (GJ)	Total CO_2 eq	CO_2	CH_4	N_2O		
1990	5 516 169	389.45	386.02	0.001	0.011	1 054	0.086	0.078	0.000004	0.000027	**5 517 223**	**390**
1991	5 765 550	407.06	403.47	0.001	0.012	1 139	0.093	0.084	0.000004	0.000029	**5 766 689**	**407**
1992	5 574 033	393.54	390.06	0.001	0.012	1 065	0.087	0.079	0.000004	0.000027	**5 575 098**	**394**
1993	5 512 762	389.21	385.78	0.001	0.011	1 430	0.117	0.106	0.000005	0.000037	**5 514 192**	**389**
1994	6 993 817	493.77	489.46	0.001	0.014	1 238	0.102	0.092	0.000005	0.000032	**6 995 055**	**494**
1995	7 927 783	559.71	554.81	0.001	0.016	1 245	0.102	0.092	0.000005	0.000033	**7 929 028**	**560**
1996	8 614 215	608.18	602.83	0.002	0.018	1 175	0.097	0.087	0.000004	0.000031	**8 615 390**	**608**
1997	10 305 632	727.59	721.22	0.002	0.021	1 134	0.093	0.084	0.000004	0.000030	**10 306 766**	**728**
1998	12 493 294	882.03	874.33	0.002	0.026	1 133	0.093	0.084	0.000004	0.000030	**12 494 427**	**882**
1999	14 095 591	995.17	986.43	0.003	0.029	1 242	0.102	0.092	0.000004	0.000034	**14 096 833**	**995**
2000	13 434 073	948.48	940.09	0.003	0.028	1 372	0.113	0.102	0.000005	0.000037	**13 435 445**	**949**
2001	14 530 054	1 025.85	1 016.79	0.003	0.030	1 372	0.113	0.102	0.000005	0.000038	**14 531 426**	**1 026**
2002	15 742 564	1 111.46	1 101.65	0.003	0.033	1 445	0.119	0.107	0.000005	0.000040	**15 744 009**	**1 112**
2003	16 399 902	1 157.87	1 147.65	0.003	0.034	1 471	0.121	0.109	0.000005	0.000040	**16 401 373**	**1 158**
2004	17 844 514	1 259.86	1 248.74	0.004	0.037	1 420	0.117	0.105	0.000005	0.000038	**17 845 934**	**1 260**
2005	18 131 067	1 280.10	1 268.75	0.004	0.038	1 901	0.155	0.141	0.000006	0.000048	**18 132 967**	**1 280**
2006	16 967 777	1 197.98	1 187.31	0.004	0.035	2 006	0.163	0.149	0.000006	0.000048	**16 969 783**	**1 198**
2007	18 238 604	1 287.69	1 276.28	0.004	0.038	1 609	0.131	0.119	0.000005	0.000038	**18 240 213**	**1 288**
2008	18 359 132	1 296.20	1 284.71	0.004	0.038	1 752	0.142	0.130	0.000005	0.000040	**18 360 884**	**1 296**
2009	17 588 864	1 241.81	1 230.83	0.004	0.037	1 404	0.113	0.104	0.000004	0.000031	**17 590 268**	**1 242**
2010	18 050 982	1 274.44	1 263.18	0.004	0.037	1 346	0.108	0.100	0.000004	0.000028	**18 052 328**	**1 275**
2011	16 887 889	1 192.33	1 181.76	0.004	0.035	1 660	0.133	0.123	0.000004	0.000034	**16 889 550**	**1 192**
2012	15 581 431	1 100.10	1 090.30	0.004	0.033	1 599	0.128	0.119	0.000004	0.000031	**15 583 030**	**1 100**
2013	15 659 460	1 105.61	1 095.76	0.004	0.033	1 318	0.105	0.098	0.000003	0.000025	**15 660 778**	**1 106**
2014	16 985 116	1 195.70	1 188.54	0.004	0.035	1 459	0.116	0.108	0.000004	0.000027	**16 986 575**	**1 196**
2015	19 161 778	1 341.05	1 340.90	0.004	0.040	1 490	0.119	0.110	0.000004	0.000027	**19 163 268**	**1 341**
2016	21 263 024	1 487.96	1 487.96	0.004	0.044	1 661	0.132	0.123	0.000004	0.000030	**21 264 686**	**1 488**
2017	24 041 916	1 682.46	1 682.46	0.005	0.050	2 080	0.166	0.154	0.000005	0.000038	**24 043 996**	**1 683**
2018	25 729 280	1 800.53	1 800.53	0.005	0.053	1 806	0.143	0.134	0.000004	0.000032	**25 731 085**	**1 801**
1990-2018	366.43%	362.32%	366.44%	350.15%	365.86%	71.32%	66.13%	71.22%	1.04%	17.64%	366.38%	362.26%

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 3.2.8.2.2).

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 a Tier 1 fuel consumption factor from the EMEP/EEA Guidebook 2019 of 824.65 kg/LTO and representative for an average fleet based on B737-400 short distance flights which is representative of the modern aircrafts operating to and from Luxembourg.
- *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 below 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 and correspond to the B737-400 aircraft type which best represents Luxembourg's modern fleet of commercial aircrafts.

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

International Bunkers - Aviation
Emission Factors for 2018

Fuel	Flight Phase	CO_2		CH_4		N_2O		Source
		EF	(unit) type	EF	(unit) type	EF	(unit) type	
Jet Kerosene	LTO	2.48	(t/LTO) D	0.00008	(t/LTO) D	0.0001	(t/LTO) D	2006 IPCC GL
	cruise	3.02	(t/t fuel) 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 3.2.8.5.

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 2019v1 are described in Table 3-13.

Table 3-13 - Recalculations done since submission 2019v1

GHG source & sink category	Revisions 2019v1 ➔ 2020v1	Type of revision
1D - Reference approach – jet kerosene	Error correction for the years 2010, 2014, and 2015	Error correction

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). 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.

Furthermore, cross-checking between national statistics and data provided by the fuel provider was also undertaken and no discrepancies were found.

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 - Aviation	Analyse LTO data per aircraft type from Eurostat for Luxembourg in order to optimize split between International Bunkers – Aviation and 1A3a – Domestic aviation.

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
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	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
Kerosene type jet fuel	kt	128	133	128	125	162	184	201	244	275	323	312	337	365	380	414	420	394	423	425	408	417	392	361	363	394	445	499
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	13 449	14 526	15 733	16 380	17 845	18 104	16 983	18 233	18 320	17 587	17 975	16 897	15 561	15 647	16 983	19 182	21 509
Kerosene type jet fuel	*TJ/kt or GJ/t*	*43.102*	*43.105*	*43.102*	*43.104*	*43.105*	*43.103*	*43.104*	*43.107*	*43.105*	*43.105*	*43.106*	*43.104*	*43.104*	*43.105*	*43.104*	*43.105*	*43.104*	*43.104*	*43.106*	*43.105*	*43.106*	*43.105*	*43.105*	*43.105*	*43.104*	*43.106*	*43.104*
Source of data	Eurostat																											
Extracted on	28.02.2018																											

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
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	7.961
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	21 296
Source of data	STATEC																											
Extracted on	28.02.2018																											

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
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	0.183
Aviation gasoline	TJ	3.410	5.180	7.310	9.460	11.190	12.050	12.308	12.480	10.742	10.986	11.380	9.612	10.259	11.035	8.535	6.250	7.069	9.009	8.492	17.889	15.173	11.940	7.772	8.578	7.888	9.483	7.876
Aviation gasoline	*TJ/kt or GJ/t*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*43.500*	*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*
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	417.187	391.764	361.458	363.269	394.323	444.519	494.049
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	17 983	16 887	15 581	15 659	16 997	19 161	21 296
Kerosene type jet fuel	*TJ/kt or GJ/t*	*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 2018v1																											
Extracted on	30.03.2017																											

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
Inventory/Eurostat	TJ	-1	32	56	124	10	-4	-51	-214	638	171	-16	3	9	19	-1	26	-16	5	38	1	8	-10	20	12	14	-21	-213
Inventory/Statec	TJ	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-0	0	0	-0	0	0	-0	-0	0	-0	-67	0	0	0	13	0	-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 CO_2 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: CO_2 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: CO_2 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: CO_2 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 2019v1.

3.2.3.7 Planned improvements

No further improvements are planned.

3.2.4 CO_2 capture from flue gases and subsequent CO_2 storage

CO_2 capture from flue gases and CO_2 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-CO_2 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 CH_4 and N_2O 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 (2000-2018) 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, were 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.

64 ARR 2010, § 21

Table 3-16 – Fuel Properties for 2018

Fuel Characteristics for 2018

Country-specific Net Calorific Values and Densities

Fuel	Net calorific value			Density		
	NCV	*Unit*	*Source*	*Density*	*Unit*	*Source*
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 CO_2 emission factor for the combustion of blast furnace gas was determined based on emission measurement data and on the CO and CO_2 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 CO_2/TJ, was used for the years 1990 to 1997.

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

Similarly, a country-specific CO_2 emission factor for blast furnace gas lost in distribution or flared was determined: 245'323 kg CO_2/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. Nm^3/h, respectively, one with Germany (Remich) with a capacity of 0.19 Mio Nm^3/h and one with France (Esch/Alzette) with a capacity of 0.02 mio. Nm^3/h.

For the calculation of the country-specific CO_2 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, CO_2 and N_2) expressed in mol%;
- physical properties: density (kg/Nm^3) and gross calorific value (GCV: MJ/Nm^3);
- monthly import/consumption (mio. Nm^3). [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 0.90 [68].

From the monthly chemical composition, a monthly average "molecular" weight for natural gas (g/mol), "molecular" density (mol/Nm^3) 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 CO_2/MJ) assuming full oxidation of carbon to carbon dioxide. By multiplying the monthly emission factor with the respective monthly natural gas consumption, a monthly CO_2 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.

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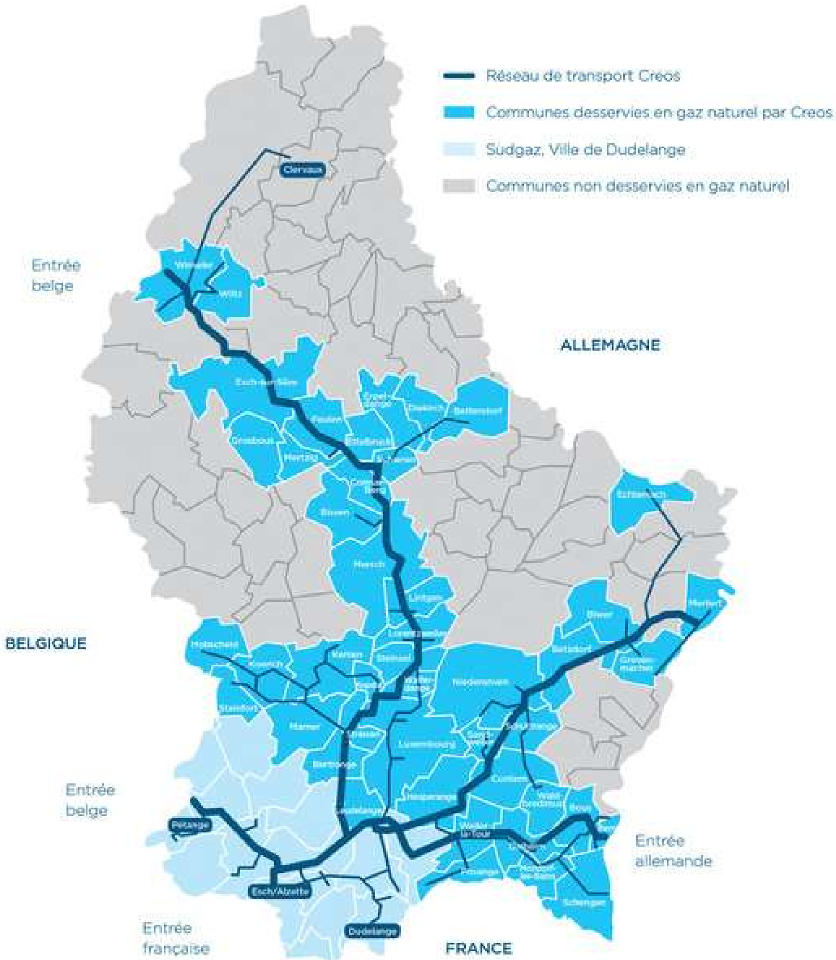
66 http://www.creos.lu

67 Nm^3 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: 1990-2018 (tCO_2/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**	
Gas/Diesel Oil	74.13	74.11	74.13	74.14	74.07	74.13	74.14	74.15	74.13	
Motor Gasoline	72.44	72.47	72.46	72.60	73.11	73.22	73.20	73.30	73.22	
LPG	64.93	64.93	64.93	64.93	64.93	64.93	65.17	65.21	65.21	

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 CO_2 EF value for gasoline used by Belgium that in turn uses the IPCC default value. CO_2 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 CO_2 emission factor for motor gasoline, based on the CO_2 emission factor of the two other neighbouring countries from which motor gasoline is imported. Indeed, as the Netherlands and Germany both used a CO_2 EF of 72 tCO_2/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 CO_2 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 CO_2 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 UNFCCC[70].

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 3-19 – Calculation of the country-specific CO_2 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)	(IPCC default EF=74.1)									
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)	(IPCC default EF=74.1)									
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**	
Belgium	1622	1793	1747	1596	1534	1536	1473	1309	1396	
Germany	281	190	215	426	288	276	316	465	432	
Netherlands	128	138	90	54	146	77	62	26	61	
Total imports	2031	2121	2052	2076	1968	1889	1851	1800	1890	
Gas/Diesel Oil EF (tCO2/TJ)	(IPCC default EF=74.1)									
Belgium	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	
Netherlands	73.04	72.69	72.49	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	

Table 3-20 - Calculation of the country-specific CO_2 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)	(IPCC default EF=69.3)									
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)	(IPCC default EF=69.3)									
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**	
Belgium	333	338	335	240	221	204	214	202	227	
Germany	15	8	0	50	70	80	81	91	89	
Netherlands	0	22	15	27	19	2	0	0	0	
Total imports	348	368	350	317	310	286	295	293	316	
Motor gasoline EF (tCO2/TJ)	(IPCC default EF=69.3)									
Belgium	72.41	72.41	72.41	72.41	72.41	72.41	72.41	72.41	72.41	
Germany	73.12	73.02	73.09	73.09	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	
Luxembourg	72.44	72.47	72.46	72.60	73.11	73.22	73.20	73.30	73.22	

Table 3-21 - Calculation of the country-specific CO_2 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**	
Belgium	14	10	12	11	9	9	10	8	6	
Germany	0	0	0	0	0	0	2	2	2	
Netherlands	0	0	0	0	0	0	0	0	0	
France	0	0	0	0	0	0	0	0	0	
Total imports	14	10	12	11	9	9	12	10	8	
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	
Germany	65.33	65.39	65.40	65.41	65.46	66.35	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	
France	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	65.21	65.21	

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 CO_2, CH_4 and N_2O emissions from combustion activities for electricity and heat production are reported, as well as CO_2, CH_4 and N_2O emissions from municipal waste incineration. 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 2018, this source category was responsible for 2.46% of GHG emissions from fuel combustion activities (0.35% in 1990) and represented 2.12% of the national total GHG emissions in CO_2e, excluding LULUCF (0.28% in 1990).

Table 3-22 summarizes GHG emissions for category 1.A.1. - Energy Industries. Compared to 2017, GHG emissions have decreased by 7.9 %.

Regarding CO_2 emissions, 1A1a - Public electricity and heat production is a key category in 2018 for gaseous fuels and other fuels (MSW): see Table 1-6 in Section 1.5.1.1.

Table 3-22 – GHG emission trends in CO_2eq category *1A1 –Energy Industries*: 1990-2018

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_2O (incl. biomass)	Total $CO_{2\,eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	Total $CO_{2\,eq}$	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)
1990	35.64	33.29	0.036	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1991	37.29	34.83	0.038	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1992	37.19	34.73	0.038	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1993	35.38	33.04	0.036	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1994	34.61	32.32	0.035	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1995	93.54	91.29	0.035	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1996	82.36	80.61	0.027	0.004	NO	NO	NO	NO	NO	NO	NO	NO
1997	89.73	87.67	0.032	0.004	NO	NO	NO	NO	NO	NO	NO	NO
1998	155.94	153.39	0.040	0.005	NO	NO	NO	NO	NO	NO	NO	NO
1999	173.47	170.55	0.045	0.006	NO	NO	NO	NO	NO	NO	NO	NO
2000	119.03	116.23	0.043	0.006	NO	NO	NO	NO	NO	NO	NO	NO
2001	280.47	277.55	0.046	0.006	NO	NO	NO	NO	NO	NO	NO	NO
2002	1 027.93	1 024.24	0.060	0.007	NO	NO	NO	NO	NO	NO	NO	NO
2003	1 035.52	1 031.72	0.061	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2004	1 255.94	1 251.79	0.067	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2005	1 241.80	1 237.79	0.065	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2006	1 304.18	1 299.99	0.068	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2007	1 180.55	1 176.38	0.067	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2008	994.81	990.75	0.065	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2009	1 190.01	1 185.90	0.067	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2010	1 204.97	1 201.05	0.064	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2011	1 003.04	999.08	0.064	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2012	1 042.04	1 038.05	0.064	0.008	NO	NO	NO	NO	NO	NO	NO	NO
2013	685.47	681.79	0.059	0.007	NO	NO	NO	NO	NO	NO	NO	NO
2014	668.59	663.72	0.077	0.010	NO	NO	NO	NO	NO	NO	NO	NO
2015	457.37	452.20	0.081	0.011	NO	NO	NO	NO	NO	NO	NO	NO
2016	252.08	246.72	0.083	0.011	NO	NO	NO	NO	NO	NO	NO	NO
2017	242.78	236.39	0.099	0.013	NO	NO	NO	NO	NO	NO	NO	NO
2018	223.60	215.52	0.125	0.017	NO	NO	NO	NO	NO	NO	NO	NO
Trend 1990-2018	527.33%	547.45%	244.07%	242.33%	NA	NA	NA	NA	NA	NA	NA	NA
Trend 2017-2018	-7.90%	-8.83%	26.44%	26.71%	NA	NA	NA	NA	NA	NA	NA	NA

Source: Environment Agency.
Notes: CH_4 emissions are converted in CO_2e 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.
N_2O emissions are converted in CO_2e 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. Since 2011 however, heat recovery is done and the installation is considered as a cogeneration plant. However, 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, which are operated on industrial sites, but which produce 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) is fed with natural gas and/or gas oil and high calorific municipal solid waste (MSW). MSW incinerated 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 MSW is untreated and partially split into a high calorific fraction which is incinerated and a low calorific fraction which is deposited on land[71]). No industrial and hazardous wastes are incinerated because they are exported. Activity data on municipal waste composition are taken from the following studies and for the years in-between a linear interpolation was carried out. For 1990-2001, the composition is calculated based on:
    - Waste Division of the Environment Agency, "Restabfallanalyse 2001 im SIDOR", Luxembourg, 2002;
    - Waste Division of the Environment Agency, "Restabfallanalyse 1992/1994", Luxembourg, 2002.

  For 2002-2018, MSW fractions are calculated similarly based on the following waste composition analysis:
    - Waste Division of the Environment Agency, "Restabfallanalyse 2013/14 im Großherzogtum Luxemburg, Band 1: Kompendium", Luxembourg, 2016;
    - Waste Division of the Environment Agency, "Restabfallanalyse 2009/10 im Großherzogtum Luxemburg, Band 1: Kompendium", Luxembourg, 2010;
    - Waste Division of the Environment Agency, "Restabfallanalyse 2004/05 im Großherzogtum Luxemburg, Band 1: Kompendium", Luxembourg, 2005;

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

However, one part of the waste incinerated originates from a pre-treatment plant (MBA Fridhaff), where a high calorific fraction is sorted out for incineration. The rest is disposed of on landfill sites. The composition of the high calorific faction is calculated based on the following studies :

- Air & Noise Division of the Environment Agency, " Estimation of emitted greenhouse gases by the selected high calorific fraction from SIDEC being incinerated ", Luxembourg, 2010
- Air & Noise Division of the Environment Agency, "Estimation of emitted greenhouse gases by the selected high calorific fraction from SIDEC being incinerated", Luxembourg, 2016

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: 1990-2018

1A1a - Public Electricity & Heat Production
Activity Data by fuel type (GJ)

Year	Activity Total (incl. biomass)	Liquid	Gaseous	Biomass	Other
		Gas Oil	Natural Gas	Biogas, Wood & MSW (biogenic fraction)	MSW (fossil fraction)
1990	NO	NO	NO	877 003	336 290
1991	1 213 293	NO	NO	917 593	351 854
1992	1 269 447	NO	NO	931 942	350 838
1993	1 282 780	NO	NO	887 411	333 762
1994	1 221 173	NO	NO	868 596	326 548
1995	1 195 144	NO	1 043 100	832 290	311 859
1996	2 187 248	900	984 600	648 213	241 274
1997	1 874 986	18 919	1 013 400	760 358	285 810
1998	2 078 487	30 783	1 709 100	687 092	584 722
1999	3 011 697	31 593	1 883 700	782 767	669 441
2000	3 367 501	60 414	920 854	777 172	650 338
2001	2 408 778	55 018	3 808 343	782 746	642 130
2002	5 288 237	48 220	17 031 071	800 879	652 711
2003	18 532 882	46 054	17 102 526	899 751	630 796
2004	18 679 127	46 606	20 850 220	931 279	692 412
2005	22 520 516	24 344	20 647 091	962 615	626 519
2006	22 260 569	24 981	21 624 432	999 055	676 217
2007	23 324 686	23 409	19 508 383	1 052 385	689 647
2008	21 273 825	49 325	16 205 838	1 088 938	714 304
2009	18 058 405	76 261	19 534 163	1 081 297	690 058
2010	21 381 778	19 416	20 082 942	1 107 901	637 389
2011	21 847 647	18 530	16 344 441	1 181 148	697 864
2012	18 241 983	19 756	17 071 478	1 197 411	705 795
2013	18 994 439	15 040	10 853 489	1 228 287	691 988
2014	12 788 804	13 595	10 369 609	1 812 733	815 020
2015	13 010 957	18 944	6 533 034	2 019 104	879 777
2016	9 450 859	32 034	2 687 859	2 135 110	1 029 919
2017	5 884 921	23 553	2 488 776	2 648 596	1 048 085
2018	6 209 011	17 868	2 106 564	3 554 012	1 069 895
Trend 1990-2018	NA	NA	NA	305.25%	218.15%
Trend 2017-2018	5.51%	-24.14%	-15.36%	34.18%	2.08%

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 and gasoil, 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 CO_2 emissions on the basis of waste fractions (such as paper, wood, plastics) in the waste incinerated, as the following equation shows:

$$CO_2\ emissions = MSW \bullet \sum_j (WF_j \bullet dm_j \bullet CF_j \bullet FCF_j \bullet OF_j) \bullet \frac{44}{12}$$

with:

CO_2 emissions	= CO_2 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 M_{CO2}(g/mol)/M_C(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 dm_j, CF_j, FCF_j and OF_j were taken.[72]

Reported CO_2 emissions of waste incineration are only CO_2 emissions from fossil MSW. However, the activity data includes both biogenic and fossil MSW fractions. This means that biogenic CO_2 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 Waste Division of the Environment Agency (see Table 3-24). (AEV, 2005)

72 2006 IPCC Guidelines, Vol. 5, Chap. 2, Tab. 2.4, p2.14

Table 3-24 – Calorific values for MSW components

MSW component	Heating value [GJ/t]	MSW component	Heating value [GJ/t]
Paper/cardboard	13	Rubber and Leather	5
Textiles	13	Multilayer composite material	15
Food waste	5	Plastics	30
Wood	5	Metal	0
Garden and Park waste	5	Glass	0
Nappies	10	Other, Inert waste	7

CH_4 emissions were estimated using 2006 IPCC Guidelines Tier 1 methodology. CH_4 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). CH_4 emissions are calculated according to the following equation:

$$CH_4\ Emissions = Fuel\ Consumption_{MSW} \bullet Emission\ Factor_{MSW}$$

with:

CH_4 Emissions = CH_4 emissions (kg GHG)

Fuel $Consumption_{MSW}$ = amount of incinerated MSW (TJ)

Emission $Factor_{MSW}$ = emission factor (kg gas/TJ)

The CH_4 emissions are relative to 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 N_2O emissions are calculated according to the following equation:

$$N_2O\ emission = \sum_j (IW_j \bullet EF_j) \bullet 10^{-6}$$

with:

N_2O Emissions = N_2O emissions in inventory year (Gg/yr)

IW_i = amount of incinerated waste of type i (Gg/yr)

EF_i = N_2O emission factor (kg N2O /Gg of waste) for waste of type i

10^{-6} = conversion from kilogram to gigagram

i = category or type of waste incinerated (MSW)

The N_2O emissions are relative to total MSW (biogenic + fossil).

3.2.6.2.3 Emission factors

Default emission factors are derived from IPCC 2006 Guidelines (Table 3-25). 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, CO_2 emissions were not calculated using an emission factor, but instead, the calculation is based on the carbon content of the waste. CO_2 emissions are calculated, as described in section 3.2.6.2.2, by applying the default values listed in Table 3-13 of the 2006 IPCC Guidelines for:

- dry matter content in % of wet weight;
- DOC content in % of wet waste;
- DOC content in % of dry waste;
- total carbon content in % of dry weight;
- fossil carbon fraction in % of total carbon.

For CO_2, implied emission factors (IEFs) for the different waste components were then calculated by dividing the calculated emission by the energy content of the MSW waste fraction.

For CH_4, it is good practice to apply the CH_4 emission factors provided in Volume 2, Chapter 2 of the 2006 IPCC Guidelines. The CH_4 default emission factor of 30 kg CH_4/TJ is applied.

For N_2O, the default emission factor of 4.0 kg N_2O/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 N_2O/t MSW on a wet basis (2006 IPCC Guidelines Vol.5, Chap.5, Table 5.6).

Table 3-25 gives an overview of the different emission factors used for 2018.

Table 3-25 – Emission factors for IPCC sub-category 1A1a – Public Electricity and Heat Production

1A1a - Public Electricity & Heat Production
Emission Factors for 2018 (kg/TJ)

Fuel	Fuel Type	CO_2 EF	CO_2 type	CH_4 EF	CH_4 type	N_2O EF	N_2O type	Source
Gas Oil	liquid	74 130	CS	3.00	D	0.60	D	AEV; 2006 IPCC GL
Natural Gas	gaseous	56 209	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
MSW (biogenic)	biomass	89 623	IEF	30.00	D	4.00	D	AEV, 2006 IPCC GL
MSW (fossil)	other	90 612	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 3-26 gives an overview of the evolution of the implied emission factors per fuel type.

Table 3-26 – Implied emission factors for IPCC sub-category 1A1a – Public Electricity and Heat Production

Year	1A1a - Public Electricity & Heat Production Implied Emission Factors (kg/TJ)											
	Liquid			Gaseous			Biomass			Other		
	Gas Oil			Natural Gas			Biogas, Wood & MSW (biogenic fraction)			MSW (fossil fraction)		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
1990	NO	NO	NO	NO	NO	NO	98 984	30.00	4.00	98 984	30.00	4.00
1991	NO	NO	NO	NO	NO	NO	98 984	30.00	4.00	98 984	30.00	4.00
1992	NO	NO	NO	NO	NO	NO	98 175	29.47	3.93	98 984	30.00	4.00
1993	NO	NO	NO	NO	NO	NO	98 134	29.44	3.93	98 984	30.00	4.00
1994	NO	NO	NO	NO	NO	NO	98 116	29.43	3.92	98 984	30.00	4.00
1995	NO	NO	NO	57 929	1.00	0.10	97 971	29.34	3.91	98 984	30.00	4.00
1996	74 192	3.00	0.60	57 546	1.00	0.10	97 684	29.15	3.89	98 984	30.00	4.00
1997	74 179	3.00	0.60	57 205	1.00	0.10	98 109	29.43	3.92	98 984	30.00	4.00
1998	74 170	3.00	0.60	56 863	1.00	0.10	91 695	29.60	3.95	92 215	30.00	4.00
1999	74 174	3.00	0.60	56 522	1.00	0.10	92 099	29.85	3.98	92 215	30.00	4.00
2000	74 212	3.00	0.60	56 221	1.00	0.10	91 427	29.30	3.91	92 215	30.00	4.00
2001	74 216	3.00	0.60	56 258	1.00	0.10	90 708	28.75	3.83	92 215	30.00	4.00
2002	74 217	3.00	0.60	56 396	1.00	0.10	90 625	28.64	3.82	92 202	30.00	4.00
2003	74 192	3.00	0.60	56 533	1.00	0.10	94 699	27.98	3.73	97 395	30.00	4.00
2004	74 154	3.00	0.60	56 671	1.00	0.10	92 615	27.38	3.65	96 373	30.00	4.00
2005	74 137	3.00	0.60	56 910	1.00	0.10	92 940	26.61	3.54	97 297	30.00	4.00
2006	74 138	3.00	0.60	57 008	1.00	0.10	91 519	26.08	3.47	96 654	30.00	4.00
2007	74 141	3.00	0.60	56 793	1.00	0.10	91 331	25.83	3.44	96 725	30.00	4.00
2008	74 085	3.00	0.60	56 665	1.00	0.10	90 154	25.17	3.35	96 301	30.00	4.00
2009	74 074	3.00	0.60	57 056	1.00	0.10	88 010	24.08	3.20	95 220	30.00	4.00
2010	74 128	3.00	0.60	56 712	1.00	0.10	85 021	22.00	2.92	95 184	30.00	4.00
2011	74 114	3.00	0.60	56 988	1.00	0.10	85 395	22.30	2.96	94 953	30.00	4.00
2012	74 134	3.00	0.60	56 793	1.00	0.10	84 866	21.79	2.90	94 995	30.00	4.00
2013	74 141	3.00	0.60	56 680	1.00	0.10	85 504	21.94	2.92	94 649	30.00	4.00
2014	74 069	3.00	0.60	56 756	1.00	0.10	89 937	23.17	3.08	91 009	30.00	4.00
2015	74 128	3.00	0.60	56 760	1.00	0.10	91 000	23.70	3.15	90 910	30.00	4.00
2016	74 136	3.00	0.60	56 561	1.00	0.10	89 790	23.24	3.09	89 635	30.00	4.00
2017	74 149	3.00	0.60	56 577	1.00	0.10	94 136	24.56	3.27	89 534	30.00	4.00
2018	74 130	3.00	0.60	56 209	1.00	0.10	97 972	25.60	3.41	89 530	30.00	4.00

Source: Environment Agency.

The unique trend of the CO_2 implied emission factor for other fuels, which is composed solely of the fossil fraction of incinerated MSW and as reported in Table 3-26, 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 fractions determined in the study of 1992/1994 were applied to the years 1990-1997; the fractions determined in the study of 2001 were applied to the period 1998-2002; the fractions of the study of 2004/2005 were applied to the years 2003-2008; the fractions of the study 2009/2010 were applied to the years 2009-2012; and the fractions of the study 2013/2014 were applied to the years 2013-2018. In addition, since 2002, a high calorific fraction of MSW, 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 MSW. Hence, the changes in the CO_2 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 3-27.

Table 3-27: 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	CO2	2%	0.5%
1A1 - Gaseous Fuels	CH4	2%	50%
1A1 - Gaseous Fuels	N2O	2%	50%
1A1 - Liquid Fuels	CO2	2%	0.5%
1A1 - Liquid Fuels	CH4	2%	50%
1A1 - Liquid Fuels	N2O	2%	50%
1A1 - Other Fuels	CO2	8%	20%
1A1 - Other Fuels	CH4	8%	50%
1A1 - Other Fuels	N2O	8%	50%
1A1 - Biomass	CH4	7%	50%
1A1 - Biomass	N2O	7%	60%
1A1 – Solid fuels	CO2	1%	3%
1A1 – Solid fuels	CH4	1%	50%
1A1 – Solid fuels	N2O	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). In the following, maintenance stops (2009, 2011) of the 350 MW gas turbine, some times during several months, greatly influence 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 gasoil 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.

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) is 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 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 *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 3-28 presents the main revisions and recalculations relevant to category *1A1a - Public Electricity and Heat Production* done since the last submission. For the quantitative aspect of these recalculations, please refer to Chapter 10.

Table 3-28 – Recalculations done since submission 2019v1

GHG source & sink category	Revisions 2019v1 ➔ 2020v1	Type of revision
1A1a – liquid fuels	The country-specific CO_2 emission factor for gasoil was revised for the entire timeseries because the emission factors of the importing countries have changed (Table 3-73).	CO_2 EF
1A1a - biomass	Activity data for wood and wood products from 2013-2017 was revised according to the national energy balance.	AD
1A1a – liquid fuels	Activity data for heating gasoil from 2000-2017 was revised according to the national energy balance.	AD

3.2.6.6 Category-specific planned improvements including those in response to the review process

Table 3-29 presents the category-specific planned improvements relevant to category *1A1a - Public Electricity and Heat Production* done since the last submission.

Table 3-29 – 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 12.82% of GHG emissions from fuel combustion activities (60.94% in 1990) and represented 11.04% of the total GHG emissions of Luxembourg, excluding LULUCF (49.18% in 1990). Compared to 2017, emissions of 1A2 increased by 1.72 %.

Table 3-30 summarizes GHG emissions for *1A2 – Manufacturing Industries and Construction* and the relevant sub-categories.

Regarding CO_2 emissions, *1A2 – Manufacturing Industries and Construction* is a key category, in 2018 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 3-30 – GHG emission trends in CO_2e for IPCC sub-category 1A2 – Fuel Combustion Activities – Manufacturing Industries and Construction: 1990-2018

Year	1A2 - Manufacturing Industries & Construction GHG emissions by source & sink category (Gg)															
	1A2a - Iron & Steel				1A2b - Non-Ferrous Metals				1A2c - Chemicals				1A2d - Pulp, Paper & Print			
	Total CO_2 eq	CO_2	CH_4	N_2O	Total CO_2 eq	CO_2	CH_4	N_2O	Total $CO_{2\,eq}$	CO_2	CH_4	N_2O	Total $CO_{2\,eq}$	CO_2	CH_4	N_2O
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	269.52	269.25	0.005	0.000	53.87	53.82	0.0010	0.0001	135.10	134.97	0.002	0.000	4.81	4.80	0.0001	0.0000
2018	284.84	284.55	0.005	0.001	49.25	49.20	0.0009	0.0001	135.50	135.36	0.002	0.000	5.44	5.44	0.0001	0.0000
Trend 1990-2018	-94.74%	-94.73%	-95.29%	-96.56%	73.46%	73.45%	89.45%	89.45%	-20.42%	-20.30%	-54.02%	-73.49%	NA	NA	NA	NA
Trend 2017-2018	0.21%	0.21%	1.00%	2.43%	6.16%	6.16%	6.13%	6.13%	-8.37%	-8.38%	-6.14%	-2.15%	-9.93%	-9.94%	-8.54%	-6.16%

Source: Environment Agency.

Notes: CH_4 emissions are converted in CO_2e 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.

N_2O emissions are converted in CO_2e 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.

3.2.7.2 Iron and Steel (1A2a)

3.2.7.2.1 Source category description

In 2018, fuel combustion in iron and steel was responsible for 3.14% of GHG emissions from fuel combustion activities (this share was 52.63% in 1990) and represented 2.70% of the total GHG emissions in CO_2eq, excluding LULUCF (42.47% in 1990). Compared to 2017, emissions have increased by 5.68% and compared to 1990, decreased by 94.74%.

3.2.7.2.2 Methodological issues

3.2.7.2.2.1 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*. CO_2 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 3-31 gives a summary of which combustion activities are included for estimating GHG emissions pertaining to category *1A2a – Iron &Steel*.

Table 3-31 – 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 operator[74] 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.

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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 Schifflange 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 has 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 was 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 3.2.7.8).

The fuel consumption data obtained by the operators (bottom-up) was then matched with the top-down data obtained from the national statistics institute (STATEC), in order to avoid double counting or underestimation.

Table 3-32 gives a summary of the amount of energy used in category *1A2a – Iron and Steel*.

Table 3-32 – Activity data for category *1A2a – Iron and Steel*: 1990-2018

1A2a - Iron & Steel

Activity Data by fuel type (GJ)

Year	Activity Total	Solid Blast Furnace Gas, Coke Oven Coke, Coking Coke, Other Bituminous Coal	Liquid Residual Fuel Oil, Gas Oil	Gaseous Natural Gas	Biomass	Other
1990	31 802 459	24 297 184	632 309	6 872 966	NO	NO
1991	29 861 529	23 212 906	1 082 023	5 566 600	NO	NO
1992	28 074 836	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	24 669 273	18 169 300	1 249 467	5 250 506	NO	NO
1995	16 128 469	9 509 657	650 277	5 968 535	NO	NO
1996	15 348 354	8 471 037	559 065	6 318 252	NO	NO
1997	11 405 449	4 700 381	505 079	6 199 990	NO	NO
1998	5 294 529	NO	498 093	4 796 436	NO	NO
1999	5 898 926	NO	634 967	5 263 959	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	4 745 745	NO	42 930	4 702 815	NO	NO
2018	5 048 373	NO	43 828	5 004 545	NO	NO
Trend 1990-2018	-84.13%	NA	-93.07%	-27.19%	NA	NA
Trend 2017-2018	6.38%	NA	2.09%	6.42%	NA	NA

Source: Environment Agency.

3.2.7.2.2.2 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 3.2.7.2.2.1), 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.

3.2.7.2.2.3 Emission factors

Default emission factors are derived from 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 3-33).

For blast furnace gas combusted in blast furnaces or combustion plants, a plant specific CO_2 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 BFG composition (see also section 3.2.5.3). The CH_4 and N_2O emission factors are default values from the 2006 IPCC Guidelines. The CO_2 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 CO_2 in the atmosphere. Therefore, the same emission factor as for flaring was used. No default values for CH_4 and N_2O from BFG lost in distribution and flaring are given neither in the 1996 Revised IPCC Guidelines nor in the 2006 IPCC Guidelines, therefore the default values for coal were applied.

Table 3-33 gives an overview of the different emission factors used in this submission.

Table 3-33 – Emission factors for category *1A2a – Iron and Steel*

1A2a Iron & Steel

Emission Factors for 2018 (kg/TJ)

Fuel	Fuel Type	CO_2		CH_4		N_2O		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	74 130	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 209	CS	1.00	D	0.10	D	AEV 2006 IPCC GL

Source: Environment Agency.

Table 3-34 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 CO_2 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 CO_2 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 3-34 – 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_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
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

Source: Environment Agency.

3.2.7.3 Non-Ferrous Metals (1A2b)

3.2.7.3.1 Source category description

In Luxembourg, non-ferrous metals activities cover mainly secondary aluminium production from aluminium scrap.

In 2018, fuel combustion due to non-ferrous metal production was responsible for 0.54% of GHG emissions from fuel combustion activities (0.28% in 1990) and represented 0.47% of the national total GHG emissions in CO_2e, excluding LULUCF (0.22% in 1990). Compared to 2017, emissions declined by 8.58% and compared to 1990, they increased by 73.46%.

3.2.7.3.2 Methodological issues & time series consistency

3.2.7.3.2.1 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 3-35.

The activity data reported here is 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 is reported for this category. Due to confidentiality reasons, this data is reported under the iron & steel industry by national statistics.

However, to avoid double counting, the bottom-up data was subtracted from the top-down data from official statistics reported for category *1A2a - Iron and Steel*.

Table 3-35 - Activity data for category *1A2b - Non-Ferrous Metals*: 1990-2018

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	875 263	NO	NO	875 263	NO	NO
Trend 1990-2018	89.45%	NA	NA	277.26%	NA	NA
Trend 2017-2018	-7.99%	NA	NA	-7.99%	NA	NA

Source: Environment Agency.

3.2.7.3.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 2 approach has been applied for liquid (LPG) and gaseous fuels (natural gas).

3.2.7.3.2.3 Emission factors

Country-specific EFs for CO_2 from LPG and natural gas were used. Default EFs from the 2006 IPCC Guidelines have been applied for CH_4 and N_2O (Table 3-36).

Table 3-36 – Emission factors for category 1A2b – Non-Ferrous Metals

1A2b - Non-Ferrous Metals
Emission Factors for 2018(kg/TJ)

Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
LPG	liquid	65 212	CS	1.00	D	0.10	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 209	CS	1.00	D	0.10	D	AEV 2006 IPCC GL

Source: Environment Agency.

3.2.7.4 Chemicals (1A2c)

3.2.7.4.1 Source category description

In Luxembourg, chemical activities cover mainly the production of tyres, 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 2018, fuel combustion from the chemical industry was responsible for 1.49% of GHG emissions from fuel combustion activities (1.66% in 1990) and represented 1.28% of the national total GHG emissions, excluding LULUCF (1.34% in 1990). Compared to 2017, emissions increased by 0.29% and compared to 1990, decreased by 20.42%.

3.2.7.4.2 Methodological issues & time-series consistency

3.2.7.4.2.1 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 is 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 is reported for this category. To avoid double counting, the bottom-up data for this period was subtracted from the top-down data from official statistics reported for category *1A2g - Other*. For natural gas (2000-2018) and liquid fuels (residual fuel oil, gas oil, diesel oil) the matching exercise was done within the category 1A2c as top-down data is reported for this category by the national statistics institute. Activity data for the chemical industry are listed in

Table 3-37.

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 happened in 2007 in comparison to the year 2006: a decrease of about 9% occurred due to maintenance on one of the gas turbines operated by the chemical industry.[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.

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[75] ARR 2009, § 61.

Table 3-37- Activity data for category *1A2c - Chemicals*: 1990-2018

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	2 373 839	NO	37 642	2 336 197	NO	NO
2018	2 395 866	NO	38 430	2 357 436	NO	NO
Trend 1990-2018	-2.44%	NA	-97.37%	136.99%	NA	NA
Trend 2017-2018	0.93%	NA	2.09%	0.91%	NA	NA

Source: Environment Agency.

3.2.7.4.2.2 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.

3.2.7.4.2.3 Emission factors

The 2006 IPCC Guidelines default EFs have been applied for CO_2 for residual fuel oil, whereas for gas oil and natural gas country-specific EFs were used. Default EFs have been applied for CH_4 and N_2O (Table 3-38).

Table 3-38 – Emission factors for category *1A2c – Chemicals*

1A2c - Chemicals
Emission Factors for 2018 (kg/TJ)

Fuel	Fuel Type	CO_2 EF	CO_2 type	CH_4 EF	CH_4 type	N_2O EF	N_2O type	Source
Residual Fuel Oil	liquid	77 400	D	3.00	D	0.60	D	2006 IPCC GL
Gas Oil	liquid	74 130	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 209	CS	1.00	D	0.10	D	AEV 2006 IPCC GL

Source: Environment Agency.

Table 3-39 gives an overview of the evolution of the implied emission factors per fuel type.

For liquid fuels, the CO_2 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 3-39 – Implied emission factors for category *1A2c – Chemicals*

1A2c - Chemicals
Implied Emission Factors (kg/TJ)

Year	Liquid			Gaseous		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
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

Source: Environment Agency.

3.2.7.5 Pulp, Paper and Print (1A2d)

3.2.7.5.1 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 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 2018, fuel combustion from the paper and print industry was responsible for 0.06% of GHG emissions from fuel combustion activities and represented 0.05% of the national total GHG emissions in CO_2e, excluding LULUCF. Compared to 2017, emissions decreased by 13.24%.

3.2.7.5.2 Methodological issues

3.2.7.5.2.1 Activity data

Annual fuel consumption data for gas oil, diesel oil and natural gas were derived from national statistics for the period 2000-2018. 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 is available from national statistics, hence the notation key IE was used in the CRF tables. For these years the data is included in *1A2g - Other*.

Activity data for the pulp, paper and print industry are listed in Table 3-40.

Table 3-40- ***Activity data for category 1A2d - Pulp, Paper and Print: 1990-2018***

1A2d - Pulp, Paper & Print Activity Data by fuel type (GJ)						
Year	Activity Total	Solid	Liquid	Gaseous	Biomass	Other
			Gas Oil, Diesel Oil	Natural Gas		
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	84 256	NO	1 902	82 354	NO	NO
2018	96 088	NO	1 942	94 146	NO	NO
Trend 1990-2018	NA	NA	NA	NA	NA	NA
Trend 2017-2018	14.04%	NA	2.09%	14.32%	NA	NA

Source: Environment Agency

3.2.7.5.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 2 approach was applied for gas oil and natural gas.

3.2.7.5.2.3 Emission factors

Country-specific CO_2 EFs were used for gasoil and natural gas, whereas 2006 IPCC default EFs have been applied for CH_4 and N_2O (Table 3-41).

Table 3-41 – Emission factors for category *1A2d - Pulp, Paper and Print*

1A2d - Pulp, Paper & Print
Emission Factors for 2018 (kg/TJ)

Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
Gas Oil	liquid	74 130	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 209	CS	1.00	D	0.10	D	AEV 2006 IPCC GL

Source: Environment Agency

Table 3-42 gives an overview of the evolution of the implied emission factors per fuel type.

Table 3-42 – 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_2O	CO_2	CH_4	N_2O
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

Source: Environment Agency

3.2.7.6 Food Processing, Beverages and Tobacco (1A2e)

3.2.7.6.1 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 2018, fuel combustion from the food processing, beverages and tobacco industry was responsible for 0.30% of GHG emissions from fuel combustion activities (0.08% in 1990) and represented 0.26% of the national total GHG emissions excluding LULUCF (0.06% in 1990). Compared to 2017, emissions increased by 4.51% and compared to 1990, increased by 228.85%.

For liquid fuels, some exceptional inter-annual changes have been observed for the years 1993/1994 (+83%), 1998/1999 (+91%), 2008/2009 (+61%), and 2016/2017 (+72%). 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).

3.2.7.6.2 Methodological issues & time-series consistency

3.2.7.6.2.1 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 (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 use of residual fuel oil stopped in 2002.

The activity data reported here is the data reported by the operators to the Environment Agency through their annual reporting obligations. 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 is reported for this category. To avoid double counting, the bottom-up data on natural gas was subtracted from the top-down data from national statistics reported for category *1A2g - Other*. For natural gas (2000-2018) and liquid fuels (residual fuel oil, gas oil, diesel oil), the matching exercise was done within the category 1A2e as top-down data is available for this sub-category from national statistics. Activity data for the food processing, beverages and tobacco industry are listed in Table 3-43.

Table 3-43- Activity data for category *1A2e - Food Processing, Beverages and Tobacco*: 1990-2018

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	518 726	NO	119 963	398 763	NO	NO
2003	282 284	NO	64 125	218 159	NO	NO
2004	299 949	NO	89 488	210 460	NO	NO
2005	282 624	NO	59 979	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	228 492	NO	50 780	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	402 990	NO	160 135	242 855	NO	NO
2018	423 179	NO	166 011	257 168	NO	NO
Trend 1990-2018	241.44%	NA	185.60%	290.76%	NA	NA
Trend 2017-2018	5.01%	NA	3.67%	5.89%	NA	NA

Table heading: 1A2e - Food Processing, Beverages & Tobacco — Activity Data by fuel type (GJ)

Source: Environment Agency.

3.2.7.6.2.2 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.

3.2.7.6.2.3 Emission factors

The 2006 IPCC Guidelines default EFs have been applied for CO_2 from residual fuel oil, whereas for gasoil and natural gas country specific EFs were used. Default EFs have been applied for CH_4 and N_2O (Table 3-44).

Table 3-44 – Emission factors for category *1A2e – Food Processing, Beverages and Tobacco*

1A2e - Food Processing, Beverages & Tobacco

Emission Factors for 2018 (kg/TJ)

Fuel	Fuel Type	CO_2		CH_4		N_2O		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	74 130	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 209	CS	1.00	D	0.10	D	AEV 2006 IPCC GL

Source: Environment Agency

Table 3-45 gives an overview of the evolution of the implied emission factors per fuel type.

Table 3-45 – Implied emission factors for category *1A2e – Food Processing, Beverages and Tobacco*

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	518 726	NO	119 963	398 763	NO	NO
2003	282 284	NO	64 125	218 159	NO	NO
2004	299 949	NO	89 488	210 460	NO	NO
2005	282 624	NO	59 979	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	228 492	NO	50 780	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	402 990	NO	160 135	242 855	NO	NO
2018	423 179	NO	166 011	257 168	NO	NO
Trend 1990-2018	241.44%	NA	185.60%	290.76%	NA	NA
Trend 2017-2018	5.01%	NA	3.67%	5.89%	NA	NA

Source: Environment Agency

The higher CO_2 IEF for liquid fuels in the early 1990s is due to the partial use of residual fuel oil in combustion plants. Residual fuel oil was then mainly phased out, which is reflected in a decreasing IEF.

3.2.7.7 Non-Metallic Minerals (1A2f)

3.2.7.7.1 Source category description

Source category *1A2f – Non-metallic minerals* covers industrial activities such as glass, clinker / cement and ceramics production.

In 2018, fuel combustion emissions reported under *1A2f – Non-metallic minerals* were responsible for 4.35% of GHG emissions from fuel combustion activities (this share was 5.24% in 1990) and represented 3.74% of the national total GHG emissions excluding LULUCF (4.23% in 1990). Compared to 2017, emissions decreased by 0.81% and compared to 1990, decreased by 26.77%.

3.2.7.7.2 Methodological issues

3.2.7.7.2.1 Activity data

Under *1A2f – Non-metallic minerals*, the following activities have been considered (Table 3-50):

Table 3-46 – 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 tyres, fluff and sewage sludge. These waste types contain a certain biogenic fraction, which is annually reported by the operator. This 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 was used in the past, but only on a minor scale.

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 3-51.

Table 3-47 – Activity data by fuel type of category *1A2f – Non-metallic minerals*: 1990-2018

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, tyres, fluff	Other tyres, 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	5 977 387	2 674 118	353 846	2 949 422	48 484	131 088
1999	6 724 103	2 819 127	458 326	3 446 649	47 267	127 797
2000	6 817 190	3 127 895	133 449	3 555 847	72 479	195 963
2001	6 777 670	3 119 891	114 647	3 543 132	157 603	426 112
2002	5 676 217	2 093 325	100 703	3 482 189	197 108	505 321
2003	4 847 118	1 793 790	97 186	2 956 142	202 949	465 191
2004	5 504 396	2 070 876	122 662	3 310 857	252 132	508 662
2005	5 613 329	2 190 698	89 426	3 333 205	236 807	537 068
2006	5 941 218	2 577 804	77 093	3 286 321	263 980	577 654
2007	5 432 189	1 989 234	70 777	3 372 178	296 661	588 562
2008	5 204 172	1 805 356	58 034	3 340 782	259 929	659 478
2009	5 395 370	2 043 207	37 557	3 314 606	198 932	478 455
2010	5 101 937	1 855 755	23 877	3 222 306	283 272	639 565
2011	5 104 308	1 819 386	29 527	3 255 395	260 635	591 265
2012	4 956 495	1 742 721	32 119	3 181 655	270 977	603 054
2013	4 029 126	1 657 980	27 785	2 343 360	278 590	709 462
2014	4 742 368	1 792 071	57 737	2 892 559	265 698	640 681
2015	4 522 416	1 527 342	51 459	2 943 615	245 290	638 714
2016	4 749 598	1 699 332	67 561	2 982 705	227 998	893 158
2017	4 522 099	1 607 521	124 655	2 789 923	234 627	949 558
2018	4 381 110	1 431 036	127 094	2 822 979	232 073	1 106 238
Trend 1990-2018	-38.32%	-56.67%	-59.91%	-18.95%	NA	NA
Trend 2017-2018	-3.12%	-10.98%	1.96%	1.18%	-1.09%	16.50%

Source: Environment Agency

3.2.7.7.2.2 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. CO_2 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.

76 http://www.vdz-online.de/fileadmin/gruppen/vdz/3LiteraturRecherche/Taetigkeitsbericht07/VDZ_Kap_II.pdf

77 http://www.aliapur.fr/media/files/RetD_new/Conferences_Publications/Pneus_usages_comme_combustible_alternatif_extrait.pdf

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 Guidelines[78].

3.2.7.7.2.3 Emission factors

The 2006 IPCC Guidelines default CO_2 EFs have been applied for residual fuel oil and for solid fuels except for tires and fluff, where plant-specific emission factors were used. For natural gas, gas oil and LPG country-specific EFs were used. IPCC default EFs have been applied for CH_4 and N_2O (Table 3-52).

Table 3-48 – Emission factors for category *1A2f – Non-metallic minerals*

1A2f - Non-Metallic Minerals
Emission Factors for 2018 (kg/TJ)

Fuel	Fuel Type	CO_2		CH_4		N_2O		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	74 130	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
LPG	liquid	65 212	CS	1.00	D	0.10	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 209	CS	1.00	D	0.10	D	AEV 2006 IPCC GL
Sewage Sludge	other/biomass	91 640	PS	30.00	D	4.00	D	ETS 2006 IPCC GL
Solvents	other	72 780	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	82 829	PS	30.00	D	4.00	D	ETS 2006 IPCC GL

Source: Environment Agency

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Table 3-53 gives an overview of the evolution of the implied emission factors per fuel type.

The increase of the CO_2 IEF of biomass from 2002 onwards is due to the use of different types of biomass over time. Indeed, tires (CO_2 EF: 88.00 t CO_2/TJ) are used since 1998 as secondary fuel in the clinker production. Since 2002, sewage sludge (CO_2 EF: 100.00 t CO_2/TJ) and since 2006, fluff, (CO_2 EF: 87.09 t CO_2/TJ) are co-incinerated in the clinker production.

78 http://ec.europa.eu/clima/policies/ets/monitoring/index_en.htm

Table 3-49 – Implied emission factors for category *1A2f – Non-metallic minerals*

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, tyres, fluff	Other tyres, 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	5 977 387	2 674 118	353 846	2 949 422	48 484	131 088
1999	6 724 103	2 819 127	458 326	3 446 649	47 267	127 797
2000	6 817 190	3 127 895	133 449	3 555 847	72 479	195 963
2001	6 777 670	3 119 891	114 647	3 543 132	157 603	426 112
2002	5 676 217	2 093 325	100 703	3 482 189	197 108	505 321
2003	4 847 118	1 793 790	97 186	2 956 142	202 949	465 191
2004	5 504 396	2 070 876	122 662	3 310 857	252 132	508 662
2005	5 613 329	2 190 698	89 426	3 333 205	236 807	537 068
2006	5 941 218	2 577 804	77 093	3 286 321	263 980	577 654
2007	5 432 189	1 989 234	70 777	3 372 178	296 661	588 562
2008	5 204 172	1 805 356	58 034	3 340 782	259 929	659 478
2009	5 395 370	2 043 207	37 557	3 314 606	198 932	478 455
2010	5 101 937	1 855 755	23 877	3 222 306	283 272	639 565
2011	5 104 308	1 819 386	29 527	3 255 395	260 635	591 265
2012	4 956 495	1 742 721	32 119	3 181 655	270 977	603 054
2013	4 029 126	1 657 980	27 785	2 343 360	278 590	709 462
2014	4 742 368	1 792 071	57 737	2 892 559	265 698	640 681
2015	4 522 416	1 527 342	51 459	2 943 615	245 290	638 714
2016	4 749 598	1 699 332	67 561	2 982 705	227 998	893 158
2017	4 522 099	1 607 521	124 655	2 789 923	234 627	949 558
2018	4 381 110	1 431 036	127 094	2 822 979	232 073	1 106 238
Trend 1990-2018	-38.32%	-56.67%	-59.91%	-18.95%	NA	NA
Trend 2017-2018	-3.12%	-10.98%	1.96%	1.18%	-1.09%	16.50%

Source: Environment Agency

3.2.7.8 Other (1A2g)

3.2.7.8.1 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 2018, fuel combustion emissions reported under *1A2g - Other* manufacturing industries and construction were responsible for 2.95% of GHG emissions from fuel combustion activities (this share was 1.05% in 1990) and represented 2.54% of the national total GHG emissions excluding LULUCF (0.85% in 1990). Compared to 2017, emissions increased by 3.90% and compared to 1990, increased by 146.82%.

3.2.7.8.2 Methodological issues

3.2.7.8.2.1 Activity data

The following combustion activities have been considered in category *1A2g - Other* (Table 3-50):

Table 3-50 – 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 was obtained by the operators.

Mobile Sources and Machinery in Industry and Other Mobile Equipment

Activity data is 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* is listed in Table 3-51.

Table 3-51 – Activity data by fuel type of category *1A2g – Other*: 1990-2018

1A2g - Other

Activity Data by fuel type (GJ)

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	Solid	Liquid	Gaseous	Biomass	Other
		Diesel Oil, Gasoline	Other Bituminous Coal, Brown Coal Briquettes	Residual fuel oil, Gas Oil, LPG	Natural Gas	Wood and Wood Waste	
1990	1 419 507	618 365	206 140	182 270	412 732	NO	NO
1991	3 608 633	700 883	199 769	293 602	2 414 379	NO	NO
1992	4 041 884	760 284	217 880	251 723	2 811 997	NO	NO
1993	4 341 605	824 978	161 445	225 392	3 129 790	NO	NO
1994	4 341 613	866 765	320 437	251 136	2 903 275	NO	NO
1995	3 932 115	922 207	160 119	264 601	2 585 188	NO	NO
1996	4 062 315	892 581	254 976	219 399	2 695 358	NO	NO
1997	5 310 457	950 701	225 135	254 493	3 880 128	NO	NO
1998	5 566 673	971 738	183 946	502 140	3 908 850	NO	NO
1999	7 081 937	1 056 669	218 107	1 685 840	4 121 321	NO	NO
2000	3 565 796	1 111 339	232 377	849 550	1 372 530	NO	NO
2001	3 488 099	1 140 315	168 958	863 745	1 315 081	NO	NO
2002	3 427 961	1 268 813	138 204	857 810	1 163 134	NO	NO
2003	3 665 092	1 320 679	145 892	1 072 329	1 126 193	NO	NO
2004	3 677 707	1 393 239	147 911	881 834	1 254 724	NO	NO
2005	3 475 687	1 395 734	144 819	726 370	1 208 763	880 933	NO
2006	3 395 901	1 505 417	136 831	465 284	1 288 369	856 579	NO
2007	3 470 963	1 786 711	142 414	485 132	1 056 706	918 261	NO
2008	3 213 936	1 665 303	139 665	501 626	907 342	979 662	NO
2009	2 969 926	1 685 511	156 912	235 671	891 832	754 820	NO
2010	2 993 883	1 752 769	211 674	268 931	760 510	863 371	NO
2011	3 076 237	1 877 816	171 154	173 690	853 577	785 914	NO
2012	2 995 145	1 770 743	191 369	172 989	860 045	682 906	NO
2013	3 189 845	1 858 567	135 996	220 157	975 125	715 237	NO
2014	3 180 519	2 126 335	147 760	108 588	797 836	872 512	NO
2015	3 246 095	2 214 344	188 807	126 160	716 784	807 701	NO
2016	3 388 986	2 259 615	153 878	185 152	790 341	813 359	NO
2017	3 465 101	2 223 163	196 635	336 847	708 457	727 688	NO
2018	3 637 209	2 295 881	183 866	357 683	799 779	442 124	NO
Trend 1990-2018	156.23%	271.28%	-10.81%	96.24%	93.78%	NA	NA
Trend 2017-2018	4.97%	3.27%	-6.49%	6.19%	12.89%	-39.24%	NA

Source: Environment Agency

3.2.7.8.2.2 Methodological choices

For CO_2, 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 CH_4 and N_2O from stationary combustion, the 2006 IPCC Guidelines Tier 1 approach has been applied for all fuels.

For CH_4 and N_2O 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.

3.2.7.8.2.3 Emission factors

The 2006 IPCC Guidelines default CO_2 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 CH_4 and N_2O.

For mobile combustion (diesel oil, motor gasoline, biofuels), country-specific values, derived from the GEORG model, have been applied for CH_4 and N_2O (Table 3-52).

The country specific CO_2 EFs for diesel oil and gasoline as described in section 3.2.5.3 were used (Tier 2). CH_4 and N_2O emissions were determined with the GEORG model (Table 3-69). The CH_4 emission factors are based on the EMEP/EEA 2016 Guidebook (Tier 3) while N_2O emission factors are based on (Hausberger, 2006). For biogasoline, biodiesel and other fossil fuels (fossil part of biodiesel, please refer to page 260 for details), the European CO_2 implied emission factors[79] for gasoline (71270 g/GJ) and diesel oil (73450 g/GJ) were applied.

[79] UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

Table 3-52 – Emission factors for category *1A2g – Other*

1A2g - Other
Emission Factors for 2018 (kg/TJ)

Fuel	Fuel Type	CO_2		CH_4		N_2O		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	74 130	CS	3.00	D	0.60	D	AEV 2006 IPCC GL
Diesel Oil	liquid	74 130	CS	0.15	CS	8.23	CS	AEV
Gasoline	liquid	73 216	CS	19.55	CS	1.60	CS	AEV
LPG	liquid	65 212	CS	1.00	D	0.10	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 209	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

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Table 3-53 gives an overview of the evolution of the implied emission factors for liquid fuels used by off-road vehicles and other machinery.

Table 3-53 – 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_2O
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	74 144	0.30	8.43
2018	74 124	0.27	8.19

Source: Environment Agency

Table 3-54 gives an overview of the evolution of the implied emission factors for fuels used in stationary combustion by other manufacturing industries.

Table 3-54 – Implied emission factors for category 1.A.2.g.viii – Other manufacturing industries

1A2f - Non-Metallic Minerals
Implied Emission Factors (kg/TJ)

Year	Solid			Liquid			Gaseous			Biomass			Other		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
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	85 577	30.00	4.00	79 101	30.00	4.00

Source: Environment Agency

3.2.7.9 Uncertainties and time-series consistency

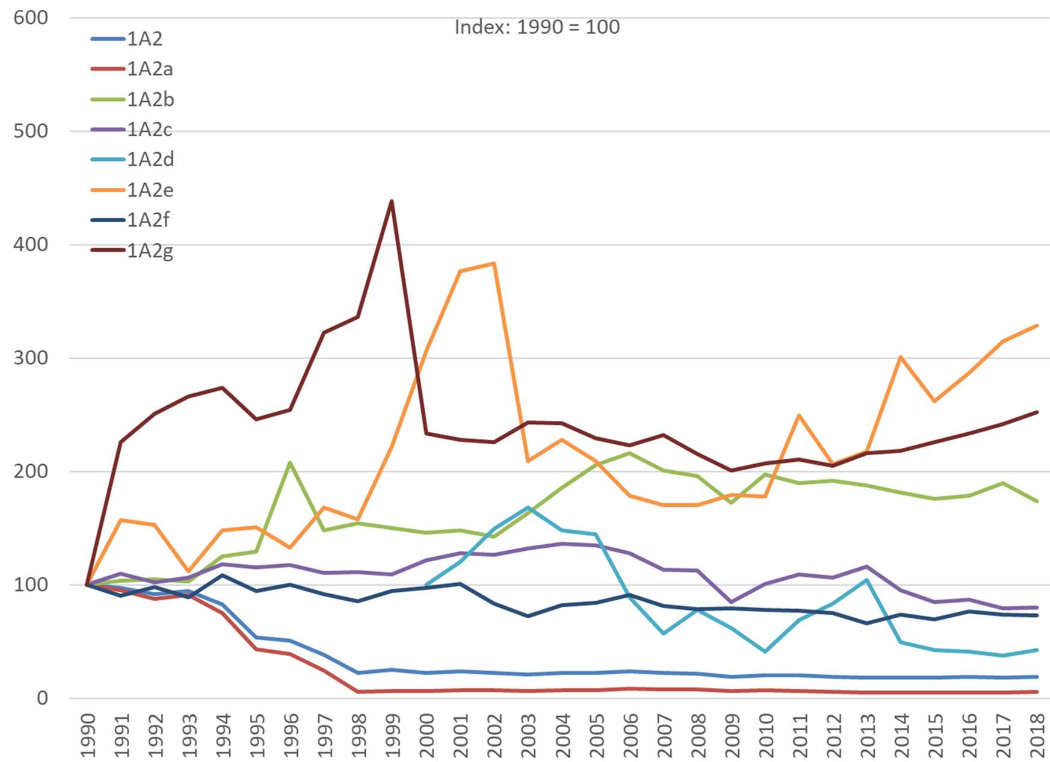
The uncertainties for activity data and emission factors used for IPCC category *1A2 – Manufacturing Industries and Construction* are presented in Table 3-55.

Table 3-55: 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	CO2	2%	0.5%
1A2 - Gaseous Fuels	CH4	2%	50%
1A2 - Gaseous Fuels	N2O	2%	50%
1A2 - Liquid Fuels	CO2	2%	0.5%
1A2 - Liquid Fuels	CH4	2%	50%
1A2 - Liquid Fuels	N2O	2%	50%
1A2 - Other Fuels	CO2	8%	20%
1A2 - Other Fuels	CH4	8%	50%
1A2 - Other Fuels	N2O	8%	50%
1A2 - Biomass	CH4	7%	50%
1A2 - Biomass	N2O	7%	60%
1A2 - Solid Fuels	CO2	1%	3%
1A2 - Solid Fuels	CH4	1%	50%
1A2 - Solid Fuels	N2O	1%	50%

Generally, the time-series, as reported in category *1A2 - Manufacturing Industries and Construction* are considered to be consistent (Figure 3-6).

Figure 3-6 – GHG emission trend indexes for category *1A2 – Manufacturing Industries and Construction*: 1990-2018



The general trend of GHG emissions in *1A2* is greatly influenced by sub-category *1A2a - Iron and Steel*. Fluctuations in emissions of the other sub-categories only influence the general trend on a minor 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*, no category-specific AD is available for the years 1990-1999, so that 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 gasoil 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.

3.2.7.10 Source-specific QA/QC and verification

Activity data for large facilities that have reporting obligations under the European Union Emission Trading System (EU-ETS) is 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.

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

Table 3-56 presents the main revisions and recalculations done since the last submission to the UNFCCC and relevant to category *1A2 - Manufacturng Industries and Construction*. For the quantitative aspect of these recalculations, please refer to Chapter 10.

Table 3-56 – Recalculations done since submission 2019v1

GHG source & sink category	Revisions 2019v1 ➔ 2020v1	Type of revision
1A2	Fuel consumption data for natural gas and heating gasoil for the years 2015-2017 was revised due to revised energy balance from the national statistics institute	AD
1A2	The country-specific CO_2 EFs for gasoil/diesel oil and gasoline were revised for the entire timeseries due to changes of the emission factors of the importing countries (Table 3-74)	CO_2 EF
1A2gvii	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. For submission 2019v1, these models used emission factors from HBEFA3.3. For submission 2020v1, the newer version HBEFA4.1 was implemented. Due to this methodological change, the allocation of fuel quantities to the different road and offroad subsectors was also revised.	AD, EFs

3.2.7.12 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 3-57 will be explored.

Table 3-57 – Planned improvements for category *1A2– Manufacturing Industries and Construction.*

GHG source & sink category	Planned improvement
1A2	No further improvements planned

3.2.8 Transport (1.A.3)

3.2.8.1 Source category description

This section describes GHG emissions resulting from fuel combustion activities in the transport sector.

The 2019 GHG inventory 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 2018, this source category was responsible for 66.39% of GHG emissions from fuel combustion activities (this share was only 25.45% in 1990) and represented 57.16% of the national total GHG emissions excluding LULUCF (coming from 20.54% in 1990). Compared to 2017, emissions increased by 6.74% and compared to 1990 they increased by 130.36%.

Table 3-58 summarizes GHG emissions for IPCC Sub-category 1A3.

Table 3-58 – GHG emission trends in CO_2eq for IPCC sub-category 1A3 – Transport: 1990-2018

1A3 - Transport GHG emissions by source & sink category (Gg)								
	1A3d - Navigation				1A3 - Transport			
Year	Total $CO_{2\ eq}$	CO_2	CH_4	N_2O	Total CO_2 eq	CO_2	CH_4	N_2O
1990	1.44	1.30	0.0013	0.00034	2 617.10	2 588.98	0.50	0.05
1991	1.57	1.42	0.0016	0.00036	3 210.61	3 177.07	0.54	0.07
1992	1.50	1.36	0.0018	0.00034	3 497.74	3 461.12	0.50	0.08
1993	1.57	1.42	0.0018	0.00036	3 545.08	3 507.79	0.43	0.09
1994	1.50	1.35	0.0017	0.00035	3 602.63	3 563.61	0.38	0.10
1995	1.29	1.16	0.0014	0.00031	3 359.81	3 322.74	0.32	0.10
1996	1.30	1.17	0.0014	0.00031	3 470.96	3 433.69	0.30	0.10
1997	1.34	1.20	0.0013	0.00033	3 731.59	3 693.95	0.28	0.10
1998	1.29	1.17	0.0013	0.00032	3 910.51	3 874.00	0.26	0.10
1999	1.43	1.29	0.0013	0.00037	4 235.24	4 198.83	0.25	0.10
2000	1.26	1.13	0.0010	0.00034	4 871.10	4 833.72	0.24	0.11
2001	1.41	1.27	0.0011	0.00038	5 117.84	5 081.48	0.23	0.10
2002	1.54	1.39	0.0012	0.00042	5 305.90	5 270.90	0.22	0.10
2003	1.61	1.45	0.0012	0.00044	5 859.60	5 824.37	0.21	0.10
2004	1.49	1.34	0.0011	0.00040	6 810.60	6 774.98	0.21	0.10
2005	1.57	1.42	0.0010	0.00041	7 187.09	7 151.73	0.18	0.10
2006	1.45	1.32	0.0008	0.00037	6 865.57	6 830.68	0.16	0.10
2007	1.46	1.32	0.0008	0.00037	6 580.91	6 543.17	0.14	0.11
2008	1.62	1.48	0.0009	0.00041	6 681.16	6 638.84	0.13	0.13
2009	1.35	1.23	0.0007	0.00033	6 157.53	6 115.41	0.12	0.13
2010	1.47	1.35	0.0007	0.00035	6 520.50	6 473.00	0.11	0.15
2011	1.38	1.27	0.0006	0.00033	6 896.47	6 842.11	0.11	0.17
2012	1.37	1.27	0.0005	0.00031	6 593.22	6 537.83	0.11	0.18
2013	1.19	1.10	0.0005	0.00026	6 452.51	6 395.35	0.10	0.18
2014	1.26	1.17	0.0005	0.00027	6 145.01	6 086.49	0.11	0.19
2015	1.11	1.03	0.0004	0.00023	5 703.77	5 645.84	0.11	0.19
2016	1.16	1.07	0.0004	0.00024	5 534.15	5 475.21	0.12	0.19
2017	1.24	1.15	0.0004	0.00027	5 648.16	5 585.85	0.13	0.20
2018	1.21	1.12	0.0004	0.00025	6 028.73	5 961.44	0.14	0.21
Trend 1990-2018	-15.98%	-13.83%	-70.70%	-26.72%	130.36%	130.26%	-72.43%	309.34%

Notes:

CH_4 emissions are converted in CO_2eq 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.

N_2O emissions are converted in CO_2eq 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.

3.2.8.2 Domestic aviation (1A3a)

3.2.8.2.1 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 2018, 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 CO_2e, excluding LULUCF (0.002% in 1990). Compared to 2017, emissions decreased by 2.69%, and compared to 1990 they increased by 162.89%. In absolute terms, *1A3a* emitted 0.57 Gg CO_2e in 2018.

Fuel consumption emissions from domestic aviation are not a key source.

3.2.8.2.2 Methodological issues & time-series consistency

3.2.8.2.2.1 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 – outbound flights - and the share that is addressed to the domestic consumption – inbound 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.

3.2.8.2.2.2 Methodological choices

The 2006 IPCC Guidelines Tier 1 approach has been applied for domestic fights. 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 3.2.2.1 were more details on the split between domestic aviation and international aviation are described.

3.2.8.2.2.3 Emission factors

Default CO_2, CH_4 and N_2O 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 3-59.

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 3-59– Activity data and emission factors for IPCC sub-category 1A3a – Domestic aviation: 1990-2018

1A3a - Civil Aviation Aviation Gasoline								
Year	Activity (GJ)	Emission Factors (kg/TJ)						
		CO_2	type	CH_4	type	N_2O	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
Trend 1990-2018	162.89%	0.00%		0.00%		0.00%		

Source: Environment Agency

3.2.8.3 Road Transportation (1A3b)

3.2.8.3.1 Source category description

In 2018, road transportation was responsible for 66.29% of GHG emissions from fuel combustion activities (this share was only 25.20% in 1990) and represented 57.08% of the national total GHG emissions excluding LULUCF (20.33% in 1990). In absolute terms, GHG emissions from road transportation reached 6020 Gg CO_2e in 2018. Compared to 2017, GHG emissions increased by 6.74%.

With 46.77% of the total GHG emissions from Luxembourg, road transportation (diesel oil) is the largest key category in 2018 (please refer to Table 1-6). Regarding CO_2, 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 N_2O, sub-category 1A3b is a key category for diesel in 2018, but only for the assessment including LULUCF (Table 1-9).

Emissions from road transportation, as reported in the CRF tables, are shown in Table 3-60.

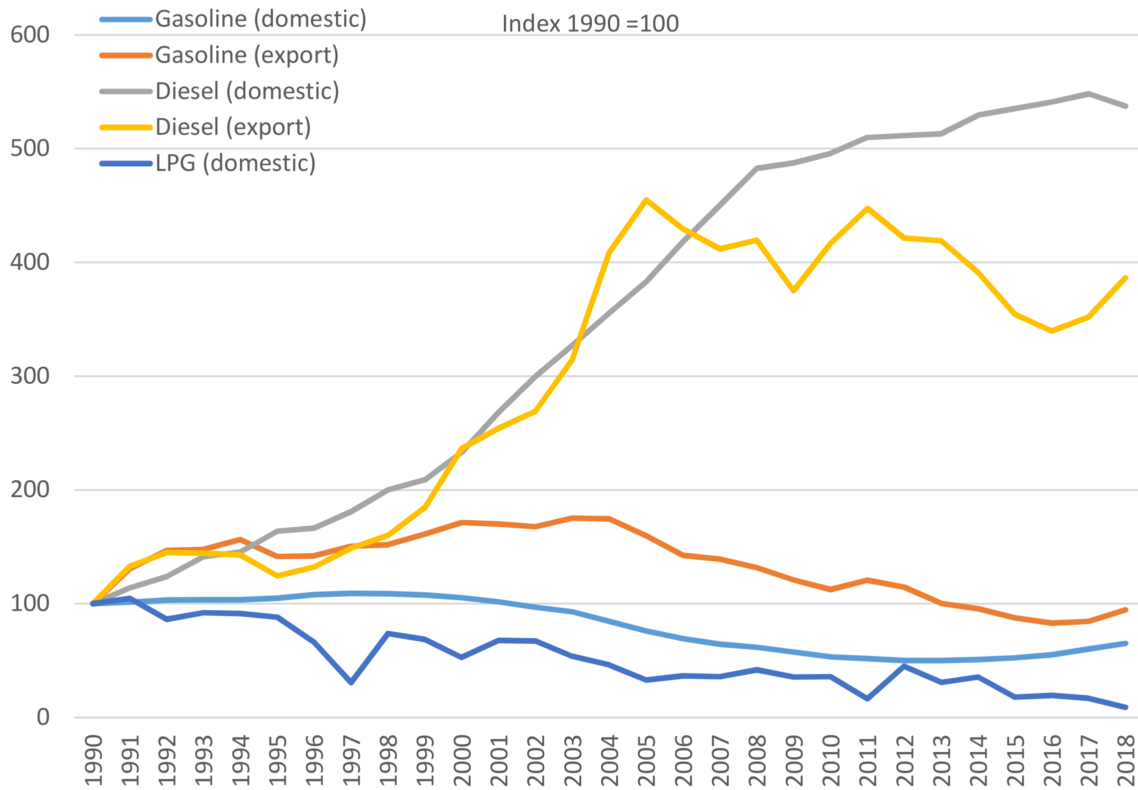
Table 3-60 – Activity data, emissions, and implied emission factor trends of IPCC sub-category 1A3b – Road Transportation: 1990-2018

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_2O (incl. biomass)	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (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	1
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	13	2
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	11	2
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	2
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	8	2
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	2
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	2
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	6	2
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	5	2
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	2
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	4	2
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	1
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	1
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	3	1
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	1
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	2	1
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	2	1
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	2	1
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	1
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	2
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	2
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	2
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	2
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	2
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	2
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	2
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	2	3
2017	75 369 541	12 504 114	62 600 092	29 070	1 735 541	5 639.73	5 577.53	0.13	0.20	74 002	1.7	3
2018	80 474 156	13 661 431	66 546 810	15 439	1 872 601	6 019.93	5 952.74	0.14	0.21	73 971	1.7	3
Trend 1990-2018	115.65%	-29.21%	265.82%	-83.33%	NA	117.71%	117.65%	-74.56%	282.01%	0.93%	-88.20%	77.14%
Trend 2017-2018	1.98%	5.71%	1.19%	-13.55%	14.29%	2.05%	2.01%	8.08%	5.59%	0.03%	5.98%	3.54%

Source: Environment Agency

Figure 3-7– Fuel sold trends - indexes - for 1A3b – Road Transportation by fuel type: 1990-2018



Source: Environment Agency

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 3-7 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 3-8 and Table 3-61 detail the quantities of blended fuel sold to the domestic fleet and the amount of fuel exported. In 2018, GHG emissions from road fuel export were more than two times higher than those from the domestic fleet.

Figure 3-8 – Domestic and exported fuel sold trends - indexes - for 1A3b – Road Transportation by fuel type: 1990-2018

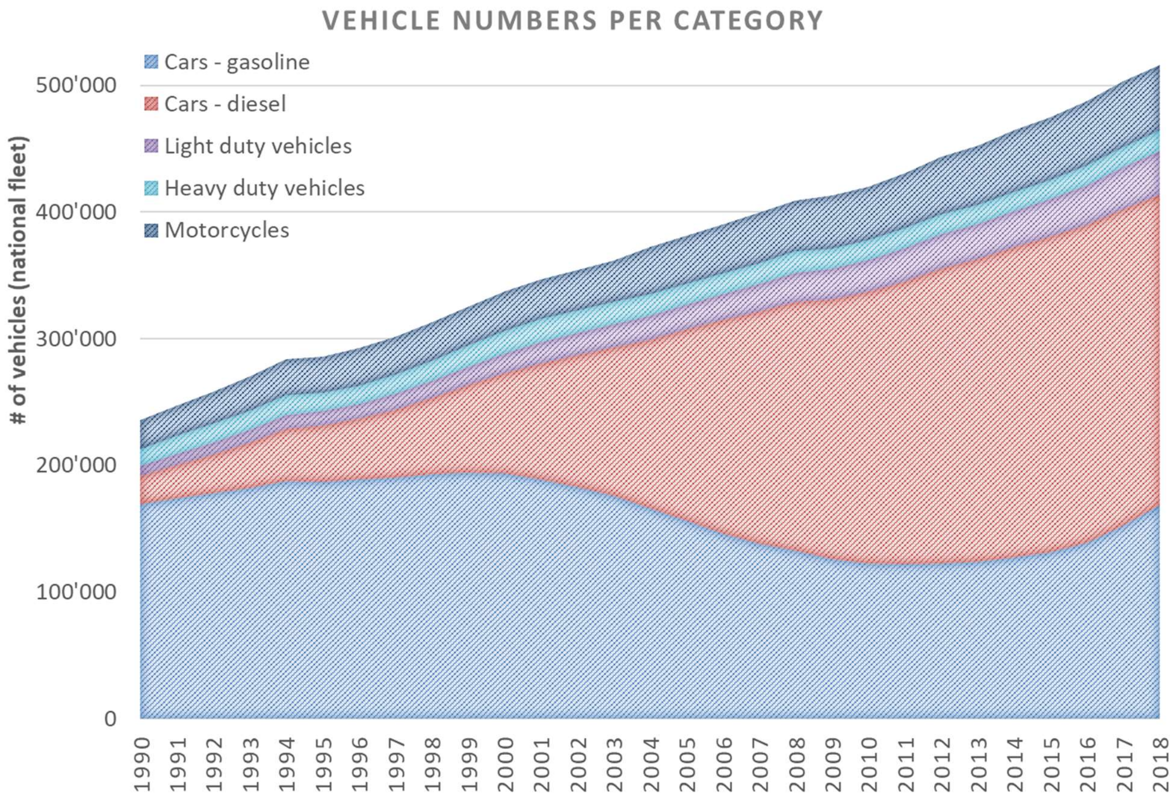


Table 3-61 – Domestic and road fuel export emissions for 1A3b - Road Transportation: 1990-2018

1A3b - Road Transportation										
CO_2 eq emissions (Gg)										
Year	National Total (excl. CO_2 from biomass)	CO_2 from biomass	CH_4 and N_2O 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	**2591**	**NO**	**NO**	**NO**	594	271	11.57	713	1002	NO
1991	**3184**	**NO**	**NO**	**NO**	602	308	12.12	932	1331	NO
1992	**3471**	**NO**	**NO**	**NO**	618	335	9.96	1055	1452	NO
1993	**3518**	**NO**	**NO**	**NO**	619	382	10.62	1058	1448	NO
1994	**3576**	**NO**	**NO**	**NO**	618	394	10.56	1120	1433	NO
1995	**3338**	**NO**	**NO**	**NO**	626	444	10.18	1013	1246	NO
1996	**3447**	**NO**	**NO**	**NO**	644	451	7.64	1018	1327	NO
1997	**3708**	**NO**	**NO**	**NO**	649	490	3.53	1075	1490	NO
1998	**3887**	**NO**	**NO**	**NO**	648	542	8.52	1084	1605	NO
1999	**4212**	**NO**	**NO**	**NO**	639	567	7.91	1148	1850	NO
2000	**4848**	**NO**	**NO**	**NO**	623	632	6.06	1216	2371	NO
2001	**5093**	**NO**	**NO**	**NO**	600	728	7.78	1207	2550	NO
2002	**5283**	**NO**	**NO**	**NO**	571	815	7.71	1187	2702	NO
2003	**5840**	**NO**	**NO**	**NO**	548	889	6.16	1241	3155	NO
2004	**6794**	**1.48**	**0.01**	**0.08**	497	965	5.27	1232	4095	NO
2005	**7176**	**1.54**	**0.01**	**0.09**	446	1040	3.75	1128	4558	NO
2006	**6857**	**1.45**	**0.01**	**0.08**	408	1135	4.17	1006	4304	NO
2007	**6570**	**134.52**	**0.74**	**7.46**	376	1189	4.08	974	4019	NO
2008	**6668**	**133.52**	**0.85**	**7.47**	360	1276	4.77	922	4097	NO
2009	**6145**	**124.58**	**0.89**	**6.99**	335	1288	4.05	845	3665	NO
2010	**6507**	**124.86**	**0.97**	**6.67**	310	1315	4.06	786	4085	NO
2011	**6883**	**138.48**	**1.16**	**6.32**	294	1357	1.87	823	4401	NO
2012	**6581**	**143.90**	**1.32**	**6.70**	291	1355	5.11	798	4125	NO
2013	**6442**	**163.77**	**1.58**	**7.60**	292	1354	3.50	701	4083	NO
2014	**6133**	**208.19**	**2.14**	**9.93**	295	1383	4.04	664	3776	NO
2015	**5695**	**243.44**	**2.63**	**12.38**	298	1388	2.03	597	3395	NO
2016	**5526**	**261.05**	**2.93**	**12.89**	310	1398	2.20	558	3241	NO
2017	**5640**	**330.91**	**3.88**	**17.35**	342	1395	1.90	577	3303	NO
2018	**6020**	**359.04**	**4.22**	**18.40**	366	1368	1.01	637	3625	NO
Trend 1990-2018	**132.37%**	**NA**	**NA**	**NA**	-38.43%	404.98%	-91.27%	-10.57%	261.96%	NA
Trend 2017-2018	**6.74%**	**8.50%**	**8.74%**	**6.02%**	6.91%	-1.92%	-46.90%	10.41%	9.77%	NA
Share 1990	**NA**	**NA**	**NA**	**NA**	22.92%	10.46%	0.45%	27.51%	38.66%	NA
Share 2018	**NA**	**NA**	**NA**	**NA**	6.07%	22.72%	0.02%	10.59%	60.23%	NA

Source: Environment Agency

3.2.8.3.2 Methodological issues & time series consistency

3.2.8.3.2.1 Activity data

Table 3-62 and Table 3-63 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 259.

Table 3-62 – 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	21'604'061	476'935	12'835'255	33'966
1991	42 938 305	25'737'702	529'652	16'633'864	37'087
1992	46 614 793	28'057'819	564'376	17'951'523	41'074
1993	47 294 933	28'405'355	628'655	18'212'937	47'986
1994	48 078 551	30'573'119	679'217	16'773'429	52'785
1995	44 887 292	29'129'518	726'669	14'978'300	52'806
1996	46 345 206	29'886'707	764'543	15'639'828	54'128
1997	49 911 918	30'959'574	820'914	18'074'830	56'600
1998	52 341 502	31'954'800	877'962	19'449'340	59'400
1999	56 749 106	33'786'411	988'564	21'912'574	61'557
2000	65 369 123	35'962'840	1'087'008	28'255'160	64'115
2001	68 650 285	36'964'513	1'140'485	30'479'583	65'704
2002	71 230 571	37'540'574	1'201'776	32'419'830	68'391
2003	78 720 260	39'644'055	1'234'347	37'771'038	70'820
2004	91 686 325	40'516'557	1'270'910	49'822'060	76'797
2005	96 783 759	39'166'733	1'320'131	56'218'337	78'559
2006	92 433 016	37'511'182	1'373'628	53'467'944	80'262
2007	90 343 091	38'095'135	1'469'858	50'696'170	81'927
2008	91 643 030	37'807'773	1'536'146	52'215'899	83'211
2009	84 452 301	36'385'253	1'540'450	46'441'624	84'974
2010	89 200 320	34'839'895	1'592'132	52'681'964	86'329
2011	94 401 212	36'453'851	1'669'024	56'189'607	88'730
2012	90 341 905	35'554'805	1'709'751	52'986'767	90'582
2013	88 630 890	33'236'427	1'740'338	53'560'117	94'008
2014	85 057 218	32'784'421	1'825'746	50'349'952	97'099
2015	79 730 032	31'646'445	1'890'630	46'093'381	99'576
2016	77 665 447	31'133'664	1'938'658	44'490'003	103'123
2017	79 985 866	32'029'647	1'988'319	45'864'358	103'542
2018	85 374 709	37'171'259	2'393'695	45'711'263	98'492
Trend 1990-2018	*144.28%*	*73.08%*	*309.51%*	*255.80%*	*135.35%*

Source: Environment Agency

Table 3-63 – 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	11 542 702	8'839'340	476'935	2'192'461	33'966
1991	12 081 741	9'159'180	529'652	2'355'821	37'087
1992	12 537 306	9'525'055	564'376	2'406'801	41'074
1993	13 186 421	9'864'742	628'655	2'645'038	47'986
1994	13 217 237	10'168'365	679'217	2'316'870	52'785
1995	13 974 456	10'525'409	726'669	2'669'572	52'806
1996	14 315 894	10'999'276	764'543	2'497'947	54'128
1997	14 906 353	11'465'549	820'914	2'563'291	56'600
1998	15 599 771	11'990'557	877'962	2'671'853	59'400
1999	15 775 885	12'359'910	988'564	2'365'855	61'557
2000	16 433 309	12'730'911	1'087'008	2'551'275	64'115
2001	17 367 299	13'229'910	1'140'485	2'931'200	65'704
2002	18 155 018	13'574'414	1'201'776	3'310'437	68'391
2003	18 541 166	13'850'400	1'234'347	3'385'599	70'820
2004	19 120 391	14'222'004	1'270'910	3'550'680	76'797
2005	19 390 399	14'385'583	1'320'131	3'606'126	78'559
2006	20 185 202	14'845'291	1'373'628	3'886'021	80'262
2007	20 904 210	15'278'712	1'469'858	4'073'713	81'927
2008	21 888 169	15'970'377	1'536'146	4'298'434	83'211
2009	21 839 889	16'087'851	1'540'450	4'126'614	84'974
2010	21 968 949	15'890'769	1'592'132	4'399'718	86'329
2011	22 404 532	16'056'767	1'669'024	4'590'010	88'730
2012	22 393 265	16'182'566	1'709'751	4'410'365	90'582
2013	22 360 601	16'278'155	1'740'338	4'248'100	94'008
2014	23 471 957	16'868'047	1'825'746	4'681'065	97'099
2015	23 853 605	17'059'485	1'890'630	4'803'913	99'576
2016	24 291 860	17'326'555	1'938'658	4'923'525	103'123
2017	24 735 315	17'611'568	1'988'319	5'031'886	103'542
2018	24 603 394	17'066'937	2'393'695	5'044'270	98'492
Trend 1990-2018	*107.80%*	*89.57%*	*309.51%*	*128.18%*	*135.35%*

Source: Environment Agency

Figure 3-9 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 3-10).

Figure 3-9 – Vehicle numbers per category (national fleet).

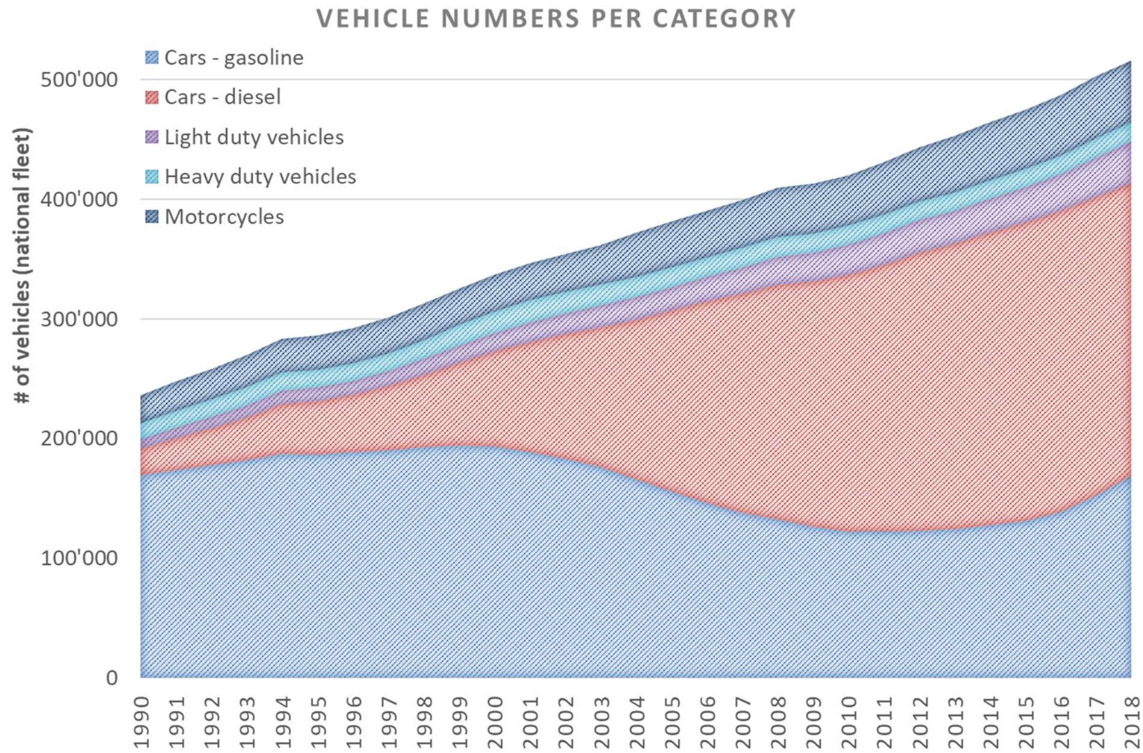


Figure 3-10 – Total mileage driven in Luxembourg.

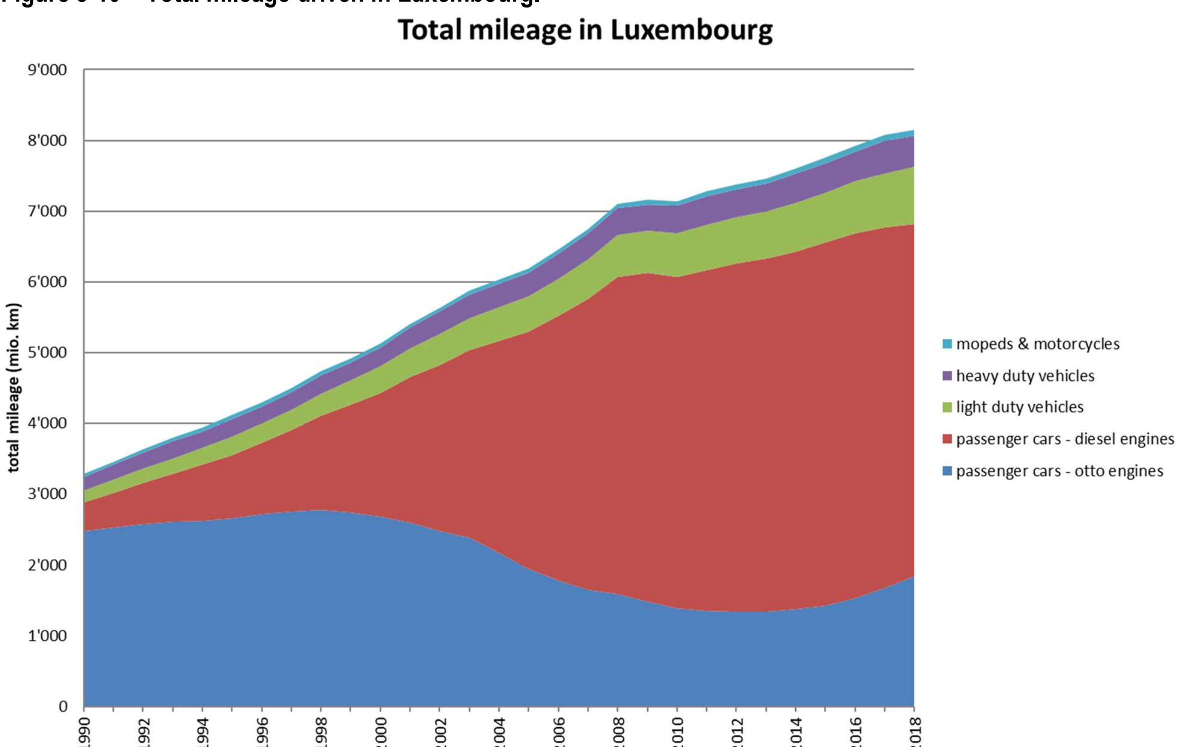
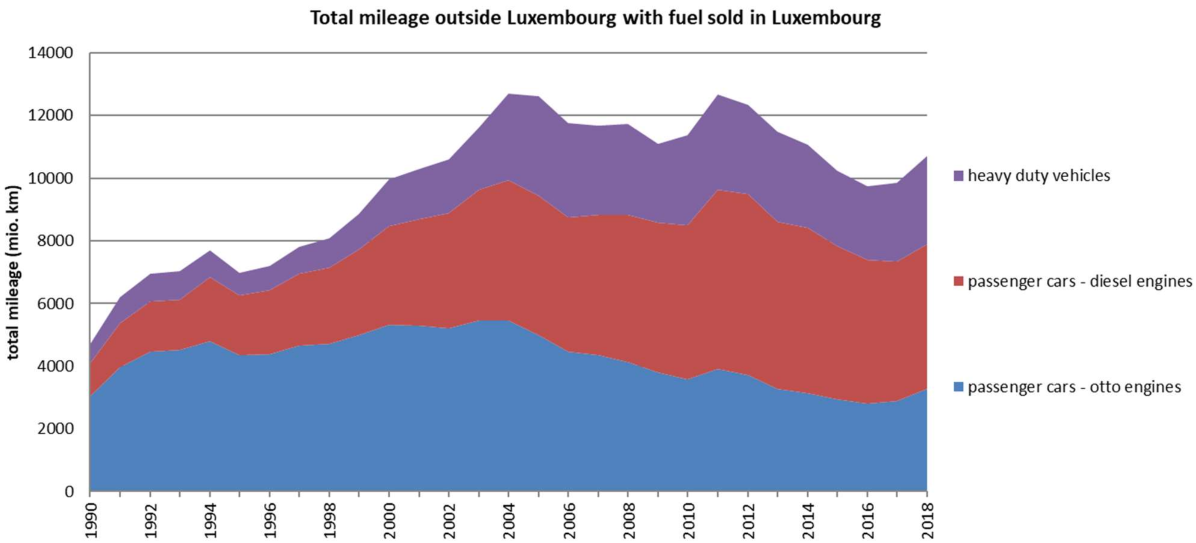


Figure 3-11 shows that the total mileage driven outside Luxembourg with fuel purchased in Luxembourg has approximately doubled since 1990. While the mileage driven with gasoline exported in passenger car tanks has remained relatively stable, the mileage driven with diesel exported from Luxembourg in the tanks of passenger cars and heavy-duty vehicles has significantly increased.

Figure 3-11 – Total mileage outside Luxembourg with fuel sold in Luxembourg.



3.2.8.3.2.2 <u>Methodology - The model NEMO and its application to Luxembourg's road transport situation</u>

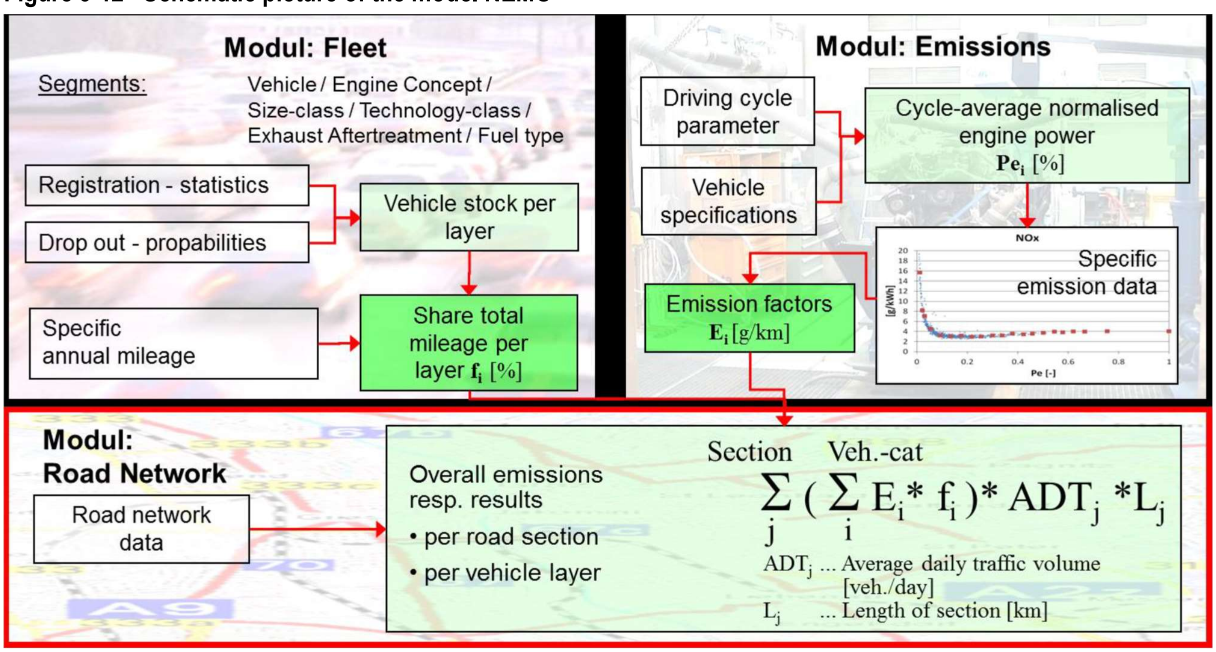
The model NEMO (Network Emission Model) was developed at the Institute for Internal Combustion Engines and Thermodynamics (IVT) at the Graz University of Technology (TUG) as tool for the simulation of traffic related emissions in road networks. Typical applications reach from emission inventories for 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 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 3-12– Schematic picture of the model NEMO



[80] http://www.hbefa.net/

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 CO_2 and SO_2 are simulated based on fuel consumption and fuel specifications. The non-regulated pollutants N_2O, NH_3, CH_4, NMVOC and C_6H_6 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 CO_2 of new registered vehicles in the NEDC type approval and literature on the discrepancies between NEDC and real world CO_2 reduction rates (HBEFA4.1)
- Evaporation from gasoline emissions (data and approach compatible to the HBEFA 4.1)
- Ambient temperature influence on NO_x 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 2020v1 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 CO_2 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, NO_2, N_2O, NH_3, 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.

In these calculations it is assumed that the composition of the commuting and transiting fleets is identical to the domestic fleet.

The GHG emissions from road transportation were calculated with the NEMO model (version 5.0.1 with HBEFA 4.1) for the timeseries 1990-2018 (TU Graz, 2019).

The values of the country-specific CO_2 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 CO_2 implied emission factors[81] for gasoline (71270 g/GJ) and diesel oil (73450 g/GJ), respectively, were used as emission factors.

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 2018 (no detailed information is currently available for other years), it has been calculated that 5.4% of the carbon atoms are of fossil origin. The fraction of 5.4% correlates very well with the value presented in [82]. 5.4% 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.

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[81] UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

[82] Environ. Sci. Technol. 2008, 42, 2476–2482 (table 2, p. 2480)

Table 3-64 – 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_2O	CO_2	CH_4	N_2O
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
Trend 2017-2018	6.02%	6.04%	6.02%	13.34%	7.77%	0.00%	6.91%	1.65%

Source: Environment Agency

Table 3-65, Table 3-66, Table 3-67 and Table 3-68 present the implied emission factors for each vehicle category.

Table 3-65 – 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_2O
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	73895	3.011	2.639
2018	73807	3.177	2.671

Table 3-66 – 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		
	CO_2 (fossil)	CH_4	N_2O
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	74135	1.816	2.918
2018	74113	2.182	3.168

Table 3-67 – 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		
	CO_2 (fossil)	CH_4	N_2O
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

Table 3-68 – 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_2O
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	73300	120.920	1.233
2018	73216	113.964	1.240

3.2.8.4 Railways (1A3c)

3.2.8.4.1 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 2018, railways fuel consumption (diesel oil and biodiesel) was responsible for 0.08% of GHG emissions from fuel combustion activities (0.24% in 1990) and represented 0.07% of the total GHG emissions in CO_2e, excluding LULUCF (0.20% in 1990). Compared to 2017, emissions increased by 6.29% to reach 7.02 Gg CO_2e in 2018. Compared to 1990, emissions decreased by 71.81%.

Activity data, GHG emissions and emission factors used to estimate emissions from *1A3c* are shown in Table 3-69. 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 3-69 – Activity data, emissions and emission factors for IPCC sub-category 1A3c – Railways: 1990-2018

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_2O	CO_2	type	CH_4	type	N_2O	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
Trend 1990-2018	-71.75%	-71.81%	-71.77%	-89.09%	-78.15%	-0.05%		-63.81%		-27.52%		

Source: Environment Agency

3.2.8.4.2 Methodological issues & time-series consistency

3.2.8.4.2.1 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 (2000-2018). 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.

3.2.8.4.2.2 Methodology

The 2006 IPCC Guidelines Tier 2 approach has been applied for CO_2 (use of country specific CO_2 emission factor). CH_4 and N_2O emissions were determined with the GEORG model (for details, please refer to section 3.2.7.8.2.2.).

3.2.8.4.2.3 Emission factors

The country specific CO_2 EF for diesel oil as described in section 3.2.5.3 was used (Tier 2). CH_4 and N_2O emissions were determined with the GEORG model based on HBEFA 4.1 (Table 3-69). The CH_4 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 N_2O emission factors are based on (Hausberger, 2006). For biodiesel and other fossil fuels (fossil part of biodiesel, please refer to page 260 for details), the European CO_2 implied emission factor[83] for diesel oil (73450 g/GJ) was applied.

3.2.8.5 Domestic Navigation (1A3d)

3.2.8.5.1 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 2018, 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 CO_2e, excluding LULUCF (0.01% in 1990). Compared to 2017, emissions have decreased by 2.38%. Compared to 1990, emissions have decreased by 15.98%.

Activity data and GHG emissions from *1A3d* are shown in Table 3-70.

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[83] UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

Navigation related GHG emissions are not a key source.

Table 3-70 – Activity data and emissions for IPCC Sub-category 1A3d – Domestic Navigation: 1990-2018

1A3d - Navigation Gas Oil, Diesel Oil, Biodiesel, Motor Gasoline, Bioethanol					
Year	Activity (GJ)	Emissions (Gg)			
		Total $CO_{2\,eq}$	CO_2	CH_4	N_2O
1990	17 686	1.44	1.30	0.0013	0.00034
1991	19 273	1.57	1.42	0.0016	0.00036
1992	18 355	1.50	1.36	0.0018	0.00034
1993	19 241	1.57	1.42	0.0018	0.00036
1994	18 300	1.50	1.35	0.0017	0.00035
1995	15 755	1.29	1.16	0.0014	0.00031
1996	15 903	1.30	1.17	0.0014	0.00031
1997	16 300	1.34	1.20	0.0013	0.00033
1998	15 785	1.29	1.17	0.0013	0.00032
1999	17 425	1.43	1.29	0.0013	0.00037
2000	15 300	1.26	1.13	0.0010	0.00034
2001	17 150	1.41	1.27	0.0011	0.00038
2002	18 758	1.54	1.39	0.0012	0.00042
2003	19 620	1.61	1.45	0.0012	0.00044
2004	18 142	1.49	1.34	0.0011	0.00040
2005	19 231	1.57	1.42	0.0010	0.00041
2006	17 815	1.45	1.32	0.0008	0.00037
2007	17 904	1.46	1.32	0.0008	0.00037
2008	20 049	1.62	1.48	0.0009	0.00041
2009	16 707	1.35	1.23	0.0007	0.00033
2010	18 263	1.47	1.35	0.0007	0.00035
2011	17 213	1.38	1.27	0.0006	0.00033
2012	17 112	1.37	1.27	0.0005	0.00031
2013	14 923	1.19	1.10	0.0005	0.00026
2014	15 846	1.26	1.17	0.0005	0.00027
2015	13 898	1.11	1.03	0.0004	0.00023
2016	14 505	1.16	1.07	0.0004	0.00024
2017	15 514	1.24	1.15	0.0004	0.00027
2018	15 190	1.21	1.12	0.0004	0.00025
Trend 1990-2018	-14.12%	-15.98%	-13.83%	-70.70%	-26.72%

Source: Environment Agency

3.2.8.5.2 Methodological issues & time-series consistency

3.2.8.5.2.1 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 3-70.

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: Schwebsange. 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).

3.2.8.5.2.2 Methodology

The Tier 2 approach has been applied for CO_2 (use of country specific CO_2 emission factors as described in section 3.2.5.3), while CH_4 and N_2O emissions were determined with the GEORG model (Tier 3, for details, please refer to section 3.2.7.8.2.2).

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 (Mertert), 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.

3.2.8.5.2.3 Emission factors

Table 3-71 shows the implied emission factors for 2018. The country-specific CO_2 EFs as described in section 3.2.5.3 were used. The CH_4 emission factors are based on the EMEP/EEA 2016 Guidebook (Tier 3 approach) while N_2O emission factors are based on (Hausberger, 2006). For biofuels and other fossil fuels (fossil part of biodiesel, please refer to page 260 for details), European CO_2 implied emission factors[85] for gasoline (71270 g/GJ) and diesel oil (73450 g/GJ) were applied.

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84 ARR 2009, §55

85 UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

Table 3-71 – Emission factors for IPCC sub-category 1A3d – Domestic Navigation

1A3d - Navigation Emission Factors for 2018 (kg/TJ)								
Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
Diesel Oil	liquid	74 130	CS	2.27	CS	17.75	CS	AEV
Motor Gasoline	liquid	73 216	CS	170.68	CS	0.78	CS	AEV

Source: Environment Agency

3.2.8.6 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.

3.2.8.7 Uncertainties and time-series consistency

The uncertainties for activity data and emission factors used for IPCC category *1A3 – Transport* are presented in Table 3-72.

Table 3-72: 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	CO2	10%	5%
1A3a - Transport - Civil Aviation	CH4	10%	100%
1A3a - Transport - Civil Aviation	N2O	10%	150%
1A3b - Road Transportation - Diesel Oil	CO2	2%	2%
1A3b - Road Transportation - Diesel Oil	CH4	2%	20%
1A3b - Road Transportation - Diesel Oil	N2O	2%	20%
1A3b - Road Transportation - Gasoline	CO2	2%	2%
1A3b - Road Transportation - Gasoline	CH4	2%	20%
1A3b - Road Transportation - Gasoline	N2O	2%	20%
1A3b - Road Transportation - LPG	CO2	2%	2%
1A3b - Road Transportation - LPG	CH4	2%	40%
1A3b - Road Transportation - LPG	N2O	2%	100%
1A3b - Road Transportation - biomass	CH4	2%	20%
1A3b - Road Transportation - biomass	N2O	2%	20%
1A3b - Road Transportation - other fossil fuels	CO2	20%	2%
1A3b - Road Transportation - other fossil fuels	CH4	20%	20%
1A3b - Road Transportation - other fossil fuels	N2O	20%	20%
1A3c - Railways - liquid fuels	CO2	2%	2%
1A3c - Railways - liquid fuels	CH4	2%	20%
1A3c - Railways - liquid fuels	N2O	2%	20%
1A3c - Railways - biomass	CH4	2%	20%
1A3c - Railways - biomass	N2O	2%	20%
1A3c - Railways - other fossil fuels	CO2	20%	2%
1A3c - Railways - other fossil fuels	CH4	20%	20%
1A3c - Railways - other fossil fuels	N2O	20%	20%
1A3d - Navigation - liquid fuels	CO2	2%	2%
1A3d - Navigation - liquid fuels	CH4	2%	20%
1A3d - Navigation - liquid fuels	N2O	2%	20%
1A3d - Navigation - biomass	CH4	2%	20%
1A3d - Navigation - biomass	N2O	2%	20%
1A3d - Navigation - other fossil fuels	CO2	20%	2%
1A3d - Navigation - other fossil fuels	CH4	20%	20%
1A3d - Navigation - other fossil fuels	N2O	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.

3.2.8.8 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.

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

Table 3-73 presents the main revisions and recalculations done since submission 2019v1 relevant to IPCC sub-category *1A3 - Transport*. For the impact of these recalculations on national total emissions, please refer to Chapter 10.

Table 3-73 – Recalculations done since submission 2019v1

GHG source & sink category	Revisions 2019v1 ➔ 2020v1	Type of revision
1A3b/c/d	Country-specific CO_2 emission factors for gasoline and diesel changed for the entire time-series because the Netherlands changed their national emission factors (see Table 3-74).	updated EF
1A3b/c	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. For submission 2019v1, these models used emission factors from HBEFA3.3. For submission 2020v1, the newer version HBEFA4.1 was implemented. Due to this methodological change, the allocation of fuel quantities to the different road and offroad subsectors was also revised. This is the case for gasoline, diesel, and biofuels. For further details, please see Table 3-75 to Table 3-79.	AD, EFs
1A3b/c/d	Update of transportation model inputs (fleet compositions and characteristics,traffic parameters).	Methodology, AD, EFs
1A3c	Revision of activity data for 2017	AD

Table 3-74 shows the recalculations made to Luxembourg's country-specific CO_2 emission factors for diesel oil / heating gasoil and motor gasoline. These changes result from modifications of the Netherlands' country-specific emissions factors for the entire timeseries.

Table 3-74 - Luxembourg's country-specific CO_2 emission factors for diesel oil / heating gasoil and gasoline for submissions 2020v.1 and 2019v.1.

	country-specific CO_2 emission factors (kg CO_2/TJ)					
	diesel oil / heating gasoil			gasoline		
	2020v.1	2019v.1	difference	2020v.1	2019v.1	difference
1990	74171	74239	-68	72583	72396	187
1991	74157	74242	-86	72612	72405	207
1992	74129	74244	-115	73253	72369	884
1993	74172	74238	-66	73039	72401	638
1994	74197	74236	-40	72984	72404	580
1995	74202	74235	-34	72932	72397	535
1996	74192	74239	-47	72964	72378	587
1997	74179	74239	-60	72829	72388	441
1998	74170	74238	-68	72876	72385	491
1999	74174	74235	-62	72816	72389	427
2000	74212	74229	-17	72625	72417	208
2001	74216	74224	-7	72700	72425	275
2002	74217	74221	-4	72682	72423	259
2003	74192	74204	-12	72757	72395	362
2004	74154	74222	-68	72559	72425	135
2005	74137	74224	-86	72629	72419	210
2006	74138	74224	-86	72660	72433	227
2007	74141	74194	-53	72547	72433	115
2008	74085	74200	-115	72515	72509	6
2009	74074	74216	-141	72473	72439	34
2010	74128	74207	-79	72436	72436	0
2011	74114	74218	-105	72468	72395	73
2012	74134	74214	-79	72455	72388	67
2013	74141	74189	-48	72597	72479	118
2014	74069	74206	-137	73106	73032	75
2015	74128	74204	-75	73216	73209	7
2016	74136	74197	-62	73197	73197	0
2017	74149	74175	-27	73300	73300	0

Table 3-75 to Table 3-79 show the recalculations of activity data and emissions that are due only to the switch from HBEFA3.3 to HBEFA4.1 for sectors 1A3b – Road transport and 1A3c - Railways. Please note that the total amounts of all fuels used for mobile combustion (road and off-road) did not change and are still equal to the amounts declared in the national energy balance.

Table 3-75 – Activity data recalculations in 1A3b – Road transportation due to the switch from HBEFA3.3 to HBEFA 4.1

1A3b - Road transport - Recalculations due to switch from HBEFA3.3 to HBEFA4.1

activity data (GJ)

	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3biii - heavy duty vehicles	1A3biii - heavy duty vehicles	1A3biv - two-wheelers	1A3biv - two-wheelers
year	**motor gasoline**	**diesel oil**	**biomass(1)**	**LPG**	**motor gasoline**	**diesel oil**	**biomass(1)**	**diesel oil**	**biomass(1)**	**motor gasoline**	**biomass**
1990	-51.49	-	-	-	51.32	94.30	-	-94.30	-	0.17	-
1991	-54.03	-	-	-	53.57	104.55	-	-104.55	-	0.46	-
1992	-54.05	-	-	-	53.27	111.66	-	-111.66	-	0.78	-
1993	-55.23	-	-	-	53.76	126.41	-	-126.41	-	1.47	-
1994	-56.33	-	-	-	53.86	136.68	-	-136.68	-	2.47	-
1995	-56.16	-	-	-	53.81	145.65	-	-145.65	-	2.35	-
1996	-56.17	-	-	-	52.74	152.93	-	-152.93	-	3.42	-
1997	-53.01	-	-	-	48.97	166.61	-	-166.61	-	4.04	-
1998	-50.11	-	-	-	45.41	179.41	-	-179.41	-	4.70	-
1999	-50.43	0.0001	-	-	44.78	201.76	-	-201.76	-	5.65	-
2000	-45.54	0.0014	-	-	39.29	222.91	-	-222.91	-	6.25	-
2001	-40.91	0.0032	-	-	34.18	231.03	-	-231.03	-	6.73	-
2002	-36.72	0.0038	-	-	29.43	237.91	-	-237.91	-	7.29	-
2003	-32.91	0.0057	-	-	25.05	237.91	-	-237.91	-	7.86	-
2004	-28.34	0.0272	0.000009	-	20.37	239.47	0.05	-239.38	-0.15	7.97	-
2005	-25.57	0.05	0.000016	-	17.69	240.92	0.04	-240.86	-0.15	7.88	-
2006	-24.58	0.06	0.000018	-	16.23	238.82	0.04	-238.77	-0.15	8.35	-
2007	-23.26	0.06	-0.07	-	14.87	233.52	3.55	-222.95	-13.45	8.40	0.02
2008	-21.61	0.06	-0.05	-	13.18	222.08	3.03	-211.33	-13.11	8.43	0.02
2009	-20.55	0.09	-0.04	-	11.80	205.00	2.63	-194.49	-12.54	8.75	0.02
2010	-19.16	0.18	-0.03	-	10.64	198.97	2.19	-188.86	-11.81	8.52	0.02
2011	-18.52	0.22	-0.32	-	9.78	197.42	2.01	-187.82	-11.03	8.75	0.15
2012	-18.09	0.20	-0.06	-	9.25	196.11	2.19	-184.68	-13.06	8.84	0.03
2013	-16.88	0.18	-0.03	-	8.37	198.97	2.57	-186.04	-14.83	8.51	0.02
2014	-16.01	0.17	-0.15	-	7.68	210.72	3.66	-192.77	-20.56	8.33	0.08
2015	-15.35	0.14	-0.37	-	7.06	216.64	4.64	-194.63	-25.21	8.29	0.20
2016	-14.78	-1.76	-0.56	-	6.35	220.99	5.16	-194.80	-27.73	8.42	0.26
2017	-13.88	-24.29	-2.04	-	5.68	223.46	6.70	-144.06	-32.76	8.20	0.18

(1) including fossil part of biodiesel

Table 3-76 – CO_2 emissions recalculations in 1A3b – Road transportation due to the switch from HBEFA3.3 to HBEFA 4.1

1A3b - Road transport - Recalculations due to switch from HBEFA3.3 to HBEFA4.1

CO_2 emissions (Gg)

	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3biii - heavy duty vehicles	1A3biii - heavy duty vehicles	1A3biv - two-wheelers	1A3biv - two-wheelers
year	motor gasoline	diesel oil	biomass(1)	LPG	motor gasoline	diesel oil	biomass(1)	diesel oil	biomass(1)	motor gasoline	biomass
1990	-3.73	-	-	-	3.72	7.00	-	-7.00	-	0.01	-
1991	-3.91	-	-	-	3.88	7.76	-	-7.76	-	0.03	-
1992	-3.91	-	-	-	3.86	8.29	-	-8.29	-	0.06	-
1993	-4.00	-	-	-	3.89	9.38	-	-9.38	-	0.11	-
1994	-4.08	-	-	-	3.90	10.15	-	-10.15	-	0.18	-
1995	-4.07	-	-	-	3.90	10.81	-	-10.81	-	0.17	-
1996	-4.07	-	-	-	3.82	11.35	-	-11.35	-	0.25	-
1997	-3.84	-	-	-	3.55	12.37	-	-12.37	-	0.29	-
1998	-3.63	-	-	-	3.29	13.32	-	-13.32	-	0.34	-
1999	-3.65	0.0000058	-	-	3.24	14.98	-	-14.98	-	0.41	-
2000	-3.30	0.0001041	-	-	2.85	16.55	-	-16.55	-	0.45	-
2001	-2.96	0.0002400	-	-	2.48	17.15	-	-17.15	-	0.49	-
2002	-2.66	0.0002857	-	-	2.13	17.66	-	-17.66	-	0.53	-
2003	-2.38	0.0004248	-	-	1.81	17.65	-	-17.65	-	0.57	-
2004	-2.05	0.0020224	0.000001	-	1.48	17.77	0.006	-17.77	-0.01	0.58	-
2005	-1.85	0.0040169	0.000001	-	1.28	17.88	0.005	-17.78	-0.01	0.57	-
2006	-1.78	0.0046616	0.000001	-	1.18	17.72	0.005	-17.51	-0.01	0.60	-
2007	-1.69	0.0043843	-0.005	-	1.08	17.11	0.459	-16.94	-0.46	0.61	0.002
2008	-1.57	0.0041391	-0.003	-	0.96	16.26	0.422	-16.24	-0.42	0.61	0.001
2009	-1.49	0.0068491	-0.003	-	0.85	15.00	0.395	-15.09	-0.39	0.63	0.001
2010	-1.39	0.0131471	-0.002	-	0.77	14.56	0.353	-14.79	-0.35	0.62	0.001
2011	-1.34	0.0161994	-0.023	-	0.71	14.45	0.330	-14.82	-0.32	0.63	0.011
2012	-1.31	0.0150701	-0.004	-	0.67	14.31	0.389	-14.74	-0.39	0.64	0.002
2013	-1.22	0.0123157	-0.002	-	0.61	14.47	0.456	-15.17	-0.46	0.62	0.001
2014	-1.17	0.0042126	-0.011	-	0.56	15.25	0.628	-16.60	-0.62	0.61	0.006
2015	-1.12	-0.0113918	-0.026	-	0.52	15.60	0.785	-17.66	-0.77	0.61	0.014
2016	-1.08	-0.1707391	-0.040	-	0.47	15.86	0.870	-18.42	-0.85	0.62	0.019
2017	-1.02	-1.8619542	-0.150	-	0.42	15.88	1.132	-15.73	-0.87	0.60	0.013

(1) including fossil part of biodiesel

Table 3-77 – CH_4 emissions recalculations in 1A3b – Road transportation due to the switch from HBEFA3.3 to HBEFA 4.1

1A3b - Road transport - Recalculations due to switch from HBEFA3.3 to HBEFA4.1

CH_4 emissions (Gg)

	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3biii - heavy duty vehicles	1A3biii - heavy duty vehicles	1A3biv - two-wheelers	1A3biv - two-wheelers
year	motor gasoline	diesel oil	biomass(1)	LPG	motor gasoline	diesel oil	biomass(1)	diesel oil	biomass(1)	motor gasoline	biomass
1990	0.012	0.00086	-	0.000111	0.00077	-0.00028	-	0.00499	-	-0.00015	-
1991	0.012	0.00089	-	0.000102	0.00079	-0.00029	-	0.00561	-	-0.00001	-
1992	0.009	0.00082	-	0.000059	0.00081	-0.00030	-	0.00530	-	0.00016	-
1993	0.005	0.00071	-	0.000036	0.00088	-0.00032	-	0.00446	-	0.00045	-
1994	0.001	0.00073	-	0.000011	0.00096	-0.00034	-	0.00333	-	0.00066	-
1995	-0.002	0.00062	-	-0.000008	0.00108	-0.00036	-	0.00284	-	0.00066	-
1996	-0.003	0.00068	-	-0.000012	0.00118	-0.00038	-	0.00248	-	0.00069	-
1997	-0.002	0.00088	-	-0.000003	0.00118	-0.00040	-	0.00217	-	0.00077	-
1998	0.002	0.00127	-	0.000010	0.00116	-0.00041	-	0.00194	-	0.00085	-
1999	0.007	0.00180	-	0.000030	0.00120	-0.00041	-	0.00155	-	0.00102	-
2000	0.012	0.00263	-	0.000040	0.00111	-0.00037	-	0.00113	-	0.00111	-
2001	0.017	0.00383	-	0.000071	0.00100	-0.00030	-	0.00098	-	0.00118	-
2002	0.020	0.00518	-	0.000087	0.00089	-0.00022	-	0.00083	-	0.00126	-
2003	0.024	0.00671	-	0.000079	0.00077	-0.00014	-	0.00071	-	0.00142	-
2004	0.025	0.00808	0.000003	0.000073	0.00063	-0.00006	-0.000000019	0.00063	0.00000020	0.00158	-
2005	0.023	0.00878	0.000003	0.000053	0.00054	0.00001	0.000000004	0.00064	0.00000019	0.00175	-
2006	0.021	0.00916	0.000003	0.000059	0.00049	0.00008	0.000000024	0.00062	0.00000018	0.00184	-
2007	0.020	0.00969	0.000317	0.000057	0.00043	0.00015	0.000005320	0.00059	0.00001592	0.00187	0.000005
2008	0.018	0.01006	0.000302	0.000065	0.00037	0.00022	0.000006443	0.00055	0.00001442	0.00188	0.000004
2009	0.016	0.01054	0.000310	0.000053	0.00031	0.00026	0.000007482	0.00044	0.00001171	0.00192	0.000004
2010	0.015	0.01200	0.000321	0.000052	0.00027	0.00034	0.000008761	0.00040	0.00000969	0.00193	0.000004
2011	0.014	0.01555	0.000593	0.000023	0.00024	0.00046	0.000014354	0.00035	0.00000783	0.00194	0.000034
2012	0.013	0.01822	0.000542	0.000058	0.00022	0.00068	0.000019218	0.00028	0.00000758	0.00200	0.000007
2013	0.011	0.02074	0.000680	0.000037	0.00020	0.00097	0.000031133	0.00023	0.00000736	0.00206	0.000004
2014	0.010	0.02717	0.001217	0.000040	0.00018	0.00137	0.000058170	0.00018	0.00000759	0.00209	0.000021
2015	0.008	0.03436	0.001919	0.000018	0.00017	0.00186	0.000097216	0.00014	0.00000707	0.00215	0.000053
2016	0.007	0.04326	0.002569	0.000016	0.00015	0.00259	0.000145709	0.00011	0.00000583	0.00225	0.000070
2017	0.006	0.05266	0.003894	0.000011	0.00014	0.00341	0.000246868	0.00008	0.00000560	0.00225	0.000050

(1) including fossil part of biodiesel

Table 3-78 – N_2O emissions recalculations in 1A3b – Road transportation due to the switch from HBEFA3.3 to HBEFA 4.1

1A3b - Road transport - Recalculations due to switch from HBEFA3.3 to HBEFA4.1

N_2O emissions (Gg)

	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3biii - heavy duty vehicles	1A3biii - heavy duty vehicles	1A3biv - two-wheelers	1A3biv - two-wheelers
year	motor gasoline	diesel oil	biomass(1)	LPG	motor gasoline	diesel oil	biomass(1)	diesel oil	biomass(1)	motor gasoline	biomass
1990	-0.0001258	-	-	-	0.0000426	-	-	-0.0002909	-	-	-
1991	-0.0001418	-	-	-	0.0001377	-	-	-0.0003833	-	-	-
1992	-0.0001594	-	-	-	0.0002287	-	-	-0.0004982	-	-	-
1993	-0.0001789	-	-	-	0.0003155	-	-	-0.0006994	-	-	-
1994	-0.0001963	-	-	-	0.0003507	-	-	-0.0007764	-	-	-
1995	-0.0002051	-	-	-	0.0003383	-	-	-0.0007450	-	-	-
1996	-0.0002058	-	-	-	0.0003181	-	-	-0.0008199	-	-	-
1997	-0.0001855	-	-	-	0.0002805	-	-	-0.0010014	-	-	-
1998	-0.0001628	-	-	-	0.0002434	-	-	-0.0011191	-	-	-
1999	-0.0001504	-1.8548098E-10	-	-	0.0002226	-	-	-0.0013023	-	-	-
2000	-0.0001248	-3.6399572E-09	-	-	0.0001822	-	-	-0.0017002	-	-	-
2001	-0.0001018	-8.4628568E-09	-	-	0.0001466	-	-	-0.0017489	-	-	-
2002	-0.0000813	-1.0026674E-08	-	-	0.0001161	-	-	-0.0017428	-	-	-
2003	-0.0000642	-1.5754381E-08	-	-	0.0000910	-	-	-0.0018676	-	-	-
2004	-0.0000485	-0.0000001	-	0.00000000	0.0000675	-	-	-0.0023073	-0.0000007	-	-
2005	-0.0000383	-0.0000001	-	0.00000000	0.0000527	-	-	-0.0029853	-0.0000009	-	-
2006	-0.0000325	-0.0000001	-	0.00000000	0.0000435	-	-	-0.0034560	-0.0000010	-	-
2007	-0.0000273	-0.0000001	-0.0000001	0.00000000	0.0000359	-	0.0000001	-0.0042259	-0.0001137	-	-
2008	-0.0000226	-0.0000001	-0.0000001	-0.00000001	0.0000285	-	0.0000001	-0.0053858	-0.0001407	-	-
2009	-0.0000194	0.0004965	0.0000131	-0.00000001	0.0000228	-	0.0000000	-0.0051831	-0.0001375	-	-
2010	-0.0000169	0.0023016	0.0000561	-0.00000001	0.0000190	0.0000376	0.0000010	-0.0061641	-0.0001502	-	-
2011	-0.0000163	0.0056237	0.0001248	-0.00000001	0.0000161	0.0001172	0.0000029	-0.0067419	-0.0001500	-	-
2012	-0.0000161	0.0088726	0.0002420	-0.00000003	0.0000143	0.0003100	0.0000085	-0.0063253	-0.0001726	-	-
2013	-0.0000155	0.0115733	0.0003676	-0.00000003	0.0000123	0.0005885	0.0000187	-0.0062714	-0.0001992	-	-
2014	-0.0000152	0.0161529	0.0006664	-0.00000004	0.0000086	0.0009425	0.0000390	-0.0053435	-0.0002205	-	-
2015	-0.0000076	0.0197946	0.0009903	-0.00000002	0.0000070	0.0013222	0.0000663	-0.0042566	-0.0002130	-	-
2016	0.0000038	0.0236829	0.0012912	-0.00000003	0.0000055	0.0018059	0.0000986	-0.0036885	-0.0002011	-	-
2017	0.0000240	0.0277012	0.0019788	-0.00000004	0.0000042	0.0023143	0.0001654	-0.0034061	-0.0002432	-	-

(1) including fossil part of biodiesel

Table 3-79 – CH_4 and N_2O emissions recalculations in 1A3c – Railways due to the switch from HBEFA3.3 to HBEFA 4.1

1A3c - Railways - Recalculations due to switch from HBEFA3.3 to HBEFA4.1				
	CH_4 (Gg)		N_2O (Gg)	
year	diesel oil	biomass(1)	diesel oil	biomass(1)
1990	7.23E-04		-8.54E-03	
1991	7.21E-04		-8.55E-03	
1992	7.19E-04		-8.55E-03	
1993	7.17E-04		-8.56E-03	
1994	6.92E-04		-8.35E-03	
1995	5.57E-04		-6.79E-03	
1996	6.19E-04		-7.62E-03	
1997	6.05E-04		-7.52E-03	
1998	6.01E-04		-7.56E-03	
1999	5.96E-04		-7.60E-03	
2000	5.86E-04		-7.55E-03	
2001	6.26E-04		-8.19E-03	
2002	5.38E-04		-7.24E-03	
2003	4.61E-04		-6.27E-03	
2004	3.60E-04	1.13E-07	-4.95E-03	-1.55E-06
2005	2.20E-04	6.47E-08	-3.08E-03	-9.06E-07
2006	1.58E-04	4.50E-08	-2.25E-03	-6.42E-07
2007	2.05E-04	5.51E-06	-3.00E-03	-8.08E-05
2008	2.19E-04	5.72E-06	-3.32E-03	-8.67E-05
2009	1.94E-04	5.16E-06	-3.06E-03	-8.13E-05
2010	1.93E-04	4.69E-06	-3.17E-03	-7.71E-05
2011	1.76E-04	3.91E-06	-3.03E-03	-6.74E-05
2012	1.51E-04	4.12E-06	-2.63E-03	-7.17E-05
2013	1.16E-04	3.68E-06	-2.12E-03	-6.73E-05
2014	1.15E-04	4.75E-06	-2.25E-03	-9.28E-05
2015	7.23E-05	3.62E-06	-1.47E-03	-7.34E-05
2016	6.39E-05	3.48E-06	-1.32E-03	-7.20E-05
2017	2.75E-05	1.96E-06	-1.75E-03	-1.25E-04
(1) including fossil part of biodiesel				

Table 3-80 to Table 3-89 show the overall recalculations in sector 1A3 due to the combination of changes listed in Table 3-73. It is important to note that the total amounts of fuels for mobile combustion have not changed and are always equal to the totals from the national energy balance published by Statec.

Table 3-80 - Activity data recalculations in 1A3b – Road transportation since submission 2019v1.

1A3b - Road transport - Recalculations since submission 2019v1 activity data (TJ)															
	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3biii - heavy duty vehicles	1A3biii - heavy duty vehicles	1A3biii - heavy duty vehicles	1A3biv - two-wheelers	1A3biv - two-wheelers	1A3b - total
year	motor gasoline	diesel oil	LPG	biomass	other fossil fuels(1)	motor gasoline	diesel oil	biomass	other fossil fuels(1)	diesel oil	biomass	other fossil fuels(1)	motor gasoline	biomass	all fuels
1990	-69.27	-58.43				61.38	46.22			12.21			7.88		
1991	-57.10	-42.12				48.94	65.56			-23.43			8.16		
1992	-40.31	-16.42				31.66	84.42			-68.00			8.65		
1993	-27.18	12.83				17.86	103.95			-116.78			9.31		
1994	-18.56	72.99				8.20	116.71			-189.70			10.36		
1995	-14.71	30.02				4.40	122.58			-152.60			10.31		
1996	-41.14	122.06				29.69	103.01			-225.06			11.45		
1997	-28.29	874.97				19.95	109.88			-984.85			8.34		
1998	-19.51	893.17				12.53	117.17			-1010.33			6.98		
1999	-14.25	1078.8741				7.60	130.36			-1209.23			6.66		
2000	-12.76	1275.8873				8.86	134.72			-1410.61			3.91		
2001	-12.82	1273.8721				9.90	142.12			-1415.99			2.93		
2002	-11.57	1459.8768				9.14	158.62			-1618.50			2.43		
2003	-11.46	1754.3422				8.47	180.50			-1934.85			2.98		
2004	-7.01	1839.7416		0.544478	0.031080	5.36	211.79	0.06	3.58E-03	-2051.53	-0.61	-0.03	1.66		
2005	-1.52	1773.93		0.493545	0.028173	3.10	238.85	0.07	3.79E-03	-2012.78	-0.56	-0.03	-1.58		
2006	0.74	1790.54		0.483289	0.027587	1.71	260.44	0.07	4.01E-03	-2050.98	-0.55	-0.03	-2.45		
2007	3.59	1646.46		41.94	2.39	1.33	269.00	6.85	0.39	-1915.46	-48.77	-2.78	-4.92	-0.01	3.10E-04
2008	1.78	2422.65		59.86	3.42	4.51	280.30	6.93	0.40	-2702.95	-66.78	-3.81	-6.29	-0.01	
2009	0.15	2872.73		72.10	4.12	3.99	280.25	7.04	0.40	-3152.98	-79.13	-4.52	-4.14	-0.01	
2010	1.10	3578.46		82.71	4.49	5.73	284.19	6.58	0.36	-3860.98	-89.24	-4.85	-6.83	-0.01	1.71
2011	1.49	4543.65		96.02	5.07	5.62	292.29	6.27	0.33	-4852.58	-102.52	-5.42	-7.21	-0.12	-17.11
2012	3.72	5168.19		134.60	6.44	5.48	287.46	7.51	0.36	-5456.02	-142.08	-6.79	-9.21	-0.03	-0.39
2013	5.98	5069.66		153.82	7.22	3.71	275.05	8.35	0.39	-5331.65	-161.76	-7.59	-9.62	-0.02	13.55
2014	-1.51	5028.77		197.64	9.86	11.14	248.98	9.90	0.49	-5297.98	-208.23	-10.39	-9.75	-0.10	-21.18
2015	3.84	4729.11		224.25	12.49	3.71	201.09	9.62	0.53	-5119.91	-242.68	-13.52	-8.64	-0.21	-200.33
2016	3.77	4290.73		221.86	12.17	3.12	266.78	13.88	0.76	-4741.66	-245.05	-13.45	-8.18	-0.25	-195.52
2017	-0.96	3511.68		237.51	13.25	5.78	279.83	19.06	1.06	-3886.48	-262.88	-14.67	-5.80	-0.13	-102.75

(1) fossil part of biodiesel

Table 3-81 – CO_2 recalculations in 1A3b – Road transportation since submission 2019v1.

1A3b - Road transport - Recalculations since submission 2019v1															
CO_2 emissions (Gg)															
	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3biii - heavy duty vehicles	1A3biii - heavy duty vehicles	1A3biii - heavy duty vehicles	1A3biv - two-wheelers	1A3biv - two-wheelers	1A3b - total
year	motor gasoline	diesel oil	LPG	biomass	other fossil fuels(1)	motor gasoline	diesel oil	biomass	other fossil fuels(1)	diesel oil	biomass	other fossil fuels(1)	motor gasoline	biomass	all fuels
1990	-1.77	-4.60				4.48	3.41			0.03			0.58		2.13
1991	0.11	-3.55				3.59	4.83			-3.16			0.60		2.41
1992	16.68	-1.87				2.46	6.21			-7.10			0.67		17.04
1993	12.24	0.56				1.41	7.68			-9.87			0.71		12.74
1994	12.07	5.13				0.70	8.64			-14.74			0.79		12.58
1995	10.60	1.99				0.41	9.08			-11.83			0.78		11.03
1996	9.99	8.69				2.26	7.61			-17.44			0.87		11.99
1997	8.10	64.43				1.52	8.11			-74.14			0.63		8.66
1998	9.97	65.66				0.98	8.64			-76.26			0.54		9.53
1999	9.21	79.4276				0.61	9.62			-91.04			0.51		8.34
2000	4.22	94.4926				0.67	9.98			-105.18			0.30		4.48
2001	5.78	94.4497				0.75	10.54			-105.32			0.23		6.43
2002	5.30	108.2924				0.69	11.77			-120.25			0.19		6.00
2003	7.93	129.9683				0.65	13.38			-144.01			0.24		8.15
2004	2.65	135.2696		0.039992	0.002283	0.40	15.62	4.60E-03	2.63E-04	-155.52	-0.04	-0.003	0.13		-1.45
2005	4.38	129.99		0.036251	0.002069	0.24	17.60	4.88E-03	2.79E-04	-152.74	-0.04	-0.002	-0.10		-0.64
2006	4.41	131.18		0.035498	0.002026	0.14	19.20	0.01	2.95E-04	-153.45	-0.04	-0.002	-0.16		1.30
2007	2.36	121.05		3.08	0.18	0.10	19.87	0.50	0.03	-139.35	-3.58	-0.20	-0.35	-1.02E-03	3.69
2008	0.23	177.22		4.40	0.25	0.33	20.60	0.51	0.03	-198.29	-4.90	-0.28	-0.46	-9.80E-04	-0.37
2009	0.56	210.01		5.30	0.30	0.29	20.55	0.52	0.03	-231.84	-5.81	-0.33	-0.30	-5.58E-04	-0.73
2010	0.08	263.73		6.08	0.33	0.42	20.95	0.48	0.03	-280.17	-6.55	-0.36	-0.49	-9.63E-04	4.51
2011	1.22	334.60		7.05	0.37	0.41	21.50	0.46	0.02	-354.00	-7.53	-0.40	-0.52	-8.91E-03	3.19
2012	1.26	381.55		9.89	0.47	0.40	21.18	0.55	0.03	-397.45	-10.44	-0.50	-0.66	-2.33E-03	6.28
2013	2.03	374.96		11.30	0.53	0.27	20.31	0.61	0.03	-386.37	-11.88	-0.56	-0.69	-1.35E-03	10.55
2014	0.86	369.91		14.52	0.72	0.82	18.21	0.73	0.04	-388.47	-15.29	-0.76	-0.71	-6.85E-03	0.55
2015	0.37	349.22		16.47	0.92	0.27	14.77	0.71	0.04	-373.51	-17.82	-0.99	-0.63	-1.51E-02	-10.21
2016	0.28	317.05		16.30	0.89	0.23	19.67	1.02	0.06	-345.52	-18.00	-0.99	-0.60	-1.81E-02	-9.63
2017	-0.07	260.00		17.44	0.97	0.42	20.71	1.40	0.08	-280.80	-19.31	-1.08	-0.43	-9.24E-03	-0.66
(1) fossil part of biodiesel															

Table 3-82 – CH_4 recalculations in 1A3b – Road transportation since submission 2019v1.

1A3b - Road transport - Recalculations since submission 2019v1															
CH_4 emissions (Gg)															
	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3biii - heavy duty vehicles	1A3biii - heavy duty vehicles	1A3biii - heavy duty vehicles	1A3biv - two-wheelers	1A3biv - two-wheelers	1A3b - total
year	motor gasoline	diesel oil	LPG	biomass	other fossil fuels(1)	motor gasoline	diesel oil	biomass	other fossil fuels(1)	diesel oil	biomass	other fossil fuels(1)	motor gasoline	biomass	all fuels (incl. biomass)
1990	0.04	1.36E-03	3.33E-04			6.39E-04	-2.43E-04			7.46E-03			2.95E-03		0.05
1991	0.04	1.50E-03	3.13E-04			5.50E-04	-2.52E-04			8.58E-03			3.08E-03		0.05
1992	0.03	1.48E-03	2.00E-04			3.91E-04	-2.50E-04			8.17E-03			3.33E-03		0.05
1993	0.03	1.36E-03	1.58E-04			2.79E-04	-2.66E-04			6.92E-03			3.61E-03		0.04
1994	0.02	1.49E-03	1.08E-04			2.17E-04	-2.78E-04			5.25E-03			3.84E-03		0.03
1995	0.01	1.24E-03	6.88E-05			2.22E-04	-2.95E-04			5.27E-03			3.86E-03		0.02
1996	0.01	1.40E-03	3.65E-05			4.60E-04	-3.17E-04			4.49E-03			3.92E-03		0.02
1997	0.01	2.37E-03	1.64E-05			2.18E-04	-3.32E-04			3.56E-03			3.83E-03		0.02
1998	0.01	2.77E-03	4.78E-05			2.15E-04	-3.32E-04			3.22E-03			3.85E-03		0.02
1999	0.01	3.51E-03	5.82E-05			2.51E-04	-3.21E-04			2.26E-03			3.75E-03		0.02
2000	0.02	4.55E-03	5.82E-05			3.09E-04	-2.85E-04			1.85E-03			3.67E-03		0.03
2001	0.02	5.83E-03	9.22E-05			3.07E-04	-2.12E-04			1.85E-03			3.63E-03		0.03
2002	0.03	7.44E-03	1.06E-04			2.80E-04	-1.28E-04			1.81E-03			3.67E-03		0.04
2003	0.03	9.37E-03	9.36E-05			2.45E-04	-4.38E-05			1.65E-03			3.79E-03		0.04
2004	0.03	1.09E-02	8.48E-05	3.22E-06	1.84E-07	1.89E-04	3.61E-05	1.07E-08	6.10E-10	2.01E-03	5.94E-07	3.39E-08	4.25E-03		0.05
2005	0.03	0.01	6.17E-05	3.19E-06	1.82E-07	1.65E-04	1.12E-04	3.10E-08	1.77E-09	2.08E-03	5.79E-07	3.30E-08	4.10E-03		0.05
2006	0.02	0.01	6.78E-05	3.18E-06	1.82E-07	1.56E-04	1.81E-04	4.89E-08	2.79E-09	1.86E-03	5.01E-07	2.86E-08	4.08E-03		0.04
2007	0.02	0.01	6.45E-05	3.74E-04	1.77E-05	1.43E-04	2.47E-04	6.70E-06	3.59E-07	1.53E-03	3.89E-05	2.22E-06	3.95E-03	1.15E-05	0.04
2008	0.02	0.01	7.15E-05	3.68E-04	1.85E-05	1.42E-04	3.09E-04	7.95E-06	4.36E-07	1.14E-03	2.81E-05	1.60E-06	3.89E-03	8.49E-06	0.04
2009	0.02	0.01	5.81E-05	3.86E-04	2.01E-05	1.07E-04	3.47E-04	8.91E-06	4.97E-07	7.20E-04	1.81E-05	1.03E-06	3.99E-03	7.55E-06	0.04
2010	0.02	0.02	5.72E-05	4.14E-04	2.08E-05	9.66E-05	4.22E-04	9.95E-06	5.30E-07	6.27E-04	1.45E-05	7.88E-07	3.89E-03	7.71E-06	0.04
2011	0.02	0.02	2.58E-05	7.42E-04	2.45E-05	7.31E-05	5.46E-04	1.28E-05	6.09E-07	4.46E-04	9.42E-06	4.98E-07	3.86E-03	6.69E-05	0.04
2012	0.01	0.03	6.47E-05	7.37E-04	3.28E-05	4.56E-05	7.68E-04	2.02E-05	9.57E-07	2.30E-04	5.98E-06	2.86E-07	4.01E-03	1.42E-05	0.05
2013	0.01	0.03	4.10E-05	9.27E-04	4.24E-05	1.99E-05	1.07E-03	3.24E-05	1.52E-06	1.66E-04	5.05E-06	2.37E-07	4.04E-03	7.93E-06	0.05
2014	0.01	0.04	4.48E-05	1.62E-03	7.52E-05	1.46E-04	1.42E-03	5.73E-05	2.79E-06	1.46E-04	5.73E-06	2.86E-07	4.05E-03	3.99E-05	0.06
2015	0.01	0.05	2.05E-05	2.47E-03	1.25E-04	8.69E-05	1.96E-03	9.48E-05	5.17E-06	8.39E-05	3.98E-06	2.21E-07	4.08E-03	9.97E-05	0.07
2016	0.01	0.06	1.92E-05	3.24E-03	1.64E-04	7.82E-05	2.71E-03	1.42E-04	7.68E-06	4.94E-05	2.55E-06	1.40E-07	4.14E-03	1.29E-04	0.08
2017	0.01	0.07	1.29E-05	4.69E-03	2.53E-04	8.35E-05	3.54E-03	2.41E-04	1.33E-05	7.48E-05	5.06E-06	2.82E-07	4.17E-03	9.31E-05	0.09

(1) fossil part of biodiesel

Table 3-83 – N_2O recalculations in 1A3b – Road transportation since submission 2019v1.

1A3b - Road transport - Recalculations since submission 2019v1															
N_2O emissions (Gg)															
	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3biii - heavy duty vehicles	1A3biii - heavy duty vehicles	1A3biii - heavy duty vehicles	1A3biv - two-wheelers	1A3biv - two-wheelers	1A3b - total
year	motor gasoline	diesel oil	LPG	biomass	other fossil fuels(1)	motor gasoline	diesel oil	biomass	other fossil fuels(1)	diesel oil	biomass	other fossil fuels(1)	motor gasoline	biomass	all fuels
1990	-1.83E-04	-2.06E-05	-2.68E-07			-3.62E-05				-3.50E-04			8.68E-06		-5.82E-04
1991	-1.68E-04	-2.49E-05	-2.89E-07			-6.52E-05				-5.13E-04			8.51E-06		-7.63E-04
1992	-1.40E-04	-1.28E-05	-2.49E-07			-9.46E-05				-6.76E-04			8.56E-06		-9.16E-04
1993	-1.11E-04	1.18E-05	-2.73E-07			-1.18E-04				-9.19E-04			8.17E-06		-1.13E-03
1994	-8.97E-05	7.45E-05	-2.76E-07			-1.66E-04	6.68E-06			-1.06E-03			7.98E-06		-1.22E-03
1995	-7.80E-05	3.29E-05	-2.68E-07			-2.24E-04	1.54E-05			-9.20E-04			8.07E-06		-1.17E-03
1996	-1.60E-04	1.56E-04	-1.20E-07			-1.18E-04	-7.07E-06			-1.05E-03			8.08E-06		-1.17E-03
1997	-7.41E-05	1.17E-03	2.66E-08			-9.88E-05	-1.52E-05			-1.62E-03			3.60E-06		-6.37E-04
1998	-1.13E-04	1.28E-03	-3.41E-07			-1.31E-04	-7.55E-07			-1.77E-03			1.14E-06		-7.37E-04
1999	-1.85E-04	1.66E-03	-7.60E-07			-1.62E-04	1.39E-05			-2.12E-03			-5.28E-07		-7.95E-04
2000	-1.97E-04	2.15E-03	-6.35E-07			-1.45E-04	8.81E-06			-2.62E-03			-4.53E-06		-8.03E-04
2001	-1.51E-04	2.35E-03	-6.17E-07			-1.24E-04	1.69E-06			-2.62E-03			-6.30E-06		-5.59E-04
2002	-7.35E-05	2.88E-03	-2.72E-07			-1.09E-04	-1.11E-05			-2.60E-03			-7.64E-06		8.33E-05
2003	-2.08E-05	3.63E-03	-1.85E-08			-9.23E-05	-1.72E-05			-2.86E-03			-7.79E-06		6.30E-04
2004	1.45E-04	3.95E-03	5.17E-07	1.17E-06	6.68E-08	-7.74E-05	-5.92E-06	-1.75E-09	-1.00E-10	-3.35E-03	-9.92E-07	-5.66E-08	-9.47E-06		6.54E-04
2005	2.60E-04	3.92E-03	6.88E-07	1.09E-06	6.23E-08	-6.68E-05	-2.27E-07	-6.30E-11	-3.59E-12	-4.32E-03	-1.20E-06	-6.86E-08	-1.33E-05		-2.19E-04
2006	2.20E-04	4.03E-03	7.13E-07	1.09E-06	6.21E-08	-5.78E-05	1.33E-06	3.59E-10	2.05E-11	-5.14E-03	-1.39E-06	-7.92E-08	-1.48E-05		-9.60E-04
2007	1.19E-04	3.76E-03	3.78E-07	9.62E-05	5.47E-06	-4.99E-05	-9.02E-07	-1.68E-07	-1.31E-09	-6.52E-03	-1.66E-04	-9.48E-06	-1.79E-05	1.15E-05	-2.77E-03
2008	-1.65E-05	0.01	-8.93E-08	1.38E-04	7.87E-06	-3.85E-05	-3.10E-06	-1.61E-07	-4.37E-09	-9.50E-03	-2.35E-04	-1.34E-05	-1.96E-05	8.49E-06	-4.09E-03
2009	-5.79E-05	0.01	-2.34E-07	1.82E-04	1.04E-05	-3.49E-05	-1.49E-06	-1.03E-07	-2.13E-09	-1.05E-02	-2.62E-04	-1.50E-05	-1.75E-05	7.55E-06	-3.38E-03
2010	2.96E-05	0.01	1.11E-07	2.60E-04	1.41E-05	-2.94E-05	2.70E-05	5.66E-07	3.39E-08	-1.35E-02	-3.11E-04	-1.69E-05	-2.05E-05	7.71E-06	-2.25E-03
2011	8.15E-05	0.02	1.49E-07	3.78E-04	1.99E-05	-2.87E-05	9.60E-05	1.53E-06	1.07E-07	-1.68E-02	-3.54E-04	-1.87E-05	-2.12E-05	6.69E-05	1.26E-03
2012	6.10E-05	0.02	3.07E-07	6.16E-04	2.94E-05	-3.02E-05	2.65E-04	6.79E-06	3.30E-07	-1.81E-02	-4.72E-04	-2.26E-05	-2.38E-05	1.42E-05	0.01
2013	2.26E-05	0.03	7.82E-08	8.14E-04	3.82E-05	-2.97E-05	5.00E-04	1.51E-05	7.12E-07	-1.85E-02	-5.60E-04	-2.63E-05	-2.44E-05	7.93E-06	0.01
2014	2.39E-05	0.03	1.11E-07	1.28E-03	6.38E-05	9.11E-08	7.19E-04	2.83E-05	1.41E-06	-1.77E-02	-6.96E-04	-3.47E-05	-2.48E-05	3.99E-05	0.02
2015	4.08E-05	0.04	9.94E-08	1.72E-03	9.59E-05	-8.14E-06	9.78E-04	4.62E-05	2.58E-06	-1.63E-02	-7.71E-04	-4.29E-05	-2.37E-05	9.97E-05	0.02
2016	4.65E-05	0.04	1.29E-07	2.04E-03	1.12E-04	-7.52E-06	1.55E-03	8.01E-05	4.41E-06	-1.49E-02	-7.70E-04	-4.23E-05	-2.37E-05	1.29E-04	0.03
2017	6.96E-06	0.04	1.89E-08	2.78E-03	1.55E-04	-5.59E-06	2.16E-03	1.46E-04	8.16E-06	-1.28E-02	-8.68E-04	-4.84E-05	-2.06E-05	9.31E-05	0.03

(1) fossil part of biodiesel

Table 3-84 – GHG recalculations in 1A3b – Road transportation since submission 2019v1.

1A3b - Road transport - Recalculations since submission 2019v1 GHG emissions (Gg CO_2eq)															
	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bi - passenger cars	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3bii - light duty vehicles	1A3biii - heavy duty vehicles	1A3biii - heavy duty vehicles	1A3biii - heavy duty vehicles	1A3biv - two-wheelers	1A3biv - two-wheelers	1A3b - total
year	motor gasoline	diesel oil	LPG	biomass	other fossil fuels[(1)]	motor gasoline	diesel oil	biomass	other fossil fuels[(1)]	diesel oil	biomass	other fossil fuels[(1)]	motor gasoline	biomass	all fuels
1990	-0.88	-4.58	8.25E-03			4.49	3.40			0.11			0.65		3.21
1991	1.07	-3.52	7.74E-03			3.58	4.82			-3.10			0.68		3.54
1992	17.49	-1.84	4.94E-03			2.44	6.21			-7.10			0.76		17.96
1993	12.85	0.60	3.87E-03			1.38	7.67			-9.97			0.80		13.34
1994	12.50	5.19	2.62E-03			0.65	8.63			-14.92			0.89		12.94
1995	10.87	2.03	1.64E-03			0.35	9.07			-11.97			0.88		11.23
1996	10.13	8.78	8.76E-04			2.24	7.60			-17.64			0.97		12.08
1997	8.28	64.84	4.17E-04			1.50	8.10			-74.53			0.73		8.92
1998	10.18	66.11	1.09E-03			0.95	8.63			-76.71			0.63		9.80
1999	9.49	80.01	1.23E-03			0.57	9.61			-91.62			0.60		8.68
2000	4.62	95.25	1.27E-03			0.63	9.98			-105.91			0.39		4.95
2001	6.29	95.29	2.12E-03			0.72	10.54			-106.05			0.32		7.11
2002	5.91	109.34	2.57E-03			0.66	11.76			-120.98			0.28		6.98
2003	8.63	131.28	2.33E-03			0.62	13.37			-144.83			0.34		9.42
2004	3.42	136.72	2.27E-03	0.04	2.31E-03	0.38	15.62	4.60E-03	2.63E-04	-156.47	-0.04	-2.56E-03	0.23		-0.09
2005	5.13	131.44	1.75E-03	0.04	2.09E-03	0.22	17.60	4.88E-03	2.79E-04	-153.98	-0.04	-2.37E-03	2.56E-04		0.42
2006	5.07	132.67	1.91E-03	0.04	2.05E-03	0.12	19.20	0.01	2.95E-04	-154.94	-0.04	-2.34E-03	-0.06		2.07
2007	2.95	122.48	1.72E-03	3.12	0.18	0.09	19.88	0.50	0.03	-141.26	-3.63	-0.21	-0.25	2.70E-03	3.88
2008	0.73	179.21	1.76E-03	4.45	0.25	0.32	20.61	0.51	0.03	-201.09	-4.97	-0.28	-0.36	1.76E-03	-0.61
2009	0.98	212.53	1.38E-03	5.36	0.31	0.28	20.56	0.52	0.03	-234.94	-5.89	-0.34	-0.20	1.88E-03	-0.80
2010	0.49	267.49	1.46E-03	6.16	0.33	0.41	20.96	0.48	0.03	-284.17	-6.65	-0.36	-0.40	1.53E-03	4.79
2011	1.64	340.46	6.89E-04	7.18	0.38	0.40	21.54	0.46	0.02	-358.99	-7.64	-0.40	-0.43	1.27E-02	4.66
2012	1.64	389.25	1.71E-03	10.09	0.48	0.39	21.28	0.55	0.03	-402.85	-10.58	-0.51	-0.57	2.27E-03	9.22
2013	2.34	383.70	1.05E-03	11.56	0.54	0.27	20.49	0.62	0.03	-391.86	-12.05	-0.57	-0.59	1.22E-03	14.48
2014	1.14	380.57	1.15E-03	14.94	0.75	0.82	18.46	0.74	0.04	-393.75	-15.50	-0.77	-0.61	6.05E-03	6.81
2015	0.61	361.23	5.42E-04	17.05	0.95	0.27	15.12	0.72	0.04	-378.36	-18.05	-1.01	-0.54	1.72E-02	-1.95
2016	0.49	330.24	5.19E-04	16.98	0.93	0.23	20.20	1.05	0.06	-349.96	-18.23	-1.00	-0.50	2.34E-02	0.50
2017	0.09	273.94	3.29E-04	18.39	1.03	0.42	21.44	1.45	0.08	-284.62	-19.57	-1.09	-0.33	2.08E-02	11.26

(1) fossil part of biodiesel

Table 3-85 – Activity data recalculations in 1A3a/c/d since submission 2019v1.

1A3a/c/d - Transport - Recalculations since submission 2019v1 activity data (TJ)								
	1A3a - aviation	1A3c - railways	1A3c - railways	1A3c - railways	1A3d - navigation	1A3d - navigation	1A3d - navigation	1A3d - navigation
year	aviation gasoline	diesel oil	biomass	other fossil fuels(1)	diesel oil	gasoline	biomass	other fossil fuels(1)
1990								
1991								
1992								
1993								
1994								
1995								
1996								
1997								
1998								
1999								
2000								
2001								
2002								
2003								
2004								
2005								
2006								
2007					-2.40E-04		-6.12E-06	-3.49E-07
2008								
2009								
2010								
2011					-6.07E-09		-1.28E-10	
2012					-1.09E-08		-2.84E-10	
2013					-1.27E-08		-3.84E-10	
2014					-2.13E-08		-8.36E-10	
2015					-2.58E-08		-1.22E-09	
2016					-4.12E-08		-2.13E-09	-1.17E-10
2017		-23.50	-0.09	-1.59	-1.92E-03		-1.30E-04	-7.25E-06

(1) fossil part of biodiesel

Table 3-86 – CO_2 recalculations in 1A3a/c/d since submission 2019v1.

1A3a/c/d - Transport - Recalculations since submission 2019v1 CO_2 emissions (Gg)								
	1A3a - aviation	1A3c - railways	1A3c - railways	1A3c - railways	1A3d - navigation	1A3d - navigation	1A3d - navigation	1A3d - navigation
year	aviation gasoline	diesel oil	biomass	other fossil fuels(1)	diesel oil	gasoline	biomass	other fossil fuels(1)
1990		-0.02			-8.99E-04	8.38E-04		
1991		-0.03			-1.19E-03	1.12E-03		
1992		-0.04			-1.47E-03	4.90E-03		
1993		-0.02			-9.18E-04	3.43E-03		
1994		-0.01			-5.19E-04	3.00E-03		
1995		-0.01			-3.91E-04	2.22E-03		
1996		-0.01			-5.53E-04	2.48E-03		
1997		-0.02			-7.43E-04	1.72E-03		
1998		-0.02			-8.14E-04	1.87E-03		
1999		-0.02			-8.32E-04	1.67E-03		
2000		-0.005			-2.15E-04	6.16E-04		
2001		-0.002			-1.02E-04	9.20E-04		
2002		-0.001			-6.11E-05	9.24E-04		
2003		-0.003			-1.97E-04	1.31E-03		
2004		-0.01			-1.03E-03	4.13E-04		
2005		-0.01			-1.41E-03	6.00E-04		
2006		-0.01			-1.32E-03	5.63E-04		
2007		-0.01			-8.34E-04	2.90E-04	-4.49E-07	-2.56E-08
2008		-0.02			-2.00E-03	1.45E-05		
2009		-0.02			-2.05E-03	7.44E-05		
2010		-0.01			-1.27E-03			
2011		-0.02			-1.62E-03	1.22E-04		
2012		-0.01			-1.23E-03	1.12E-04		
2013		-0.01			-6.34E-04	2.00E-04		
2014		-0.02			-1.84E-03	1.40E-04		
2015		-0.01			-7.47E-04	1.34E-05		
2016		-0.01			-4.05E-04		-1.56E-10	
2017		-1.75	-0.01	-0.12	2.64E-04		-9.54E-06	-5.32E-07

(1) fossil part of biodiesel

Table 3-87 – CH_4 recalculations in 1A3a/c/d since submission 2019v1.

1A3a/c/d - Transport - Recalculations since submission 2019v1 CH4 emissions (Gg)								
	1A3a - aviation	1A3c - railways	1A3c - railways	1A3c - railways	1A3d - navigation	1A3d - navigation	1A3d - navigation	1A3d - navigation
year	aviation gasoline	diesel oil	biomass	other fossil fuels(1)	diesel oil	gasoline	biomass	other fossil fuels(1)
1990		7.23E-04			8.73E-08			
1991		7.21E-04			9.41E-08			
1992		7.19E-04			8.79E-08			
1993		7.17E-04			1.18E-07			
1994		6.92E-04			1.02E-07			
1995		5.57E-04			1.02E-07			
1996		6.19E-04			9.65E-08			
1997		6.05E-04			9.30E-08			
1998		6.01E-04			9.30E-08			
1999		5.96E-04			1.02E-07			
2000		5.86E-04			1.12E-07			
2001		6.26E-04			1.12E-07			
2002		5.38E-04			1.17E-07			
2003		4.61E-04			1.17E-07			
2004		3.60E-04	6.08E-09	1.07E-07	1.12E-07			
2005		2.20E-04	3.50E-09	6.12E-08	1.41E-07			
2006		1.58E-04	2.43E-09	4.26E-08	1.44E-07			
2007		2.05E-04	2.97E-07	5.21E-06	1.15E-07		2.92E-09	1.67E-10
2008		2.19E-04	3.09E-07	5.41E-06	1.25E-07		3.10E-09	1.77E-10
2009		1.94E-04	2.78E-07	4.88E-06	1.00E-07		2.51E-09	1.43E-10
2010		1.93E-04	2.42E-07	4.45E-06	9.54E-08		2.20E-09	1.20E-10
2011		1.76E-04	1.96E-07	3.72E-06	1.17E-07		2.48E-09	1.31E-10
2012		1.51E-04	1.88E-07	3.93E-06	1.30E-07		3.38E-09	1.62E-10
2013		1.16E-04	1.65E-07	3.51E-06	1.33E-07		4.02E-09	1.89E-10
2014		1.15E-04	2.26E-07	4.52E-06	1.74E-07		6.85E-09	3.42E-10
2015		7.23E-05	1.91E-07	3.43E-06	2.06E-07		9.75E-09	5.43E-10
2016		6.39E-05	1.81E-07	3.30E-06	2.60E-07		1.34E-08	7.38E-10
2017		2.75E-05	1.04E-07	1.86E-06	3.60E-07		2.43E-08	1.36E-09

(1) fossil part of biodiesel

Table 3-88 – N_2O recalculations in 1A3a/c/d since submission 2019v1.

1A3a/c/d - Transport - Recalculations since submission 2019v1								
N_2O emissions (Gg)								
	1A3a - aviation	1A3c - railways	1A3c - railways	1A3c - railways	1A3d - navigation	1A3d - navigation	1A3d - navigation	1A3d - navigation
year	aviation gasoline	diesel oil	biomass	other fossil fuels(1)	diesel oil	gasoline	biomass	other fossil fuels(1)
1990		-8.54E-03						
1991		-8.55E-03						
1992		-8.55E-03						
1993		-8.56E-03						
1994		-8.35E-03						
1995		-6.79E-03						
1996		-7.62E-03						
1997		-7.52E-03						
1998		-7.56E-03						
1999		-7.60E-03						
2000		-7.55E-03						
2001		-8.19E-03						
2002		-7.24E-03						
2003		-6.27E-03						
2004		-4.95E-03	-8.36E-08	-1.46E-06				
2005		-3.08E-03	-4.89E-08	-8.57E-07				
2006		-2.25E-03	-3.47E-08	-6.07E-07				
2007		-3.00E-03	-4.37E-06	-7.65E-05	-5.59E-09		-1.42E-10	
2008		-3.32E-03	-4.68E-06	-8.20E-05				
2009		-3.06E-03	-4.39E-06	-7.69E-05				
2010		-3.17E-03	-3.98E-06	-7.32E-05				
2011		-3.03E-03	-3.38E-06	-6.40E-05				
2012		-2.63E-03	-3.27E-06	-6.85E-05				
2013		-2.12E-03	-3.02E-06	-6.43E-05				
2014		-2.25E-03	-4.41E-06	-8.84E-05				
2015		-1.47E-03	-3.88E-06	-6.96E-05				
2016		-1.32E-03	-3.75E-06	-6.83E-05				
2017		-1.75E-03	-6.62E-06	-1.19E-04	-3.54E-08		-2.40E-09	-1.34E-10
(1) fossil part of biodiesel								

Table 3-89 – GHG recalculations in 1A3a/c/d since submission 2019v1.

1A3a/c/d - Transport - Recalculations since submission 2019v1 GHG emissions (Gg CO_2eq)								
	1A3a - aviation	1A3c - railways	1A3c - railways	1A3c - railways	1A3d - navigation	1A3d - navigation	1A3d - navigation	1A3d - navigation
year	aviation gasoline	diesel oil	biomass	other fossil fuels(1)	diesel oil	gasoline	biomass	other fossil fuels(1)
1990		-2.55			-8.97E-04	8.38E-04		
1991		-2.56			-1.18E-03	1.12E-03		
1992		-2.57			-1.47E-03	4.90E-03		
1993		-2.56			-9.15E-04	3.43E-03		
1994		-2.48			-5.16E-04	3.00E-03		
1995		-2.02			-3.88E-04	2.22E-03		
1996		-2.27			-5.51E-04	2.48E-03		
1997		-2.24			-7.40E-04	1.72E-03		
1998		-2.26			-8.12E-04	1.87E-03		
1999		-2.27			-8.29E-04	1.67E-03		
2000		-2.24			-2.12E-04	6.16E-04		
2001		-2.43			-9.96E-05	9.20E-04		
2002		-2.14			-5.82E-05	9.24E-04		
2003		-1.86			-1.94E-04	1.31E-03		
2004		-1.48	-2.48E-05	-4.34E-04	-1.02E-03	4.13E-04		
2005		-0.92	-1.45E-05	-2.54E-04	-1.41E-03	6.00E-04		
2006		-0.67	-1.03E-05	-1.80E-04	-1.32E-03	5.63E-04		
2007		-0.90	-1.29E-03	-0.02	-8.33E-04	2.90E-04	-4.19E-07	-2.15E-08
2008		-1.00	-1.39E-03	-0.02	-2.00E-03	1.45E-05	3.10E-09	1.77E-10
2009		-0.93	-1.30E-03	-0.02	-2.04E-03	7.44E-05	2.51E-09	1.43E-10
2010		-0.95	-1.18E-03	-0.02	-1.27E-03		2.20E-09	1.20E-10
2011		-0.91	-1.00E-03	-0.02	-1.62E-03	1.22E-04	6.20E-08	3.27E-09
2012		-0.79	-9.71E-04	-0.02	-1.22E-03	1.12E-04	8.44E-08	4.04E-09
2013		-0.63	-8.95E-04	-0.02	-6.31E-04	2.00E-04	1.01E-07	4.72E-09
2014		-0.69	-1.31E-03	-0.03	-1.84E-03	1.40E-04	1.71E-07	8.54E-09
2015		-0.44	-1.15E-03	-0.02	-7.42E-04	1.34E-05	2.44E-07	1.36E-08
2016		-0.40	-1.11E-03	-0.02	-3.98E-04		3.36E-07	1.84E-08
2017		-2.27	-8.48E-03	-0.15	2.62E-04		-9.65E-06	-5.38E-07

(1) fossil part of biodiesel

3.2.8.10 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 3-90 will be explored.

Table 3-90 – Planned improvements for IPCC Sub-category 1A3 – Transport

GHG source & sink category	Planned improvement
1A3 - Transportation	No planned improvements

3.2.9 Other Sectors (1.A.4)

3.2.9.1 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 2018, category *1A4 - Other sectors* was responsible for 18.33% of GHG emissions from fuel combustion activities (this share was 13.23% in 1990) and represented around 15.78% of the total GHG emissions excluding LULUCF (10.67% in 1990).

Compared to 2017, emissions decreased by 3.64%, to attain the level of 1664.47 Gg CO_2e. Compared to 1990 emissions increased by 22.39%, mainly due to the steady increase in population and economic activity over the last two decades.

1A4 – Other Sectors is a key category regarding CO_2 emissions. It has been a key category for gaseous and liquid fuels without interruption since 1990, see Table 3-6 in Section 3.2.

Table 3-91 – GHG emission trends for category *1A4 – Other Sectors*: 1990-2018

Year	1A4 - Other Sectors: GHG emissions by source & sink category excluding CO_2 emissions from biomass (Gg)											
	1A4a - Commercial/Institutional				1A4b - Residential				1A4c - Agriculture/Forestry/Fisheries			
	Total CO_2 eq	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	Total CO_2 eq	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (incl. biomass)	Total CO_2 eq	CO_2 (excl. biomass)	CH_4 (incl. biomass)	N_2O (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	564.99	562.46	0.07	0.003	1 138.42	1 125.36	0.42	0.009	24.01	22.69	0.003	0.004
2018	594.85	592.21	0.07	0.003	1 045.30	1 032.03	0.43	0.009	24.33	23.05	0.004	0.004
Trend 1990-2018	-7.34%	-7.31%	-11.38%	-20.77%	53.47%	54.08%	15.39%	25.68%	-34.02%	-32.32%	-37.84%	-55.41%
Trend 2017-2018	5.28%	5.29%	4.89%	3.27%	-8.18%	-8.29%	2.21%	-1.12%	1.33%	1.56%	2.25%	-2.96%

Source: Environment Agency

Notes:

CO_2 emissions do not include CO2 emissions from biomass which are reported under Memo Items.

CH_4 emissions are converted in CO_2e 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.

N_2O emissions are converted in CO_2e 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.

3.2.9.2 Commercial/Institutional (1.A.4.a)

3.2.9.2.1 Source category description

In 2018, fuel combustion activities from the commercial and institutional sector were responsible for 6.55% 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 5.64% in 2018 and 5.04% in 1990. Compared to 2017, GHG emissions have increased by 5.28% to reach the level of 595 Gg CO_2e in 2018. Compared to 1990, emissions in this sub-category decreased by 7.34%.

3.2.9.2.2 Methodological issues & time-series consistency

3.2.9.2.2.1 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 is 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 is 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 was distributed arbitrarily, *i.e.* 50% is reported under *1A4a - Commercial/Institutional* and 50% under *1A4b - Residential*. From 2000 onwards, the consumption data reported by the national energy balance is properly split between the two categories *1A4a* and *1A4b*.

The total activity rate of category *1A4a* has been relatively constant in recent years (Table 3-92), with sharp decreases in 2007, 2011 and 2014, probably due to relatively mild winters.

Table 3-92 – 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	Other
1990	9 296 234	NO	6 359 553	2 936 681	NO	NO
1991	11 122 561	NO	7 822 330	3 300 231	NO	NO
1992	10 323 786	NO	6 985 232	3 338 553	NO	NO
1993	10 259 446	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	11 278 089	NO	6 794 806	4 483 283	NO	NO
1997	10 906 999	NO	6 718 170	4 188 829	NO	NO
1998	11 463 249	NO	6 954 434	4 506 815	2 000	NO
1999	10 387 398	NO	5 942 758	4 441 640	3 000	NO
2000	8 915 370	NO	2 673 823	6 220 885	20 662	NO
2001	7 837 822	NO	3 312 877	4 491 584	33 361	NO
2002	7 957 180	NO	3 009 270	4 902 833	45 078	NO
2003	7 974 408	NO	2 693 297	5 243 119	37 993	NO
2004	7 357 752	NO	2 685 214	4 642 785	29 753	NO
2005	6 615 090	NO	2 495 701	4 091 000	28 389	NO
2006	6 505 067	NO	1 498 922	4 977 905	28 240	NO
2007	5 730 623	NO	1 383 477	4 319 537	27 609	NO
2008	6 344 565	NO	1 090 665	5 220 321	33 579	NO
2009	6 397 614	NO	1 079 899	5 275 683	42 033	NO
2010	8 175 626	NO	2 428 020	5 710 750	36 856	NO
2011	5 383 896	NO	1 927 682	3 416 530	39 684	NO
2012	7 169 998	NO	2 107 114	5 018 938	43 946	NO
2013	7 474 883	NO	2 527 936	4 887 692	59 255	NO
2014	6 406 079	NO	2 292 116	4 045 292	68 671	NO
2015	7 673 470	NO	3 316 512	4 302 114	54 843	NO
2016	8 156 522	NO	3 218 903	4 850 237	87 382	NO
2017	8 576 206	NO	4 751 812	3 772 602	51 792	NO
2018	9 103 209	NO	4 803 316	4 253 639	46 254	NO
Trend 1990-2018	-2.08%	NA	-24.47%	44.85%	NA	NA
Trend 2017-2018	6.14%	NA	1.08%	12.75%	-10.69%	NA

Source: Environment Agency

3.2.9.2.2.2 Methodology

The 2006 IPCC Guidelines Tier 2 approach has been applied for CO_2 for all fuels except for biomass (only biogas is used) for which a Tier 1 approach was used, while the Tier 1 approach was used for CH_4 and N_2O.

3.2.9.2.2.3 Emission factors

Default CH_4 and N_2O emission factors have been applied for all fuels. For biomass (biogas, wood&wood wastes) the IPCC default EFs were applied. For gas oil, diesel oil, LPG and natural gas, country specific CO_2 emission factors were used (Table 3-93).

Table 3-93 – Emission factors for category *1A4a – Commercial/Institutional*

1A4a - Commercial/Institutional
Emission Factors for 2018 (kg/TJ)

Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
LPG	liquid	65 212	CS	5.00	D	0.10	D	AEV 2006 IPCC GL
Gas Oil	liquid	74 130	CS	10.00	D	0.60	D	AEV 2006 IPCC GL
Natural Gas	gaseous	56 209	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	30.00	D	4.00	D	2006 IPCC GL

Source: Environment Agency

Table 3-94 gives an overview of the evolution of the implied emission factors per fuel type. The slight fluctuations for the CH_4 and NO_2 IEFs for liquid fuels are due to fluctuations in the fuel mix (gasoil and LPG).

Table 3-94 – 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_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
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	73 449	9.61	0.56	56 577	5.00	0.10
2018	55 949	11.93	0.19	73 514	9.65	0.57	56 209	5.00	0.10

Source: Environment Agency

3.2.9.3 Residential (1A4b)

3.2.9.3.1 Source category description

In 2018, fuel combustion activities in the residential sector were responsible for 11.51% of GHG emissions from fuel combustion activities (6.62% in 1990). With regard to total GHG emissions excluding LULUCF emissions from *1A4b – Residential* reached 9.91% in 2018 and 5.35% in 1990. Compared to 2017, GHG emissions decreased by 8.18%.

3.2.9.3.2 Methodological issues & time-series consistency

3.2.9.3.2.1 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 is 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 gasoil 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 was distributed arbitrarily, *i.e.* 50% was allocated to *1A4a - Commercial/Institutional* and 50% to *1A4b - Residential*. From 2000-2018, 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).

Activity data for both stationary and mobile sources, as described above, are listed in Table 3-95.

Table 3-95 – 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 and similar wood wastes	
1990	9 630 362	268 741	6 424 941	2 936 681	645 000	NO
1991	12 146 417	313 244	7 887 942	3 300 231	645 000	NO
1992	11 287 935	253 192	7 051 190	3 338 553	645 000	NO
1993	11 242 074	271 499	6 774 996	3 550 579	645 000	NO
1994	10 788 362	179 141	6 472 934	3 491 287	645 000	NO
1995	10 967 208	214 226	6 289 581	3 818 401	645 000	NO
1996	12 121 949	133 647	6 860 019	4 483 283	645 000	NO
1997	11 740 381	123 577	6 782 975	4 188 829	645 000	NO
1998	12 260 387	89 753	7 018 819	4 506 815	645 000	NO
1999	11 177 514	83 642	6 007 233	4 441 640	645 000	NO
2000	16 638 357	63 651	9 381 808	6 560 642	632 256	NO
2001	18 091 223	51 351	10 115 994	7 241 170	682 708	NO
2002	17 288 926	40 632	9 297 132	7 320 304	630 859	NO
2003	17 994 471	29 511	9 464 317	7 856 398	644 245	NO
2004	19 260 236	27 390	10 030 033	8 516 240	686 572	NO
2005	18 869 333	30 074	9 645 313	8 536 993	656 953	NO
2006	18 551 659	25 786	9 967 333	7 899 632	658 908	NO
2007	17 966 188	21 523	9 495 483	7 861 031	588 324	NO
2008	18 609 088	19 861	9 536 065	8 407 485	645 803	NO
2009	18 413 800	21 702	9 448 809	8 226 956	716 440	NO
2010	18 498 143	25 322	8 127 993	9 602 707	742 230	NO
2011	16 875 901	22 774	7 246 272	9 027 820	579 968	NO
2012	17 114 085	18 751	8 054 899	8 315 615	725 014	NO
2013	17 202 206	26 584	7 580 067	8 797 046	798 616	NO
2014	15 816 121	20 855	6 466 468	8 443 674	885 662	NO
2015	17 550 722	25 796	7 390 590	9 195 335	940 318	NO
2016	18 263 989	24 557	7 399 980	9 781 925	1 059 203	NO
2017	18 782 817	15 951	6 600 491	11 216 050	951 554	NO
2018	17 408 929	9 964	6 167 406	10 213 505	1 019 718	NO
Trend 1990-2018	80.77%	-96.29%	-4.01%	247.79%	58.10%	NA
Trend 2017-2018	-7.31%	-37.53%	-6.56%	-8.94%	7.16%	NA

Source: Environment Agency

3.2.9.3.2.2 Methodology

For stationary sources, the 2006 IPCC Guidelines Tier 2 approach has been applied for CO_2, while the Tier 1 approach was used for CH_4 and N_2O.

For mobile sources, the 2006 IPCC Guidelines Tier 2 approach has been applied for CO_2, while the method used for CH_4 and N_2O 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 3.2.7.8.2.2.

3.2.9.3.2.3 Emission factors

For stationary combustion sources, country specific CO_2 emission factors and default CH_4 and N_2O emission factors from the 2006 IPCC Guidelines were used for the main fuels: see Table 3-96. For mobile machinery, the country specific CO_2 EF for gasoline as described in section 3.2.5.3 was used (Tier 2). CH_4 and N_2O emissions were determined with the GEORG model (Table 3-69). The CH_4 emission factors are based on the EMEP/EEA 2016 Guidebook (Tier 3) while N_2O emission factors are based on (Hausberger, 2006). For biogasoline, the European CO_2 implied emission factor[86] for gasoline (71270 g/GJ) was applied.

Table 3-96 – Emission factors for IPCC sub-category 1A4b – Residential

1A4b - Residential
Emission Factors for 2018 (kg/TJ)

Fuel	Fuel Type	CO_2		CH_4		N_2O		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	65 212	CS	5.00	D	0.10	D	AEV 2006 IPCC GL
Gas Oil	liquid	74 130	CS	10.00	D	0.60	D	AEV 2006 IPCC GL
Gasoline	liquid	73 216	CS	82.76	CS	1.13	CS	AEV
Natural Gas	gaseous	56 209	CS	5.00	D	0.10	D	AEV 2006 IPCC GL
Wood and similar wood wastes	biomass	112 000	D	300.00	D	4.00	D	2006 IPCC GL

Source: Environment Agency

86 UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

Table 3-97 gives an overview of the evolution of the implied emission factors per fuel type.

Table 3-97 – 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_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
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	74 094	10.63	0.60	56 209	5.00	0.10

Source: Environment Agency

3.2.9.4 Agriculture/Forestry/Fishing (1A4c)

3.2.9.4.1 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 2018, fuel combustion activities in agriculture and forestry were responsible for 0.27% 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 0.23% in 2018 and 0.29% in 1990. Compared to 2017, GHG emissions decreased by 1.33%.

Emissions of *1A4c - Agriculture/Forestry/Fishing* are shown in Table 3-91 at the beginning of this section.

3.2.9.4.2 Methodological issues & time-series consistency

3.2.9.4.2.1 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 is 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 2014-2018, but its consumption is very small (around 7.8 TJ for 2018). 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 3-98.

Table 3-98 – Activity data and implied emission factors for category *1A4c – Agriculture/Forestry/Fishing*

Year	Activity (GJ)	Liquid			Gaseous			Biomass		
		CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
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	8.56	14.19	56 760	5.00	0.10	56 645	4.99	1.64
2016	472 297	74 122	8.35	13.30	56 561	5.00	0.10	56 423	5.04	1.38
2017	487 592	74 136	8.55	12.75	56 577	5.00	0.10	56 702	4.82	1.53
2018	511 561	74 116	8.32	12.19	56 209	5.00	0.10	56 526	4.92	1.35

1A4c - Agriculture/Forestry/Fishing
Activity Data and Implied Emission Factors (kg/TJ)

Source: Environment Agency

3.2.9.4.2.2 Methodological issues

For stationary sources, the 2006 IPCC Guidelines Tier 2 approach has been applied for CO_2, while the Tier 1 approach was used for CH_4 and N_2O.

For mobile sources, the 2006 IPCC Guidelines Tier 2 approach has been applied for CO_2, while the method used for CH_4 and N_2O 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 3.2.7.8.2.2.

3.2.9.4.2.3 Emission factors

Country-specific CO_2 emission factors have been applied for natural gas, gas oil and diesel oil. For stationary sources, default 2006 IPCC emission factors were used for CH_4, N_2O and CO_2 from biomass. For mobile sources, the country specific CO_2 EFs for diesel oil and gasoline as described in section 3.2.5.3 were used (Tier 2). CH_4 and N_2O emissions were determined with the GEORG model (Table 3-69). The CH_4 emission factors are based on the EMEP/EEA 2016 Guidebook (Tier 3) while N_2O emission factors are based on (Hausberger, 2006). For biogasoline, biodiesel and other fossil fuels (fossil part of biodiesel, please refer to page 260 for details), the European CO_2 implied emission factors[87] for gasoline (71270 g/GJ) and diesel oil (73450 g/GJ) were applied (Table 3-99).

Table 3-99 – Emission factors for category *1A4c – Agriculture/Forestry/Fishing*

1A4c - Agriculture/Forestry/Fishing
Emission Factors for 2018 (kg/TJ)

Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
Gas Oil	liquid	74 130	CS	10.00	D	0.60	D	AEV 2006 IPCC GL
Diesel Oil	liquid	74 130	CS	0.73	CS	12.37	CS	AEV
Gasoline	liquid	73 216	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	56 209	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 3-98.

87 UNFCCC SAI Report 2008, FCCC/WEB/SAI/2008, Table 1.30, p.66

3.2.9.5 Uncertainties and time-series consistency

The uncertainties for activity data and emission factors used for IPCC category *1A4 – Other Sectors* are presented in Table 3-100.

Table 3-100: 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	CO2	2%	0.5%
1A4 - Gaseous Fuels	CH4	2%	50%
1A4 - Gaseous Fuels	N2O	2%	50%
1A4 - Liquid Fuels	CO2	2%	0.5%
1A4 - Liquid Fuels	CH4	2%	50%
1A4 - Liquid Fuels	N2O	2%	50%
1A4 - Biomass	CH4	7%	50%
1A4 - Biomass	N2O	7%	60%
1A4 - Solid Fuels	CO2	1%	3%
1A4 - Solid Fuels	CH4	1%	50%
1A4 - Solid Fuels	N2O	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.

3.2.9.6 Source-specific QA/QC and verification

Standard QA/QC procedures (including consistency and completeness checks) were executed according to the QA/QC policy.

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

Table 3-101 presents the main revisions and recalculations relevant to category *1A4 – Other Sectors* since the last submission to the UNFCCC.

Table 3-101 – Recalculations done since submission 2019v1

GHG source & sink category	Revisions 2019v1 ➔ 2020v1	Type of revision
1A4	Fuel consumption data for natural gas for 2017 was revised due to revised energy balance from the national statistics institute	AD
1A4bii/cii	The country-specific CO_2 EF for gas/diesel oil and gasoline was revised for the entire timeseries due to changes of the emission factors of the importing countries (Table 3-74)	CO_2 EF
1A4bii/cii	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. For submission 2019v1, these models used emission factors from HBEFA3.3. For submission 2020v1, the newer version HBEFA4.1 was implemented. Due to this methodological change, the allocation of fuel quantities to the different road and offroad subsectors was also revised.	AD
1A4bii/cii	CH4 and N2O EFs for offroad machinery were modified from HBEFA3.3 to HBEFA4.1	CH_4 / N_2O EF

3.2.9.8 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 3-102 will be explored.

Table 3-102 – 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.

3.2.11 Other (1.A.5.)

3.2.11.1 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 2018, 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 (0.02% in 1990).

Compared to 2017, emissions decreased by 0.11%, to attain the level of 0.12 Gg CO2e. Compared to 1990 emissions decreased by 96.23%.

1A5 - Other related CO_2 emissions from liquid fuels have been identified as a key category in 1999. Table 3-103 summarizes GHG emissions for category *1A5 – Other*.

Table 3-103 – GHG emission trends in CO_2e for category 1A5 – Other: 1990-2018

Year	1A5 - Other GHG emissions by source & sink category (Gg)											
	1A5a - Stationary				1A5b - Mobile				1A5 - Other			
	Total CO_2	CO_2	CH_4	N_2O	Total CO_2	CO_2	CH_4	N_2O	Total CO_2	CO_2	CH_4	N_2O
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
1990-2018	NA	NA	NA	NA	-16.36%	-10.84%	-82.77%	-67.50%	-96.23%	-96.34%	-99.58%	-70.47%

Source: Environment Agency

Notes:

CO_2 emissions do not include CO_2 emissions from biomass which are reported under Memo Items.

CH_4 emissions are converted in CO_2e 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.

N_2O emissions are converted in CO_2e 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.

3.2.11.2 Stationary (1A5a)

3.2.11.2.1 Source category description

In 2018, 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.

3.2.11.2.2 Methodological issues & time-series consistency:

3.2.11.2.2.1 Activity data

Fuel consumption data (gas oil, LPG) is obtained from the national statistics institute and was attributed to this sub-category based on expert judgement. Activity data is listed in Table 3-104.

3.2.11.2.2.2 Methodology

The 2006 IPCC Guidelines Tier 2 approach has been applied to CO_2, whereas the Tier 1 approach was applied to CH_4 and N_2O.

Table 3-104 – 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_2O	Activity (GJ)	CO_2	CH_4	N_2O
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

Source: Environment Agency

3.2.11.2.2.3 Emission factors

Country specific CO_2 emission factors were applied to gas oil and LPG, whereas for CH_4 and N_2O, default 2006 IPCC emission factors were used (Table 3-105).

Table 3-105 – Emission factors for category *1A5 – Other*

1A5 - Other Emission Factors for 2018 (kg/TJ)								
Fuel	Fuel Type	CO_2		CH_4		N_2O		Source
		EF	type	EF	type	EF	type	
LPG	liquid	65 212	CS	5.00	D	0.10	D	AEV 2006 IPCC GL
Gas Oil	liquid	74 130	CS	10.00	D	0.60	D	AEV 2006 IPCC GL
Diesel Oil	liquid	74 130	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 3-104 .

3.2.11.3 Mobile (1A5b)

3.2.11.3.1 Source category description

In 2018, 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 2018 and 0.001% in 1990. Compared to 2017, GHG emissions decreased by 0.11%.

3.2.11.3.2 Methodological issues & time-series consistency

3.2.11.3.2.1 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 3-104.

3.2.11.3.2.2 Methodology

The 2006 IPCC Guidelines Tier 2 approach has been applied for CO_2, while the method used for CH_4 and N_2O 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 3.2.7.8.2.2.

3.2.11.3.2.3 Emission factors

The country specific CO_2 EF for diesel oil as described in section 3.2.5.3 was used (Tier 2). CH_4 and N_2O emissions were determined with the GEORG model (Table 3-69). The CH_4 emission factors are based on the EMEP/EEA 2016 Guidebook (Tier 3) while N_2O emission factors are based on (Hausberger, 2006).

For biodiesel and other fossil fuels (fossil part of biodiesel, please refer to 260 for details), the European CO_2 implied emission factor for diesel oil (73450 g/GJ) was applied.

3.2.11.4 Uncertainties and time-series consistency

The uncertainties for activity data and emission factors used for IPCC category *1A5 – Other* are presented in Table 3-106.

Table 3-106: 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.

3.2.11.5 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 3-108 presents the main revisions and recalculations relevant to category *1A5 – Other* since the last submission to the UNFCCC.

Table 3-107 – Recalculations done since submission 2019v1

GHG source & sink category	Revisions 2019v1 ➔ 2020v1	Type of revision
1A5b	The country-specific CO_2 EF for gas/diesel oil was revised for the entire timeseries due to changes of the emission factors of the importing countries (Table 3-74)	CO_2 EF
1A5b	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. For submission 2019v1, these models used emission factors from HBEFA3.3. For submission 2020v1, the newer version HBEFA4.1 was implemented. Due to this methodological change, the allocation of fuel quantities to the different road and offroad subsectors was also revised.	AD
1A5b	CH4 and N2O EFs for offroad machinery were modified from HBEFA3.3 to HBEFA4.1	EF

3.2.11.6 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*). 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 2018, 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 2017, fugitive GHG emissions decreased by 1.09% due to a lower natural gas consumption.

Table 3-108 summarizes GHG emissions for category *1B2 – Oil and natural gas and other emissions from energy production*. Exceptional inter-annual changes in 2001/2002 (+43%) and 2012/2013 (-15%) are due to the operational start of a new power plant (gas turbine), and its partial shutdown.

Fugitive emissions from *1B2 – Oil and natural gas and other emissions from energy production* are not a key category.

Table 3-108 – GHG emission trends in CO_2e for category *1B2 – Oil and natural gas and other emissions from energy production*: 1990-2018

Year	1B2 - Oil and Natural Gas CO_2e emissions (Gg) 1B2a - Oil Total	1B2a CO_2	1B2a CH_4	1B2a N_2O	1B2b - Natural Gas Total	1B2b CO_2	1B2b CH_4	1B2b N_2O	1B2c - Venting & Flaring Total	1B2c CO_2	1B2c CH_4	1B2c N_2O	1B2d - Other Total	1B2d CO_2	1B2d CH_4	1B2d N_2O
1990	NA	NA	NA	NO	19.39	0.03	0.77	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
1991	NA	NA	NA	NO	20.11	0.03	0.80	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
1992	NA	NA	NA	NO	20.99	0.03	0.84	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
1993	NA	NA	NA	NO	21.79	0.03	0.87	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
1994	NA	NA	NA	NO	21.94	0.03	0.88	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
1995	NA	NA	NA	NO	25.01	0.03	1.00	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
1996	NA	NA	NA	NO	27.36	0.04	1.09	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
1997	NA	NA	NA	NO	27.98	0.04	1.12	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
1998	NA	NA	NA	NO	28.20	0.04	1.13	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
1999	NA	NA	NA	NO	29.20	0.04	1.17	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2000	NA	NA	NA	NO	29.98	0.04	1.20	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2001	NA	NA	NA	NO	33.32	0.04	1.33	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2002	NA	NA	NA	NO	47.72	0.06	1.91	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2003	NA	NA	NA	NO	48.36	0.06	1.93	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2004	NA	NA	NA	NO	53.67	0.07	2.14	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2005	NA	NA	NA	NO	52.87	0.07	2.11	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2006	NA	NA	NA	NO	55.48	0.07	2.22	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2007	NA	NA	NA	NO	51.91	0.07	2.07	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2008	NA	NA	NA	NO	49.64	0.07	1.98	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2009	NA	NA	NA	NO	50.18	0.07	2.00	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2010	NA	NA	NA	NO	53.96	0.07	2.16	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2011	NA	NA	NA	NO	46.78	0.06	1.87	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2012	NA	NA	NA	NO	47.85	0.06	1.91	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2013	NA	NA	NA	NO	40.74	0.05	1.63	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2014	NA	NA	NA	NO	38.47	0.05	1.54	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2015	NA	NA	NA	NO	34.60	0.05	1.38	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2016	NA	NA	NA	NO	31.80	0.04	1.27	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2017	NA	NA	NA	NO	31.32	0.04	1.25	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
2018	NA	NA	NA	NO	30.98	0.04	1.24	NO,NA	NO,NA	NO	NO	NO	NA	NA	NA	NA
Trend 1990-2018	NA	NA	NA	NA	59.77%	59.77%	59.77%	NA	NA	NA	NA	NA	NA	NA	NA	NA
Trend 2017-2018	NA	NA	NA	NA	-1.09%	-1.09%	-1.09%	NA	NA	NA	NA	NA	NA	NA	NA	NA

Source: Environment Agency

Notes: CH_4 emissions are converted in CO_2e 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 3-109.

Table 3-109 – Activity data for category *1B2 – Oil and natural gas and other emissions from energy production*: 1990-2018

Natural Gas Consumption (GJ)

1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
17'933'317	18'646'148	19'434'013	20'184'361	20'334'431	23'237'685	25'491'947	26'121'115	26'375'108	27'358'063
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**	
50'108'059	43'235'365	44'010'941	37'284'498	35'310'029	32'201'184	29'685'081	29'283'800	28'792'801	

Source: STATEC: national energy balance.

3.3.2.2.2 Methodology

The 2006 IPCC Guidelines Tier 1 approach has been applied.

3.3.2.2.3 Emission factors

2006 IPCC Guidelines default emission factors have been applied:

- Natural Gas Transmission - CO_2: .... $8.8*10^{-7}$ Gg/10^6 m^3
- Natural Gas Distribution - CO_2: .... $5.1*10^{-5}$ Gg/10^6 m^3
- Natural Gas Transmission - CH_4: .... $4.8*10^{-4}$ Gg/10^6 m^3
- Natural Gas Distribution - CH_4: .... $1.1*10^{-3}$ Gg/10^6 m^3

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.

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 3-110.

Table 3-110: 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 (%)
1B2b – Natural Gas	CO2	2%	100%
1B2b – Natural Gas	CH4	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 3-111 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 3-111 – Recalculations done since submission 2019v1

GHG source & sink category	Revisions 2019v1 → 2020v1	Type of revision
1B2	No revisions were made.	

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 3-112 will be explored.

Table 3-112 – 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 3.1 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 2018.

Emissions from this sector comprise emissions from the following categories: mineral products (2A), metal production (2C) and consumption of halocarbons (2F), SF_6 and N_2O (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 3.2.7).

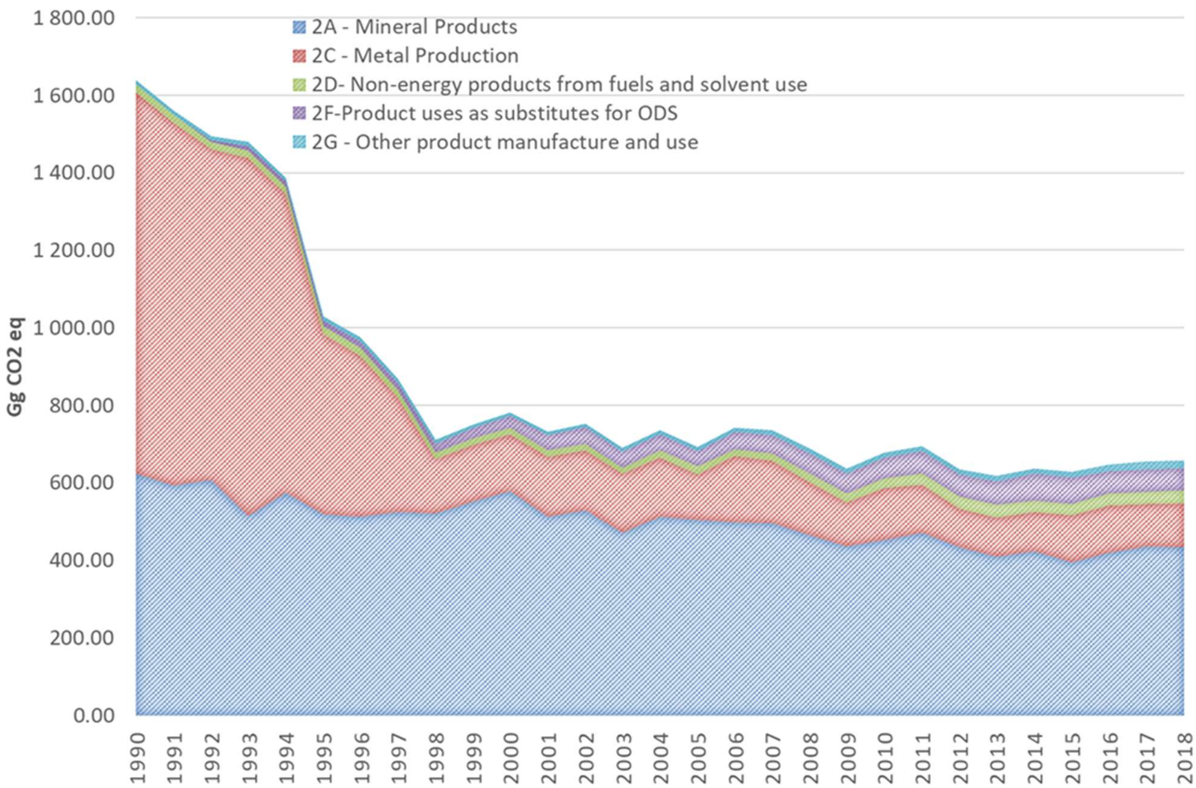
4.1.1 Emission Trends

This section briefly describes the emission trends from 1990 to 2018 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 SF_6 (the fluorinated gases (HFCs and SF_6) 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.

As shown in Figure 4-1 and Table 4-1, emissions of GHG due to industrial processes have decreased by about 59.83% between 1990 and 2018, (-64.30%-for carbon dioxide but +9752.96% for F-gases). 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 CO_2 emissions have decreased the most over the same period: 88.39%. For IPCC Category 2A – Mineral Products the decline is limited to 30.34%- for CO_2 emissions.

Figure 4-1 – GHG emission trends for CRF Sector 2 – Industrial Processes: 1990-2018



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, but also of the hypothesis made for their estimation: see Section 4.7.

Figure 4-2 and Figure 4-3 provide a quick overview on industrial processes related emission trends between 1990 and 2018. More explanations are presented in the subsequent sections detailing each of the sector source sub-categories.

Table 4-1 – GHG emission trends in CO_2e for CRF Sector 2 – Industrial Processes: 1990-2018

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_2O	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O
1990	623.45	623.45	NO	NO	984.91	984.91	NO	NO	20.54	20.54	NO	NO
1991	592.76	592.76	NO	NO	937.74	937.74	NO	NO	20.09	20.09	NO	NO
1992	607.15	607.15	NO	NO	853.29	853.29	NO	NO	19.08	19.08	NO	NO
1993	515.03	515.03	NO	NO	923.19	923.19	NO	NO	18.81	18.81	NO	NO
1994	575.35	575.35	NO	NO	770.83	770.83	NO	NO	18.09	18.09	NO	NO
1995	519.11	519.11	NO	NO	465.38	465.38	NO	NO	19.76	19.76	NO	NO
1996	512.12	512.12	NO	NO	416.60	416.60	NO	NO	19.52	19.52	NO	NO
1997	525.97	525.97	NO	NO	294.10	294.10	NO	NO	18.45	18.45	NO	NO
1998	520.30	520.30	NO	NO	140.69	140.69	NO	NO	17.52	17.52	NO	NO
1999	551.34	551.34	NO	NO	147.70	147.70	NO	NO	16.86	16.86	NO	NO
2000	579.74	579.74	NO	NO	146.05	146.05	NO	NO	16.04	16.04	NO	NO
2001	513.12	513.12	NO	NO	154.76	154.76	NO	NO	16.23	16.23	NO	NO
2002	528.32	528.32	NO	NO	155.40	155.40	NO	NO	17.76	17.76	NO	NO
2003	471.66	471.66	NO	NO	151.94	151.94	NO	NO	15.24	15.24	NO	NO
2004	513.37	513.37	NO	NO	152.45	152.45	NO	NO	17.81	17.81	NO	NO
2005	503.80	503.80	NO	NO	119.13	119.13	NO	NO	18.97	18.97	NO	NO
2006	499.08	499.08	NO	NO	170.49	170.49	NO	NO	17.24	17.24	NO	NO
2007	495.96	495.96	NO	NO	162.22	162.22	NO	NO	17.42	17.42	NO	NO
2008	466.02	466.02	NO	NO	134.69	134.69	NO	NO	23.67	23.67	NO	NO
2009	437.09	437.09	NO	NO	112.66	112.66	NO	NO	21.72	21.72	NO	NO
2010	453.57	453.57	NO	NO	133.61	133.61	NO	NO	23.67	23.67	NO	NO
2011	471.94	471.94	NO	NO	123.86	123.86	NO	NO	28.18	28.18	NO	NO
2012	433.31	433.31	NO	NO	100.23	100.23	NO	NO	28.55	28.55	NO	NO
2013	409.16	409.16	NO	NO	101.59	101.59	NO	NO	30.92	30.92	NO	NO
2014	422.99	422.99	NO	NO	102.46	102.46	NO	NO	27.81	27.81	NO	NO
2015	394.53	394.53	NO	NO	122.80	122.80	NO	NO	27.34	27.34	NO	NO
2016	420.12	420.12	NO	NO	121.66	121.66	NO	NO	29.02	29.02	NO	NO
2017	436.40	436.40	NO	NO	109.48	109.48	NO	NO	30.03	30.03	NO	NO
2018	434.32	434.32	NO	NO	114.39	114.39	NO	NO	31.59	31.59	NO	NO
Trend 2017-2018	-0.47%	-0.47%	NA	NA	4.48%	4.48%	NA	NA	5.20%	5.20%	NA	NA
Trend 1990-2018	-30.34%	-30.34%	NA	NA	-88.39%	-88.39%	NA	NA	53.77%	53.77%	NA	NA

2 - Industrial Processes

GHG emissions by source & sink category (Gg CO_2 eq)

Year	2F-Product uses as substitutes for ODS			2G - Other product manufacture and use					2 - Industrial Processes				
	Total	HFCs	PFC	Total	HFC	PFC	SF6	N_2O	Total	CO_2	CH_4	N_2O	F-gases
1990	0.00	0.00	NO	9.92	NO	NO	0.73	9.19	1 638.83	1 628.91	NO	9.19	0.73
1991	0.00	0.00	NO	9.61	NO	NO	0.74	8.86	1 560.20	1 550.60	NO	8.86	0.74
1992	5.50	5.50	NO	9.28	NO	NO	0.76	8.52	1 494.31	1 479.53	NO	8.52	6.26
1993	12.95	12.95	NO	8.98	NO	NO	0.78	8.20	1 478.98	1 457.04	NO	8.20	13.74
1994	14.26	14.26	NO	8.71	NO	NO	0.81	7.90	1 387.25	1 364.28	NO	7.90	15.07
1995	15.22	15.22	NO	9.34	NO	NO	1.75	7.58	1 028.81	1 004.26	NO	7.58	16.97
1996	17.40	17.40	NO	9.20	NO	NO	1.94	7.26	974.85	948.24	NO	7.26	19.35
1997	20.17	20.17	NO	9.03	NO	NO	2.10	6.93	867.73	838.52	NO	6.93	22.27
1998	23.04	23.04	NO	8.77	NO	NO	2.16	6.61	710.32	678.51	NO	6.61	25.20
1999	26.34	26.34	NO	8.52	NO	NO	2.24	6.27	750.76	715.90	NO	6.27	28.59
2000	31.23	31.23	NO	8.28	NO	NO	2.36	5.92	781.33	741.82	NO	5.92	33.59
2001	38.51	38.51	NO	8.51	NO	NO	2.97	5.54	731.13	684.11	NO	5.54	41.48
2002	41.77	41.77	NO	9.17	NO	NO	3.58	5.59	752.43	701.48	NO	5.59	45.36
2003	42.09	42.09	NO	9.60	NO	NO	4.17	5.42	690.52	638.84	NO	5.42	46.26
2004	42.27	42.27	NO	9.67	NO	NO	4.73	4.94	735.58	683.63	NO	4.94	47.00
2005	40.86	40.86	NO	9.92	NO	NO	5.31	4.61	692.68	641.90	NO	4.61	46.17
2006	43.87	43.87	NO	10.64	NO	NO	5.73	4.91	741.32	686.81	NO	4.91	49.60
2007	48.38	48.38	NO	11.40	NO	NO	6.17	5.24	735.38	675.60	NO	5.24	54.54
2008	50.98	50.98	NO	12.27	NO	NO	6.58	5.69	687.64	624.38	NO	5.69	57.57
2009	52.15	52.15	NO	12.05	NO	NO	6.99	5.05	635.66	571.47	NO	5.05	59.14
2010	54.48	54.48	NO	11.25	NO	NO	7.29	3.95	676.57	610.85	NO	3.95	61.77
2011	57.39	57.39	NO	11.55	NO	NO	7.75	3.80	692.91	623.98	NO	3.80	65.14
2012	59.80	59.80	NO	11.81	NO	NO	8.14	3.67	633.69	562.09	NO	3.67	67.94
2013	60.79	60.79	NO	14.43	2.56	NO	8.51	3.36	616.90	541.68	NO	3.36	71.87
2014	68.67	68.67	NO	14.18	1.71	NO	8.90	3.58	636.11	553.26	NO	3.58	79.27
2015	67.61	67.61	NO	14.83	1.99	NO	9.37	3.48	627.12	544.67	NO	3.48	78.96
2016	58.77	58.77	NO	15.86	2.02	NO	9.72	4.13	645.43	570.80	NO	4.13	70.51
2017	58.36	58.36	NO	19.03	4.89	NO	9.90	4.24	653.30	575.91	NO	4.24	73.15
2018	57.56	57.56	NO	19.20	4.56	NO	10.20	4.44	657.06	580.30	NO	4.44	72.32
2017-2018	-1.37%	-1.37%	NA	0.89%	-6.81%	NA	3.01%	4.80%	0.58%	0.76%	NA	4.80%	-1.14%
1990-2018	80507064.90%	80507064.90%	NA	93.52%	NA	NA	1290.10%	-51.68%	-59.91%	-64.37%	NA	-51.68%	9752.96%

Source: Environment Agency

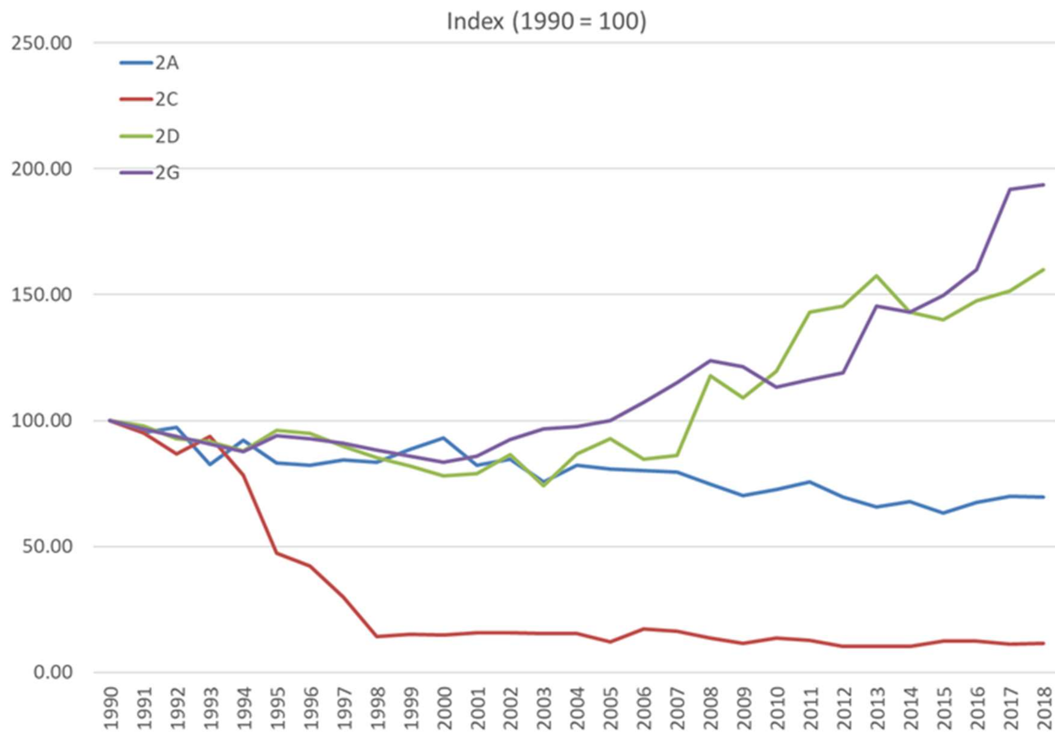
Notes:

CH_4 emissions are converted in CO_2e 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.

N_2O emissions are converted in CO_2e 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: 1990-2018



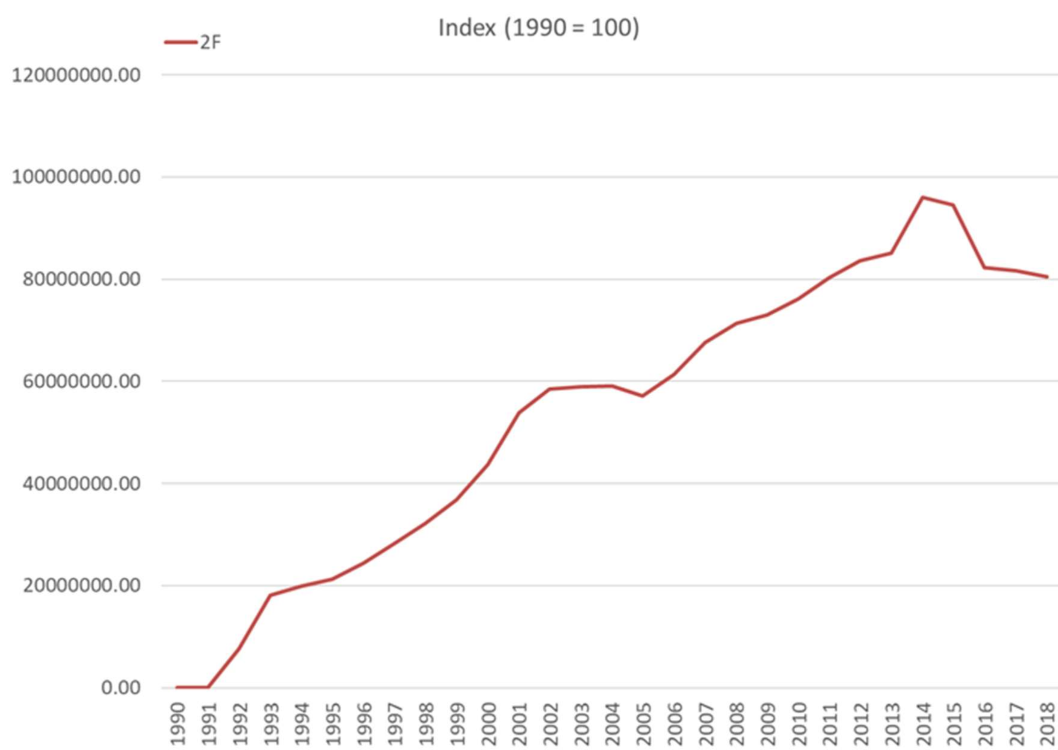
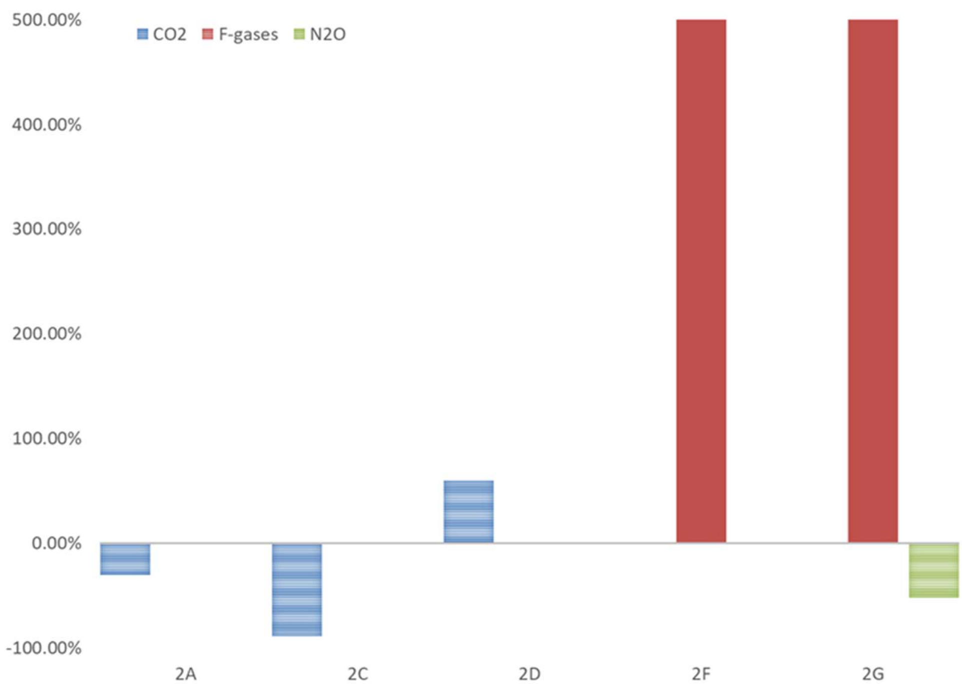
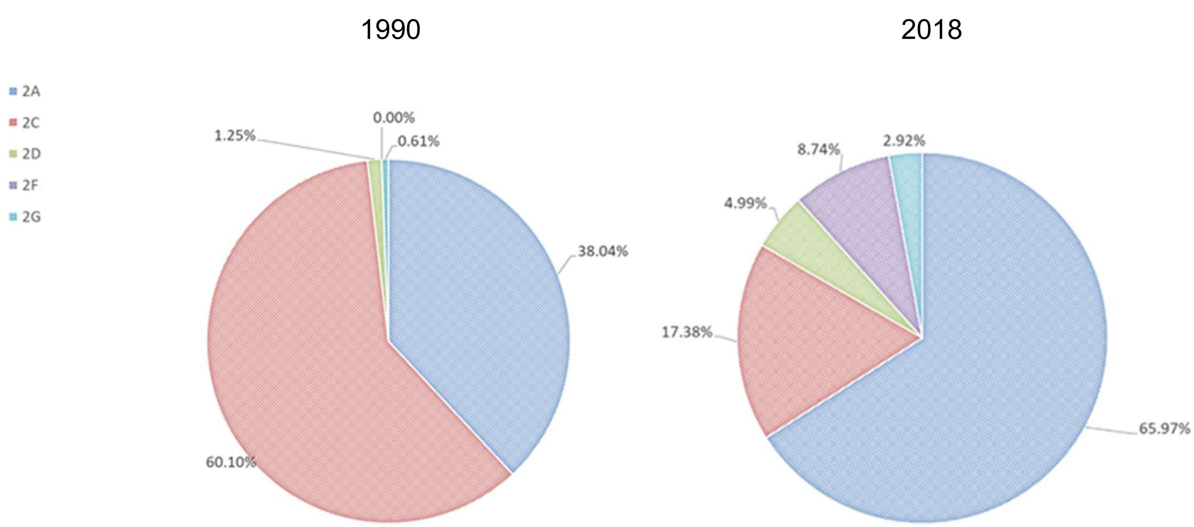


Figure 4-3 – GHG emission trends in % for CRF Sector 2 – Industrial Processes: 1990-2018



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 2018



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	90-18	90-18	X	X
2A3	Glass Production	CO_2	97, 00, 10, 14-18	96-97, 00-01, 10-12, 14-18		
2C1	Iron & Steel Production	CO_2	90-18	90-18	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 2018 (Tier 1) including respectively excluding LULUCF

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 CO_2, CH_4 and N_2O

GHG source & sink category	Description	Status		
		CO_2	CH_4	N_2O
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		

GHG source & sink category	Description	Status		
		CO_2	CH_4	N_2O
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	
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 us - lubricant use	X		
2.D.2	non-energy products from fuels and solvent us - paraffin wax use	X		
2.D.3	non-energy products from fuels and solvent us - 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 - N2O 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, SF_6 and NF_3

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	SF6 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 2018, this source category was responsible for 65.99% of GHG emissions in CO_2e from industrial processes – but only 38.27% in 1990 – and for 4.54% of the total CO_2 emissions estimated for Luxembourg. It represented 4.12% of the total GHG emissions in CO_2e (excluding LULUCF) in 2018 and 4.89% in 1990. Compared to 2017, emissions decreased by 0.47% to attain the level of 434.32 Gg CO_2 in 2018. Compared to 1990, emissions decreased by 30.34%.

4.2.1 Cement Production (2.A.1)

4.2.1.1 Source category description

In 2018, clinker production was responsible for 56.47%of GHG emissions in CO_2e from industrial processes – but only 34.98% in 1990 – and for 3.43% of the total CO_2 emissions estimated for Luxembourg. It represented 3.88% of the total GHG emissions in CO_2e (excluding LULUCF). Compared to 2017, emissions decreased by 0.23% to attain the level of 371.68 Gg CO_2 in 2018. Compared to 1990, emissions decreased by 34.78%.

2A1 - Cement Production is a key source with regard to CO_2 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 ($CaCO_3$), is calcined to produce lime (CaO) and CO_2 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 CO_2 emissions, the ETS 2007 method using clinker production data is applied:

$$CO_2\ Emissions = EF_{clinker} \bullet CF_{clinker} \bullet Clinker\ Production$$

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:

$$EF_{clinker} = 0.785 \bullet CaO\ Content + 1.092 \bullet MgO\ Content\ (Weight\ Fraction\ in\ Clinker)$$

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

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 - CO_2 emissions trend, activity data and IEFs for IPCC sub-category 2A1 – Cement Production: 1990-2018

2A1 - Clinker Production			
Activity data, emissions and implied emission factors			
Year	AD	CO_2	IEF
	t	Gg	kg CO_2 /t clinker
1990	1048 000	569.88	543.78
1991	1001 637	544.10	543.21
1992	1013 452	549.88	542.58
1993	842 855	456.79	541.95
1994	950 854	514.72	541.33
1995	848 455	458.76	540.70
1996	837 518	452.38	540.14
1997	865 659	467.09	539.58
1998	870 053	468.98	539.02
1999	913 265	491.76	538.47
2000	965 369	519.28	537.91
2001	843 608	452.71	536.64
2002	874 577	468.22	535.37
2003	769 754	411.12	534.10
2004	847 389	451.51	532.83
2005	833 798	443.21	531.56
2006	826 131	438.74	531.08
2007	816 688	433.34	530.60
2008	761 816	403.86	530.13
2009	708 048	378.06	533.94
2010	736 019	391.49	531.90
2011	770 232	411.12	533.76
2012	758 241	374.86	494.38
2013	743 260	365.43	491.66
2014	731 076	359.55	483.55
2015	677 731	329.47	474.95
2016	750 566	354.81	462.62
2017	761 255	372.53	479.40
2018	746 704	371.68	487.60
Trend 2017-2018	-1.91%	-0.23%	1.71%
Trend 1990-2018	-28.75%	-34.78%	-10.33%

Sources: AD: plant operator: CO2 and IEF: Environment Agency

Table 4-6 – Effective and interpolated CaO content in % and EFs: 1990-2018

2A1 - Cement Production

CaO content & emission factors

Year	CaO (%) operator	CaO (%) interpolation	MgO (%) operator	MgO (%) interpolation	EF kg CO_2 / t clinker	CF -
1990	67.72	67.72	1.12	1.12	543.78	1.00
1991		67.67		1.10	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		1.01	540.14	1.00
1997		67.34		1.00	539.58	1.00
1998		67.28		1.00	539.02	1.00
1999		67.22		0.99	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		0.90	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	0.90	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

Sources: plant operator and Environment Agency

4.2.1.2.4 Conversion factor (CF)

In 2013, the raw material composition was changed so that it can no longer be assumed that all the CaO and MgO in the clinker are from carbonate source (*e.g.* $CaCO_3$ and $MgCO_3$ in limestone). 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.

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 (%) IPCC GPG 2000 Table 3.1 (Tier 2)	Error (%) 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 uncertainty .... 1.5 %
- Emission factor uncertainty .... 2.5 %
- Emissions uncertainty .... 2.9 %

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 CO_2/t clinker.

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

Consistency of the figures reported in the NIR and the CRF tables was ensured (ARR 2013, §38).

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 2018, glass production was responsible for 9.52% of GHG emissions in CO_2e from industrial processes – but only 3.29% in 1990 – and for 0.65% of the total CO_2 emissions estimated for Luxembourg. It represented 0.59% of the total GHG emissions in CO_2e (excluding LULUCF). Compared to 2017, emissions decreased by 1.91% to attain the level of 62.65 Gg CO_2 in 2018. Compared to 1990, emissions increased by 16.95%.

2.A.3 - Glass Production is a key source with regard to CO_2 emissions. It has been a key source since for several years: see Table 4-2 in Section 3234.1.2.

4.2.3.2 Methodological issues

4.2.3.2.1 Activity data

In Luxembourg, one company runs two flat glass production plants. CO_2 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:

$$CO_2\ emissions = EF_{glass} \bullet Glass\ Production$$

Estimates from the CS method, as well as activity data and IEFs, are summarized in Table 4-8.

Table 4-8 – CO_2 emission trend, activity data and IEFs for IPCC sub-category 2.A.3 – Other – Glass Production: 1990-2018

2A3 - Glass Production			
Activity data, emissions and implied emission factors			
Year	AD	CO_2	IEF
	t	Gg	kg CO_2 / t glass
1990	377 240	53.57	142.00
1991	342 745	48.67	142.00
1992	403 328	57.27	142.00
1993	410 176	58.24	142.00
1994	426 991	60.63	142.00
1995	425 026	60.35	142.00
1996	420 750	59.75	142.00
1997	414 616	58.88	142.00
1998	361 401	51.32	142.00
1999	419 579	59.58	142.00
2000	425 751	60.46	142.00
2001	425 391	60.41	142.00
2002	423 240	60.10	142.00
2003	426 299	60.53	142.00
2004	435 595	61.85	142.00
2005	435 073	60.59	139.27
2006	435 806	60.34	138.45
2007	443 094	62.63	141.34
2008	440 538	62.16	141.10
2009	437 319	59.03	134.99
2010	430 140	62.07	144.31
2011	433 676	60.82	140.24
2012	423 081	58.45	138.15
2013	304 453	43.74	143.66
2014	430 098	63.44	147.51
2015	420 703	65.06	154.65
2016	430 103	65.31	151.85
2017	433 178	63.87	147.44
2018	422 078	62.65	148.42
2017-2018	-2.56%	-1.91%	0.67%
1990-2018	11.89%	16.95%	4.52%

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 2017 in the glass production was 73602.28 t (Source: verified ETS data). In 2018, the use of soda ash amounted to 73365.245 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 CO_2 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 uncertainty .... 2.0 %
- Emission factor uncertainty .... 5.0 %
- Cumulative emission uncertainty .... 5.4 %

4.2.3.4 Source-specific QA/QC and verification

The calculated CO_2 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 emissions[88] (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 2018, iron and steel production was responsible for 19.32% of GHG emissions in CO_2e from industrial processes – but 60.46% in 1990 – and for 1.17% of the total CO_2 emissions estimated for Luxembourg. It represented 1.06% of the total GHG emissions in CO_2e (excluding LULUCF). Compared to 2017, emissions increased by 4.38% to attain the level of 112.14 Gg CO_2 in 2018. Compared to 1990, emissions decreased by 88.61% 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 CO_2 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 – CO_2 emissions trend, activity data and IEFs for IPCC sub-category 2C1 – Iron and Steel Production: 1990-2018

2C1 - Iron & Steel Production					
	Steel Production (t)				Filter Dust (t)
Year	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	2126283	NO
2016	NO	NO	NO	2175409	NO
2017	NO	NO	NO	2171696	NO
2018	NO	NO	NO	2227951	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					
Emissions, AD, IEFs					
Year	CO_2 (Gg)	BOF (t)	EAF (t)	Total (t)	IEF kg CO_2/t steel
1990	984.91	3506 230	NO	3506 230	280.90
1991	937.74	3379 440	NO	3379 440	277.48
1992	853.29	3068 463	NO	3068 463	278.08
1993	923.19	3288 847	4 095	3292 942	280.36
1994	770.83	2627 278	445 990	3073 268	250.82
1995	465.38	1410 469	1202 668	2613 137	178.09
1996	416.60	1168 070	1333 758	2501 828	166.52
1997	294.10	597 814	1982 405	2580 219	113.98
1998	140.69	NO	2476 909	2476 909	56.80
1999	147.70	NO	2600 324	2600 324	56.80
2000	146.05	NO	2571 243	2571 243	56.80
2001	154.76	NO	2724 679	2724 679	56.80
2002	155.40	NO	2736 000	2736 000	56.80
2003	151.94	NO	2675 000	2675 000	56.80
2004	152.45	NO	2684 000	2684 000	56.80
2005	119.13	NO	2194 485	2194 485	54.29
2006	170.49	NO	2802 049	2802 049	60.85
2007	162.22	NO	2845 872	2845 872	57.00
2008	134.69	NO	2584 341	2584 341	52.12
2009	112.66	NO	2103 281	2103 281	53.56
2010	133.61	NO	2633 613	2633 613	50.73
2011	123.86	NO	2525 697	2525 697	49.04
2012	100.23	NO	2208 000	2208 000	45.39
2013	101.59	NO	2089 000	2089 000	48.63
2014	102.46	NO	2192 999	2192 999	46.72
2015	122.80	NO	2126283	2126 283	57.75
2016	119.33	NO	2175409	2175 409	54.86
2017	107.43	NO	2171696	2171 696	49.47
2018	112.14	NO	2227951	2227 951	50.33

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 CO_2 emissions. It has been a key source since 1990: see Table 4-2 in Section Key Categories4.1.2.

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= (CCarbon+CAnthracite) * 3.664 + EElectrodes+EPig iron+EPetroleum coke+ECaC2+Eflux

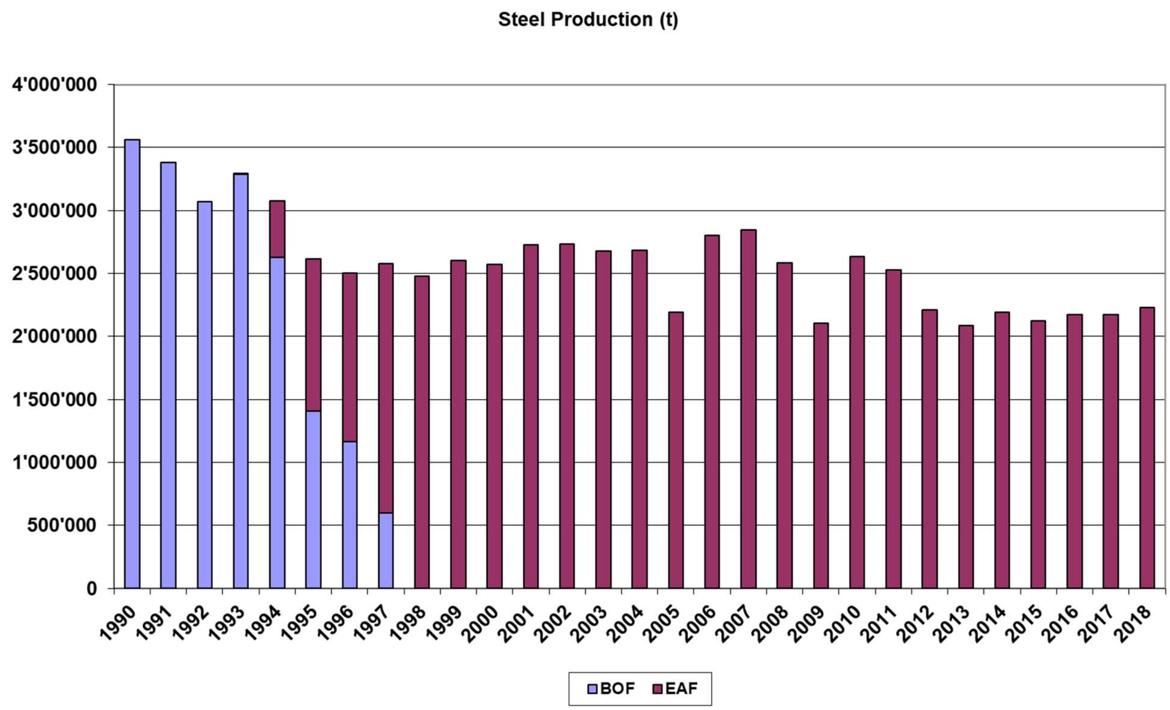
Ei= ADi * EFi   with i= electrodes, pig iron, petroleum coke, CaC2, fluxes

All materials introduced in the furnace and containing carbon are considered (carbon, anthracite, electrodes, pig iron, petroleum coke, CaC2 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: 1990-2018



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. CO_2 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 CO_2.

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 CO_2 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-heath 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: 1990-2018

2C1 - Iron & Steel Production Emissions, AD, IEFs					
Year	CO_2 (Gg)	BOF (t)	EAF (t)	Total (t)	IEF kg CO_2/t steel
1990	984.91	3506 230	NO	3506 230	280.90
1991	937.74	3379 440	NO	3379 440	277.48
1992	853.29	3068 463	NO	3068 463	278.08
1993	923.19	3288 847	4 095	3292 942	280.36
1994	770.83	2627 278	445 990	3073 268	250.82
1995	465.38	1410 469	1202 668	2613 137	178.09
1996	416.60	1168 070	1333 758	2501 828	166.52
1997	294.10	597 814	1982 405	2580 219	113.98
1998	140.69	NO	2476 909	2476 909	56.80
1999	147.70	NO	2600 324	2600 324	56.80
2000	146.05	NO	2571 243	2571 243	56.80
2001	154.76	NO	2724 679	2724 679	56.80
2002	155.40	NO	2736 000	2736 000	56.80
2003	151.94	NO	2675 000	2675 000	56.80
2004	152.45	NO	2684 000	2684 000	56.80
2005	119.13	NO	2194 485	2194 485	54.29
2006	170.49	NO	2802 049	2802 049	60.85
2007	162.22	NO	2845 872	2845 872	57.00
2008	134.69	NO	2584 341	2584 341	52.12
2009	112.66	NO	2103 281	2103 281	53.56
2010	133.61	NO	2633 613	2633 613	50.73
2011	123.86	NO	2525 697	2525 697	49.04
2012	100.23	NO	2208 000	2208 000	45.39
2013	101.59	NO	2089 000	2089 000	48.63
2014	102.46	NO	2192 999	2192 999	46.72
2015	122.80	NO	2126283	2126 283	57.75
2016	119.33	NO	2175409	2175 409	54.86
2017	107.43	NO	2171696	2171 696	49.47
2018	112.14	NO	2227951	2227 951	50.33

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 CO_2 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:

$$CO_2\ Emissions_{SP} = EF_{SP} \bullet Sinter\ Production$$

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.

$$Emissions_{BF} = E_{Iron} = (C_{Reducing\ Agent} + C_{Ore} - C_{Iron}) \bullet 44/12$$

$$Emissions_{BOF} = E_{Steel} = (C_{Iron} + C_{Scrap} + C_{AddBOF} - C_{Steel}) \bullet 44/12$$

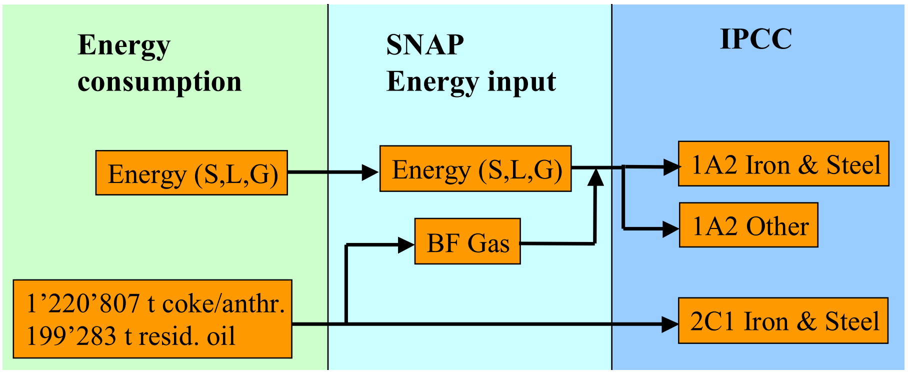
With:

$C_{Reducing\ Agent}$	= 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:

$$C_{Reducing\ Agent} = C_{2C1} = C_{(1\ 220\ 807\ t\ coke/anthracite\ +\ 199\ 283\ t\ residual\ oil)} - C_{BFGas}$$

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:

$$CO_2\ Emissions_{BF} = 200.00\ Gg\ CO_2$$

$$CO_2\ Emissions_{BOF} = 404.48\ Gg\ CO_2$$

For the subsequent years (1991 to 1997), a country specific methodology has been applied based on the emission factor determined for the year 1990:

$$CO_2 \ Emissions_{BF} = EF_{BF} \bullet Pig \ Iron \ Production$$

$$CO_2 \ Emissions_{BOF} = EF_{BOF} \bullet Steel \ Production$$

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.

$$E= (C_{Carbon}+C_{Anthracite}) \bullet 3.664 + E_{Electrodes}+E_{Pig\ iron}+E_{Petroleum\ coke}+E_{CaC2}+E_{Scrap}- E_{Steel}$$

$$E_i= AD_i \bullet EF_i \quad with\ i= \text{electrodes, pig iron, petroleum coke, CaC2}$$

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:

$$2018 – CO2 \ Emissions_{EAF} = 112.14 \ Gg \ CO2$$

$$2017 – CO_2 \ Emissions_{EAF} = 107.43 \ Gg \ CO2$$

$$2016 – CO_2 \ Emissions_{EAF} = 119.33 \ Gg \ CO2$$

$$2015 – CO_2\ Emissions_{EAF} = 122.80\ Gg\ CO2$$

$$2014 – CO_2\ Emissions_{EAF} = 102.46\ Gg\ CO2$$

$$2013 – CO_2\ Emissions_{EAF} = 101.59\ Gg\ CO_2$$

$$2012 – CO_2\ Emissions_{EAF} = 100.23\ Gg\ CO_2$$

$$2011 – CO_2\ Emissions_{EAF} = 123.86\ Gg\ CO_2$$

$$2010 – CO_2\ Emissions_{EAF} = 133.61\ Gg\ CO_2$$

$$2009 – CO_2\ Emissions_{EAF} = 112.66\ Gg\ CO_2$$

$$2008 – CO_2\ Emissions_{EAF} = 134.69\ Gg\ CO_2$$

$$2007 – CO_2\ Emissions_{EAF} = 162.22\ Gg\ CO_2$$

$$2006 – CO_2\ Emissions_{EAF} = 170.49\ Gg\ CO_2$$

$$2005 – CO_2\ Emissions_{EAF} = 119.13\ Gg\ CO_2$$

$$2004 – CO_2\ Emissions_{EAF} = 152.45\ Gg\ CO_2$$

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:

$$CO_2\ Emissions_{EAF} = EF_{EAF} \bullet Steel\ Production$$

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.

$$E_{Primus} = (C_{Raw\ materials} + C_{Electrodes} + C_{Carbon} + C_{Anthracite} – C_{Products})\ x\ 44/12$$

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:

$$Emissions_{PRIMUS} = 16.00\ Gg\ CO_2$$

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

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 CO_2 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 CO_2 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

Year	Production t steel	Emissions Gg CO2	EF_{EAF} *(kg CO_2 / t steel)*
2005	2 194 485	119.13	57.86
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

The calculated emission factor for steel production in 2004 (EF_{EAF} = 56.80 kg CO_2 / 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 2018).

For the PRIMUS® process, the implied emission factors EF_{PRIMUS}, for the years 2005-2009, are calculated from the determined CO_2 emissions and the introduced filter dust (Table 4-16).

Table 4-16 – AD, emissions and IEF for Primus

Year	Filter dust (t)	Emissions (Gg CO2)	EF PRIMUS (Mg CO2 / 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

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 (%) IPCC GPG 2000 Chap. 3.1.3.1	Error (%) 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 kg CO_2 / 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 CO_2 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 and 2.2473 kt in 2018.

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 2018, this source category was responsible for 5.44% of CO_2 emissions from industrial processes – but only 1.26% in 1990 – and for 0.33% of the total CO_2 emissions estimated for Luxembourg. It represented 0.30% of the total GHG emissions in CO_2e (excluding LULUCF) in 2017 and 0.16% in 1990. Compared to 2017, emissions increased by 5.20% to attain the level of 31.59 Gg CO_2 in 2018. Compared to 1990, emissions increased by 53.77%.

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. In 2018, this source category was responsible for 0.06% of the total CO_2 emissions estimated for Luxembourg. It represented 0.05% of the total GHG emissions in CO_2e (excluding LULUCF) in 2018 and 0.05% in 1990. Compared to 2017, emissions increased by 15.25% to attain the level of 5.38 Gg CO_2 in 2018. Compared to 1990, emissions decreased by 13.24%.

An overview of the lubricant related CO_2 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	CO_2	Fraction of	Carbon stored
	t	Gg	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
Trend 2017-2018	15.25%	15.25%	0.00%	15.25%
1990-2018	-13.24%	-13.24%	0.00%	-13.24%

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 2018, this source category was responsible for 0.02% of the total CO2 emissions estimated for Luxembourg. It represented 0.02% of the total GHG emissions in CO2e (excluding LULUCF) in 2018 and 0.002% in 1990. Compared to 2017, emissions decreased by 12.40% to attain the level of 2.24 Gg CO2 in 2018. Compared to 1990, emissions increased by 965.93%. Starting 2010, activity data for paraffin wax strongly increases, which is due to the implementation of a new 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 t	CO_2 Gg
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	4346.18	2.56
2018	3807.10	2.24
2017-2018	-12.40%	-12.40%
1999-2018	924.77%	924.77%

Sources: AD: STATEC ; CO2 and IEF: Environment Agency

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

No revisions and recalculations have been done since the last submission.

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 CO_2.

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 2018, this source category was responsible for 0.11% of the total CO_2 emissions estimated for Luxembourg. Furthermore, in 2018, 0.10% of total GHG emissions (excluding LULUCF) in Luxembourg originated from *Solvent and Other Product Use*, compared to 0.11% in 1990. Compared to 2017, GHG emissions from *Solvent and Other Product Use* decreased by 3.46% in 2018. Compared to 1990, emissions decreased by 23.05%.

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 – 2018 by Sub-Categories of 2.D.3.1 - Solvent and Other Product Use.

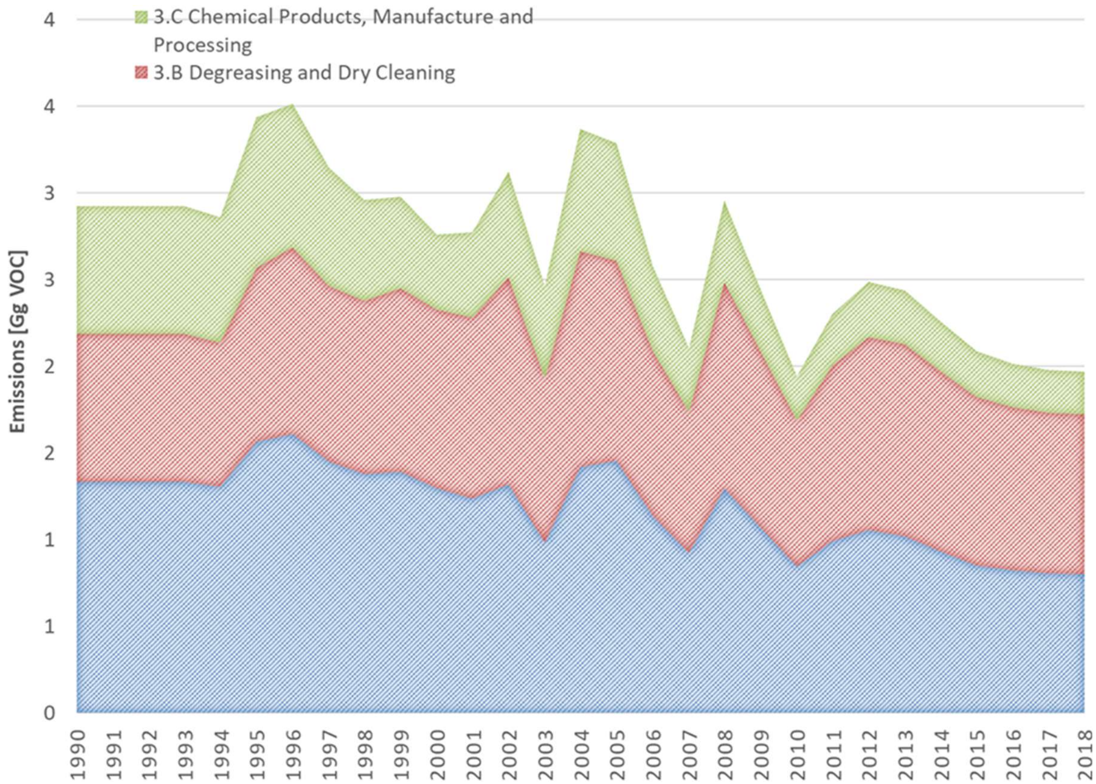


Table 4-20 - Emissions and trend from 1990 – 2018 by Sub-Categories of 2.D.3.1 *- Solvent and Other Product Use.*

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
Trend 2017-2018	-3%	-1%	-1%	-1%	-6%
Trend 1990-2018	-23%	-48%	-35%	-79%	40%

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 ozone[89];

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).

- 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 ozone[90]
- 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:
    - 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;

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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)

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;.*

- 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		CO_2	N_2O
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 CO_2 Emissions from Solvent and Other Product Use

4.5.3.1.4.1 Methodology Overview

CO_2 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 Austria[98] (WINDSPERGER *et al*. 2002a, 2004) and was in the meantime applied for different European countries within the network "non-energy use of fossils and CO_2 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.

97 Règlement grand-ducal du 12 juillet 1995, relatif aux générateurs d'aérosols.

98

Figure 4-8 - Top-down-Approach compared to Bottom-up-Approach.

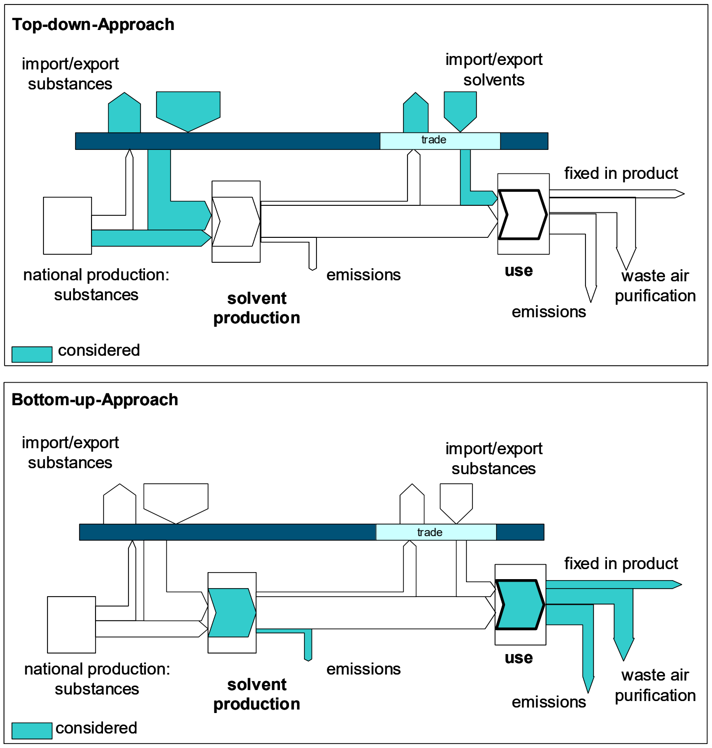


Figure 4-9 - Overview of the methodology for solvent emissions.

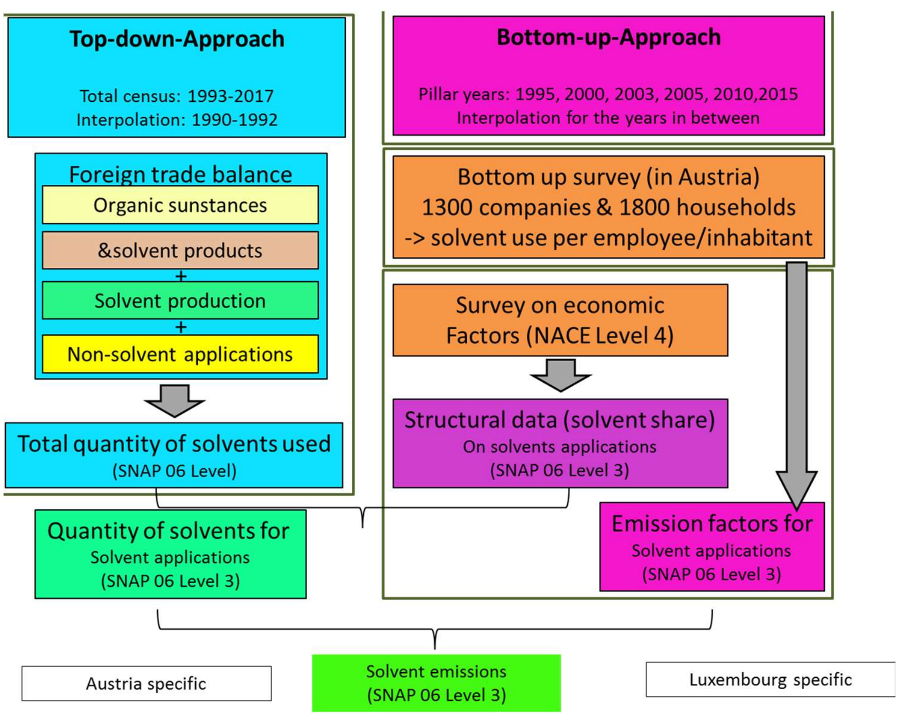


Figure 4-10 - Data of Top-down-Approach and Bottom-up-Approach for 2013.

Top-down: CRF Sector 3	
Imp/Exp Solvent products	2
Inland Solvent production	10
Imp/Exp Organic Substances	14
Non-solvent applications	-19
Substances used as solvents	-5
Solvents in applications	5
Solvent Activity	7

Bottom-up: CRF Sector 3A-3D	SNAP Level 3		Solvent Share CRF 3	Solvent Share CRF 3A-D	Solvent Share SNAP Lev 3	Solvent Emission Factor CRF 3	Solvent Emission Factor CRF 3A-D	Solvent Emission Factor SNAP Lev 3	Combination Top-down to Bottom-up: Solvent Activity CRF 3	Solvent Activity CRF 3A-D	Solvent Activity SNAP Lev 3	Solvent Emissions CRF 3	Solvent Emissions CRF 3A-D	Solvent Emissions SNAP Lev 3
3 A, Paint application	060101	Manufacture of automobiles	100%	26%	0.3%	68%	67%	64%	7.4	1.9	0.0	5.0	1.3	0.0
	060102	Car repairing			1.0%			86%			0.1			0.1
	060103	Construction and buildings			6.6%			89%			0.5			0.4
	060104	Domestic use			1.3%			89%			0.1			0.1
	060105	Coil coating			2.4%			52%			0.2			0.1
	060107	Wood coating			2.3%			90%			0.2			0.2
	060108	Other industrial paint application			11.9%			50%			0.9			0.4
3 B, Degreasing and Dry Cleaning	060201	Metal degreasing		31%	13.6%		51%	29%		2.3	1.0		1.2	0.3
	060202	Dry cleaning			0.3%			84%			0.0			0.0
	060203	Electronic components manufact.			0.0%			82%			0.0			0.0
	060204	Other industrial cleaning			16.7%			68%			1.2			0.8
3 C, Chemical Products, Manufacture and Processing	060305	Rubber processing		10%	6.3%		83%	93%		0.7	0.5		0.6	0.4
	060306	Pharmaceutical products manufact.			0.7%			26%			0.1			0.0
	060307	Paints manufacturing			0.5%			100%			0.0			0.0
	060308	Inks manufacturing			0.7%			100%			0.0			0.0
	060309	Glues manufacturing			0.0%			100%			0.0			0.0
	060310	Asphalt blowing			0.7%			1%			0.0			0.0
	060311	Adhesive, films & photographs			0.0%			94%			0.0			0.0
	060312	Textile finishing			0.0%			90%			0.0			0.0
	060314	Other manufacturing			0.9%			100%			0.1			0.1
3 D, Other	060403	Printing industry		34%	9.7%		79%	65%		2.5	0.7		2.0	0.5
	060404	Fat and oil extraction			0.3%			20%			0.0			0.0
	060405	Application of glues and adhesives			0.0%			63%			0.0			0.0
	060406	Preservation of wood			0.1%			99%			0.0			0.0
	060407	Treatment & conservation of vehicles			0.3%			85%			0.0			0.0
	060408	Domestic solvent use (other)			17.3%			84%			1.3			1.1
	060411	Domestic use of pharmac. products			4.0%			94%			0.3			0.3
	060412	Other (preservation of seeds,...)			2.1%			78%			0.2			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).

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

99 http://epp.eurostat.ec.europa.eu

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%
		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%

SNAP category	description	year	Distribution of used paints		Part of waste gas treatment	
			Solvent based paints	Water based paints	application	Purification
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%

SNAP	Description	Changes in the number of employees compared to the year 2000				
		1990	1995	2000	2003	2005
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)					
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] 1990-2018

	Solvents used (Gg)									
	2D3	2D3a	2D3b	2D3c	2D3d	2D3e	2D3f	2D3g	2D3h	2D3i
Year	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
Trend 1990-2018	-20.50%	34.20%	NA	NA	-37.69%	-11.42%	4.42%	-70.03%	-57.47%	96.50%
2005-2018	-33.00%	-9.74%	NA	NA	-50.75%	-20.21%	-22.51%	-63.94%	-62.70%	56.83%
2016-2018	-0.59%	-0.59%	NA	NA	-0.59%	-0.59%	-0.59%	-0.59%	-0.59%	-0.59%

	NMVOC emissions (Gg)									
	2D3	2D3a	2D3b	2D3c	2D3d	2D3e	2D3f	2D3g	2D3h	2D3i
Year	TOTAL	Dometics solvent use including fungicides	Road paving with asphalt	Asphalt roofing	Coating applications	Degreasing	Dry cleaning	Chemical products	Printing	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	0.003	NO	0.99	0.99	0.020	0.30	0.16	0.17
2012	5.23	2.39	0.003	NO	1.06	1.09	0.022	0.32	0.17	0.18
2013	5.12	2.35	0.003	NO	1.02	1.08	0.022	0.31	0.15	0.18
2014	4.43	1.88	0.004	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	0.004	NO	0.82	0.92	0.018	0.25	0.11	0.15
2017	4.51	2.28	0.004	NO	0.81	0.91	0.018	0.25	0.11	0.14
2018	4.35	2.13	0.004	NO	0.80	0.90	0.018	0.25	0.11	0.14
Trend 1990-2018	-5.46%	105.60%	-56.78%	NA	-39.80%	8.00%	0.15%	-66.69%	-78.35%	-0.82%
2005-2018	-26.65%	9.76%	-16.71%	NA	-44.89%	-20.44%	-22.51%	-63.47%	-79.95%	-17.12%
2016-2018	-3.51%	-6.42%	0.00%	NA	-0.59%	-0.59%	-0.59%	-0.59%	-0.59%	0.11%

2D3 - Solvent and Product Use										
Solvents used (Gg)										
	2D3	2D3a	2D3b	2D3c	2D3d	2D3e	2D3f	2D3g	2D3h	2D3i
Year	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
Trend 1990-2018	-20.50%	34.20%	NA	NA	-37.69%	-11.42%	4.42%	-70.03%	-57.47%	96.50%
2005-2018	-33.00%	-9.74%	NA	NA	-50.75%	-20.21%	-22.51%	-63.94%	-62.70%	56.83%
2017-2018	-0.59%	-0.59%	NA	NA	-0.59%	-0.59%	-0.59%	-0.59%	-0.59%	-0.59%

Amounts correspond to amounts of solvent used.

Tables 4-28 - Implied NMVOC emission factors for Solvent Use 1990–2018 and NMVOC emissions

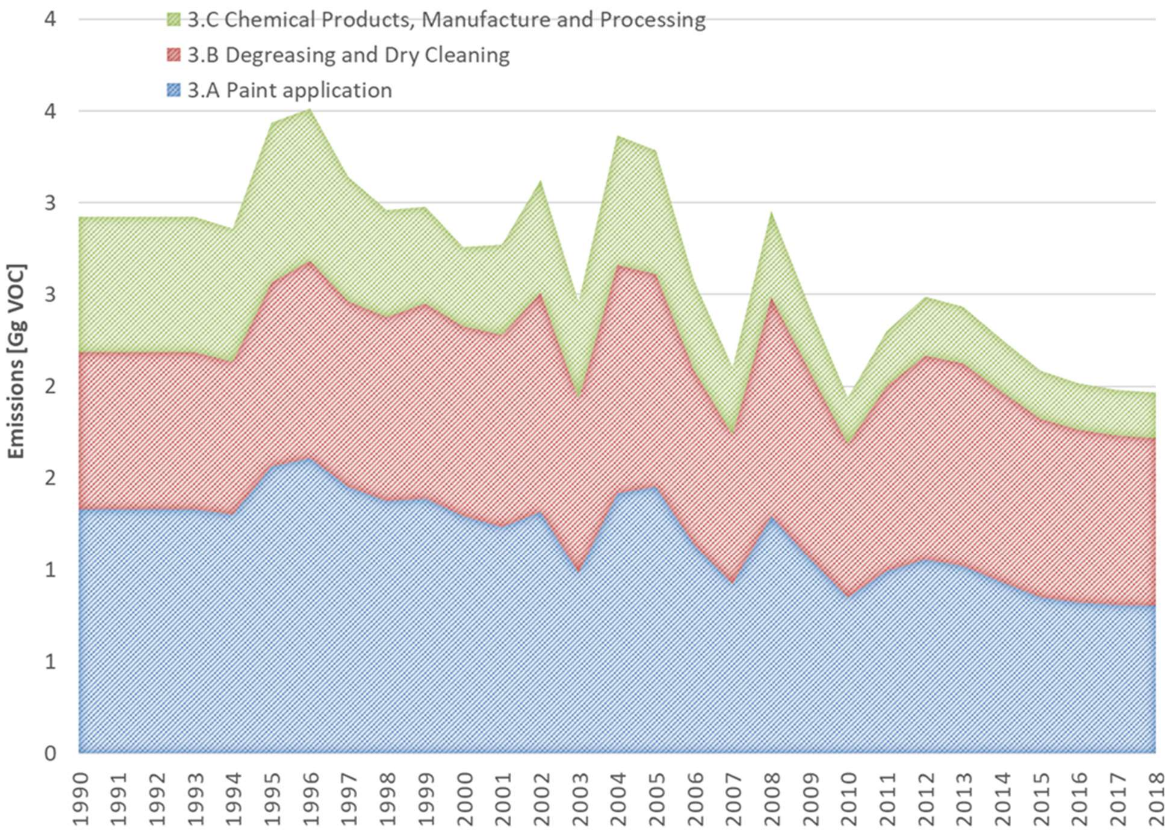
	NMVOC implied emission factor (g NMVOC/g solvents)									
	2D3	2D3a	2D3b	2D3c	2D3d	2D3e	2D3f	2D3g	2D3h	2D3i
Year	TOTAL	Dometics solvent use including fungicides	Road paving with asphalt	Asphalt roofing	Coating applications	Degreasing	Dry cleaning	Chemical products	Printing	Other solvent use
1990	0.704	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
Trend 1990-2018	18.92%	53.20%	NA	NA	-3.38%	21.92%	-4.09%	11.17%	-49.09%	-49.53%
2005-2018	9.47%	21.60%	NA	NA	11.90%	-0.28%	0.00%	1.29%	-46.24%	-47.15%
2016-2018	-2.94%	-5.86%	NA	NA	0.00%	0.00%	0.00%	0.00%	0.00%	0.70%

2D3 - Solvent and Product Use

	NMVOC implied emission factor (g NMVOC/g solvents)									
	2D3	2D3a	2D3b	2D3c	2D3d	2D3e	2D3f	2D3g	2D3h	2D3i
Year	TOTAL	Dometics solvent use including fungicides	Road paving with asphalt	Asphalt roofing	Coating applications	Degreasing	Dry cleaning	Chemical products	Printing	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
Trend 1990-2018	18.92%	53.20%	NA	NA	-3.38%	21.92%	-4.09%	11.17%	-49.09%	-49.53%
2005-2018	9.47%	21.60%	NA	NA	11.90%	-0.28%	0.00%	1.29%	-46.24%	-47.15%
2017-2018	-2.94%	-5.86%	NA	NA	0.00%	0.00%	0.00%	0.00%	0.00%	0.70%

2D3 - Solvent and Product Use										
NMVOC emissions (Gg)										
	2D3	2D3a	2D3b	2D3c	2D3d	2D3e	2D3f	2D3g	2D3h	2D3i
Year	TOTAL	Dometics solvent use including fungicides	Road paving with asphalt	Asphalt roofing	Coating applications	Degreasing	Dry cleaning	Chemical products	Printing	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	0.003	NO	0.99	0.99	0.020	0.30	0.16	0.17
2012	5.23	2.39	0.003	NO	1.06	1.09	0.022	0.32	0.17	0.18
2013	5.12	2.35	0.003	NO	1.02	1.08	0.022	0.31	0.15	0.18
2014	4.43	1.88	0.004	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	0.004	NO	0.82	0.92	0.018	0.25	0.11	0.15
2017	4.51	2.28	0.004	NO	0.81	0.91	0.018	0.25	0.11	0.14
2018	4.35	2.13	0.004	NO	0.80	0.90	0.018	0.25	0.11	0.14
Trend 1990-2018	-5.46%	105.60%	-56.78%	NA	-39.80%	8.00%	0.15%	-66.69%	-78.35%	-0.82%
2005-2018	-26.65%	9.76%	-16.71%	NA	-44.89%	-20.44%	-22.51%	-63.47%	-79.95%	-17.12%
2017-2018	-3.51%	-6.42%	0.00%	NA	-0.59%	-0.59%	-0.59%	-0.59%	-0.59%	0.11%

Figure 4-11 - NMVOC emissions and trend from 1990–2018 by subcategories of Category 2.D.3.1 - Solvent and Other Product Use



4.5.3.1.4.5 Calculation of CO_2 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 CO_2.

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
Cydic Hydrocarbons	3.14	Solvent naphta	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 CO_2 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 - CO_2 emission of Category 2.D.3.1 Solvent and Other Product Use 1990–2018.

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

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

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

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

Table 4-31 - Implied CO2 Emission factors for Category 2.D.3.1 Solvent and Other Product Use 1990–2018.

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

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

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

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

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 conern 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 1A2gviii, 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	0.004	4.870
2012	703.165	0.004	5.170
2013	607.814	0.003	5.168
2014	690.515	0.005	6.604
2015	607.760	0.004	6.097
2016	768.686	0.004	5.486
2017	685.024	0.004	5.894
2018	671.173	0.026	38.379
Trend 2017-2018	-2.02%	537.98%	551.15%
2005-2018	19.75%	443.46%	353.84%
1990-2018	10.23%	182.04%	155.86%

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 2018, CO_2 emissions resulting from the use of urea-based catalysts in SCR-equipped vehicles was responsible for 2.26% of GHG emissions CO_2e from industrial processes and product use and for 0.12% of the total GHG emissions in CO_2e (excluding LULUCF). Compared to 2017, emissions increased by 13.50% to reach 13.09 Gg CO_2 in 2018. An overview of the related CO_2 emissions is provided in

Table 4-32.

2.D.3.2 – Urea-based catalysts is not a key source with regard to CO_2 emissions.

Table 4-32 - CO_2 emissions trend, activity data and IEFs for IPCC sub-category 2.D.3.2 – Urea-based catalysts: 1990-2018.

2D3 - Urea-based catalysts			
Year	activity data (t)	CO_2 emissions (Gg)	implied emission factor (t CO_2/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	44'369	10.57	0.238
2015	43'011	10.25	0.238
2016	44'069	10.50	0.238
2017	48'390	11.53	0.238
2018	54'922	13.09	0.238
Trend 1990-2018	*NA*	*NA*	
Trend 2017-2018	*13.50%*	*13.50%*	

Total sales volumes or import/export data for urea-based catalysts are not available for Luxembourg. Therefore the NEMO model (details in Chapter 3.2.8.3.2.2) 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

CO_2 emissions from urea-based catalysts used in SCR-equipped vehicles are calculated separately by the NEMO model (described in chapter 3.2.8.3.2.2.). This approach considers the specific operating condition of the SCR exhaust gas after-treatment system in any driving condition[100]. The calculation is based on the assumption that one mole of urea generates one mole of CO_2 and converts 0.9 mole of NO_x as illustrated by Equation 4-1.

Equation 4-1: Formula used by the NEMO model to determine CO_2 emissions from the use of AdBlue® in SCR-equipped vehicles.

$$CO_2\,[g] = \frac{(NO_{x,EO} - NO_{x,TP})[g]}{\underbrace{46\left[\frac{g}{mol}\right]}_{\text{molar mass } NO_2}} \cdot \left(\frac{1}{1 - s_{NH3,loss}}\right) \cdot \underbrace{\frac{1}{2}}_{CO_2 / NH_3 \text{ mole ratio}} \cdot \underbrace{44\left[\frac{g}{mol}\right]}_{\text{molar mass } CO_2}$$

With:

$NO_{x,EO}$: NO_x emissions (in NO_2 mass equivalent) at engine out

$NO_{x,TP}$: NO_x emissions (in NO_2 mass equivalent) at tailpipe

$s_{NH3,loss}$: share of NH_3 losses caused by NH_3 slip through SCR catalyst without NO_x conversion and by NH_3 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 CO_2 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 guidelines[101].

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.

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[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

[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

The activity data for the years 2005 to 2017 was updated due to updates of fleet parameters and emission factors in the NEMO model.

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 SF_6 (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 2018, this category represented 9.58% of the GHG emissions in CO_2e from industrial processes and 0.60% of the total GHG emissions in CO_2e (excluding LULUCF). This percentage was only 0.10% in 1995. As shown in Figure 4-12, the related emissions experienced an increase between 1995 and 2018 (+278%). Compared to 2017, emissions decreased by 1.37% to attain the level of 63.03 Gg CO_2 in 2018. This important 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 banes 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 2015 and is even more pronounced for the year 2016, where the usage of F-gases such as R134a, R143a, R32 and R125 have, in most cases, dropped to zero. These trends corroborate with the general observations made by the European Environmental Agency in their F-gas report No 20/2017. The decrease for the year 2015 is less important than for the year 2016 as suppliers were in possession of ample stocks and prices did not increase that much at that point in time. Furthermore, the Directive 2006/40/EC of the European parliament and of the council of 17 May 2006 prohibites 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 sharp 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: 1990-2018

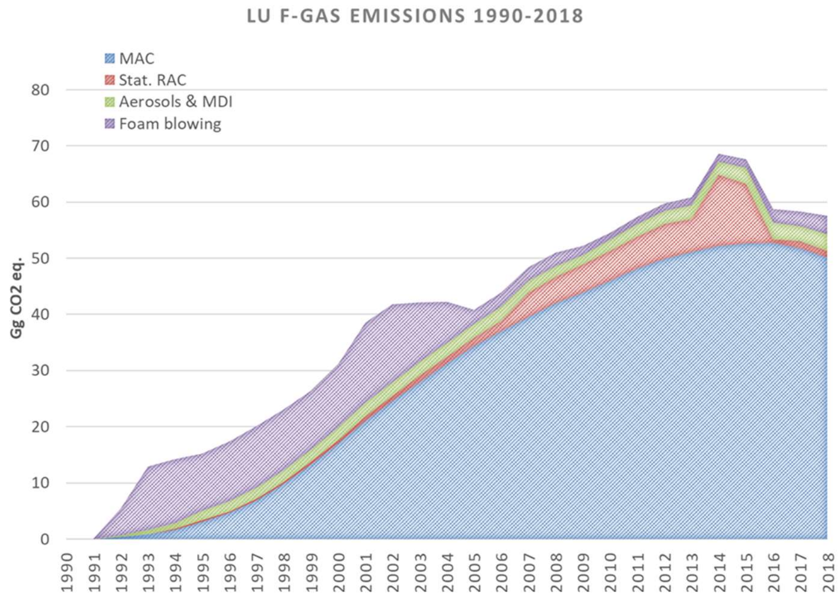


Table 4-33 – Estimated emissions of HFCs: 1990-2018

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	5.50	0.48	0.03	0.45	4.79	0.23
1993	12.95	0.92	0.05	0.87	11.34	0.70
1994	14.26	1.82	0.22	1.60	11.45	0.99
1995	15.22	3.35	0.24	3.11	10.22	1.65
1996	17.40	4.98	0.29	4.69	10.63	1.80
1997	20.17	7.23	0.32	6.91	11.02	1.92
1998	23.04	10.21	0.35	9.86	10.79	2.04
1999	26.34	13.77	0.51	13.26	10.42	2.15
2000	31.23	17.61	0.57	17.04	11.36	2.27
2001	38.51	21.93	0.89	21.04	14.21	2.37
2002	41.77	25.54	0.96	24.59	13.82	2.41
2003	42.09	29.10	1.20	27.90	10.53	2.46
2004	42.27	32.56	1.29	31.26	7.31	2.40
2005	40.86	35.86	1.46	34.39	2.54	2.46
2006	43.87	38.88	1.86	37.02	2.53	2.45
2007	48.38	43.85	4.38	39.47	2.41	2.12
2008	50.98	46.71	4.71	41.99	2.35	1.93
2009	52.15	48.87	4.99	43.87	1.55	1.73
2010	54.48	51.29	5.32	45.97	1.23	1.95
2011	57.39	53.79	5.67	48.12	1.33	2.27
2012	59.80	56.18	6.27	49.91	1.40	2.22
2013	60.79	57.06	5.98	51.08	1.39	2.34
2014	68.67	64.92	12.75	52.17	1.43	2.32
2015	67.61	63.27	10.65	52.62	1.54	2.80
2016	59.50	54.09	0.58	53.51	2.43	2.99
2017	61.34	56.03	1.24	54.78	2.71	2.61
2018	63.03	56.82	1.25	55.57	3.25	2.96
Trend 1995-2018	*314%*	*1597%*	*417%*	*1689%*	*-68%*	*79%*
Trend 2017-2018	*2.74%*	*1.42%*	*0.59%*	*1.44%*	*19.77%*	*13.49%*

Source: Environment Agency

2F – Product uses as substitutes for ODS is a key source with regard to F-gas emissions since 2003: see Table 4-2 in Section 4.1.2.

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 onemission-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 SF_6 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.

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. An additional source of emission are accidental releases, which for 2017, as an example, amounted to a total of 1.4kg. 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 a 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, staring 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 ingression 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 error values which are assumed on the various calculations are as given:

- Activity data uncertainty 30%
- Emission factor uncertainty 20%

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

2F2 Foam blowing: data has been revised for the years 2009-2017.2F1 - Mobile refrigeration and air conditioning in passenger vehicles: new data regarding the population of cars using alternatives to R134a, such as R1234yf, has been obtained and implemented for the years 2016-2018. See methodology for more details.

2F4 Aerosols/Metered dose inhalers: data for the year 2017 has been revised and updated.

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 2018, the category 2.G represented 2.92% of the GHG emissions in CO_2e from industrial processes and 0.14% of the total GHG emissions in CO_2e (excluding LULUCF). This percentage was 0.10% in 1995. As shown in Figure 4-13, emissions from category 2.G experienced an increase of 106% between 1995 and 2018. Compared to 2017, emissions increased by 0.89% to attain the level of 19.20 Gg CO_2 in 2018.

F-gas emission estimates are presented in Table 4-35.

Figure 4-13 - GHG emission trends for CRF Sector 2G : 1990-2018

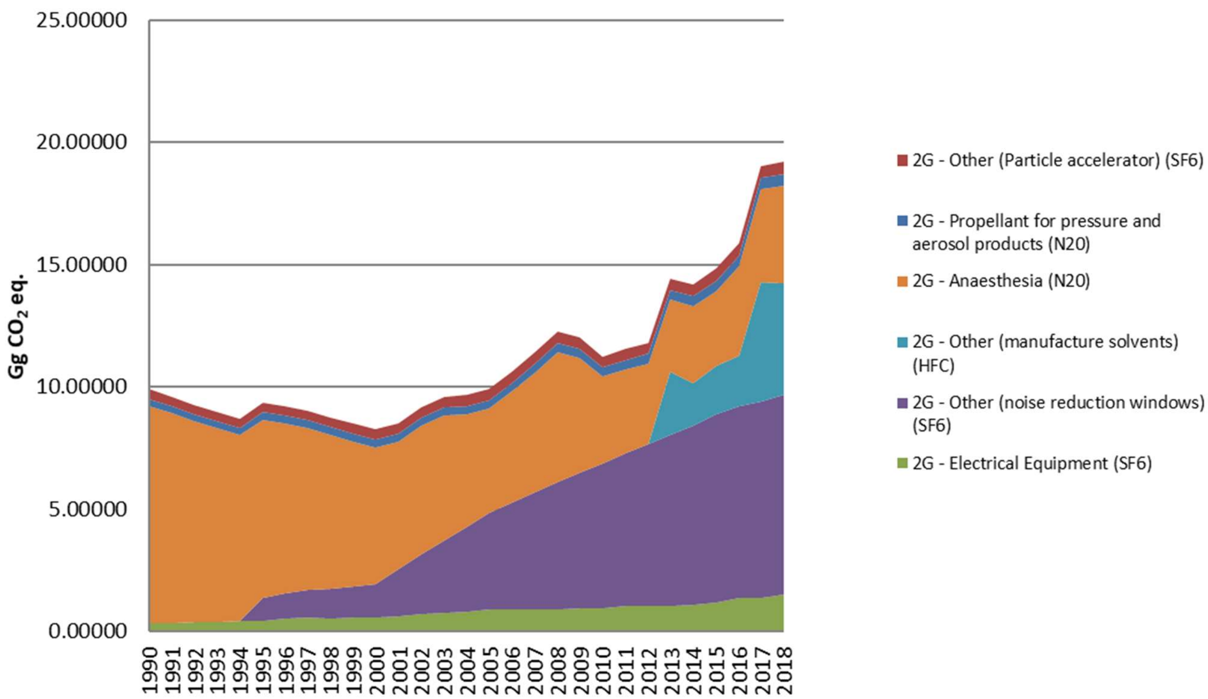


Table 4-35 - Estimated emissions for CRF Sector 2F: 1990-2018

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_20)	2G - Propellant for pressure and aerosol products (N_20)
				Gg CO_2 e			
1990	9.92	0.33	0.41	0.00	0.00	8.91	0.2806171
1991	9.61	0.35	0.39	0.00	0.00	8.58	0.2844131
1992	9.28	0.37	0.39	0.00	0.00	8.23	0.2882092
1993	8.98	0.40	0.38	0.00	0.00	7.91	0.2921513
1994	8.71	0.43	0.38	0.00	0.00	7.60	0.2961664
1995	9.34	0.43	0.36	0.96	0.00	7.28	0.3004734
1996	9.20	0.52	0.39	1.04	0.00	6.95	0.3043425
1997	9.03	0.57	0.40	1.12	0.00	6.63	0.3081386
1998	8.77	0.54	0.42	1.20	0.00	6.30	0.3120076
1999	8.52	0.56	0.42	1.27	0.00	5.95	0.3165337
2000	8.28	0.58	0.43	1.35	0.00	5.59	0.3204758
2001	8.51	0.64	0.43	1.90	0.00	5.22	0.3241259
2002	9.17	0.70	0.43	2.44	0.00	5.26	0.3272649
2003	9.60	0.77	0.44	2.96	0.00	5.09	0.332156
2004	9.67	0.82	0.45	3.47	0.00	4.61	0.3366821
2005	9.92	0.93	0.46	3.93	0.00	4.27	0.3424492
2006	10.64	0.91	0.46	4.36	0.00	4.56	0.3476323
2007	11.40	0.91	0.47	4.78	0.00	4.88	0.3531804
2008	12.27	0.93	0.49	5.17	0.00	5.33	0.3602615
2009	12.05	0.95	0.50	5.54	0.00	4.69	0.3665396
2010	11.25	0.96	0.42	5.91	0.00	3.58	0.3736208
2011	11.55	1.03	0.44	6.28	0.00	3.41	0.3814642
2012	11.81	1.04	0.45	6.64	0.00	3.28	0.3899359
2013	14.43	1.05	0.46	7.00	2.56	2.97	0.3834332
2014	14.18	1.07	0.47	7.35	1.71	3.17	0.4090357
2015	14.83	1.18	0.48	7.71	1.99	3.06	0.4205772
2016	15.86	1.37	0.49	7.86	2.02	3.70	0.4295034
2017	19.03	1.39	0.50	8.02	4.89	3.80	0.4377198
2018	19.20	1.53	0.50	8.17	4.56	3.99	0.4463724
1995-2018	106%	253%	39%	754%	NA	-45%	49%
2017-2018	0.89%	9.85%	1.64%	1.91%	-6.81%	5.12%	1.98%

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).

4.8.3 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 CO_2-eq

Noise reduction windows (2.G.2.C)

A life-cycle approach is applied:

$$Emissions = EF \bullet AR + D$$

The activity rate (*AR*) is the calculated SF_6 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 SF_6 is assumed to be 1% (EF=1%) and the lifespan 25 years. Disposal emissions (D) of the remaining SF_6 stock occur after a lifetime of 25 years. The resulting emissions in 2018 are 8.17 Gg CO_2-eq.

4.8.4 N_2O from product uses (2.G.3)

4.8.4.1 Medical applications (2.G.3.a)

N_2O emissions from Anaesthesia

In 2018, 0.0001% of total GHG emissions (excluding LULUCF) in Luxembourg originated from *2G3 - N_2O emissions from anaesthesia*, compared to 0.0002% in 1990. Compared to 2017, N_2O emissions from anaesthesia for the year 2018 increased by 5.12% and decreased by 55.17% compared to 1990.

It was assumed that all the N_2O 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 N_2O could be obtained. Hence, N_2O 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 N_2O 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 N_2O for anaesthesia in all hospitals of Luxembourg. The revised data from Germany (CRF 2015) for N_2O use in anaesthesia have been implemented and taken into account for the comparison.

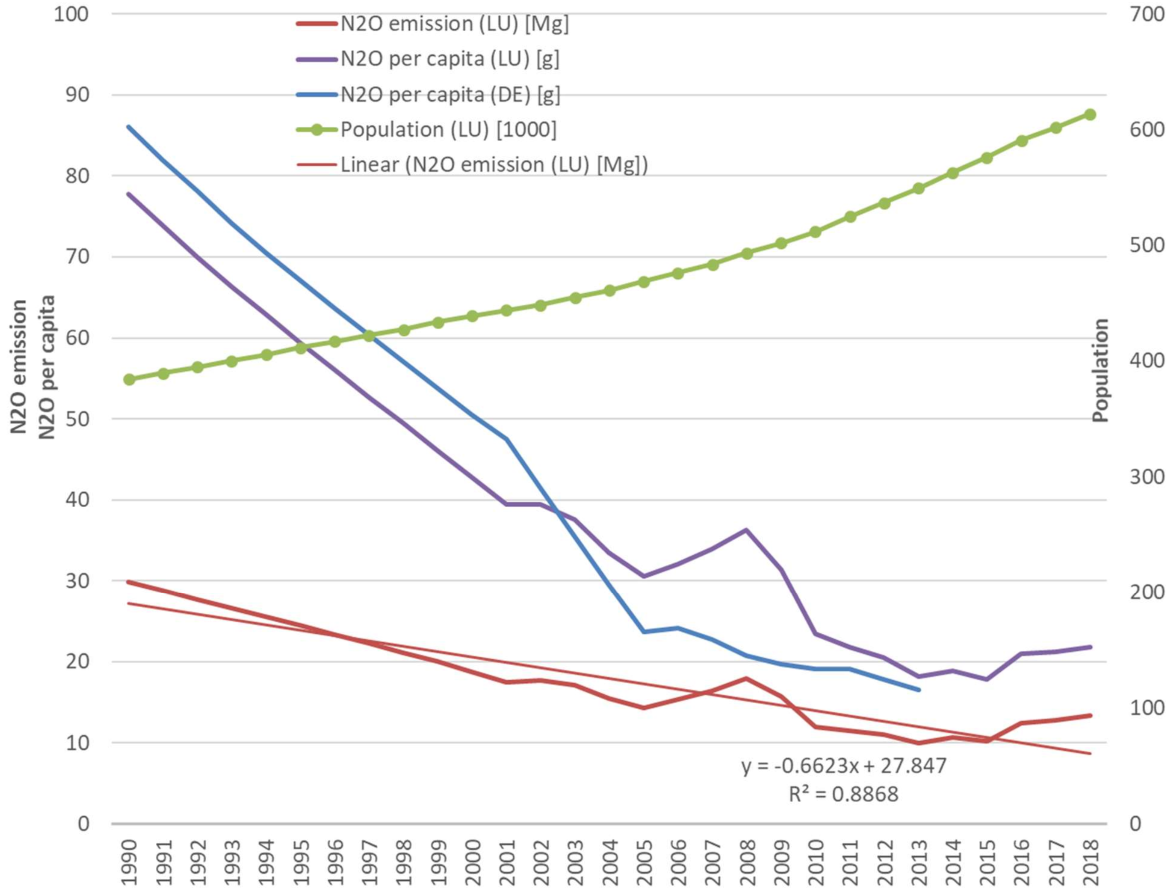
Although two different methods for the estimation of N_2O from anaesthesia are used over the time period (1990-2002 and 2003-2018), it is estimated that the time-series consistency is ensured. Indeed, when comparing the 2002 and 2003 values of emissions per capita of Germany with Luxembourg's value, 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 "Lëtzebuerger Associatioun vun de Klengdéierepraktiker", which is an association representing all the veterinaries active in Luxembourg, no N_2O is used as anaesthesia in veterinary cabinets or clinics in Luxembourg.

Table 4-36 – 2.G.3.a - Use of N_2O for Anaesthesia: 1990–2018.

	Luxembourg			Germany
	N_2O emission (LU) [Mg]	Population (LU) [1000]	N_2O per capita (LU) [g]	N_2O 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

Figure 4-14 – N_2O emissions and N_2O consumption for anaesthesia per capita and trend: 1990–2018



4.8.4.1.1 Uncertainties and time-series consistency

Direct use of N_2O 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 N_2O is used Table 4-37. In contrast to Ramirez, it is assumed that virtually all of the N_2O actually used is also fully released, thus no additional uncertainty is applied.

Table 4-37 - Uncertainties for category 2.G.3.a - N_2O emissions from anaesthesia.

IPCC Source category	Gas	AD	EF	Combined
		Uncertainty [%]		
2G3a - N_2O emissions from anaesthesia	N_2O	20.0	0	20.0

4.8.4.1.3 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?

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

No changes have been made.

4.8.4.3 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.

4.8.4.4 Other (2.G.3.b)

Propellant for pressure and aerosol products

For the period 1990-2018, no data regarding exclusively the consumption of food aerosol cans, and the related N_2O emission in Luxembourg, could be obtained. Hence, N_2O emissions from propellant for pressure and aerosol products usage were estimated by combining reported emissions in Belgium with the relative population in Luxembourg. In 2018, 0.00001% of total GHG emissions (excluding LULUCF) in Luxembourg originated from 2.G.3.b - Propellant for pressure and aerosol products compared to 0.00001% in 1990. Compared to 2017, N_2O emissions from Propellant for pressure and aerosol products, for the year 2018, increased by 1.98% and by 59.07% compared to 1990 (Table 4-38).

Table 4-38- 2.G.3.b - Use of N2O for Propellant for pressure and aerosol products: 1990–2018.

1.8.4.2 Other (2.G.3.b) Propellant for pressure and aerosol products		
	N_2O 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

4.8.4.4.1 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%

4.8.4.4.2 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?

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

No changes were made for this submission.

4.8.4.4.4 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

4.8.4.5 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.

4.8.4.5.1 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%

4.8.4.5.2 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?

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

No revisions and recalculations have been done since the last submission.

4.8.4.5.4 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. N_2O 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 1990-2018.

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)
- N_2O Emissions from Manure Management (CRF 3Bb)
- N_2O Emissions from Managed Soils (CRF 3D)
- CO_2 Emissions from Liming (CRF 3G)

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.

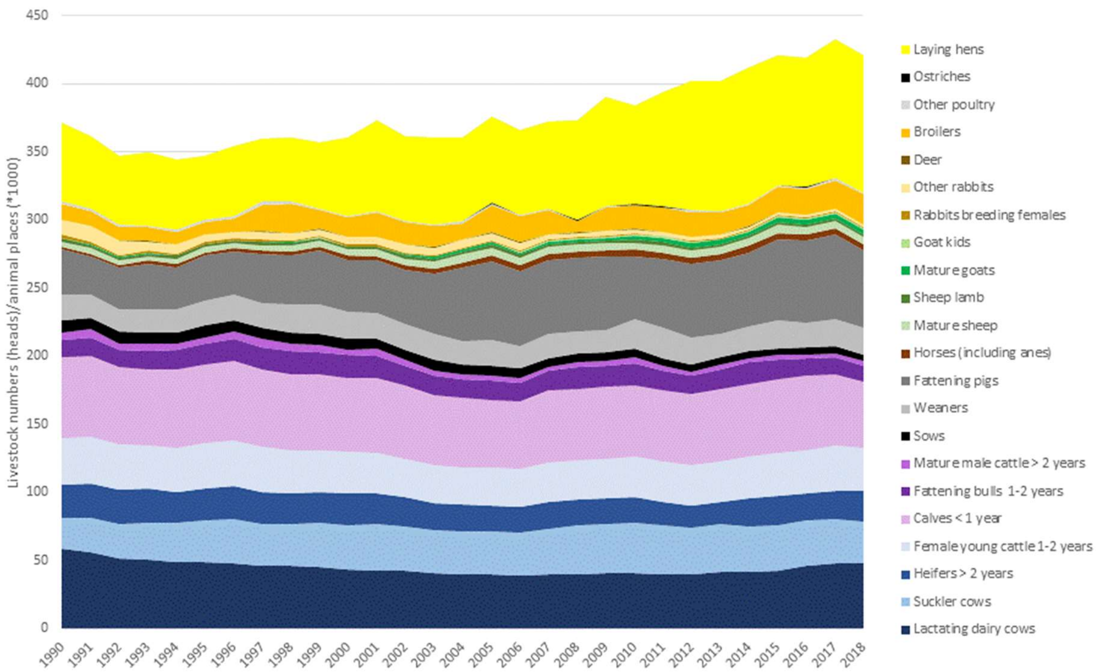
Hereafter a short overview of the Luxemburgish agricultural sector.

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 2019a). 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 Luxemburg, 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. This trend was reversed with the abolishment of the milk quota system in Europe on 31st March 2015, with a sharp increase of dairy cows up to 2017 and slowing down in 2018, partly compensated by a decrease in suckler cows, see Figure 5-1 (STATEC 2019c).

Swine and poultry is in Luxembourg of far less importance than cattle, and is 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 2019c).

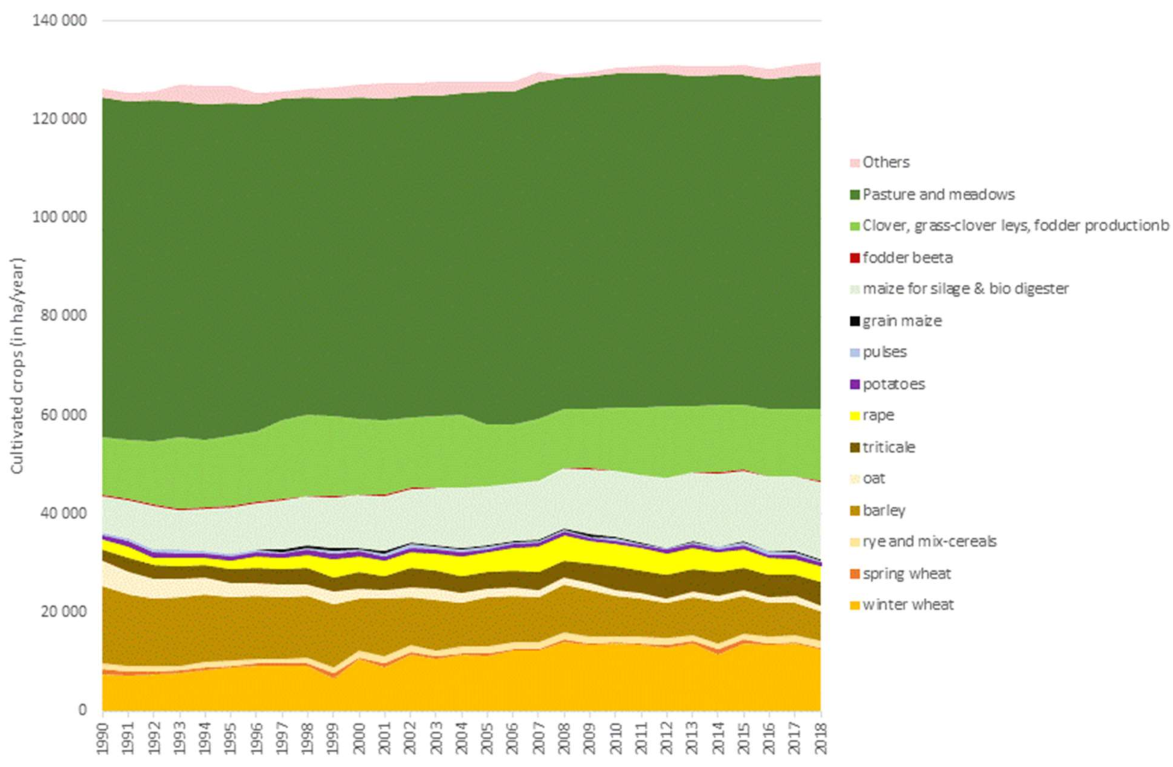
Permanent grassland is with more than 50% of the used agriculture surface predominant in Luxembourg. Grass, cover-grass and maize for silage (whole plant) are and were the main forage crops grown in Luxembourg, see Figure 5-2 (STATEC 2019a). Grains such as wheat, barley and triticale, but also rapeseed 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 1990-2018



Source: (STATEC 2019c)

Figure 5-2 – Cultivated crops (ha/year) for the period 1990-2018

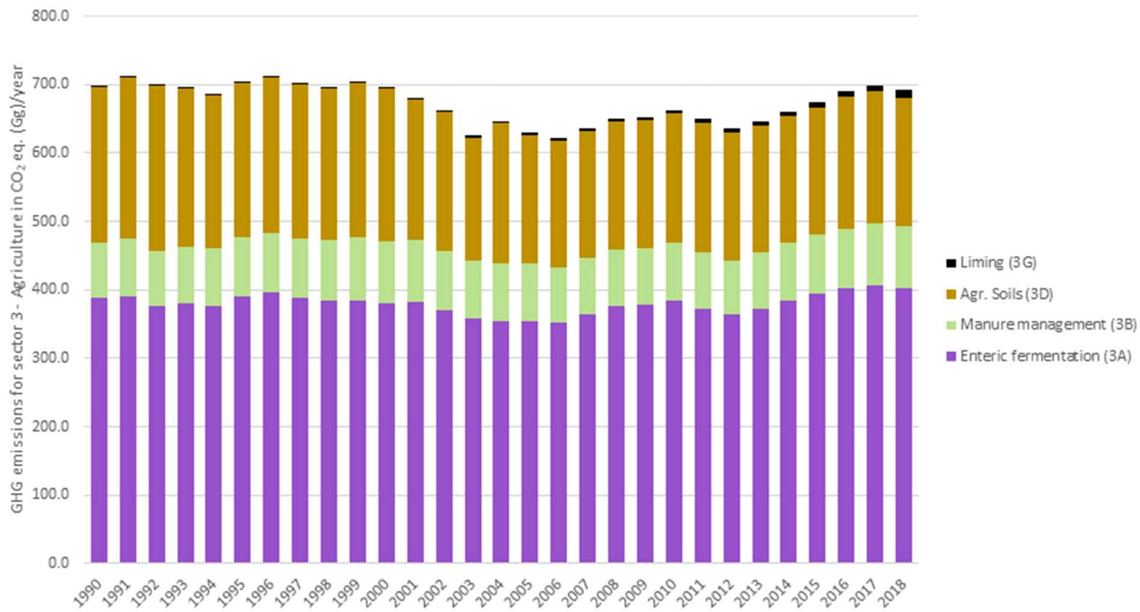


Source: (STATEC 2019a)

5.1.1 Emission Trends

In 2018, the agricultural sector contributed 6.55% to the total of Luxembourgish greenhouse gas emissions without LULUCF. The 2018, GHG emissions are in the same magnitude than the GHG emissions from 1990 (see Figure 5-3 and Table 5-1, Table 5-2).

Figure 5-3 – Emissions from Agriculture, total and per category (CO_2 eq.): 1990 - 2018



Source: Service d'Economie Rurale (SER)

There was a decrease over time, mainly due to a decrease in activity data, both decreasing livestock numbers and lower amounts of N-fertilizer. But this trend was lately reinverted due to increased numbers of dairy cattle after the abolishment of milk quota in Europe, with as result that the total GHG emissions from Agriculture are in 2018 in the same order of magnitude as in 1990, although 1.04% lower than in 2017.

Fluctuations which can be seen for agricultural soils 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.

Table 5-1– GHG emission trends in Gg CO2 eq. for CRF Sector 3 – Agriculture (without LULUCF): 1990-2018

	Enteric fermentation Gg CO_2 eq.				Manure management Gg CO2 eq.				Agricultural soils (without LULUCF) Gg CO2 eq.				Agriculture (without LULUCF) Gg CO2 eq.			
Year	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O
1990	387.8	NA	387.8	NA	80.3	NA	47.7	32.6	228.8	0.26	NA	228.6	696.9	0.26	435.5	261.1
1991	390.5	NA	390.5	NA	84.2	NA	53.0	31.2	236.1	0.46	NA	235.7	710.8	0.46	443.5	266.8
1992	375.3	NA	375.3	NA	82.3	NA	53.0	29.3	242.3	0.66	NA	241.6	699.9	0.66	428.4	270.9
1993	379.4	NA	379.4	NA	83.8	NA	54.5	29.3	232.6	1.02	NA	231.6	695.8	1.02	433.8	260.9
1994	376.9	NA	376.9	NA	83.6	NA	54.9	28.7	225.6	1.49	NA	224.2	686.2	1.49	431.8	252.9
1995	389.6	NA	389.6	NA	87.1	NA	57.7	29.4	226.9	1.22	NA	225.7	703.7	1.22	447.3	255.1
1996	395.5	NA	395.5	NA	88.0	NA	58.2	29.8	227.8	1.07	NA	226.8	711.4	1.07	453.8	256.5
1997	387.9	NA	387.9	NA	88.1	NA	59.0	29.1	225.4	1.59	NA	223.8	701.4	1.59	446.8	252.9
1998	384.1	NA	384.1	NA	88.7	NA	60.1	28.6	223.2	2.19	NA	221.0	696.1	2.19	444.3	249.6
1999	384.1	NA	384.1	NA	92.9	NA	65.3	27.6	226.9	1.22	NA	225.7	703.8	1.22	449.4	253.2
2000	380.0	NA	380.0	NA	90.5	NA	63.6	26.9	225.7	2.04	NA	223.7	696.2	2.04	443.6	250.6
2001	382.5	NA	382.5	NA	89.9	NA	63.2	26.7	207.7	2.48	NA	205.3	680.1	2.48	445.7	232.0
2002	369.8	NA	369.8	NA	86.9	NA	61.2	25.7	206.3	3.15	NA	203.2	663.0	3.15	431.0	228.9
2003	358.4	NA	358.4	NA	84.2	NA	58.9	25.3	183.6	3.05	NA	180.5	626.1	3.05	417.3	205.8
2004	354.4	NA	354.4	NA	84.0	NA	58.5	25.5	207.6	2.62	NA	204.9	645.9	2.62	412.8	230.5
2005	354.9	NA	354.9	NA	83.6	NA	58.4	25.2	191.8	4.23	NA	187.6	630.3	4.23	413.3	212.8
2006	351.4	NA	351.4	NA	81.2	NA	56.3	24.9	189.1	3.30	NA	185.8	621.7	3.30	407.7	210.7
2007	363.7	NA	363.7	NA	82.8	NA	57.0	25.8	189.5	3.34	NA	186.2	636.0	3.34	420.7	212.0
2008	375.7	NA	375.7	NA	83.4	NA	57.1	26.4	190.7	3.10	NA	187.6	649.8	3.10	432.8	214.0
2009	378.1	NA	378.1	NA	82.6	NA	56.5	26.2	191.2	4.41	NA	186.8	652.0	4.41	434.6	213.0
2010	385.1	NA	385.1	NA	83.0	NA	56.3	26.7	193.4	3.81	NA	189.6	661.4	3.81	441.4	216.2
2011	372.8	NA	372.8	NA	81.3	NA	55.4	25.9	195.2	5.29	NA	189.9	649.3	5.29	428.2	215.8
2012	364.0	NA	364.0	NA	79.4	NA	54.2	25.2	192.5	5.48	NA	187.0	635.9	5.48	418.2	212.2
2013	373.2	NA	373.2	NA	81.0	NA	55.3	25.7	192.1	6.29	NA	185.8	646.3	6.29	428.5	211.5
2014	385.1	NA	385.1	NA	83.7	NA	57.3	26.4	192.3	6.95	NA	185.4	661.2	6.95	442.4	211.8
2015	395.3	NA	395.3	NA	86.4	NA	59.7	26.7	192.7	7.36	NA	185.4	674.4	7.36	455.0	212.1
2016	401.9	NA	401.9	NA	87.9	NA	60.8	27.1	200.0	6.99	NA	193.0	689.8	6.99	462.7	220.1
2017	407.4	NA	407.4	NA	90.0	NA	62.3	27.7	202.0	8.80	NA	193.2	699.4	8.80	469.7	220.9
2018	403.4	NA	403.4	NA	89.0	NA	61.7	27.3	199.8	10.98	NA	188.8	692.2	10.98	465.2	216.1
Trend 1990 -2018	4.0%		4.0%		10.8%		29.3%	-16.2%	-12.7%	4194%		-17.4%	-0.7%	4194%	6.8%	-17.2%
Trend 2017 -2018	-1.0%		-1.0%		-1.1%		-0.9%	-1.5%	-1.1%	24.8%		-2.3%	-1.0%	24.8%	-1.0%	-2.2%

Source: SER

Note: CH_4 emissions were converted in CO_2-eq. by multiplying the emissions by 25 and N_2O emissions were converted in CO_2-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

	Agriculture (without LULUCF) Gg CO2 eq.				Agriculture (with LULUCF) Gg CO2 eq.			
Year	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O
1990	696.9	0.26	435.5	261.1	696.9	0.26	435.5	261.2
1991	710.8	0.46	443.5	266.8	710.9	0.46	443.5	266.9
1992	699.9	0.66	428.4	270.9	700.0	0.66	428.4	271.0
1993	695.8	1.02	433.8	260.9	695.9	1.02	433.8	261.0
1994	686.2	1.49	431.8	252.9	686.3	1.49	431.8	253.0
1995	703.7	1.22	447.3	255.1	703.8	1.22	447.3	255.2
1996	711.4	1.07	453.8	256.5	711.4	1.07	453.8	256.6
1997	701.4	1.59	446.8	252.9	701.4	1.59	446.8	253.0
1998	696.1	2.19	444.3	249.6	696.1	2.19	444.3	249.7
1999	703.8	1.22	449.4	253.2	703.9	1.22	449.4	253.3
2000	696.2	2.04	443.6	250.6	696.3	2.04	443.6	250.6
2001	680.1	2.48	445.7	232.0	680.2	2.48	445.7	232.0
2002	663.0	3.15	431.0	228.9	663.1	3.15	431.0	228.9
2003	626.1	3.05	417.3	205.8	626.2	3.05	417.3	205.8
2004	645.9	2.62	412.8	230.5	646.0	2.62	412.8	230.5
2005	630.3	4.23	413.3	212.8	630.4	4.23	413.3	212.8
2006	621.7	3.30	407.7	210.7	621.7	3.30	407.7	210.7
2007	636.0	3.34	420.7	212.0	636.1	3.34	420.7	212.0
2008	649.8	3.10	432.8	214.0	649.9	3.10	432.8	214.0
2009	652.0	4.41	434.6	213.0	652.0	4.41	434.6	213.0
2010	661.4	3.81	441.4	216.2	661.5	3.81	441.4	216.3
2011	649.3	5.29	428.2	215.8	649.3	5.29	428.2	215.8
2012	635.9	5.48	418.2	212.2	635.9	5.48	418.2	212.2
2013	646.3	6.29	428.5	211.5	646.4	6.29	428.5	211.6
2014	661.2	6.95	442.4	211.8	661.2	6.95	442.4	211.8
2015	674.4	7.36	455.0	212.1	674.4	7.36	455.0	212.1
2016	689.8	6.99	462.7	220.1	689.8	6.99	462.7	220.1
2017	699.4	8.80	469.7	220.9	699.4	8.80	469.7	220.9
2018	692.2	10.98	465.2	216.1	692.2	10.98	465.2	216.1
Trend 1990 -2018	-0.7%	4194%	6.8%	-17.2%	-0.7%	4194%	6.8%	-17.3%
Trend 2017 -2018	-1.0%	24.8%	-1.0%	-2.2%	-1.0%	24.8%	-1.0%	-2.2%

Source: SER

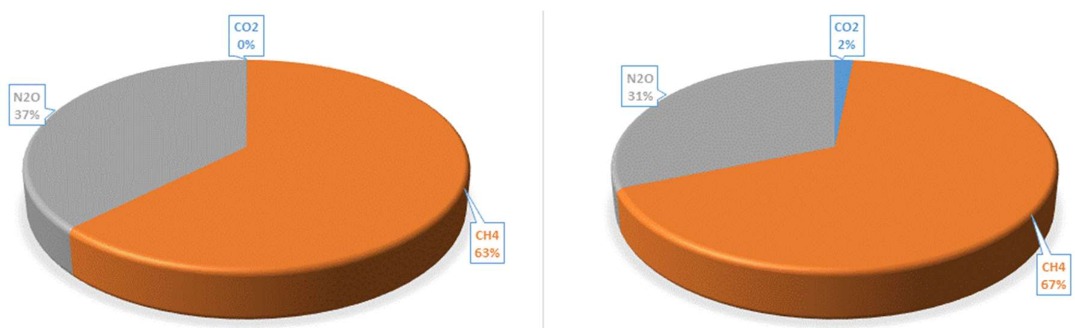
5.1.1.1 Emission trends per gas

From 1990 to 2018 CO_2 emissions from agriculture (i.e. CO_2 emissions from liming) increased by 4193.5%, although they account for <2% of the emissions from agriculture in 2018. CH_4 emissions from agriculture increased by 6.73%. Whereas N_2O emissions decreased in the same time by 17.26%. 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 2018 about 67% of emissions from agriculture originate from CH_4 (in 1990 63%), 31% from N_2O (in 1990 37%) and <2% from CO_2 (in 1990 0.3%).

Figure 5-4 – Share of gases from Agriculture (CO_2 eq.): 1990 and 2018

1990 2018



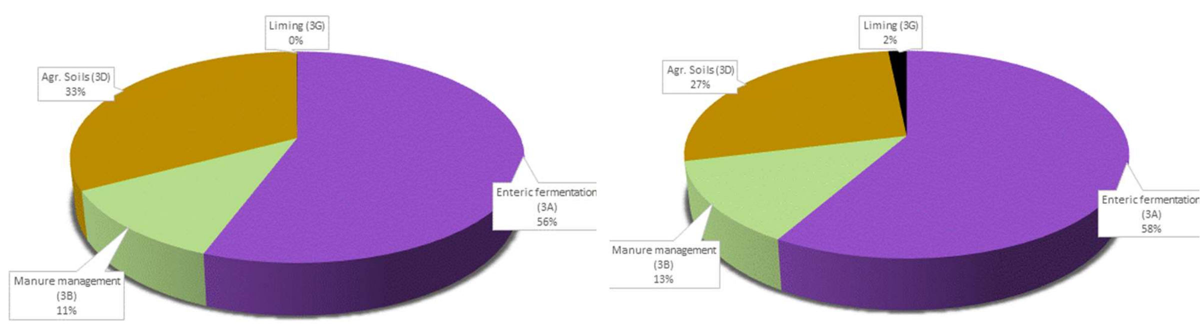
5.1.1.2 Emission trends per subcategory

GHG emissions by subcategories are presented in Figure 5-3 and Table 5-1. Important categories are 3A enteric fermentation (Trend 1990-2018: +4.04%) and 3.D agricultural soils (Trend 1990-2018: -17%) followed by 3.B manure management (Trend 1990-2018: +10.5%). Although of less importance, liming (3 G) associated emissions were increasing since 1990 to 2018 by 4193.5%.

Enteric fermentation (3A) emissions are responsible for 58% of the emissions from agriculture in 2018 (in 1990 56%), followed by N_2O emissions from agricultural soils (3D) (27% versus 33% 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 2018 (in 1990 0.3%).

Figure 5-5 – Share of categories from Agriculture (CO_2 eq.): 1990 and 2018

1990 2018



5.1.2 Key Categories

The methodology and results of the key source analysis are presented in Chapter 5.6.1. Table 5-3 presents the key source categories of Sector 3 – Agriculture.

Table 5-3 – Key sources of IPCC Sector 3 – Agriculture 2018

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	90-18	90-18	X	X
3B	Manure Management	CH_4	98-01	98-01, 15-18		
3D1	Direct N_2O Emissions from Managed Soils	N_2O	90-18	90-18		

Source: Environment Agency

Notes: LA = Level Assessement (Tier 1) including respectively exluding LULUCF

TA = Trend Assessement 2018 (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. Category 3H is listed as NE. Emissions from 3H are under the significance threshold (0.05% and 500kt CO_2eq), for more details see section 5.10.

Table 5-4 –Overview of subcategories of CRF 3 – Agriculture: Status

CRF source category		CO_2		CH_4		N_2O	
		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, CS
E.	Prescribed burning of savannahs	NA	NA	NO	NO	NO	NO
F.	Field burning of agricultural residues	NA	NA	NO	NO	NO	NO
G.	Liming	T1	D	NA	NA	NA	NA
H.	Urea application	NE	NE	NA	NA	NA	NA
I.	Other carbon-containing fertilizers	NO	NO	NA	NA	NA	NA
J.	Other	NO	NO	NA	NA	NA	NA

Used abbreviations: NA = not applicable; NE = not estimated; 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 only 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 ($P_{cull\ cows}$) (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 ($N_{lactating\ dairy\ cows}=N_{dairy\ cows\ (total)} - N_{cull\ cows}$) and the number of cull cows ($N_{non-lactating\ dairy\ cows} = [N_{dairy\ cows\ (total)} * P_{cull\ cows}]$) 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 reported as one category, namely "calves"; furthermore female young cattle 1-2 years and heifers >2 years were 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.

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.

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 we distinguish between laying hens, broilers, other poultry and ostriches:

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.
Ostriches	Comprising only ostriches

Note: in the CRF tables laying hens, broilers and other poultry were reported as one category, namely "poultry". Ostriches was considered under "others" and reported as a separate category.

For goats 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.
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].

Note in the CRF tables were goats reported as one category.

[103] Own survey conducted in November 2018 between goat famers 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 Luxemburgish 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.

For rabbits 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

Note in the CRF tables were rabbits reported as one category.

Other animal categories considered were horses, including mules and asses, and deer:

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.
Deer	All other registered animals are considered in this category, the majority (>90%) were deer's.

Note emissions from mules and asses were considered together with horses, why using in the CRF tables the key notification "IE".

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 spring[105] by STATEC (Institut national de la statistique et des études économiques du Grand-Duché de Luxembourg) (STATEC 2019c); 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 Luxemburg 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 ~95%. However, since 2012 is the number of cattle – the most important livestock category in Luxemburg – 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 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).

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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/enterprises/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 1990-2018*

	Calves < 1 year	Female young cattle 1-2 years[a]	Heifers >2 years[a]	Fattening bulls 1-2 years	Mature male cattle > 2 years	Lactating dairy cows[b]	Suckler cows[b]	Sows	Fattening pigs[c]	Weaners[c,d]	Mature sheep	Sheep lambs < 1 year[e]	Mature goats[f]	Goat kids < 1 year[e,f]	Horses[g]	Broilers[h]	Laying hens[h]	Other poultry[i]	Ostriches[i]	Rabbits - Breeding animals[j]	Other rabbits[j]	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
Trend 1990 -2018	-18%	-6%	-10%	-13%	-40%	-19%	40%	-42%	72%	0%	36%	1%	1092%	634%	171%	97%	75%	-66%	NA	-75%	-80%	65%
Trend 2017 -2018	-7%	-4%	10%	-8%	-2%	0%	-6%	-2%	-8%	-3%	0%	5%	3%	-22%	-1%	6%	0%	-39%	7%	4%	20%	27%

Explication notes for Table 5-5:

a) In the CRF Tables were female young cattle 1-2 years and heifers >2 years reported as one category, namely "young cattle".

b) 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 2019c). 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".

c) 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 famers work on contract basis - in particularly those raising weaners and fattening pigs – is an explication for the observed fluctuations between years.

d) 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 2019c), and other international statistical institutes such as EUROSTAT.

e) The majority of sheep lambs and goat kids are fattened and sold previous to one year of age. Following the IPPC 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 2019c), and other international statistical institutes.

f) 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.

g) Mules and asses are included in the category "horses".

h) 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.

i) In the published statistics were ostriches included in "other poultry". Ostriches were considered as a separate category and therefore subtracted from this category.

j) 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

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).

The yearly agricultural census in 2010 has 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., Haupert J., & Hoffmann J.-P., 2014). Without new data, the manure management systems for the years 2012-2018 were assumed to be the same as in 2011, except for goats. Up to 2001, the few goats kept on Luxemburgish farms (<200 mature goats in the whole country) were a kind of "backyard" animals. Those animals were kept, similar as sheep, for most of the year on pasture. With the installation of the first professional dairy farmer with a few hundred dairy goats in 2001/2002, and a few more professional dairy farmers following him, the vast majority of goats are dairy goats that are kept in buildings with a solid manure management system. For simplicity reason it was therefore assumed that since 2002, 100% of the goats would be kept in buildings on straw.

More recent data are expected to be published in the near future, also will be new data collected in 2020, allowing an update, and interpolation, of the manure management system in the next submissions.

The proportion of excreta deposited during grazing, referred hereafter as manure management system (MMS) – pasture (MMS- $pasture_{(i)}$) for animal category *i* and for the years 1990-2018 is summarized in Table 5-6, whereby *i* are all the different animal categories considered in the emission calculations.

For excreta deposited during housing we do distinguish 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 slurry[108]:
    a. was spread directly ($x_{spread\_direct\_slurry}$)
    b. was stored before application (x_{store_slurry})
    c. was used as feedstocks in biogas facilities (x_{feed_slurry}).
d) for solid manure was further required, what proportion of solid manure[109]:
    a. was stored before application (x_{store_solid}).

These different fractions/proportions were derived from the above mentioned MMS, whereby:

$x_{grazing(i)}$ = MMS- pasture$_{(i)}$.

$x_{build(i)}$ = (1 - $x_{grazing(i)}$).

$x_{slurry(i)}$ = ((MMS-liquid$_{(i)}$ + MMS-digest$_{(i)}$) / (MMS-liquid$_{(i)}$ + MMS-digest$_{(i)}$ + MMS-solid$_{(i)}$))

$x_{solid(i)}$ = (1 – $x_{slurry(i)}$).

$x_{feed\_slurry(i)}$ = ((MMS-digest$_{(i)}$) / (MMS-liquid$_{(i)}$ + MMS-digest$_{(i)}$)).

$x_{store\_slurry(i)}$ = (1 – $x_{feed\_slurry(i)}$)

$x_{store\_solid(i)}$ = MMS-solid$_{(i)}$.

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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 x_{build}.

108 Note: Slurry is either stored on the farm or used as feedstocks. Direct spreading of slurry is not occurring in Luxemburg.

109 Note: Solid manure is stored on the farm before spreading. Direct spreading is not occurring in Luxemburg. Also is it not common practice to use solid manure as feedstocks, why assumed to be zero.

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., Haupert J., & Hoffmann J.-P., 2014); with. 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 a natural crust, and swine slurry stored in slurry tanks without 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: 1990-2018.

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%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2012	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2013	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2014	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2015	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2016	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2017	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	0%	0%	0%	75%	0%	75%
2018	37%	49%	49%	0%	0%	25%	49%	0%	0%	0%	75%	0%	49%	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., Haupert J., & Hoffmann J.-P., 2014).

Table 5-7 – Manure management system solid (MMS-solid) for all animal categories: 1990-2018.

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%	31%	38%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2012	46%	18%	18%	67%	67%	31%	38%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2013	46%	18%	18%	67%	67%	31%	38%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2014	46%	18%	18%	67%	67%	31%	38%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2015	46%	18%	18%	67%	67%	31%	38%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2016	46%	18%	18%	67%	67%	31%	38%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2017	46%	18%	18%	67%	67%	31%	38%	5%	5%	5%	25%	100%	51%	100%	100%	100%	25%	100%	25%
2018	46%	18%	18%	67%	67%	31%	38%	5%	5%	5%	25%	100%	51%	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., Haupert J., & Hoffmann J.-P., 2014).

Table 5-8 – Manure management system – liquid (MMS-liquid) for all animal categories: 1990-2018.

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%	37%	7%	72%	82%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2014	11%	26%	26%	26%	26%	37%	7%	72%	82%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2015	11%	26%	26%	26%	26%	37%	7%	72%	82%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2016	11%	26%	26%	26%	26%	37%	7%	72%	82%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2017	11%	26%	26%	26%	26%	37%	7%	72%	82%	82%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2018	11%	26%	26%	26%	26%	37%	7%	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., Haupert J., & Hoffmann J.-P., 2014).

Table 5-9 – Manure management system – digester (MMS-digester) for all animal categories: 1990-2018.

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%	6%	23%	13%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2014	6%	6%	6%	7%	7%	7%	6%	23%	13%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2015	6%	6%	6%	7%	7%	7%	6%	23%	13%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2016	6%	6%	6%	7%	7%	7%	6%	23%	13%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2017	6%	6%	6%	7%	7%	7%	6%	23%	13%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2018	6%	6%	6%	7%	7%	7%	6%	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., Haupert J., & Hoffmann J.-P., 2014).

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:

$$N.ex = \left(320 * \left(124 + \left(1320 * milk\ urea\ N[\frac{g}{day}]\right) + \left(1.87 * milk\ N[\frac{g}{day}]\right) - (6.9 * daily\ milk\ yield)\right)\right) + (45 * 256)$$

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%)[110]; 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, 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. (Source: ASTA - Service d'analyse du lait, Tom Engel, pers. communication 9th November 2018).

The estimated N.ex per lactating dairy cow and per year for the years 1990-2018 is summarized in Table 5-10.

[110] 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

	Annual milk production[a] (*1000 tons)	Milk fat (%)	Milk protein (%)	Milk urea (ppm)[b]	Daily milk yield[c] (kg/day)	N.ex (kg N per head)[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
Trend 1990 -2018	45%	1%	5%	-1%	78%	13%
Trend 2017 -2018	5%	0%	1%	3%	5%	3%

a) Source: (SER 2019). 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.

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), (Ruyssenaars, 2019), (Anonymous, Informative Inventory Report about Belgiums' 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 is provided in Annex 3:A.

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	82	(KTBL 2006) page 490
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, et al., 2018) et al. 2018, Rösemann et al. 2019)

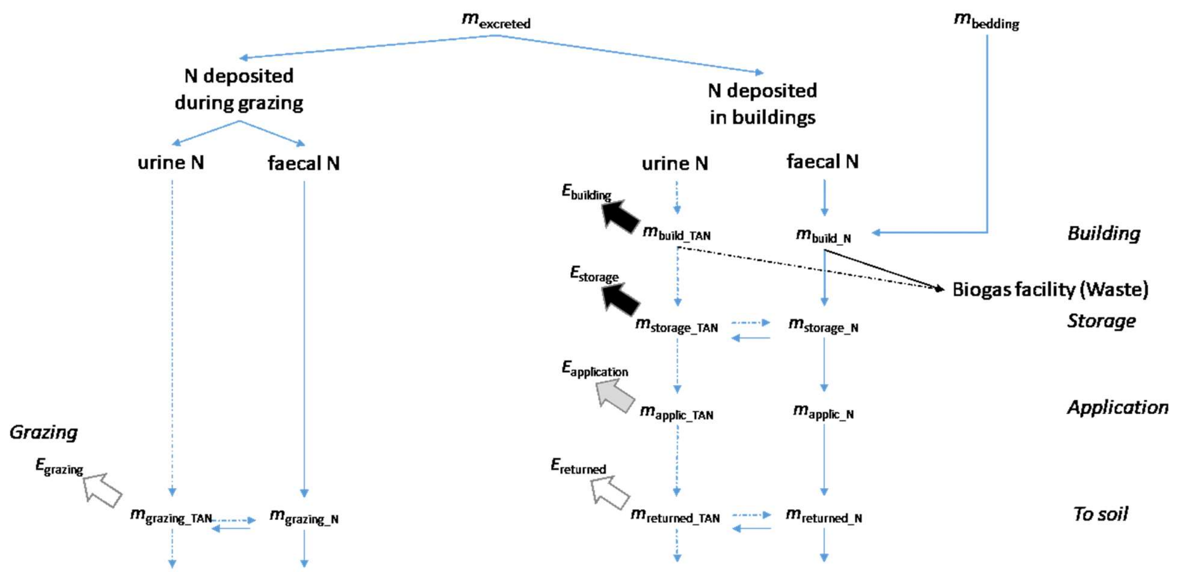
* Using more detailed statistics than the one provided in Table 5-5.

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* 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 arrows mark emissions from application: (E_{applic} NH_3 emissions during and after spreading). Broad white arrows mark emissions from soils: ($E_{grazing}$ NH_3, N_2O, NO_x and N_2 emissions during and after grazing; $E_{returned}$ N_2O, NO_x and N_2 emissions from soil resulting from manure input). Red arrows indicate the flow to another sector (i.e. the proportion of manure that was used as feedstock for anaerobic digestions in biogas facilities).

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 2016 guidelines (EMEP/EEA, 2016).

The first step is the definition of livestock subcategories "that are homogeneous with respect to feeding, excretion and age/weight range" (EMEP/EEA, 2016), 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 ith 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/EEA, 2016) :

$$m_{grazing\_N(i)} = x_{grazing(i)} * N_{ex(i)}$$
$$m_{build\_N(i)} = x_{build(i)} * N_{ex(i)}$$

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 underneath a slatted floor, 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/EEA 2016):

$$m_{grazing\_TAN(i)} = x_{TAN(i)} * m_{grazing\_N(i)}$$
$$m_{build\_TAN(i)} = x_{TAN(i)} * m_{build\_N(i)}$$

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/EEA guidelines (EMEP/EEA 2016) 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/EEA 2016))
Female young female cattle 1-2 years	0.6	Default value for non-dairy cattle (Table 3.9; (EMEP/EEA 2016))
Heifers > 2 years	0.6	Default value for non-dairy cattle (Table 3.9; (EMEP/EEA 2016))
Fattening bulls 1-2 years	0.6	Default value for non-dairy cattle (Table 3.9; (EMEP/EEA 2016))
Mature male cattle > 2 years	0.6	Default value for non-dairy cattle (Table 3.9; (EMEP/EEA 2016))
Lactating dairy cows	0.6	Default value for dairy cattle (Table 3.9; (EMEP/EEA 2016))
Suckler cows	0.6	Default value for non-dairy cattle (Table 3.9; (EMEP/EEA 2016))
Sows	0.7	Default value for sows and piglets to 8 kg (Table 3.9; (EMEP/EEA 2016))
Fattening pigs	0.7	Default value for fattening pigs, 8- 110 kg (Table 3.9; (EMEP/EEA 2016))
Weaners	0.7	Default value for fattening pigs, 8-110 kg (Table 3.9; (EMEP/EEA 2016))
Sheep (mature sheep and lambs)	0.5	Default value for sheep (Table 3.9; (EMEP/EEA 2016))
Goats (mature goats and kids)	0.5	Default value for goats (Table 3.9; (EMEP/EEA 2016))
Horses (including assess and mules)	0.6	Default value for horses (Table 3.9; (EMEP/EEA 2016))
Broilers	0.7	Default value for broilers (Table 3.9; (EMEP/EEA 2016))
Laying hens	0.7	Default value for laying hens (Table 3.9; (EMEP/EEA 2016))
Other poultry	0.7	Default values for turkeys, ducks and geese (Table 3.9; (EMEP/EEA 2016))
Ostriches	0.7	Default value for geese (Table 3.9; (EMEP/EEA 2016)), similar as (Haenel, et al., 2018)
Rabbits (breeding female animals and other rabbits)	0.6	Default value for horses (Table 3.9; (EMEP/EEA 2016)), similar as (Haenel, et al., 2018)
Deer	0.5	Default value for sheep and goats (Table 3.9; (EMEP/EEA 2016))

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/EEA 2016):

$$m_{build\_slurry\_TAN(i)} = x_{slurry(i)} * m_{build\_TAN(i)}$$
$$m_{build\_slurry\_N(i)} = x_{slurry(i)} * m_{build\_N(i)}$$
$$m_{build\_solid\_TAN(i)} = (1 - x_{slurry(i)}) * m_{build\_TAN(i)}$$
$$m_{build\_solid\_N(i)} = (1 - x_{slurry(i)}) * m_{build\_N(i)}$$

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 2016 guidelines (EMEP/EEA 2016):

$$E_{build\_slurry\_NH3-N(i)} = m_{build\_slurry\_TAN(i)} * EF_{build\_slurry\_NH3-N(i)}$$
$$E_{build\_solid\_NH3-N(i)} = m_{build\_solid\_TAN(i)} * EF_{build\_solid\_NH3-N(i)}$$

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) 2020 (Schuman, Becker, Hadzic, Mangen, & Mirgain, 2020) in section 5.3.3. The NH_3 emissions are reported in NFR category 3B.

In step 7, N in animal bedding ($m_{bedding(i)}$) in litter-based housing systems is added, whereby accounting for the consequent immobilisation of TAN (f_{imm}) in that bedding.

$m_{bedding(i)}$ was estimated using the figures provided in Table 3.7 in the 2016 guidelines (EMEP/EEA 2016) 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.

Table 5-13 – Estimated N added in straw in animal bedding ($m_{bedding(i)}$) for livestock category *i (kg N/year/head or place)**

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
1990	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.24	2.05
1991	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.24	2.05
1992	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.24	2.05
1993	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.24	2.05
1994	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.24	2.05
1995	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.24	2.05
1996	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.24	2.05
1997	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.24	2.05
1998	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.24	2.05
1999	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.24	2.05
2000	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.24	2.05
2001	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.24	2.05
2002	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2003	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2004	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2005	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2006	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2007	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2008	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2009	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2010	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2011	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2012	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2013	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2014	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2015	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2016	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2017	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05
2018	2.55	2.05	2.05	4.06	4.06	9.16	2.05	2.40	0.80	0.80	0.24	0.97	2.05

*Note : Given the low numbers of poultry, ostriches, rabbits and deer, and given that no data were provided in Table 3.7 in the 2016 Guidelines (EMEP/EEA 2016) for these categories, no estimates of additional N in animal bedding in litter-based housing systems were made for poultry, ostriches, rabbits and deer

Further were the amounts of total-N and total-TAN in solid manure that are removed from buildings calculated ($m_{ex\text{-}build\_solid\_TAN}$ and $m_{ex\text{-}build\_solid\_N}$), whereby following equation 18 and equation 19 from the 2016 guidelines (EMEP/EEA 2016):

$$m_{ex-build\_solid\_TAN(i)} = \left\{\left(m_{build\_solid\_TAN(i)} \quad - E_{build\_solid\_NH3-N(i)}\right) * \ (1 - f_{imm})\right\}$$

$$m_{ex-build\_solid\_N(i)} = \left\{\left(m_{build\_solid\_N(i)} + m_{bedding\_N(i)} + \ f_{imm}\right) - \ E_{build\_solid(i)}\right\}$$

with f_{imm} assumed to be 0.0067, according to the 2016 guidelines (EMEP/EEA 2016).

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 ($x_{feed\_slurry\ (i)}$, assumed to be only slurry, for details see section 5.2.3) as emissions were calculated and reported in NFR Category 5B2. 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, 21, 24 and 25, respectively from the 2016 guidelines (EMEP/EEA 2016), namely:

whereby for slurry:

$$m_{storage\_slurry\_TAN(i)} = \{(m_{build\_slurry\_TAN(i)} - E_{build\_slurry\_NH3-N(i)})\} * x_{store\_slurry(i)}$$
$$m_{storage\_slurry\_N(i)} = \{(m_{build\_slurry\_N(i)} - E_{build\_sl\qquad\_NH3-N(i)})\} * x_{store\_slurry(i)}$$

and for solid manure:

$$m_{storage\_solid\_TAN(i)} = m_{ex-build\_solid\_TAN(i)} * \ x_{store\_solid(i)}$$
$$m_{storage\_solid\_N(i)} = m_{ex-build\_solid\_N(i)} * \ x_{store\_solid(i)}.$$

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 28 from the 2016 guidelines (EMEP/EEA 2016), 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 2016 guidelines (EMEP/EEA 2016).

In Step 10, the emissions of NH_3, N_2O, NO and N_2 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 29 and 30 from the 2016 guidelines (EMEP/EEA 2016), namely:

for slurry:

$$E_{storage\_slurry(i)} = E_{storage\_slurry\_NH_{3-N}(i)} + E_{storage\_slurry\_N_2O-N(i)} + E_{storage\_slurry\_NO-N(i)} + E_{storage\_slurry\_N_2-N(i)}$$

and for solid:

$$E_{storage\_solid(i)} = E_{storage\_solid\_NH_3-N(i)} + E_{storage\_solid\_N_2O-N(i)} + E_{storage\_solid\_NO-N(i)} + E_{storage\_solid\_N_2-N(i)}$$

Detailed information on the calculations and the used EFs for the N_2O 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) 2020 (Schuman, Becker, Hadzic, Mangen, & Mirgain, 2020). The N_2O emissions are reported in CRF category 3B, and the NH_3 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 31-34 from the 2016 guidelines (EMEP/EEA 2016), namely:

for slurry:

$$m_{applic\_slurry\_TAN(i)} = mm_{storage\_slurry\_TAN(i)} - E_{storage\_slurry(i)}$$
$$m_{applic\_slurry\_N(i)} = mm_{storage\_slurry\_N(i)} - E_{storage\_slurry(i)}$$

and for solid:

$$m_{applic\_solid\_TAN(i)} = m_{storage\_slolid\_TAN(i)} - E_{storage\_solid(i)}$$
$$m_{applic\_solid\_N(i)} = m_{storage\_solid\_N(i)} - E_{storage\_solid(i)}$$

In Step 12, the emissions of NH_3-N during and immediately after field application was calculated , according to equation 35 and 36 from the 2016 guidelines (EMEP/EEA 2016), namely:

for slurry:

$$E_{applic\_slurry\_NH3-N(i)} = m_{applic\_slurry\_TAN(i)} * \ EF_{applic\_slurry\_NH3-N(i)}$$

and for solid:

$$E_{applic\_solid\_NH3-N(i)} = m_{applic\_solid\_TAN(i)} * \ EF_{applic\_solid\_NH3-N(i)}$$

Detailed information on the calculations and the used EFs are provided in section 5.4.3. in the Informative Inventory Report (IIR) 2020 (Schuman, Becker, Hadzic, Mangen, & Mirgain, 2020). The NH_3 emissions are reported in NFR category 3D2.

In Step 13, the net amount of N returned to soil from manure ($m_{returned\_N}$ and $m_{returned\_TAN}$) after losses of NH_3-N were calculated, according to equations 37 - 40 from the 2016 guidelines (EMEP/EEA 2016), namely:

for slurry:

$$m_{returned\_slurry\_TAN(i)} = m_{applic\_slurry\_TAN(i)} - \ E_{applic\_slurry\_NH3-N(i)}$$
$$m_{returned\_slurry\_N(i)} = m_{applic\_slurry\_N(i)} - \ E_{applic\_slurry\_NH3-N(i)}$$

and for solid:

$$m_{returned\_solid\_TAN(i)} = m_{applic\_solid\_TAN(i)} - \ E_{applic\_solid\_NH3-N(i)}$$
$$m_{returned\_solid\_N(i)} = m_{applic\_solid\_N(i)} - \ E_{applic\_solid\_NH3-N(i)}$$

In Step 14, the NH_3-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 41 from the 2016 guidelines (EMEP/EEA 2016), namely:

$$E_{grazing_{NH} -N(i)} = m_{grazing\_TAN(i)} * \ EF_{grazing_{NH} -N(i)}$$

Detailed information on the calculations and the used EFs are provided in section 5.4.3 in the Informative Inventory Report (IIR) 2020 (Schuman, Becker, Hadzic, Mangen, & Mirgain, 2020). The NH_3 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 2017 provisional livestock activity data were revised and updated, where necessary.
- The used N excretion (N.ex) for livestock categories others than dairy cows in the previous submissions were based on national fertilizer units, (GDR, 30 juillet 2015) which were considered to be inadequate and therefore revised in the current submission.
- The N.ex for dairy cows had to be updated, as there had been an error in the calculation for the weighted average of milk urea.
- For the calculations of the N available in manure applied to soil, and for indirect N_2O 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.

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 implement 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.

5.2.10 Planned improvement

The planned update of the manure management system had to be postponed until the next submission, as it took longer than planned to set-up legal contracts to transfer the raw data from the 2016 SPAM from STATEC to the SER. Furthermore, with additional data on MMS, on building types and on manure storage systems – all to be collected during the 2020 agriculture census - additional changes will be made in future submissions, ones analysed and published.

In the next submission, the flow of total ammoniacal nitrogen (TAN) through the manure management will be revised, following the 2019 EMEP/EEA guidelines. 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 2018, this source category was responsible for 87% of agricultural methane emissions and for 68.65% of the total methane emissions estimated for Luxembourg. It represented 58% of the total GHG emissions from the agriculture sector and 3.83% of the total GHG emissions in CO_2eq (excluding LULUCF).

5.3.1 Key source

With 3.83% of the total GHG emissions in CO_2 eq., excluding LULUCF in 2018, 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 – CH_4 emission trends for IPCC Category 3A – Enteric Fermentation: 1990-2018 (Gg)

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	TOTAL
1990	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	15.51
1991	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	15.62
1992	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	15.01
1993	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	15.17
1994	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	15.08
1995	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	15.59
1996	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	15.82
1997	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	15.51
1998	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	15.36
1999	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	15.36
2000	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	15.20
2001	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	15.30
2002	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	14.79
2003	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	14.34
2004	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	14.17
2005	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	14.20
2006	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	14.06
2007	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	14.55
2008	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	15.03
2009	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	15.13
2010	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	15.40
2011	1.49	1.79	0.97	1.13	0.25	5.50	3.48	0.009	0.076	0.033	0.049	0.008	0.023	0.083	NO	NO	NO	NO	NE	0.009	14.91
2012	1.50	1.80	0.92	1.04	0.22	5.44	3.36	0.009	0.081	0.029	0.046	0.007	0.022	0.088	NO	NO	NO	NO	NE	0.008	14.56
2013	1.52	1.82	0.92	1.14	0.24	5.66	3.35	0.008	0.081	0.026	0.049	0.008	0.020	0.084	NO	NO	NO	NO	NE	0.005	14.93
2014	1.52	1.85	1.16	1.24	0.28	5.85	3.24	0.008	0.082	0.026	0.050	0.008	0.019	0.085	NO	NO	NO	NO	NE	0.005	15.41
2015	1.54	1.91	1.20	1.12	0.29	6.19	3.26	0.007	0.090	0.030	0.053	0.009	0.021	0.085	NO	NO	NO	NO	NE	0.005	15.81
2016	1.56	1.90	1.14	0.99	0.25	6.73	3.23	0.007	0.090	0.028	0.049	0.008	0.022	0.082	NO	NO	NO	NO	NE	0.003	16.07
2017	1.50	2.01	1.14	0.97	0.26	6.93	3.19	0.008	0.093	0.030	0.048	0.008	0.023	0.084	NO	NO	NO	NO	NE	0.002	16.30
2018	1.39	1.92	1.25	0.89	0.26	7.14	3.00	0.008	0.086	0.029	0.048	0.008	0.022	0.084	NO	NO	NO	NO	NE	0.003	16.14
Trend 1990 -2018	-18%	-6%	-10%	-13%	-40%	8%	40%	-42%	72%	0%	36%	1%	964%	171%						65%	4%
Trend 2017 -2018	-7%	-4%	10%	-8%	-2%	3%	-6%	-2%	-8%	-3%	0%	5%	-3%	-1%						27%	-1%

Source: 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

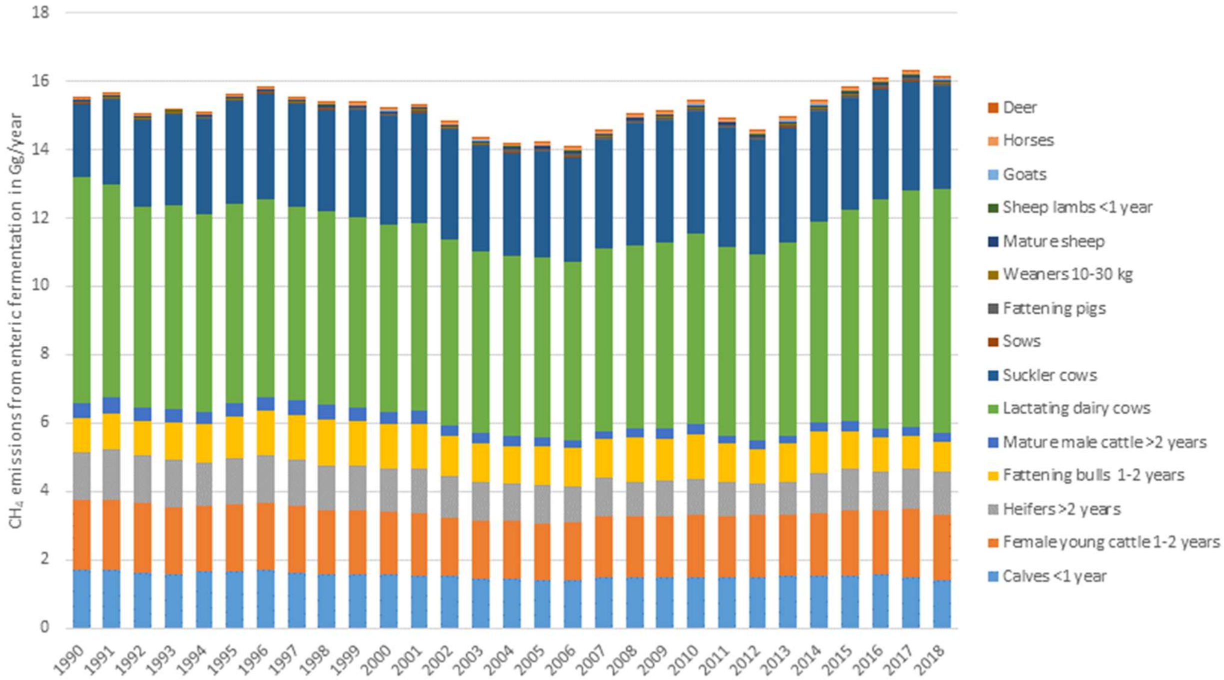
Livestock statistics in Luxembourg are detailed enough to go for option C. Cattle, the main livestock category in Luxembourg is split into 7 categories, namely calves <1 year; young female cattle 1-2 years; heifers >2years; fattening bulls 1-2 years, mature male >2 years, lactating dairy cows and suckler 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 1990-2018 (Table 5-5), and consequently also the biggest increase in methane emission from enteric fermentation for the same time period (>950%), see Table 5-14. However, methane emission from enteric fermentation from goats represent <0.15% of the total methane emission from enteric fermentation in 2018 (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 2018, 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 2018, 44% 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 1990-2018. This results mainly from raising emission of dairy cows (+8%) and suckler cows (+40%). Raising emissions of other livestock categories, such as horses (+171%) and fattening pigs (+72%) 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 at the end of the milk production system, and since then is the population of dairy cows increasing. Although according to the year 2018 the situation seems to stabilise. Another factor influencing cattle population is, of course, fodder and milk prices (which, themselves are affected by agricultural policy changes and targets). 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 - 2018



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). We therefore assume that there are 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 method is used for cattle and sheep, and an IPCC Tier 1 method is applied to 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 have been estimated.

a) 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.
b) Including also ponys, mules and asses.
c) Goats are split in 2 sub-categories: i) mature goats and ii) goat kits for the calculations, but reported in the CRF as one category.
d) In the 2006 IPCC guidelines, no EFs were developed for poultry, ostrich and rabbits, why assumed to not occur (NO).

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 are 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 method, default emission factors (EF) for enteric fermentation related methane emissions in kg CH_4 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 Luxembourg
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, Kirchgessner 2014f)	2.4-2.7 kg[a] (KTBL 2018a)		1.33 kg [a,b]	
Deer	4.6-4.9 kg[a] (KTBL 2018a)	42.5-72.5 kg[a] (KTBL 2018a)		31 kg [a,b]	

Notes: 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 Kirchgessner, both standard references for the German agriculture, apply also to the Luxemburgish 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 CH_4 per head per year was estimated following equation 10.21 from the 2006 IPCC guidelines (IPCC 2006a):

Emission factors for swine, goats, horses and deer

For the Tier 1 method, default emission factors (EF) for enteric fermentation related methane emissions in kg CH_4 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.

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 CH_4 per head per year was estimated following equation 10.21 from the 2006 IPCC guidelines (IPCC 2006a)(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 conversation 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 3.5% 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 ($x_{grazing}$[111]), 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):

[111] x.grazing is equal to the proportion of excreta deposited during grazing (MMS – pasture).

$$NE_a = C_a * (live - weight\ (kg)$$

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.

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 Luxemburgish 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 2019c).
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):

$$NE_g = \frac{WG_{lamb} * (a + 0.5 * b\left(BW_i + BW_f\right))}{365}$$

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. [112]

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).

[112] 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)

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):

$$REG = \left(1.164 - (5.160 * 10^{-3} * DE\%) + [1.308 * 10^{-5} * (DE\%)^2] - \left(\frac{37.44}{DE\%}\right)\right)$$

Table 5-18 – Estimated gross energy (GE) for cattle and sheep categories for the years 1990-2018

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	322.2	228.3	22.3	12.6
2012	66.8	141.5	132.4	185.4	184.5	323.4	228.3	22.3	12.6
2013	66.8	141.5	132.4	185.4	184.5	316.2	228.3	22.3	12.6
2014	66.8	141.5	132.4	185.4	184.5	326.9	228.3	22.3	12.6
2015	66.8	141.5	132.4	185.4	184.5	340.6	228.3	22.3	12.6
2016	66.8	141.5	132.4	185.4	184.5	340.6	228.3	22.3	12.6
2017	66.8	141.5	132.4	185.4	184.5	339.6	228.3	22.3	12.6
2018	66.8	141.5	132.4	185.4	184.5	349.9	228.3	22.3	12.6

Source: SER

Table 5-19 – Estimated emission factors for enteric fermentation related methane emissions in kg CH_4 per head per year for the different cattle and sheep categories for the years 1990-2018

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	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	137.4	97.3	9.5	3.7
2012	28.5	60.3	56.5	79.1	78.7	137.9	97.3	9.5	3.7
2013	28.5	60.3	56.5	79.1	78.7	134.8	97.3	9.5	3.7
2014	28.5	60.3	56.5	79.1	78.7	139.4	97.3	9.5	3.7
2015	28.5	60.3	56.5	79.1	78.7	145.2	97.3	9.5	3.7
2016	28.5	60.3	56.5	79.1	78.7	145.2	97.3	9.5	3.7
2017	28.5	60.3	56.5	79.1	78.7	144.8	97.3	9.5	3.7
2018	28.5	60.3	56.5	79.1	78.7	149.2	97.3	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 provisional livestock numbers from 2018 were revised.

When calculating the net energy for maintenance for sheep, the used Cf_i for adult sheep and lamb had been mixed-up. This was corrected.

A detailed description is provided in Annex 3: A, and the recalculations are provided in Table A3-6 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 2018, 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 CO_2e (excluding LULUCF). For each of the two gases reported, excluding LULUCF, in 2018:

- CH_4 represented 13.3% of agricultural methane emissions and 10.20% of the total methane emissions estimated for Luxembourg;
- N_2O represented 12.6% of agricultural nitrous oxide emissions and 8.42% of the total nitrous oxide emissions estimated for Luxembourg.

5.4.1 Key source

With 0.83% of the total GHG emissions in CO_2e, excluding LULUCF in 2018, methane emissions from cattle (IPCC Sub-category 3Ba) were a key source from 1998 to 2001, excluding LULUCF and from 1998-2001 and 2015-2018 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 1990-2018 (Table 5-5), and consequently also the biggest increase in methane (964%) from manure management, see Table 5-20. For N_2O emission the increase was even higher (4736%), 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 2018 (see Table 5-20 and Figure 5-8), and <0.1% of the total N_2O 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 2018 responsible for 83% of the total methane emission from manure management (Table 5-20 and Figure 5-8) and for 93% of the total N_2O 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 N_2O emission from manure management (Figure 5-8 and Figure 5-9). In 2018 48% of the methane emission from manure management (Table 5-20 and Figure 5-8) and 41.5% of the total N_2O 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 29.27% over the period 1990-2018, a result mainly due to raising emission of dairy cows (+62%). Raising emissions of other livestock categories, such as goats (+964%), horses (+171%) and laying hens (+75%) had only a marginal impact on the total methane emissions from enteric fermentation.

Direct N_2O emissions from manure management decreased by 19% over the period 1990-2018, 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 N_2O. With fewer cattle now-a-days on straw, emissions were decreasing over time.

Indirect atmospheric N_2O emissions decreased by 11% (Table 5-23).

Combining both gases – CH_4 and N_2O (direct and indirect) – manure management related emissions, expressed in CO_2e, show an increase of 11% (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 at the end of the milk production system, and since then is the population of dairy cows increasing. Although according to the 2018 numbers the situation seems to slow down. Another factor influencing cattle population is, of course, fodder and milk prices (which, themselves are affected by agricultural policy changes and targets).

Table 5-20 – CH_4 emission trends for IPCC Category 3B – Manure Management: 1990-2018 (Gg)

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	TOTAL
1990	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	1.91
1991	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	2.12
1992	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	2.12
1993	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	2.18
1994	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	2.20
1995	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	2.31
1996	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	2.33
1997	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	2.36
1998	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	2.41
1999	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	2.61
2000	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	2.54
2001	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	2.53
2002	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	2.45
2003	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	2.36
2004	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	2.34
2005	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	2.34
2006	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	2.25
2007	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	2.28
2008	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	2.28
2009	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	2.26
2010	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	2.25
2011	0.12	0.23	0.12	0.16	0.04	0.91	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	2.21
2012	0.12	0.23	0.12	0.14	0.03	0.90	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	2.17
2013	0.12	0.23	0.12	0.16	0.03	0.94	0.22	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	2.21
2014	0.12	0.23	0.15	0.17	0.04	0.97	0.21	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	2.29
2015	0.12	0.24	0.15	0.15	0.04	1.02	0.21	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	2.39
2016	0.12	0.24	0.14	0.14	0.03	1.11	0.21	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	2.43
2017	0.12	0.25	0.14	0.13	0.04	1.15	0.21	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	2.49
2018	0.11	0.24	0.16	0.12	0.04	1.18	0.20	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	2.47
Trend 1990 -2018	-31%	28%	23%	17%	-19%	62%	0%	-51%	58%	-8%	36%	1%	964%	171%	97%	75%	-66%	NA	-79%	65%	29%
Trend 2017 -2018	-7%	-4%	10%	-8%	-2%	3%	-6%	-2%	-8%	-3%	0%	5%	-3%	-1%	6%	0%	-39%	7%	17%	27%	-1%

Source: SER.

Notes: Mules and asses are include with horses

Table 5-21 – N_2O emission trends for IPCC Category 3B – Manure Management: 1990-2018 (Gg)

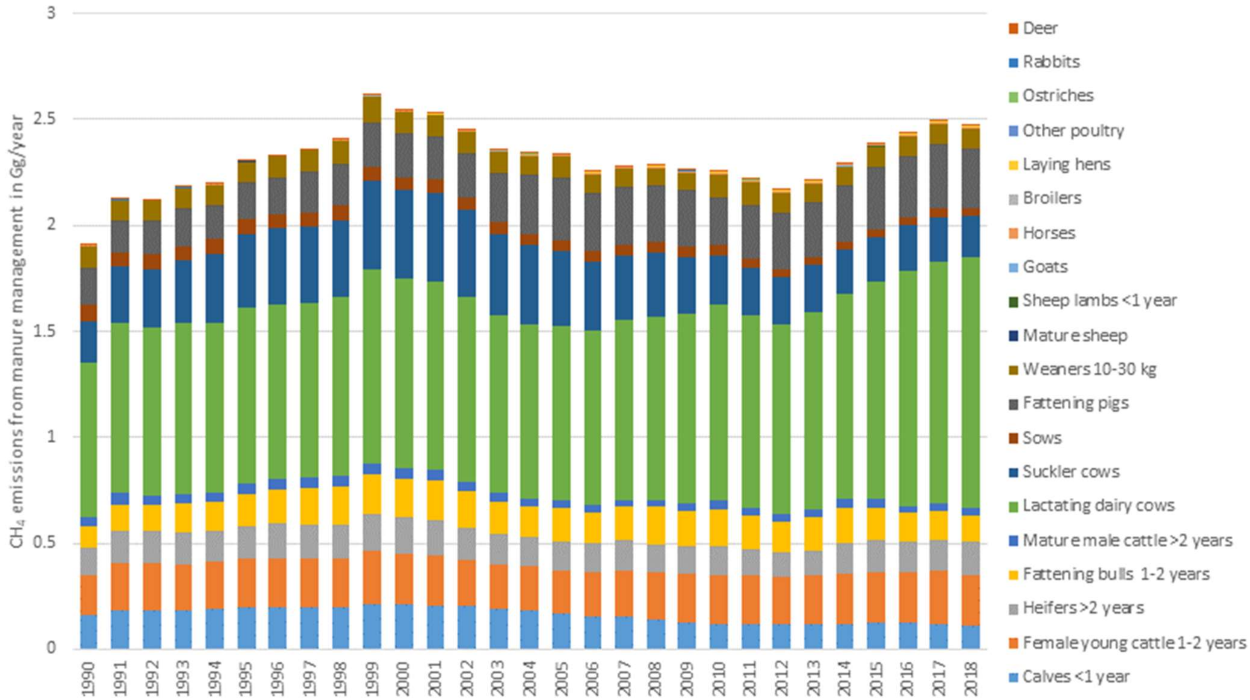
Year	Calves <1 year	Female young cattle 1-2 years	Heifers >2 years	Fattening bulls 1-2 years	Mature male cattle >2 years	Lactating dairy cows	Suckler cows	Sows	Fattening pigs >30 kg	Weaners 10-30 kg	Sheep	Goats	Horses	Broilers	Laying hens	Other poultry	Ostriches	Rabbits	Deer	TOTAL
1990	0.008	0.007	0.006	0.005	0.003	0.033	0.006	0.001	0.001	0.0003	0.0001	0.0000	0.0004	0.000005	0.00007	0.000001	NO	0.000115	0.000003	0.072
1991	0.008	0.006	0.006	0.006	0.003	0.030	0.007	0.001	0.001	0.0002	0.0001	0.0000	0.0004	0.000005	0.00007	0.000001	NO	0.000106	0.000005	0.069
1992	0.007	0.006	0.006	0.005	0.003	0.028	0.007	0.001	0.001	0.0002	0.0001	0.0000	0.0004	0.000004	0.00006	0.000001	NO	0.000094	0.000004	0.065
1993	0.007	0.006	0.006	0.006	0.003	0.027	0.007	0.001	0.001	0.0002	0.0001	0.0000	0.0004	0.000005	0.00007	0.000001	NO	0.000073	0.000004	0.065
1994	0.008	0.006	0.005	0.006	0.002	0.026	0.007	0.001	0.001	0.0002	0.0001	0.0000	0.0004	0.000004	0.00007	0.000001	NO	0.000066	0.000006	0.063
1995	0.008	0.006	0.006	0.006	0.003	0.026	0.008	0.001	0.001	0.0002	0.0001	0.0000	0.0005	0.000004	0.00006	0.000001	NO	0.000064	0.000006	0.065
1996	0.008	0.006	0.006	0.006	0.003	0.026	0.008	0.001	0.001	0.0003	0.0001	0.0000	0.0005	0.000005	0.00007	0.000001	NO	0.000053	0.000004	0.066
1997	0.007	0.006	0.005	0.007	0.003	0.025	0.008	0.001	0.001	0.0002	0.0001	0.0000	0.0005	0.000009	0.00006	0.000001	NO	0.000062	0.000005	0.064
1998	0.007	0.005	0.005	0.007	0.003	0.025	0.007	0.001	0.002	0.0003	0.0001	0.0000	0.0005	0.000010	0.00006	0.000001	NO	0.000056	0.000009	0.063
1999	0.007	0.005	0.005	0.006	0.002	0.023	0.008	0.001	0.002	0.0003	0.0001	0.0000	0.0006	0.000006	0.00006	0.000001	NO	0.000051	0.000010	0.060
2000	0.007	0.005	0.005	0.006	0.002	0.022	0.008	0.001	0.002	0.0003	0.0001	0.0000	0.0006	0.000007	0.00007	0.000001	NO	0.000063	0.000012	0.059
2001	0.007	0.005	0.005	0.006	0.002	0.022	0.008	0.001	0.002	0.0002	0.0001	0.0000	0.0006	0.000008	0.00008	0.000001	NO	0.000054	0.000011	0.058
2002	0.007	0.005	0.005	0.006	0.002	0.021	0.008	0.001	0.002	0.0002	0.0001	0.0001	0.0006	0.000008	0.00008	0.000001	NO	0.000058	0.000010	0.056
2003	0.006	0.005	0.004	0.006	0.002	0.021	0.007	0.001	0.002	0.0002	0.0001	0.0001	0.0007	0.000007	0.00008	0.000001	0.0000012	0.000053	0.000007	0.055
2004	0.006	0.004	0.004	0.005	0.002	0.022	0.007	0.001	0.002	0.0002	0.0001	0.0002	0.0008	0.000006	0.00008	0.000001	0.0000017	0.000051	0.000009	0.055
2005	0.006	0.004	0.004	0.006	0.002	0.020	0.007	0.001	0.002	0.0002	0.0001	0.0002	0.0008	0.000010	0.00008	0.000001	0.0000013	0.000052	0.000008	0.054
2006	0.006	0.004	0.004	0.005	0.002	0.020	0.008	0.001	0.002	0.0002	0.0001	0.0002	0.0008	0.000009	0.00008	0.000001	0.0000010	0.000053	0.000008	0.054
2007	0.007	0.005	0.004	0.005	0.001	0.021	0.008	0.001	0.002	0.0002	0.0001	0.0002	0.0008	0.000008	0.00008	0.000000	0.0000011	0.000040	0.000006	0.055
2008	0.007	0.004	0.004	0.006	0.002	0.020	0.009	0.000	0.002	0.0002	0.0001	0.0003	0.0008	0.000004	0.00009	0.000000	0.0000013	0.000035	0.000011	0.057
2009	0.007	0.004	0.004	0.006	0.002	0.020	0.010	0.000	0.002	0.0002	0.0001	0.0003	0.0009	0.000008	0.00010	0.000000	0.0000014	0.000036	0.000011	0.056
2010	0.007	0.004	0.004	0.006	0.002	0.020	0.010	0.000	0.002	0.0003	0.0001	0.0004	0.0008	0.000008	0.00009	0.000000	0.0000012	0.000031	0.000010	0.057
2011	0.007	0.004	0.003	0.005	0.002	0.020	0.010	0.000	0.002	0.0003	0.0001	0.0005	0.0008	0.000008	0.00011	0.000000	0.0000020	0.000027	0.000013	0.055
2012	0.007	0.004	0.003	0.005	0.001	0.019	0.009	0.000	0.002	0.0002	0.0001	0.0005	0.0009	0.000008	0.00012	0.000001	0.0000013	0.000032	0.000012	0.054
2013	0.007	0.004	0.003	0.005	0.002	0.020	0.009	0.000	0.002	0.0002	0.0001	0.0005	0.0008	0.000007	0.00012	0.000001	0.0000021	0.000032	0.000008	0.055
2014	0.007	0.005	0.004	0.006	0.002	0.020	0.009	0.000	0.002	0.0002	0.0001	0.0004	0.0009	0.000007	0.00013	0.000001	0.0000011	0.000030	0.000008	0.056
2015	0.007	0.005	0.004	0.005	0.002	0.020	0.009	0.000	0.002	0.0002	0.0001	0.0005	0.0009	0.000009	0.00012	0.000001	0.0000016	0.000029	0.000007	0.057
2016	0.007	0.005	0.004	0.005	0.002	0.022	0.009	0.000	0.002	0.0002	0.0001	0.0005	0.0008	0.000009	0.00012	0.000001	0.0000015	0.000027	0.000005	0.058
2017	0.007	0.005	0.004	0.005	0.002	0.024	0.009	0.000	0.002	0.0002	0.0001	0.0005	0.0009	0.000010	0.00013	0.000001	0.0000012	0.000023	0.000004	0.059
2018	0.007	0.005	0.004	0.004	0.002	0.024	0.008	0.000	0.002	0.0002	0.0001	0.0005	0.0008	0.000010	0.00013	0.000000	0.0000013	0.000026	0.000005	0.058
Trend 1990 -2018	-21%	-28%	-30%	-23%	-47%	-27%	38%	-55%	51%	-12%	29%	4736%	128%	97%	75%	-66%	NA	-78%	65%	-19%
Trend 2017 -2018	-7%	-4%	10%	-8%	-2%	2%	-6%	-2%	-8%	-3%	1%	3%	-2%	6%	0%	-39%	7%	11%	27%	-1%

Source: SER.

Notes:

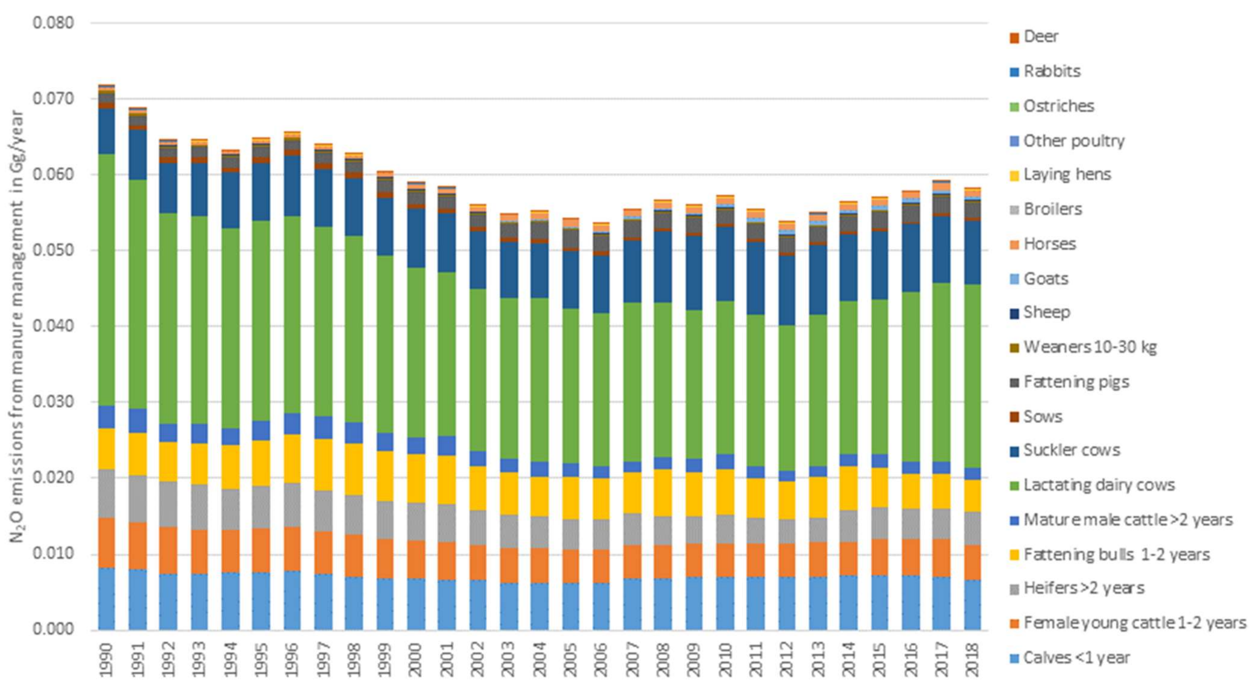
- Mules and asses are include with horses
- N_2O emissions by livestock category excluding emissions from pasture.

Figure 5-8 – CH_4 emissions from manure management (Gg/year) per animal category: 1990 - 2018



Source: SER.

Figure 5-9 – N_2O emissions from manure management (Gg/year) per animal category: 1990 - 2018



Source: SER.

Table 5-22 – N_2O emission trends for IPCC Category 3B – Manure Management: 1990-2018 (Gg)

Year	Aerobic lagoon	Liquid	Solid	Pasture	Digester	TOTAL
1990	NO	0.016	0.056	IE	NO	0.072
1991	NO	0.019	0.050	IE	NO	0.069
1992	NO	0.019	0.045	IE	NO	0.065
1993	NO	0.020	0.045	IE	NO	0.065
1994	NO	0.020	0.043	IE	NO	0.063
1995	NO	0.021	0.044	IE	NO	0.065
1996	NO	0.021	0.044	IE	NO	0.066
1997	NO	0.021	0.043	IE	NO	0.064
1998	NO	0.022	0.041	IE	NO	0.063
1999	NO	0.024	0.036	IE	NO	0.060
2000	NO	0.024	0.035	IE	NO	0.059
2001	NO	0.023	0.036	IE	NO	0.058
2002	NO	0.022	0.034	IE	NO	0.056
2003	NO	0.021	0.034	IE	NO	0.055
2004	NO	0.020	0.035	IE	NO	0.055
2005	NO	0.019	0.035	IE	NO	0.054
2006	NO	0.019	0.035	IE	NO	0.054
2007	NO	0.019	0.037	IE	NO	0.055
2008	NO	0.018	0.038	IE	NO	0.057
2009	NO	0.017	0.039	IE	NO	0.056
2010	NO	0.017	0.040	IE	NO	0.057
2011	NO	0.017	0.039	IE	NO	0.055
2012	NO	0.016	0.038	IE	NO	0.054
2013	NO	0.016	0.039	IE	NO	0.055
2014	NO	0.017	0.039	IE	NO	0.056
2015	NO	0.017	0.040	IE	NO	0.057
2016	NO	0.018	0.040	IE	NO	0.058
2017	NO	0.019	0.041	IE	NO	0.059
2018	NO	0.018	0.040	IE	NO	0.058
Trend 1990 -2018		16%	-29%			-19%
Trend 2017 -2018		0%	-2%			-1%

Source: SER.

Notes: N_2O emissions from pasture are excluded from the total N_2O emissions in IPCC Category 3B since they have to be accounted for in IPCC Sub-category 3D2 – Emissions from PRP Manure.

Table 5-23 – CH_4 & N_2O emission trends for IPCC Category 3B – Manure Management and indirect atmospheric N_2O emissions: 1990-2018

Year	Manure management (3B) - direct emissions Gg CO2 eq.			Indirect atmospheric N_2O emissions Gg CO2 eq.	TOTAL Gg CO2 eq.
	CH_4	N_2O	Total	N_2O	
1990	47.7	21.4	69.1	11.17	80.3
1991	53.0	20.5	73.5	10.69	84.2
1992	53.0	19.2	72.2	10.07	82.3
1993	54.5	19.2	73.7	10.11	83.8
1994	54.9	18.8	73.8	9.89	83.6
1995	57.7	19.3	77.0	10.13	87.1
1996	58.2	19.5	77.8	10.25	88.0
1997	59.0	19.1	78.0	10.04	88.1
1998	60.1	18.7	78.8	9.88	88.7
1999	65.3	18.0	83.3	9.56	92.9
2000	63.6	17.5	81.2	9.37	90.5
2001	63.2	17.4	80.5	9.34	89.9
2002	61.2	16.7	77.9	9.03	86.9
2003	58.9	16.3	75.2	8.94	84.2
2004	58.5	16.4	74.9	9.10	84.0
2005	58.4	16.2	74.6	9.04	83.6
2006	56.3	16.0	72.3	8.94	81.2
2007	57.0	16.5	73.5	9.28	82.8
2008	57.1	16.9	73.9	9.50	83.4
2009	56.5	16.7	73.1	9.47	82.6
2010	56.3	17.0	73.4	9.64	83.0
2011	55.4	16.5	71.9	9.40	81.3
2012	54.2	16.0	70.2	9.17	79.4
2013	55.3	16.4	71.7	9.34	81.0
2014	57.3	16.8	74.1	9.59	83.7
2015	59.7	17.0	76.6	9.73	86.4
2016	60.8	17.2	78.1	9.86	87.9
2017	62.3	17.6	79.9	10.09	90.0
2018	61.7	17.3	79.1	9.92	89.0
Trend 1990 -2018	29%	-18.9%	14.4%	-11%	11%
Trend 2017 -2018	-1%	-1.4%	-1.0%	-2%	-1%

Source: SER.

Note: CH_4 emissions were converted in CO_2-eq. by multiplying the emissions by 25 and N_2O emissions were converted in CO_2-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_2O		
		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_2O emissions	NA			x	T2	D

Notes: An "x" indicates that emissions from this sub-category have been estimated.

a) 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).
b) Goats are split in 2 sub-categories: i) mature goats and ii) goat kit for the calculations, but reported in the CRF as one category.
c) Poultry, excluding ostriches are split in 3 sub-categories: i) broilers; ii) laying hens; iii) other poultry for the calculations.
d) 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.
e) Direct N_2O emissions from manure management are further split up into

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 N_2O 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 NH_3-N emissions (kg NH_3-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 NH_3 and NO_x are the activity data used to estimate the indirect N_2O 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) 2020 (Schuman, Becker, Hadzic, Mangen, & Mirgain, 2020) in section 5.3.3.

Table 5-25 – Activity data - Volatilisation of N from manure management in forms of NH3 and NOx

	NRF Category 3B (Manure management) Emissions		
	E_{build_NH3-N}	$E_{storage\_NH3-N}$	$E_{storage\_NO-N}$
Year	kg NH_3-N/ year	kg NH_3-N/ year	kg NO-N/ year
1990	2 350 993	35 011	35 011
1991	2 250 882	31 252	31 252
1992	2 122 171	28 587	28 587
1993	2 129 532	28 388	28 388
1994	2 085 064	27 393	27 393
1995	2 135 799	27 700	27 700
1996	2 160 135	28 106	28 106
1997	2 117 463	26 966	26 966
1998	2 083 312	25 950	25 950
1999	2 017 612	23 002	23 002
2000	1 978 054	22 646	22 646
2001	1 971 868	22 762	22 762
2002	1 906 546	21 880	21 880
2003	1 887 509	21 892	21 892
2004	1 920 142	22 202	22 202
2005	1 908 009	22 146	22 146
2006	1 887 806	22 204	22 204
2007	1 958 609	23 325	23 325
2008	2 004 932	24 359	24 359
2009	1 998 280	24 543	24 543
2010	2 034 217	25 423	25 423
2011	1 982 794	24 514	24 514
2012	1 935 160	23 868	23 868
2013	1 970 949	24 394	24 394
2014	2 023 917	24 979	24 979
2015	2 051 769	25 113	25 113
2016	2 080 990	25 337	25 337
2017	2 128 835	25 736	25 736
2018	2 093 136	25 238	25 238
Trend 1990 -2018	-11%	-28%	-28%
Trend 2017 -2018	-2%	-2%	-2%

Source: IIR 2020 (Schuman, Becker, Hadzic, Mangen, & Mirgain, 2020)

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 CH_4 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 CH_4/head/year, were estimated following equation 10.23 of the 2006 IPCC guidelines (IPCC 2006a)

$$IEF\ CH_4\ 3B_i = (VS_i * 365) * \left[B_{o(i)} * 0.67 * \sum_j \frac{MCF_j}{100} * MMS_{(i,j)}\right]$$

with:

VS_i	= Daily volatile solid excreted for livestock category i, 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, m^3 CH_4 kg^{-1} of VS excreted
0.67	= conversation factor of m^3 CH_4 to kilograms CH_4
MCF_j	= methane conversation factors for each manure management system, %
$MMS_{(i,j)}$	= fraction of livestock category i's manure handled using manure management system j 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 manure management system (MCFs) for livestock category *i* in emission calculations.

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 Bo (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 IPPC 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 livestock category *i* ($B_{o(i)}$).

Animal category	VS_i	ASH	UE	B_o
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 1990-2018

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	22.7	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
2012	2.27	7.59	7.10	10.91	10.85	22.8	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
2013	2.27	7.59	7.10	10.91	10.85	22.3	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
2014	2.27	7.59	7.10	10.91	10.85	23.0	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
2015	2.27	7.59	7.10	10.91	10.85	24.0	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
2016	2.27	7.59	7.10	10.91	10.85	24.0	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
2017	2.27	7.59	7.10	10.91	10.85	23.9	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
2018	2.27	7.59	7.10	10.91	10.85	24.7	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

Source: SER.

Note: Mules and asses were recorded together with horses.

5.4.3.2.2 Emission factors – direct N_2O emissions from manure management

The IPCC Tier 2 method has been applied to all farm animal categories when estimating the N_2O emissions related to manure management.

Direct N_2O emissions from manure management in the country ($N_2O_{D(mm)}$), expressed in kg N_2O 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 N_2O-N emissions from manure management in the country, kg N_2O-N/year
44/28	= conversion of $N_2O-N_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions.

Direct N_2O-N emissions from manure management in the country ($N_2O - N_{D(mm)}$), expressed as kg N_2O-N per year, whereby estimated following equation 10.25 of the 2006 IPCC guidelines (IPCC 2006a):

$$N_2O - N_{D(mm)} = \left[\sum_j \left[\sum_i (n_i * N.ex_{(i)} * MMS_{(ij)})\right] * EF_{dN2O\,(j)}\right]$$

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
$EF_{dN2O(j)}$	= emission factor for direct N_2O emissions from manure management system *j* in the country, kg N_2O-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 N_2O 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 N_2O emissions from manure management

The indirect N_2O emissions due to volatilisation of N from manure management in forms of NH_3 and NO_x in the country, expressed as kg N_2O 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 N_2O emissions due to volatilisation of N from manure management in the country ($N_2O_{G(mm)}$), expressed in kg N_2O per year was obtained by:

$$N_2O_{G(mm)} \quad = N_2O - N_{G(mm)} * \left(\frac{44}{28}\right)$$

with:

$N_2O - N_{G(mm)}$ = indirect N_2O-N emissions due to volatilization of N from manure management in the country, kg N_2O-N per year

44/28 = conversion of N_2O-$N_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions.

Indirect N_2O-N emissions due to volatilisation of N from manure management in the country ($N_2O - N_{G(mm)}$), expressed as kg N_2O-N per year, were estimated by multiplying the total emissions of NH_3 and NO_x from animal housing, manure management and NH_3 from manure storage by an emission factor.

$$N_2O - N_{G(mm)} = \{[NH_3 - N\ emissions\ manure\ management + NO_x - N\ emissions\ manure\ management] * EF_{iN_2O-N}\}$$

with:

NH_3-N emissions manure management = NH_3-N emissions (kg NH_3-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 NIR 2020 (Schuman, Becker, Hadzic, Mangen, & Mirgain, 2020)); Note: n_i= the number of animals in the *i*-th livestock category.

$$= \sum_i [\{E_{build\_slurry\_NH3-N(i)} + E_{build\_solid\_NH3-N(i)} + E_{storage\_slurry\_NH3-N(i)} + E_{storage\_solid\_NH3-N(i)}\} * n_i]$$

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 NIR 2020 (Schuman, Becker, Hadzic, Mangen, & Mirgain, 2020); Note: n_i= the number of animals in the *i*-th livestock category.

$$= \sum_i [\{E_{storage\_slurry\_NO-N(i)} + E_{storage\_solid\_NO-N(i)}\} * n_i]$$

EF_{iN2O}-N manure management indirect = Nitrous oxide emission factor for indirect emission following atmospheric deposition of NH3 and NOx, 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 N_2O emissions from leaching and runoff was calculated for the manure management. This was done so for all years since 1990.

Indirect N_2O 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 livestock activity data for the year 2017 and updated B_o for cattle and swine, as well as updated MCFs for cattle and swine 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 A3-7 in Annex 3:A.

Revised livestock activity data for the year 2017 and the updated N.ex per head/place influenced the N_2O emissions from manure management, both direct and indirect. Furthermore, the direct N_2O emissions for liquid manure management were revised because of additional information on storage system for liquid manure. Furthermore was the methodology updated to estimate the indirect N_2O emissions from manure management (i.e. housing, storage; without spreading). The Tier 1 methodology was replace by an N-flow model.

A detailed description of the different changes is provided in Annex 3:A, and the recalculations are provided in Table A3-8 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 N_2O 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

An update of the manure management system using more recent data is planned for the following submission. Furthermore, in the next submission the N flow model will be updated to comply with the 2019 EMEP/EEA guidelines. With the publication of future IPCC guidelines, the necessary changes, where applicable, will be made.

5.5 Rice Cultivation (IPCC Source Category 3.C)

This source category does not exist in Luxembourg.

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 2018, this source category was responsible for 87% of agricultural nitrous oxide emissions and for 58.29% of the total nitrous oxide emissions estimated for Luxembourg. N_2O emissions linked to agricultural soils represented 27% of the total GHG emissions from the agriculture sector and represented 1.87% of the total GHG emissions in CO_2e (excluding LULUCF).

5.6.1 Key source

With 1.87% of the total GHG emissions in CO_2e, excluding LULUCF in 2018, 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)

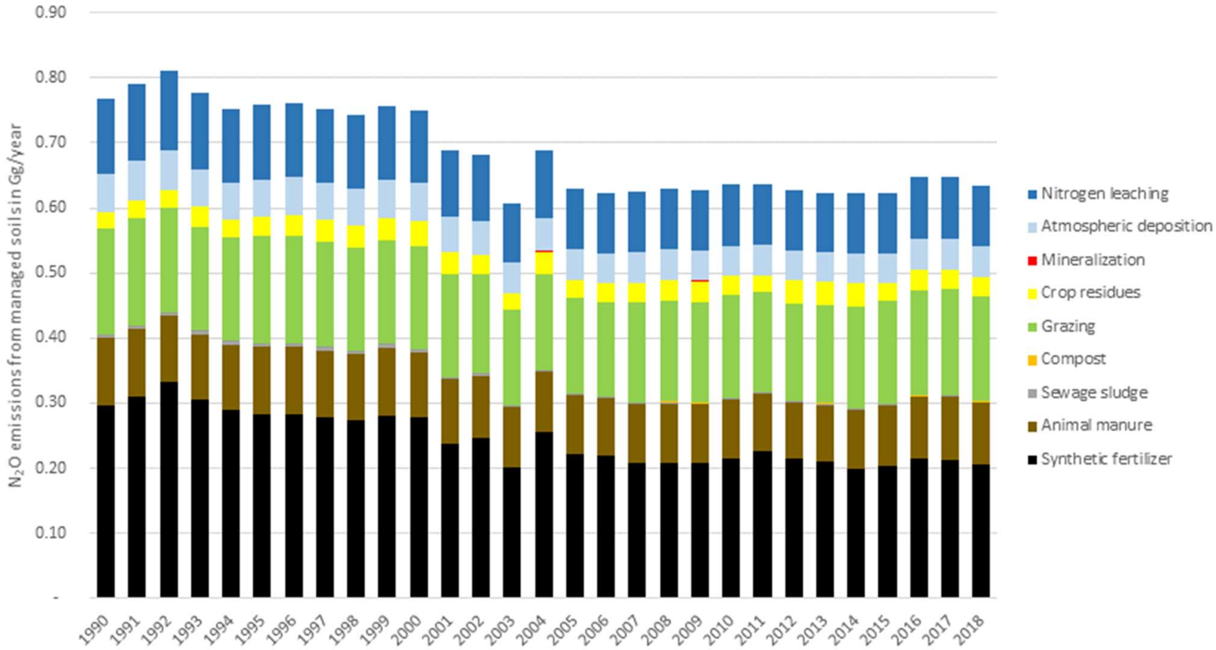
5.6.2 Source category description

The source category agricultural soils covers:

- direct N_2O soil emissions (IPCC Sub-category 3D1) resulting from manure application, grazing, application of mineral fertiliser, sewage sludge, compost and crop residues.
- and indirect N_2O soil emissions (IPCC Sub-category 3D2) resulting from deposition of reactive nitrogen and via leaching and run-off.

Since 1990, agricultural soil N_2O related emissions declined by 17%, Table 5-30 and Figure 5-10. The largest decline was observed for sewage sludge (-83%), mineralisation (-83%) and synthetic fertilizer (-31%). N_2O emissions from crop residues increased by 17%. The most important category in absolute terms was synthetic fertilizer, which was in 2018 responsible for 32% of the direct N_2O emission from managed soils (Table 5-30 and Figure 5-10).

Figure 5-10 – N_2O emissions from managed soils (Gg/year): 1990 -2018



Source: SER

Table 5-30 – N_2O emission trends (Gg) for IPCC Category 3D – Agricultural Soils: 1990-2018

Year	Synthetic fertilizer	Animal manure	Sewage sludge	Compost	Grazing	Crop residues	Mineral-ization	Organic soils	Other	Atmospheric deposition	Nitrogen leaching	TOTAL
1990	0.30	0.10	0.0058	NO	0.16	0.026	0.00021	NO	NO	0.057	0.12	0.77
1991	0.31	0.10	0.0058	NO	0.17	0.027	0.00021	NO	NO	0.059	0.12	0.79
1992	0.33	0.10	0.0059	NO	0.16	0.028	0.00021	NO	NO	0.059	0.12	0.81
1993	0.30	0.10	0.0061	NO	0.16	0.030	0.00021	NO	NO	0.058	0.12	0.78
1994	0.29	0.10	0.0064	NO	0.16	0.028	0.00021	NO	NO	0.057	0.11	0.75
1995	0.28	0.10	0.0064	NO	0.16	0.030	0.00021	NO	NO	0.058	0.11	0.76
1996	0.28	0.10	0.0055	NO	0.17	0.031	0.00021	NO	NO	0.058	0.11	0.76
1997	0.28	0.10	0.0058	NO	0.16	0.034	0.00021	NO	NO	0.057	0.11	0.75
1998	0.27	0.10	0.0058	NO	0.16	0.034	0.00021	NO	NO	0.057	0.11	0.74
1999	0.28	0.10	0.0058	NO	0.16	0.035	0.00021	NO	NO	0.058	0.11	0.76
2000	0.28	0.10	0.0030	0.0015	0.16	0.039	0.00020	NO	NO	0.057	0.11	0.75
2001	0.24	0.10	0.0028	0.0007	0.16	0.036	0.00019	NO	NO	0.053	0.10	0.69
2002	0.25	0.09	0.0030	0.0008	0.15	0.029	0.00019	NO	NO	0.052	0.10	0.68
2003	0.20	0.09	0.0023	0.0004	0.15	0.024	0.00018	NO	NO	0.048	0.09	0.61
2004	0.26	0.09	0.0019	0.0005	0.15	0.034	0.00017	NO	NO	0.051	0.10	0.69
2005	0.22	0.09	0.0025	0.0013	0.15	0.026	0.00016	NO	NO	0.048	0.09	0.63
2006	0.22	0.09	0.0022	0.0012	0.15	0.028	0.00016	NO	NO	0.047	0.09	0.62
2007	0.21	0.09	0.0026	0.0012	0.15	0.031	0.00015	NO	NO	0.047	0.09	0.62
2008	0.21	0.09	0.0025	0.0014	0.15	0.032	0.00014	NO	NO	0.047	0.09	0.63
2009	0.21	0.09	0.0016	0.0013	0.15	0.032	0.00013	NO	NO	0.046	0.09	0.63
2010	0.22	0.09	0.0016	0.0016	0.16	0.029	0.00012	NO	NO	0.047	0.09	0.64
2011	0.23	0.09	0.0022	0.0011	0.15	0.025	0.00011	NO	NO	0.047	0.09	0.64
2012	0.21	0.09	0.0026	0.0008	0.15	0.036	0.00010	NO	NO	0.045	0.09	0.63
2013	0.21	0.09	0.0021	0.0007	0.15	0.035	0.00009	NO	NO	0.045	0.09	0.62
2014	0.20	0.09	0.0019	0.0008	0.16	0.037	0.00008	NO	NO	0.045	0.09	0.62
2015	0.20	0.09	0.0023	0.0009	0.16	0.027	0.00007	NO	NO	0.046	0.09	0.62
2016	0.22	0.09	0.0012	0.0009	0.16	0.033	0.00006	NO	NO	0.046	0.10	0.65
2017	0.21	0.10	0.0012	0.0011	0.16	0.030	0.00005	NO	NO	0.047	0.10	0.65
2018	0.20	0.10	0.0010	0.0009	0.16	0.030	0.00004	NO	NO	0.046	0.09	0.63
Trend 1990 -2018	-31%	-7%	-83%		-1%	17%	-83%			-20%	-19%	-17%
Trend 2017 -2018	-4%	-1%	-18%	-19%	-1%	1%	-23%			-2%	-2%	-2%

Source: SER.

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_2O		
		Status	Method	EF
3.D.1	*Direct soil Emissions*			
	Synthetic Fertilizers	x	T1	D
	Animal Manure Applied to Soils	x	T2	D
	Sewage sludge	x	T1	D
	Compost	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	*Indirect soil emissions*			
	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 N_2O estimates for IPCC Category 3D are:

- Synthetic N fertilizer, see Table 5-32.

Applied organic N fertiliser, including animal manure, compost and sewage sludge, 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 NH_3 and NO_x from inorganic N fertilizer, the application of animal manure, grazing, sewage sludge and compost, see Table 5-36.

Table 5-32 – Activity data (kg N) for IPCC Category 3D: 1990-2018

Year	Synthetic fertilizer	Animal manure	Sewage sludge	Compost	Grazing	Crop residues	Organic soils	Other	Atmospheric deposition	Nitrogen leaching
1990	18 895 444	6 559 364	371 985	NO	5 207 264	1 643 597	NO	NO	3 653 866	9 807 290
1991	19 688 595	6 638 622	372 205	NO	5 319 549	1 703 159	NO	NO	3 786 326	10 120 633
1992	21 245 368	6 355 030	376 491	NO	5 141 968	1 791 330	NO	NO	3 780 583	10 477 050
1993	19 381 205	6 395 089	391 126	NO	5 139 483	1 932 991	NO	NO	3 685 987	9 975 961
1994	18 399 940	6 336 368	409 055	NO	5 105 693	1 784 346	NO	NO	3 616 644	9 614 614
1995	18 054 158	6 527 369	406 178	NO	5 251 261	1 902 935	NO	NO	3 674 767	9 646 564
1996	17 992 452	6 593 516	352 796	NO	5 338 079	1 956 771	NO	NO	3 696 057	9 674 078
1997	17 718 714	6 515 815	369 747	NO	5 164 851	2 142 122	NO	NO	3 645 701	9 577 368
1998	17 375 970	6 487 233	370 828	NO	5 091 872	2 181 055	NO	NO	3 617 416	9 456 081
1999	17 917 875	6 574 300	368 839	NO	5 127 300	2 229 136	NO	NO	3 709 726	9 669 229
2000	17 730 456	6 374 466	193 515	93 077	5 092 607	2 501 279	NO	NO	3 613 120	9 599 471
2001	15 118 132	6 285 082	181 353	43 384	5 066 604	2 283 852	NO	NO	3 394 735	8 697 232
2002	15 761 472	6 044 021	191 920	49 819	4 905 811	1 846 480	NO	NO	3 324 015	8 643 424
2003	12 846 702	5 861 174	146 205	25 282	4 785 648	1 515 546	NO	NO	3 056 474	7 557 592
2004	16 293 626	5 870 104	121 081	34 736	4 786 944	2 190 137	NO	NO	3 239 230	8 792 271
2005	14 082 348	5 760 694	159 100	84 921	4 723 550	1 676 528	NO	NO	3 046 182	7 949 283
2006	13 900 105	5 627 852	139 750	74 971	4 714 227	1 771 669	NO	NO	2 983 297	7 871 570
2007	13 199 745	5 768 340	165 609	77 357	4 930 866	1 961 830	NO	NO	3 000 351	7 833 981
2008	13 198 210	5 789 762	156 780	87 340	5 005 268	2 054 186	NO	NO	3 006 017	7 890 122
2009	13 277 456	5 701 004	103 488	82 833	4 991 818	2 057 322	NO	NO	2 943 396	7 866 637
2010	13 700 295	5 738 306	103 729	99 310	5 075 891	1 876 481	NO	NO	2 985 333	7 980 466
2011	14 387 670	5 602 758	137 317	70 731	4 959 507	1 614 139	NO	NO	2 960 962	8 033 701
2012	13 643 864	5 452 123	165 135	50 606	4 830 312	2 317 347	NO	NO	2 857 900	7 939 682
2013	13 341 600	5 591 830	132 854	43 191	4 881 841	2 217 483	NO	NO	2 856 500	7 864 308
2014	12 677 997	5 758 662	122 577	48 488	5 018 048	2 385 921	NO	NO	2 867 616	7 804 977
2015	12 984 741	5 857 339	144 931	59 767	5 121 415	1 722 323	NO	NO	2 906 672	7 768 426
2016	13 700 554	6 015 026	77 569	59 835	5 186 513	2 091 599	NO	NO	2 949 195	8 140 402
2017	13 575 361	6 170 566	78 285	72 794	5 267 485	1 902 189	NO	NO	2 991 017	8 120 879
2018	13 037 517	6 098 798	64 282	58 868	5 213 230	1 921 389	NO	NO	2 929 048	7 918 902

Sources: SER, MECDD, (STATEC 2019a) (STATEC, 2019b)

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 Luxemburgish "landwirtschaftliche Testbetriebsnetz (LTBN)"[113], using a nutrient balance methodology (in German the so-called "Feld – Stall Bilanz"), (Weckbecker, 2018)

National utilisation was obtained by multipling the weighted average kg N per ha used agriculture surface (STATEC 2019b) by the used agriculture surface (STATEC 2019a).

5.6.3.1.2 Applied organic N fertiliser

Applied organic N fertilizers comprise animal manure, sewage sludge and compost. 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)

$$F_{ON} = F_{AM} + F_{SEW} + F_{COMP}$$

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.

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 2016 guidelines (EMEP/EEA 2016a), 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. Only at the end of the calculation is the combined loss subtracted in order to yield the remaining N available for application. This corresponds to step 13 described in section 5.2.6.

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[113] Luxemburg 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 Luxemburgish "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).

$$F_{AM} = \left[\sum_i \left(\left[m_{returned\_slurry\_N(i)} + m_{returned\_solid\_N(i)} \right] * n_i \right) \right]$$

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* and shown in Table 5-5;

The annual amount of total sewage N applied to soils, in kg per year and 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 and use, 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.[114] 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 2018, as data collection was still on-going.

Recent compost statistics were obtained from annual reports.[115] 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.

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114 See https://data.public.lu/en/datasets/boues-depuration/.

115 See https://data.public.lu/en/datasets/biodechets/# .

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)

$$F_{CR} = \sum_k \{Crop_k * Frac_{Renew(k)} * \left(Area_k * R_{AG(k)} * N_{AG(k)} * \left(1 - Frac_{Renew(k)}\right) + Area_k * R_{BG(k)} * N_{BG(k)}\right)\}$$

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 Luxemburg, and therefore assumed to not occur.

The cultivated crop area for 1990-2018 ($Area_k$) is summarized in Table 5-33, and the harvest yield for the different crop cultivated ($Crop_k$) is summarized in Table 5-33 **– Cash crop plants, fodder plants, pasture and total agricultural area (ha): 1990-2018**

Year	winter wheat	spring wheat	rye and mix-cereals	barley	oat	triticale	rape	potatoes	pulses	grain maize	maize for silage & bio digester	fodder beet	Clover, grass-clover leys, fodder production*	P me
1990	7 647	978	1 255	15 682	5 146	2 272	1 951	826	537	NO	7 473	231	11 573	
1991	7 334	621	1 147	14 755	4 499	2 670	2 595	859	591	NO	7 844	246	11 862	
1992	7 574	574	1 107	13 658	4 104	2 717	1 520	946	761	NO	8 676	280	12 749	
1993	7 706	662	923	13 746	3 819	2 665	1 686	834	835	NO	7 951	248	14 428	
1994	8 361	668	1 097	13 564	3 524	2 423	1 665	784	614	NO	8 540	234	13 564	
1995	8 917	418	1 094	12 681	2 790	2 874	1 954	802	474	NO	9 385	221	14 166	
1996	9 360	432	927	12 836	2 595	3 032	2 443	797	404	NO	9 528	178	14 111	
1997	9 299	443	973	12 584	2 517	3 095	2 250	842	421	457	10 024	165	16 075	
1998	9 342	462	1 263	12 260	2 299	3 419	2 862	842	414	505	9 881	129	16 381	
1999	6 629	1 168	1 234	12 798	2 456	2 756	4 069	840	557	502	10 491	106	16 238	
2000	10 590	381	1 331	10 538	1 909	3 635	3 245	829	431	255	10 799	77	15 281	
2001	9 065	760	1 315	11 622	1 725	3 066	3 084	734	693	476	11 241	61	15 171	
2002	11 552	466	1 466	9 585	1 963	4 010	3 492	672	667	326	11 016	51	14 436	
2003	10 738	449	1 142	10 355	2 163	3 724	3 674	623	601	337	11 621	43	14 539	
2004	11 380	340	1 427	8 882	1 907	3 578	4 190	635	507	350	12 284	43	14 663	
2005	11 296	630	1 309	9 938	1 696	3 411	4 061	608	467	215	12 100	51	12 288	
2006	12 257	408	1 411	9 512	1 502	3 470	4 782	594	372	288	11 566	37	11 860	
2007	12 246	340	1 431	9 226	1 443	3 546	5 394	628	367	281	11 985	39	12 480	
2008	14 179	418	1 557	9 674	1 252	3 608	5 208	604	222	379	12 192	30	12 039	
2009	13 369	472	1 343	9 370	1 383	4 055	4 629	604	305	409	13 261	32	12 221	
2010	13 668	342	1 150	8 261	1 136	4 780	4 715	615	336	375	13 435	27	12 818	
2011	13 367	511	1 206	7 940	1 123	4 340	4 674	635	268	300	13 690	32	13 653	
2012	13 055	462	1 328	7 142	919	4 736	4 596	639	166	196	14 131	59	14 567	
2013	13 740	511	1 148	7 740	1 130	4 561	4 496	593	282	243	13 996	75	13 493	
2014	11 506	1 159	1 235	8 318	1 178	4 787	4 146	607	378	216	14 745	102	13 790	
2015	13 698	796	1 141	7 714	1 194	4 604	3 975	570	588	141	14 448	137	13 089	
2016	13 373	435	1 319	6 901	1 094	4 609	3 508	615	682	125	14 938	154	13 501	
2017	13 696	488	1 243	6 594	1 309	4 520	3 267	622	621	108	15 194	111	13 647	
2018	12 633	351	1 353	6 004	1 238	4 669	3 393	627	409	61	15 876	77	14 658	

* 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 2019a) and SER (unpublished data : Fränk Steichen, pers. communication; December 2019; SER – Statistiques agricoles, marchés agricole et relations extérieures).

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 2019a)). Official statistics were consulted for the harvest yield data (STATEC, Consommation d'engrais chimiques 1936-2018 - Consommation totale (en tonnes d'éléments nutritifs) - Engrais azotes (N), 2019b)), 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 are all crops annually renewed (see Table 5-35). Clover and grass-clover leys are renewed every 3 years, similar to Germany (Haenel, 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 calculating according to 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 are annually completely removed from the field and used as bedding material. Maize for silage, is a whole plant silage, and accordingly also here is the whole plant removed from the field during the harvest. Fodder beet, clover, grass-clover, pasture and meadows are used as forage plants, whereby the whole plant is used, see Table 5-35.

Values used for $N_{AG(k)}$, $R_{BG\text{-}BIO(k)}$ 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 are 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 2019a). 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.

Table 5-33 – Cash crop plants, fodder plants, pasture and total agricultural area (ha): 1990-2018

Year	winter wheat	spring wheat	rye and mix-cereals	barley	oat	triticale	rape	potatoes	pulses	grain maize	maize for silage & bio digester	fodder beet	Clover, grass-clover leys, fodder production*	Pasture and meadows	Agricultural area
1990	7 647	978	1 255	15 682	5 146	2 272	1 951	826	537	NO	7 473	231	11 573	68 827	126 298
1991	7 334	621	1 147	14 755	4 499	2 670	2 595	859	591	NO	7 844	246	11 862	68 531	125 469
1992	7 574	574	1 107	13 658	4 104	2 717	1 520	946	761	NO	8 676	280	12 749	69 192	125 742
1993	7 706	662	923	13 746	3 819	2 665	1 686	834	835	NO	7 951	248	14 428	68 186	127 215
1994	8 361	668	1 097	13 564	3 524	2 423	1 665	784	614	NO	8 540	234	13 564	68 025	126 765
1995	8 917	418	1 094	12 681	2 790	2 874	1 954	802	474	NO	9 385	221	14 166	67 515	126 865
1996	9 360	432	927	12 836	2 595	3 032	2 443	797	404	NO	9 528	178	14 111	66 513	125 348
1997	9 299	443	973	12 584	2 517	3 095	2 250	842	421	457	10 024	165	16 075	64 965	125 629
1998	9 342	462	1 263	12 260	2 299	3 419	2 862	842	414	505	9 881	129	16 381	64 441	126 235
1999	6 629	1 168	1 234	12 798	2 456	2 756	4 069	840	557	502	10 491	106	16 238	64 377	126 494
2000	10 590	381	1 331	10 538	1 909	3 635	3 245	829	431	255	10 799	77	15 281	65 277	127 009
2001	9 065	760	1 315	11 622	1 725	3 066	3 084	734	693	476	11 241	61	15 171	65 114	127 257
2002	11 552	466	1 466	9 585	1 963	4 010	3 492	672	667	326	11 016	51	14 436	65 042	127 520
2003	10 738	449	1 142	10 355	2 163	3 724	3 674	623	601	337	11 621	43	14 539	64 828	127 574
2004	11 380	340	1 427	8 882	1 907	3 578	4 190	635	507	350	12 284	43	14 663	65 068	127 593
2005	11 296	630	1 309	9 938	1 696	3 411	4 061	608	467	215	12 100	51	12 288	67 504	127 789
2006	12 257	408	1 411	9 512	1 502	3 470	4 782	594	372	288	11 566	37	11 860	67 659	127 641
2007	12 246	340	1 431	9 226	1 443	3 546	5 394	628	367	281	11 985	39	12 480	68 290	129 791
2008	14 179	418	1 557	9 674	1 252	3 608	5 208	604	222	379	12 192	30	12 039	67 172	129 141
2009	13 369	472	1 343	9 370	1 383	4 055	4 629	604	305	409	13 261	32	12 221	67 367	129 726
2010	13 668	342	1 150	8 261	1 136	4 780	4 715	615	336	375	13 435	27	12 818	67 593	130 479
2011	13 367	511	1 206	7 940	1 123	4 340	4 674	635	268	300	13 690	32	13 653	67 638	130 797
2012	13 055	462	1 328	7 142	919	4 736	4 596	639	166	196	14 131	59	14 567	67 292	131 191
2013	13 740	511	1 148	7 740	1 130	4 561	4 496	593	282	243	13 996	75	13 493	66 897	130 800
2014	11 506	1 159	1 235	8 318	1 178	4 787	4 146	607	378	216	14 745	102	13 790	66 827	130 701
2015	13 698	796	1 141	7 714	1 194	4 604	3 975	570	588	141	14 448	137	13 089	66 923	131 159
2016	13 373	435	1 319	6 901	1 094	4 609	3 508	615	682	125	14 938	154	13 501	67 115	130 357
2017	13 696	488	1 243	6 594	1 309	4 520	3 267	622	621	108	15 194	111	13 647	67 413	131 163
2018	12 633	351	1 353	6 004	1 238	4 669	3 393	627	409	61	15 876	77	14 658	67 705	131 559

* 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 2019a) and SER (unpublished data : Fränk Steichen, pers. communication; December 2019; SER – Statistiques agricoles, marchés agricole et relations extérieures).

Table 5-34 – Crop harvest (kg/ha): 1990-2018

Year	winter wheat	spring wheat	rye and mix-cereals	barley	oat	triticale	rape	potatoes	pulses	grain maize	maize for silage & bio digester[a,b,c]	fodder beet[a,b]	Clover, grass-clover leys, fodder production[a,b]	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

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, 2019b)

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, 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 2016 guidelines (EMEP/EEA 2016a), 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.

$$F_{PRP} = \left[\sum_i \left(\left[m_{grazing\_N(i)} \right] * n_i \right) \right]$$

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, grazing, sewage sludge and compost, see Table 5-36. The methodology used to determine the NH_3-N and NO_x-N emissions is described in the IIR 2020 (Schuman, Becker, Hadzic, Mangen, & Mirgain, 2020).

Table 5-36 – Activity data: 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, grazing, sewage sludge and compost

	NRF Category 3B (Managed soil) Emissions									
	Mineral fertilizer		Animal manure		Sewage sludge		Compost		Grazing	
Year	kg NH_3-N/ year	kg NO-N/ year	kg NH3-N/ year	kg NO-N/ year	kg NH3-N/ year	kg NO-N/ year	kg NH3-N/ year	kg NO-N/ year	kg NH3-N/ year	kg NO-N/ year
1990	778 048	352 715	2 026 859	122 441	39 824	6 944	-	-	234 204	92 830
1991	778 048	367 520	2 105 511	123 917	39 848	6 948	-	-	236 918	94 876
1992	810 707	396 580	2 023 643	118 623	40 307	7 028	-	-	227 776	91 732
1993	874 809	361 782	2 038 084	119 370	41 873	7 301	-	-	227 750	91 686
1994	798 050	343 466	2 028 091	118 275	43 793	7 636	-	-	226 577	91 077
1995	757 645	337 011	2 095 696	121 840	43 485	7 582	-	-	231 963	93 694
1996	743 407	335 859	2 121 672	123 075	37 770	6 586	-	-	234 883	95 260
1997	740 866	330 749	2 096 936	121 624	39 585	6 902	-	-	228 063	92 153
1998	729 594	324 351	2 093 469	121 090	39 700	6 922	-	-	225 465	90 840
1999	715 481	334 467	2 148 481	122 715	39 487	6 885	-	-	228 347	91 447
2000	737 795	330 969	2 082 471	118 985	20 717	3 612	6 132	1 737	227 508	90 815
2001	730 078	282 205	2 030 358	117 317	19 415	3 385	2 858	810	225 414	90 369
2002	622 511	294 214	1 932 773	112 817	20 547	3 583	3 282	930	219 295	87 482
2003	649 002	239 805	1 856 162	109 404	15 653	2 729	1 666	472	216 211	85 296
2004	528 982	304 148	1 832 886	109 570	12 963	2 260	2 288	648	218 163	85 284
2005	670 914	262 870	1 768 623	107 527	17 033	2 970	5 595	1 585	215 865	84 143
2006	579 861	259 469	1 722 702	105 048	14 961	2 609	4 939	1 399	215 741	83 972
2007	572 357	246 395	1 762 749	107 670	17 730	3 091	5 096	1 444	224 710	87 848
2008	543 519	246 367	1 764 215	108 070	16 785	2 927	5 754	1 630	227 535	89 184
2009	543 456	247 846	1 706 730	106 414	11 079	1 932	5 457	1 546	226 632	88 950
2010	546 719	255 739	1 715 441	107 110	11 105	1 936	6 543	1 854	230 955	90 439
2011	564 130	268 570	1 657 379	104 580	14 701	2 563	4 660	1 320	226 317	88 353
2012	592 433	254 685	1 606 724	101 768	17 679	3 083	3 334	945	221 763	86 026
2013	561 806	249 043	1 623 041	104 376	14 223	2 480	2 846	806	223 283	86 960
2014	549 360	236 656	1 663 630	107 490	13 123	2 288	3 194	905	228 813	89 399
2015	522 035	242 382	1 672 871	109 332	15 516	2 705	3 938	1 116	232 806	91 254
2016	534 666	255 744	1 672 269	112 275	8 304	1 448	3 942	1 117	237 491	92 382
2017	564 140	253 407	1 710 828	115 178	8 381	1 461	4 796	1 359	242 740	93 795
2018	558 985	243 367	1 687 724	113 839	6 882	1 200	3 878	1 099	241 332	92 809
Trend 1990 -2018	-28%	-31%	-17%	-7%	-83%	-83%			3%	0%
Trend 2017 -2018	-1%	-4%	-1%	-1%	-18%	-18%	-19%	-19%	-1%	-1%

Source: IIR 2020 (Schuman, Becker, Hadzic, Mangen, & Mirgain, 2020)

5.6.3.2 Emission factors

5.6.3.2.1 Emission factors – direct N_2O emissions from managed soil

The direct N_2O emissions from managed soil (N_2O_{Direct}), expressed as kg N_2O per year were estimated using an IPCC Tier 1 approach, whereby following equation 11.1 of the 2006 IPCC guidelines (IPCC 2006b):

$$N_2O_{Direct} = \left[N_2O_{N\ inputs} + N_2O_{PRP}\right]$$

Whereby

$$N_2O_{N\ inputs} = [(F_{SN} + F_{ON} + F_{CR} + F_{SOM}) * EF_1] * (\frac{44}{28})$$

with:

$N_2O_{N\ inputs}$	= annual direct N_2O emissions from N inputs to managed soils, kg N_2O 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 animal manure, compost, sewage sludge and other 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_{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_2O inputs, kg N_2O-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_2O-$N_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions.

And further

$$N_2O_{PRP} = \left[\left(F_{PRP,CPP} * EF_{3PRP,CPP}\right) + \left(F_{PRP,SO} * EF_{3PRP,SO}\right)\right] * (\frac{44}{28})$$

with:

N_2O_{PRP}	= annual direct N_2O emissions from urine and dung inputs to grazed soils, kg N_2O 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_2O emissions from urine and dung N deposited on pasture by grazing animals, kg N_2O-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 $N_2O\text{-}N_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions.

Direct N_2O 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 N_2O emissions from managed soil

The indirect N_2O emissions from managed soils consist of a) N_2O emissions from atmospheric deposition of N volatilised from managed soils and b) N_2O emissions from leaching and runoff.

The indirect N_2O emissions occurring after 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, grazing, sewage sludge and compost (all attributed to agricultural soils) were calculated using the following formula:

$$indirect\ soil\ N_2O\ emissions = \{[E_{NH3-N} + E_{NO-N}]_{fert} + [E_{NH3-N} + E_{NO-N}]_{SAM} + [E_{NH3-N} + E_{NO-N}]_{SSS} + [E_{NH3-N} + E_{NO-}\ ]_{Comp} + [E_{NH3-N} + E_{NO-N}]_{graz}\} * EF_{N_2O-N\ indirect\ soil} * \left(\frac{44}{28}\right)$$

Where:

- Indirect N_2O emissions resulting from the deposition of NH_3 and NO_x emitted from agricultural soils, in Gg/year
- $[E_{NH3-N} + E_{NO-N}]_{fert}$: NH3-N and NO-N emissions from mineral fertilizer, in Gg/year, see .
- $[E_{NH3-N} + E_{NO-N}]_{SAM}$: NH3-N and NO-N emissions from spreading of animal manure, in Gg/year.
- $[E_{NH3-N} + E_{NO-N}]_{SSS}$: NH3-N and NO-N emissions from spreading of sewage sludge, in Gg/year.
- $[E_{NH3-N} + E_{NO-N}]_{Comp}$: NH3-N and NO-N emissions from spreading of compost, in Gg/year.
- $[E_{NH3-N} + E_{NO-N}]_{graz}$: NH3-N and NO-N emissions from grazing, Gg/year.
- $EF_{N2O\text{-}N\ indirect\ soil}$: Default IPCC N_2O-N emission factor for indirect emissions from deposition (i.e. (0.01 (IPCC 2006b)), expressed in kg N_2O-N/kg N
- 44/28 : Conversion factor from kg N_2O-N to kg N_2O

And consequently the fraction of synthetic fertilizer N ($Frac_{GASF}$) that volatilizes as NH_3 and NO_x, was calculated by using the following formula:

$$Frac_{GASF} = {[E_{NH3-N} + E_{NO-N}]_{fert}} / {F_{SN}}$$

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 NH_3 and NO_x, calculated by using the following formula:

$$Frac_{GASM} = \left[\frac{\{[E_{NH3-N}+E_{NO-N}]_{SAM}+[E_{NH3-N}+E_{NO-N}]_{SSS}+[E_{NH3-N}+E_{NO-N}]_{Comp}+[E_{NH3-N}+E_{NO-N}]_{graz}\}}{\{F_{ON}+F_{PRP}\}}\right]$$

Where:

- F_{ON}: annual amount of managed animal manure, of sewage sludge and compost 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 fertilizers, animal manures and other that is lost through leaching and run-off, N_2O emissions have 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, compost, sewage sludge and other 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_2O emissions from atmospheric deposition of N on soils and water surfaces, kg N_2O-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_2O-$N_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions.

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

A few errors in the agricultural surface area in different years for the period 1990-2017 were updated, with consequently also a revision of the annual amount of synthetic fertilizer used, and the estimated N associated with crop residuals. The annual amount of animal manure N applied to soils (kg N per year) were revised and updated following an N-flow model. The same was applied for N in urine and dung deposited during grazing. Also was the activity data for compost revised as erroneously the fresh quantities were used, rather than the dry matter quantities, when estimating the N quantities of the applied compost to soils. Further was a Tier 2 approach taken for indirect N_2O-emissions from soil management.

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 and compost and 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 more recent data is planned for the following submission. Furthermore, in the next submission the N flow model will be updated to comply with 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 – strongly 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 Luxembourg 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 2018, this source category was responsible for 1.6% of the total GHG emissions from the agriculture sector and represented 0.11% of the total GHG emissions in CO_2eq (excluding LULUCF).

5.9.1 Source category description

This category consists of emissions resulting from the agricultural use of dolomite and limestone.

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.

The use of lime increases significantly over time, see Table 5-37. This is probably a result linked to intensive consultancy on the use of fertilizer. 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.

Table 5-37 - CO_2 emission trends for IPCC Category 3G – Liming: 1990-2018 (Gg)

Year	Lime	Dolomite	TOTAL
1990	NO	0.26	0.26
1991	NO	0.46	0.46
1992	NO	0.66	0.66
1993	NO	1.02	1.02
1994	NO	1.49	1.49
1995	NO	1.22	1.22
1996	NO	1.07	1.07
1997	NO	1.59	1.59
1998	NO	2.19	2.19
1999	NO	1.22	1.22
2000	NO	2.04	2.04
2001	NO	2.48	2.48
2002	NO	3.15	3.15
2003	NO	3.05	3.05
2004	NO	2.62	2.62
2005	NO	4.23	4.23
2006	NO	3.30	3.30
2007	NO	3.34	3.34
2008	NO	3.10	3.10
2009	NO	4.41	4.41
2010	NO	3.81	3.81
2011	NO	5.29	5.29
2012	NO	5.48	5.48
2013	NO	6.29	6.29
2014	NO	6.95	6.95
2015	NO	7.36	7.36
2016	NO	6.99	6.99
2017	NO	8.80	8.80
2018	0.53	10.45	10.98
Trend 1990 -2018		3987%	4194%
Trend 2017 -2018		19%	25%

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 (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 2014-2018 own investigations at the Service d'Economie Rurale took place (Turmes 2018, (Hess, November 2019) Palzkill 2019). For the years 2013-2018, 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: 1990-2018

	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	1 200	21 925

Sources: 1990-1992: Trend estimations; 1993-2013: ASTA (Marc Weyland); 2014-2017: (Turmes 2018) ; 2018 (Hess, November 2019), Palzkill 2019).

5.9.2.2 Emission factors

An IPCC Tier 1 method was used for estimating CO_2 emissions from liming.

CO_2 emissions from liming in tonnes per year were calculated according to equation 11.12 see equation (IPCC 2006b):

$$CO_2\ Emissions = [(M_{Dolomite} * EF_{Dolomite}) + (M_{Limestone} * EF_{Limestone})] * (\frac{44}{12})$$

with,

$M_{Dolomit}$	= the annual amount of dolomite (in tonnes per year).
$EF_{Dolomit}$	= 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 CO_2-C emissions to CO_2 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

Statistics of limestone and dolomite 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)

Category 3H is listed as NE. Emissions from 3H are under the significance threshold (0.05% and 500kt CO_2eq).

The use of urea as fertilizer was, and is not common practice in Luxemburg. Earlier estimates in previous submissions had shown that the emissions would be below the significance threshold of 0.05%.

This has not really changed since then, as is shown hereafter based on recently collected data for the years 2016-2018 within the LTBN"[116]. In order to cover more than 60% of the used agricultural surface area in Luxemburg, all farms (~850) providing accountancy data to the LTBN were taken into consideration. The quantities bought by LTBN farmers, the agricultural surface used by LTBN farmers and the total agricultural surface used in Luxemburg is summarized in Table 5-39. The LTBN quantity was extrapolated to the whole country, by assuming that farmers outside the LTBN would apply the same sort of fertilizer as the one in the LTBN (although this might be an overestimation as the more professional farms are in the LTBN). CO_2 emissions from urea in tonnes per year were calculated according to equation 11.13 see equation (IPCC 2006b):

$$CO_2\ Emissions = (M_{Urea} * EF_{Urea})$$

with,

M_{Urea}	= the annual amount of urea used in Luxemburg (in tonnes per year), see Table 5-39.
EF_{Ureat}	= emission factor, the 2006 IPCC default emissions factor for urea (EF_{Urea}), i.e. 0.2 (IPCC 2006b) was used.

Emissions from urea application for the year 2016-2018 are rather marginal as shown in Table 5-39. They are below the significance threshold of 0.05% CO_2 eq., and hence the use of notation key "NE" in CRF table 3G-I.

[116] Luxemburg 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 Luxemburgish "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).

Table 5-39 – Emissions from urea application in CO2-equivalent (Gg) for 2016-2018

Year	Total used urea quantities (dt/year) by LTBN farmers*	Agriculture surface area used by LTBN farmers (ha)*	Total agriculture surface area used in LU (ha)	Estimated annual amount of urea fertilisation (tonnes / year)	Used EF (Source: IPCC 2006b)	Estimated CO_2 Emissions (Gg) from urea application
2016	9156.95	84 140	130 651	1422	0.2	0.00028
2017	2913.05	85 607	131 163	446	0.2	0.00009
2018	1487.90	79 384	131 559	247	0.2	0.00005

*Karl Weckbecker (SER - Division de la gestion, de la comptabilité et de l'entraide agricoles; personal communication 21 February 2020); based on the accountancy data of all farmers within the LTBN.

5.11 Other carbon containing fertilizer and others (IPCC Source Category 3I an 3J)

These source categories are not used in Luxembourg's GHG inventory.

5.12 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 2018.

6.1 Sector Overview

In 2018, *Land Use, Land Use Change and Forestry* was a net sink in Luxembourg (Table 6-1). Net removals from the LULUCF sector amounted to 213.28 Gg CO_2e. Since 1990, net emissions have decreased by -310.65% per cent (the sector was a source of net emissions in 1990 (101.25 Gg CO_2e) and a source of net removals in 2018). 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 (-259.27 Gg CO_2e and -41.52 Gg CO_2e, respectively). All other categories resulted in net emissions: the largest source of emissions was from settlements (60.6 Gg CO_2e), followed by cropland (35.28 Gg CO_2e), wetlands (4.16 Gg CO_2e) and other land (0.15 Gg CO_2e).

Table 6-1 - Emissions and Removals from CRF category 4 - LULUCF

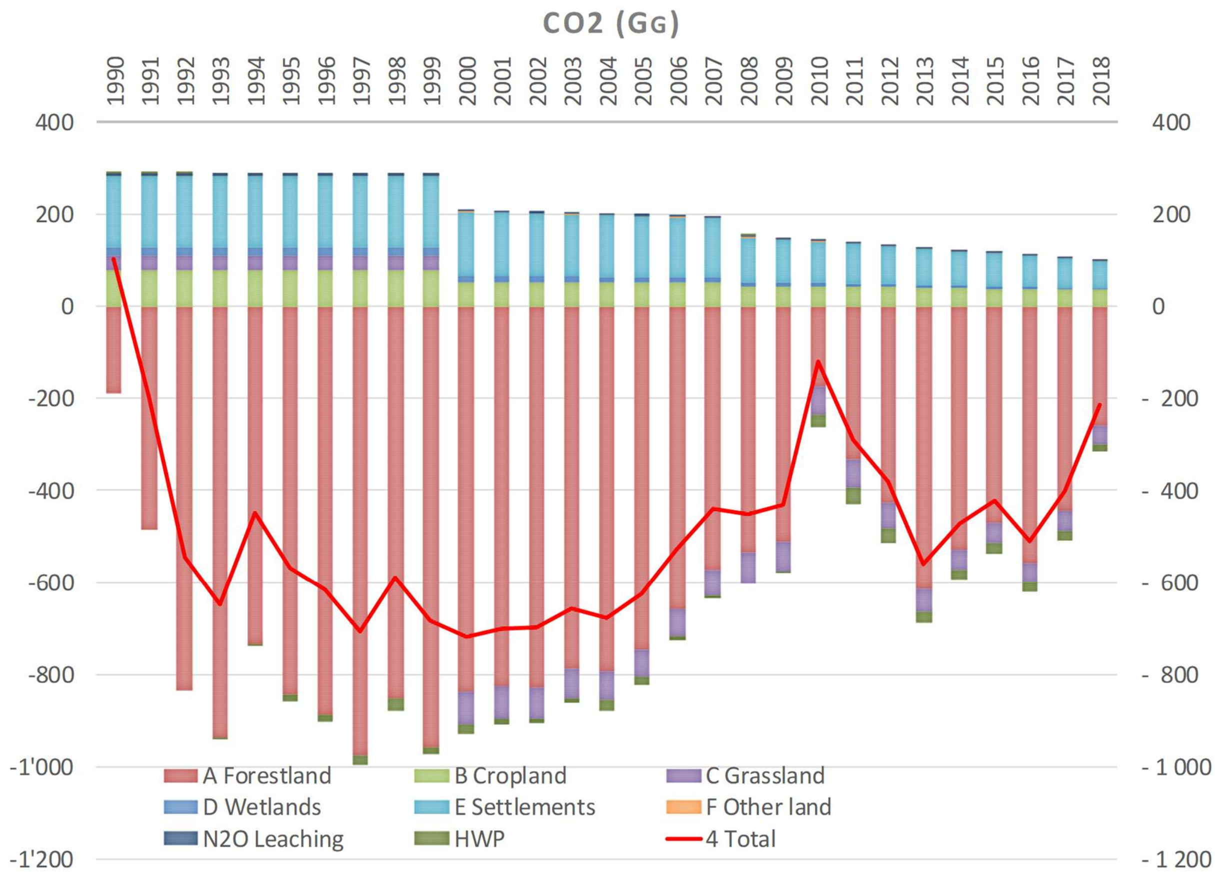
Year	4 Total	A Forestland	B Cropland	C Grassland	D Wetlands	E Settlements	F Other land	N2O Leaching	HWP
1990	101.25	- 188.74	77.80	32.52	16.20	155.69	1.76	3.92	2.11
1991	- 194.21	- 484.05	77.80	32.52	16.20	155.69	1.76	3.92	1.97
1992	- 544.60	- 834.68	77.80	32.52	16.20	155.69	1.76	3.92	2.21
1993	- 648.55	- 935.97	77.80	32.52	16.20	155.69	1.76	3.92	-0.45
1994	- 448.90	- 734.54	77.80	32.52	16.20	155.69	1.76	3.92	-2.23
1995	- 568.93	- 844.37	77.80	32.52	16.20	155.69	1.76	3.92	-12.44
1996	- 615.05	- 887.46	77.80	32.52	16.20	155.69	1.76	3.92	-15.46
1997	- 707.04	- 975.62	77.80	32.52	16.20	155.69	1.76	3.92	-19.29
1998	- 589.97	- 852.57	77.80	32.52	16.20	155.69	1.76	3.92	-25.27
1999	- 683.97	- 956.68	77.80	32.52	16.20	155.69	1.76	3.92	-15.17
2000	- 717.53	- 836.22	52.63	- 72.51	13.85	138.28	0.98	3.86	-18.40
2001	- 701.08	- 824.74	52.25	- 70.04	13.68	136.95	0.94	3.80	-13.92
2002	- 699.25	- 827.16	51.87	- 67.57	13.52	135.61	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	- 676.95	- 792.85	51.11	- 62.62	13.18	132.94	0.82	3.63	-23.16
2005	- 623.72	- 745.58	50.72	- 60.15	13.02	131.61	0.78	3.57	-17.69
2006	- 529.11	- 658.30	50.34	- 57.68	12.85	130.28	0.74	3.51	-10.86
2007	- 438.50	- 574.18	49.96	- 55.21	12.68	128.94	0.70	3.45	-4.86
2008	- 450.22	- 536.53	42.52	- 67.44	9.76	97.14	0.59	3.32	0.42
2009	- 431.75	- 511.35	41.93	- 63.77	9.20	93.43	0.55	3.19	-4.94
2010	- 119.48	- 173.35	42.17	- 63.29	8.64	89.72	0.50	3.07	-26.95
2011	- 290.95	- 333.76	41.53	- 59.36	8.08	86.02	0.46	2.94	-36.85
2012	- 381.75	- 426.98	41.18	- 54.38	7.52	82.31	0.42	2.81	-34.62
2013	- 559.28	- 613.54	39.88	- 50.07	6.96	78.60	0.37	2.68	-24.16
2014	- 472.30	- 529.50	38.66	- 44.77	6.40	74.89	0.33	2.54	-20.84
2015	- 421.57	- 470.49	37.50	- 44.49	5.84	71.19	0.28	2.39	-23.78
2016	- 509.36	- 557.50	36.08	- 42.37	5.28	67.48	0.24	2.25	-20.81
2017	- 402.41	- 444.82	35.96	- 42.59	4.72	63.77	0.19	2.12	-21.75
2018	- 213.28	- 259.27	35.28	- 41.52	4.16	60.06	0.15	1.98	-14.12
Trend 1990-2018	-310.65%	37.37%	-54.65%	-227.69%	-74.34%	-61.42%	-91.65%	-49.37%	-769.80%
Trend 2017-2018	-47.00%	-41.71%	-1.87%	-2.51%	-11.87%	-5.81%	-23.41%	-6.28%	-35.09%

6.1.1 Emission Trends

In 2018, removals from category forest land corresponded to 2.46% of total GHG in Luxembourg (incl. LULUCF). The net removals have increased from the base year to 2018, 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, 11-18	NA	X
4A2	Land Converted to Forest Land	CO_2	NA	90-18	NA	X
4B2	Land Converted to Crop Land	CO_2	NA	95-99	NA	
4C2	Land Converted to Grassland	CO_2, N_2O	NA	00-03, 09-11	NA	
4E2	Land Converted to Settlements	CO_2, N_2O	NA	90-18	NA	X

Source: Environment Agency

Notes: LA = Level Assessement (Tier 1) including respectively exluding LULUCF

TA = Trend Assessement 2018 (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 2018, the respective areas were 89.5%, 10.0% and 0.5%. Thus, Luxembourg has some 96 175 ha of forests, some 135 195 ha of agriculturally used land, and some 25 943 ha covered by buildings and roads. Rivers, lakes, wetlands and other lands cover a surface of some 1 287 ha.

Meteorologically, Luxembourg is situated in an area with temperate maritime climate, with an annual average temperature of 10.5°C in Luxembourg-city (Statec, Average yearly temperature of Luxembourg - Table A2100, 2019) (year 2018), 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 according to the FAO TBRA2000 definition: • Minimum land area: 0.5 ha • tree crown cover >= 10 % • tree 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.
Annual Cropland 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 yearly changed rhythm including artificial meadows (not permanent) including land temporarily set aside 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.e.* 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 (*e.g.* 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**
	31	forets	Wald			Forest Area
P	312	forets de coniferes	Nadelwald	Coniferous Forest	Coniferous Forest	Forest Area
Pe	3121	epiceas, sapins	Fichte, Tannen	Coniferous Forest	Coniferous Forest	Forest Area
Pm	3122	pins, mezeles	Kiefern, Lärchen	Coniferous Forest	Coniferous Forest	Forest Area
Pr	3123	autres resineux	Other Land Nadelbaeume	Coniferous Forest	Coniferous Forest	Forest Area
	311	forets de feuillus	Laubwald	Deciduous Forest	Deciduous Forest	Forest Area
F/Q	3111	forets acidophiles	Saure Wälder	Deciduous Forest	Deciduous Forest	Forest Area
Qb	31111	chenaie acidophile tres pauvre	artenarmer saurer Eichenwald	Deciduous Forest	Deciduous Forest	Forest Area
Fs	31112	hetraie et chenaie-hetraie acidophile	saurer Buchen und Eichen-Buchenwald	Deciduous Forest	Deciduous Forest	Forest Area
Qs	31113	chenaie acidophile	saurer Eichenwald	Deciduous Forest	Deciduous Forest	Forest Area
Fl	31114	hetraie a luzule blanche	Buchen mit weissen Luzernen	Deciduous Forest	Deciduous Forest	Forest Area
Ql	31115	chenaie a luzule blanche	Eichenwald mit Luzernen	Deciduous Forest	Deciduous Forest	Forest Area
Ff	31116	hetraie a grande fetuque	Buchenwald mit hohen Graesern	Deciduous Forest	Deciduous Forest	Forest Area
Qx	31117	chenaie a charmes xerophile sur schistes et gres	besondere trockenheitsliebende Eichenart auf Schiefer und 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 basiclines	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	ormaie ruderale	Ulmenwald in Aufschuettungen	Deciduous Forest	Deciduous Forest	Forest Area
P	3115	plantation de feuillus	Laubwald Anpflanzung	Deciduous Forest	Deciduous Forest	Forest Area
Ps	31151	peupleraie en site sec	Pappelwald in trockenen Gebieten	Deciduous Forest	Deciduous Forest	Forest Area
Ph	31152	peupleraie en site humide	Pappelwald in feuchten Gebieten	Deciduous Forest	Deciduous Forest	Forest Area
Pf	31153	plantation d'autres essences feuillus	Anpflanzungen Other Landr Laubbaeume	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 alluviales sur sols mineraux	Auewald auf mineralischem Boden	Deciduous Forest	Deciduous Forest	Forest Area
Va	31171	ormaie-frenaie alluviale	Ulmen-Eschenwald in Flusssedimenten	Deciduous Forest	Deciduous Forest	Forest Area
Vb	31172	aulnaie-frenaie alluviale mesotrophe	Erlen-Eschenwaelder in Flusssedimenten	Deciduous Forest	Deciduous Forest	Forest Area
Vn	31173	aulnaie alluviale nitrophile	Erlenwaelder in nitratreichen Flusssedimenten	Deciduous Forest	Deciduous Forest	Forest Area
Vc	31174	aulnaie-frenaie des sources et ruisseaux	Erlen-Eschenwaelder in Quellgebieten und an Rinnsalen	Deciduous Forest	Deciduous Forest	Forest Area
V	3118	forets marecageuses a sedimentation organique	Moorbruchwälder	Deciduous Forest	Deciduous Forest	Forest Area
Vm	31181	aulnaie mesotrophe a laiches	Erlenwaelder mit Seggen	Deciduous Forest	Deciduous Forest	Forest Area
Vx	31182	boulaie marcageuse	sumpfiger Birkenwald	Deciduous Forest	Deciduous Forest	Forest Area
	323	vegetations sclerophylles	Holzartiges Gebüsch	Deciduous Forest	Deciduous Forest	Forest Area
S	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 Waldrodungsflaechen	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	saulaie humide sur sol tourbeux ou acide	Weidenbaeume auf einem feuchten, torfigen oder sauren Boden	Deciduous Forest	Deciduous Forest	Forest Area
Sf	32422	saulnaie humide mesotrophe ou eutrophe	Weidenbaeume auf einem feuchten, mittelmaessig oder gut mit Naehrstoffen versorgten Boden	Deciduous Forest	Deciduous Forest	Forest Area
P	313	forets melangees	Mischwald	Mixed Forest	Mixed Forest	Forest Area
Pl	3131	par pied ou par bouquet	truppenweise Mischung (uebernommen 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 geduengt	Grassland	Non-Forest Area	Non-Forest Area
Hj	23112	prairie humide peu ou non fertilisee à joncs	Feuchtwiese kaum oder nicht geduengt mit Binsen	Grassland	Non-Forest Area	Non-Forest Area
Hf	23113	prairie humide a reine des pres	Feuchtwiese mit einem krautigen Rosaceaengewaechs	Grassland	Non-Forest Area	Non-Forest Area
Hm	23114	prairie humide non fertilisee a molinie	ungeduengte Feuchtwiese mit bestimmtem Suessgrasgewaechs	Grassland	Non-Forest Area	Non-Forest Area
Hmo	231141	type oligotrophe	wenig Naehrstoffe	Grassland	Non-Forest Area	Non-Forest Area
Hmm	231142	type mesotrophe	mittelmaessig Naehrstoffe	Grassland	Non-Forest Area	Non-Forest Area
Hme	231143	type eutrophe	viel Naehrstoffe	Grassland	Non-Forest Area	Non-Forest Area
	2312	prairies mesophiles ameliorees	mesophile Weidewiese	Grassland	Non-Forest Area	Non-Forest Area
Hu	23121	prairie mesophile de fauche	mesophile Mahdwiese	Grassland	Non-Forest Area	Non-Forest Area
Hua	23122	prairie mesophile de fauche atypique	untypische mesophile Mahdwiese	Grassland	Non-Forest Area	Non-Forest Area
Hp	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 ruderale	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	Silikatraseen 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	Pionierrasen 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 broussailes	Heide und Buschwerk	Grassland	Non-Forest Area	Non-Forest Area
Cg	3221	lande seche a callune	trockene Heide mit irgendeinem speziellen Heidekrautgewaechs	Grassland	Non-Forest Area	Non-Forest Area
Cj	3222	lande a callune genevrier	Heidekrautgewaechse mit Strauch mit widerstaendigen, stacheligen Blaettern, der Beeren ausbildet	Grassland	Non-Forest Area	Non-Forest Area
Cd	3223	lande a callune degradee	degradierte Heide mit speziellem Heidekrautgewaechs	Grassland	Non-Forest Area	Non-Forest Area
Cdm	32231	a dominance de molinie	mit Dominanz irgendeines Suessgrasgewaechses	Grassland	Non-Forest Area	Non-Forest Area
Cdc	32232	a dominance de canche flexueuse	mit Dominanz einer flexible 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
	211	terres arables hors perimetre d'irrigation	Ackerland, nicht bewässert	Cropland annual	Non-Forest Area	Non-Forest Area
Ba	2111	culture annuelle	jaehrliche Kulturen	Cropland annual	Non-Forest Area	Non-Forest Area
Bp	2112	pepiniere	Baumschule	Cropland permanent	Non-Forest Area	Non-Forest Area
B	22	cultures permanentes	Dauerkulturen	Cropland permanent	Non-Forest Area	Non-Forest Area
Bv	221	vignobles	Weinberge	Cropland permanent	Non-Forest Area	Non-Forest Area
Bvn	2211	vignobles en pentes	Weinberge in Steillagen	Cropland permanent	Non-Forest Area	Non-Forest Area
Bvt	2212	vignobels 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
	111	tissu urbain continu	Zusammenhängendes Stadtgebiet	Settlements	Non-Forest Area	Non-Forest Area
Uh	1111	zone urbaine dense	dicht besiedeltes Gebiet	Settlements	Non-Forest Area	Non-Forest Area
Uhh	11111	batiments hauts	mit hohen Gebaeuden	Settlements	Non-Forest Area	Non-Forest Area
Uhb	11112	batiments bas	mit niedrigen Gebaeuden	Settlements	Non-Forest Area	Non-Forest Area
	112	tissu urbain discontinu	Unzusammenhängendes Stadtgebiet	Settlements	Non-Forest Area	Non-Forest Area
Uf	1121	zone semi-urbaine	semiurbaner 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	extention 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 staedtischer 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
	121	zones industrielles, commerciales et socio-culturelles	Flächen genutzt von Industrie, Handel und Kultur	Settlements	Non-Forest Area	Non-Forest Area
	1211	industrie et commerce	Industrie- und Handelsflächen	Settlements	Non-Forest Area	Non-Forest Area
Il	12111	industrie lourde	Schwerindustrie	Settlements	Non-Forest Area	Non-Forest Area
Iz	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
	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
	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
	122	reseau routier, ferroviaire et espaces associes	Schienewegenetz und zugehörige Flächen	Settlements	Non-Forest Area	Non-Forest Area
	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
	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	Schienennetz	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	Yachthaften	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
	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
	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
	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 ruderale ou remblais	Aufschuettungen	Settlements	Non-Forest Area	Non-Forest Area
N	14	espcaes verts artificialises, non agricoles	Grünflachen, nicht landwirtschaftlich genutzt	Settlements	Non-Forest Area	Non-Forest Area
	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 bordee 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
	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	Feuchtflächen im Binnenland	Wetland	Non-Forest Area	Non-Forest Area
	411	marais interieurs	Sumpfgebiete	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 schmalblaettrigem 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 Flächen 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 abondonnee	aufgegebener Steinbruch	Other Land	Non-Forest Area	Non-Forest Area
A	51	eaux continentales	Wasserflächen im Binnenland	Water	Non-Forest Area	Non-Forest Area
	511	cours et voies d'eaux	Wasserläufe und -strassen	Water	Non-Forest Area	Non-Forest Area
An	5111	cours d'eau natuels	natuerliche Wasserlaeufe	Water	Non-Forest Area	Non-Forest Area
Ac	5112	voies d'eau artificielles	kuenstliche Wasserlaeufe	Water	Non-Forest Area	Non-Forest Area
	512	plans d'eau	Wasserflächen (Seen, Teiche etc.)	Water	Non-Forest Area	Non-Forest Area
Al	5121	plan d'eau naturel	natuerliche Wasserflaeche	Water	Non-Forest Area	Non-Forest Area
Alh	51211	plus ou mojns 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	mittelmaessig 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 Wasserflaeche	Water	Non-Forest Area	Non-Forest Area
Aah	51221	plus ou mojns 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	mittelmaessig 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	mittelmaessig 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	Futaie feuillue α dominance de chene	Deciduous Forest	Deciduous Forest	Forest
WLB	FFH	3.1.1.2	Laubwald, Buche	Futaie feuillue α dominance de hetre	Deciduous Forest	Deciduous Forest	Forest
WLS	FFD	3.1.1.3	Laubwald, sonstige Laubbaumarten	Futaie de feuillus divers	Deciduous Forest	Deciduous Forest	Forest
WLM	FFM	3.1.1.4	Laubwald, gemischt, Eiche, Buche	Futaie feuillue melangee de chenes et de hetres	Deciduous Forest	Deciduous Forest	Forest
WLN	FTC	3.1.1.5	Eichen-Niederwald	Taillis de chene	Deciduous Forest	Deciduous Forest	Forest
WL0	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, Vorwaelder trockener Standorte	Buissons, prebois sur sols secs	Deciduous Forest	Deciduous Forest	Forest
SBM	BPF	3.2.4.2	Buschwerk, Vorwaelder mittlerer Standorte	Buissons, prebois sur sols frais	Deciduous Forest	Deciduous Forest	Forest
SBF	BPH	3.2.4.3	Buschwerk, Vorwaelder feuchter Standorte	Buissons, prebois sur sols humides	Deciduous Forest	Deciduous Forest	Forest
SBG	BPE	3.2.4.4	Blockschutt- und Geroellwaelder	Forets, prebois sur eboulis	Deciduous Forest	Deciduous Forest	Forest
SBP	BPA	3.2.4.5	Gehoelzplanzungen	Plantations cubustives	Deciduous Forest	Deciduous Forest	Forest
WNF	FRE	3.1.2.1	Nadelwald, Fichte/Douglasie/Tanne	Foret resineuse (epiceas, douglas, sapins)	Coniferous Forest	Coniferous, Spruce/Douglas Fir/Fir	Forest
WNK	FRP	3.1.2.2	Nadelwald, Kiefer/Laerche	Foret resineuse (pins, melezes et autres resineux)	Coniferous Forest	Coniferous Pine/Larch	Forest
WNM	FRM	3.1.2.3	Nadelwald, gemischt	Foret resineuse melangee	Coniferous Forest	Coniferous mixed	Forest
WMT	FMP	3.1.3.1	Mischwald (Laub/Nadel), truppweise Mischung	Foret melangee (feuillus/resineux) par pied, par bouquet	Mixed forest	Mixed forest	Forest
WMF	FMM	3.1.3.2	Mischwald (Laub/Nadel), fliessende Mischung	Foret melangee (feuillus/resineux), melange intime	Mixed forest	Mixed forest	Forest
WAU	FCD	3.1.3.3	Aufforstungen, Landungen, Dickungen (Baumart nicht erkennbar)	Culture forestiere d'essences non definies	Mixed forest	Mixed forest	Forest
WSF	FSD	3.1.3.4	Sonstige Forest Landflaechen (Schlagflur, Windbruch)	Autres surfaces forestieres (coupes rases, chablis)	Mixed forest	Mixed forest	Forest
LAA	RAA	2.1.1.1	Acker	Terres agricoles, cultures annuelles	Cropland annual	Non-Forest	Non-Forest
LBG	RAH	2.1.1.2	Baumschule, Gartenbau	Pepinieres, 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 vignoble	Cropland permanent	Non-Forest	Non-Forest
LSH	RHT	2.2.2.1	Streuobst, Hochstamm	Verger α hautes tiges	Cropland permanent	Non-Forest	Non-Forest
LSN	RBT	2.2.2.2	Obst, Niederstamm	Verger α basses tiges	Cropland permanent	Non-Forest	Non-Forest
LFG	RPR	2.3.1.1	Feuchtgruenland	Prairie humide	Grassland	Non-Forest	Non-Forest
LMG	RPM	2.3.1.2	Mesophiles Gruenland	Prairie mesophile	Grassland	Non-Forest	Non-Forest
KSI	PSI	3.2.1.1	Silicattrockenrasen	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 pionnieres (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 ruderalisees et friches sur sols secs α frais	Grassland	Non-Forest	Non-Forest
KRF	PFH	3.2.3.2	Ruderalstandorte, Staudenfluren feuchter Standorte	Surfaces ruderalisees et friches sur sols humides	Grassland	Non-Forest	Non-Forest
BSC	UAD	1.1.1	Siedlungsgebiet, Verdichtungsgrad >80%, City	Tissu urbain dense (degree de l'imperméabilisation des sols >80%)	Settlements	Non-Forest	Non-Forest
BSM	UAA	1.1.2.1.1	Siedlungsgebiet mit Verdichtunggrad von 50-80%	Zone semi-urbaine, degree 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, degree 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 urbanisees 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 dissemine 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'activites economiques, terrain militaire	Settlements	Non-Forest	Non-Forest
BIO	UPS	1.2.1.2	Oeffentliche Bebauung	BΓtiments et installations α destination socio-culturelle	Settlements	Non-Forest	Non-Forest
BIS	UPE	1.2.1.3.1	Sondergebiete, Stromversorgung	Installations de distribution electrique	Settlements	Non-Forest	Non-Forest
BIW	UPU	1.2.1.3.2	Sondergebiete, Wasserversorgung	Installation de traitement des eaux usees	Settlements	Non-Forest	Non-Forest
BIA	UPH	1.2.1.3.3	Sondergebiete, Gasversorgung	Installations de stockage d'hydrocarbures et de gaz	Settlements	Non-Forest	Non-Forest
BIL	UAC	1.2.1.4	gewerbliche Landwirtschaft (Stallanlagen, Gewaechshaeuser)	Constructions agricoles et horticoles, etables, 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	Aeroport; terminal, hangar	Settlements	Non-Forest	Non-Forest
BVL	UTT	1.2.4.2	Flughafen, Landebahn	Aeroport; piste et taxiways	Settlements	Non-Forest	Non-Forest
BAF	UEM	1.3.1	Abbauflaeche, Tagebau	Zone d'extraction de materiaux	Settlements	Non-Forest	Non-Forest
BAA	UER	1.3.2.1	Aufschuettung, Deponie	Remblais et decharges	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	Cimetiere	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 recreatif, camping, golf etc.	Settlements	Non-Forest	Non-Forest
BGK	UVJ	1.4.2.2	Kleingartenanlagen	Cite jardiniere	Settlements	Non-Forest	Non-Forest
FRO	ROS	4.1.1.1	Roehrichte	Roseliere	Wetland	Non-Forest	Non-Forest
FGS	MAG	4.1.1.2	Grossseggenrieder	Magnocaritaie	Wetland	Non-Forest	Non-Forest
FKS	MBA	4.1.1.3	Kleinseggenrieder	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 colonises	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, naturfern	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	Stillgewaesser natuerlicher Entstehung	Plans d'eau anthropogene proche de l'etat naturel	Water	Non-Forest	Non-Forest
GSK	EPA	5.1.2.2	Stillgewaesser 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	Bassin, reservoir ayant un interet ecologique	Water	Non-Forest	Non-Forest
GBO	BRS	5.1.2.5.2	Becken, Reservoir ohne biol. Wert	Bassin, reservoir α ciel ouvert sans interet ecologique	Water	Non-Forest	Non-Forest

6.1.3.3 Methodology used to develop the land transition matrix

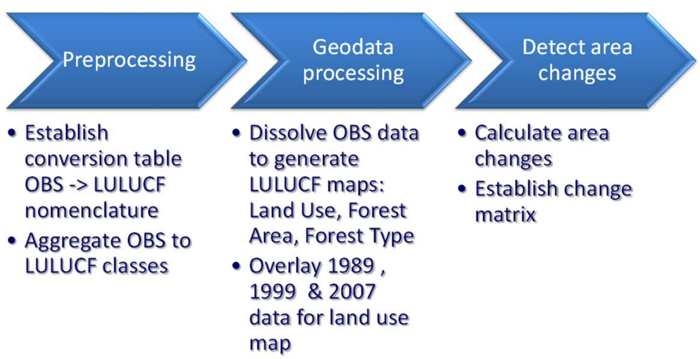
The generation of the LULUCF maps is based on the OBS and RE data. Data processing of OBS89, OBS99 and OBS07 follows the same processing scheme.

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.

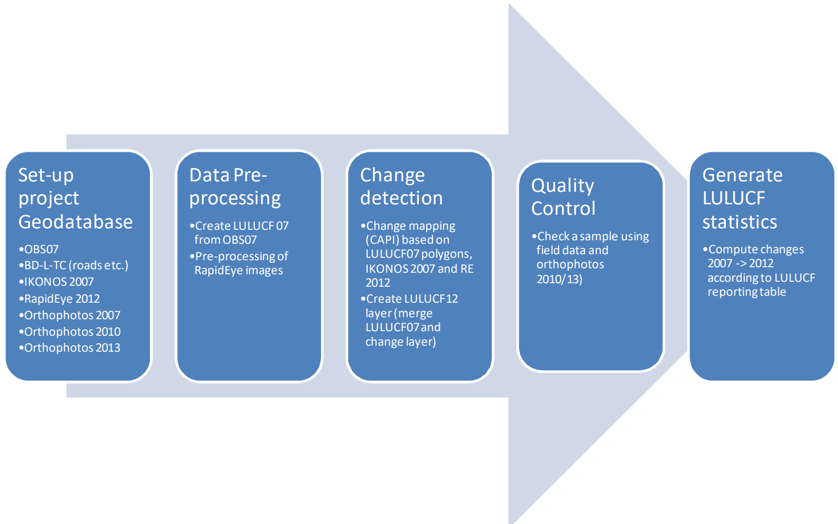
In order to preserve the detail in the data for the generation of the area statistics, no generalisation was performed before the change detection. Change detection of Land Use / Forest types between the selected reference years 1989, 1999 and 2007 has been carried out by overlay (intersect) of the Land 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 km^2. 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)

		1989										
	LULUCF 1999 (raw data ha)	settlements	cropland	permanent crops	grassland	deciduous forest	coniferous forest	mixed forest	forest without trees	other land	wetland	water	Totals 1999
1999	settlements	17	1 107.7	480.6	2	619.1	238.3	27.7		55.0	14.7	67.4	**23 195**
	cropland	289.3	36	172.8	9	358.5	229.3	4.7		5.7	9.1	14.1	**46 653**
	permanent	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	956.2	36.8		188.3	143.9	140.6	**87 257**
	deciduous	1 176.3	580.1	407.6	2	49	3	371.2		571.7	51.9	108.5	**58 587**
	coniferous	90.4	218.7	37.0	578.6	2	18	129.8		18.8	3.9	12.5	**22 622**
	mixed forest	155.4	198.2	32.2	467.8	7	5	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)

1999 \ 1989 — LULUCF 1999 (modified data ha	settlements	Cropland	permanent crops	grassland	deciduous forest	coniferous forest	mixed forest	forest without trees	other land	wetland	water	**Totals 1999**
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	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	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	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**

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)

LULUCF 2007 (raw data ha)	1999											
	Settlements	cropland	permanent crops	grassland	deciduous forest	coniferous forest	mixed forest	forest without trees	other land	wetland	water	Totals 2007
2007 settlements	21	430.7	149.2	1 798.1	378.2	55.5	62.2	0.0	1.2	2.0	16.3	**24 620**
cropland	108.1	42	39.8	14	31.3	17.9	37.2	0.0	0.0	2.1	0.2	**57 366**
permanent	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	289.7	61.5	42.2	475.0	55	139.5	179.7	0.0	0.9	1.4	9.3	**56 519**
coniferous	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**

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)

LULUCF 1999 (modified data ha)	1999											
	settlements	cropland	permanent crops	grassland	deciduous forest	coniferous forest	mixed forest	forest without trees	other land	wetland	water	**Totals 2007**
2007 Settlements	21	430.7	149.2	1 798.1	378.2	55.5	62.2	0.0	1.2	2.0	16.3	**24**
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	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	289.7	61.5	42.2	475.0	55	139.5	179.7	0.0	0.9	1.4	9.3	**56**
coniferous	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**

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)

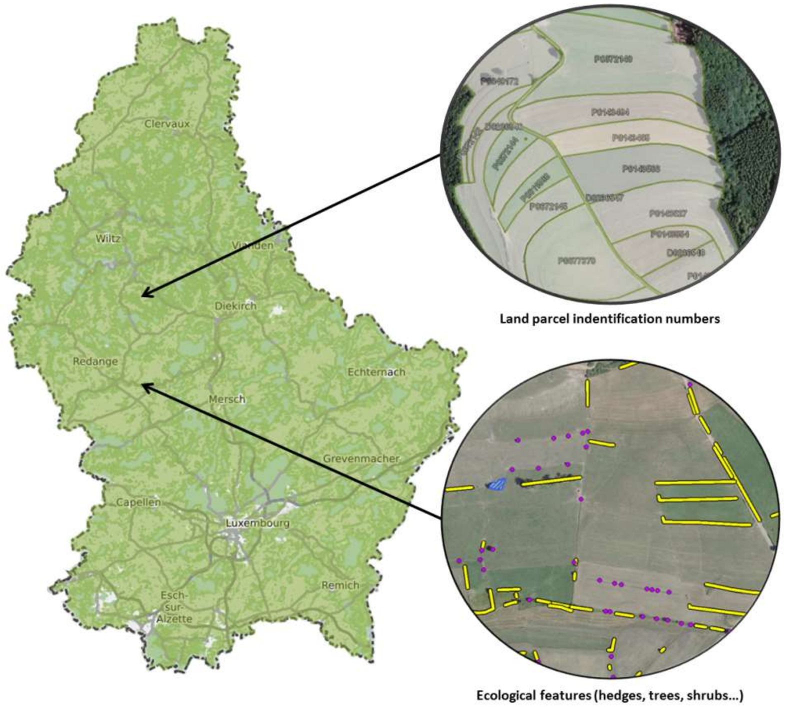
LULUCF 2007 (raw data ha)	2007: settlements	cropland	permanent crops	grassland	deciduous forest	coniferous forest	mixed forest	forest without trees	other land	wetland	water	Totals 2012
2012: settlements	24	140.1	23.7	450.3	44.4	5.1	19.9	1.3	0.0	0.0	3.5	25 281
cropland	0.7	57	0.7	300.9	1.4	14.4	0.6	13.1	0.0	0.0	0.0	57 422
permanent	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	0.3	5.3	0.1	88.6	56	0.1	0.0	22.3	0.0	0.5	0.1	56 471
coniferous	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**	**57 366**	**4 906**	**74 379**	**56 519**	**20 419**	**17 797**	**1 304**	**56**	**218**	**1 016**	**258**

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 lead 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 lead 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 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											
	LULUCF 2007 (raw data ha)	settlements	cropland	permanent crops	Grassland	deciduous forest	coniferous forest	mixed forest	forest without trees	other land	wetland	water	Totals 2012
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	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	0.3	5.3	0.1	88.6	56	0.1	0.0	22.3	0.0	0.5	0.1	56 471
	coniferous	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**	**57 366**	**4 906**	**74 379**	**56 519**	**20 419**	**17 797**	**1 304**	**56**	**218**	**1 016**	**258**

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**
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*	*OBS99*
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*	*LU12*
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*	
Trend 1990-2018	*3.08%*	*-12.52%*	*3.98%*	*-9.81%*	*16.69%*	*-93.33%*	*NA*
Trend 2013-2018	*0.07%*	*-3.08%*	*1.59%*	*-0.06%*	*2.60%*	*-1.68%*	*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 2018	*37.20%*	*23.18%*	*29.04%*	*0.48%*	*10.08%*	*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_2O
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.
(*) CO_2 emissions from cropland remaining cropland due to land use change from perennial to annual cropland are included in agriculture
(**) CO_2 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 96 189 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 CO_2 emissions/removals of the reported period 1990-2018 range from -189 Gg CO_2 (removal) to -976 Gg CO_2 (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 CO_2 balance.

For the reported period 1990 to 2018, the total annual net CO_2 removals (biomass and soil) from land use changes to forest range from about -306 Gg CO_2 to -72 Gg CO_2 (Table 6-15).

Table 6-15 – CO_2 removals/emissions from category 4A – Forest Land from 1990-2018

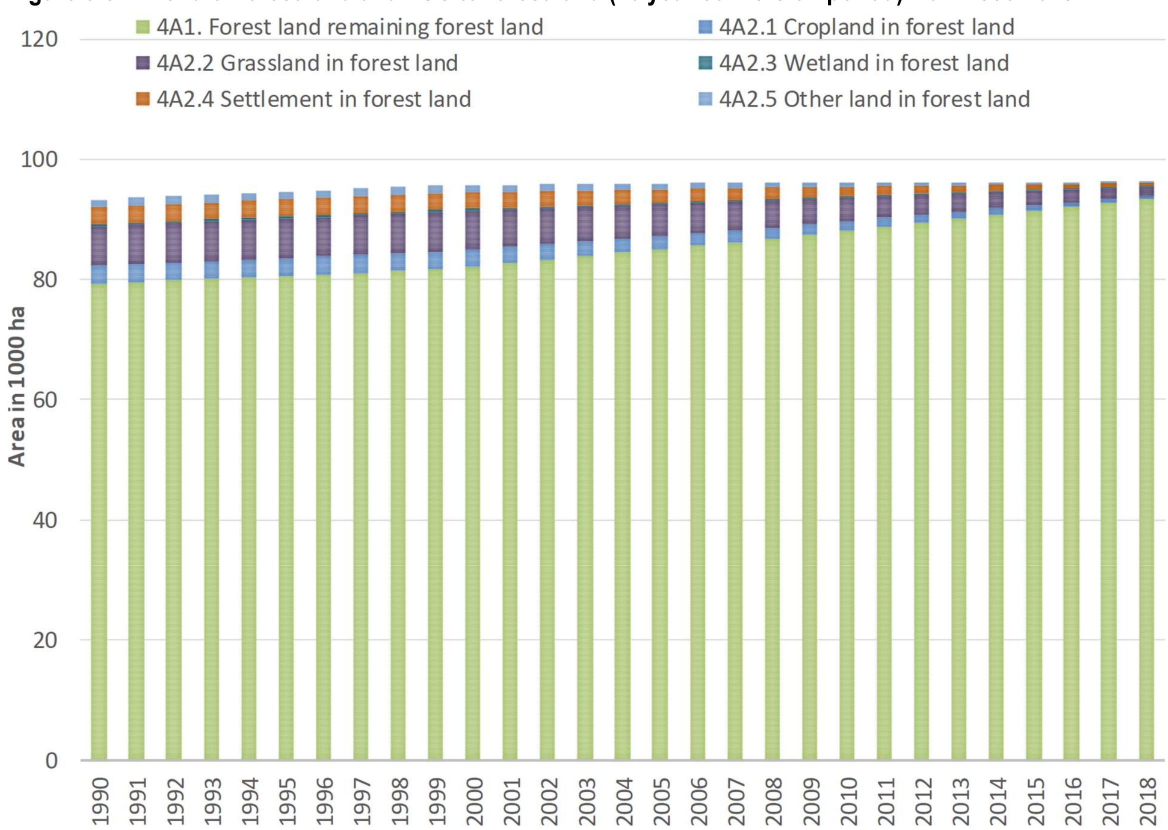
Greenhouse gas emissions/removals (Gg CO_2 e)

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
Trend 1990-2018	37.37%	-276.76%	-81.29%	-85.59%	-73.84%	-90.75%	-79.12%	-94.45%
Trend 2017-2018	-41.71%	-45.71%	-20.99%	-25.80%	-15.44%	-35.09%	-19.82%	-47.62%

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 considerable between single years. The reason is that the figures for annual harvest of forest biomass and to a lesser extend forest area differ significantly year by year. The annual harvest will be analysed in chapter 6.2.4.1.1 (page 539) 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 CO_2 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 1990-2018



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: • Minimum land area: 0.5 ha • tree crown cover >= 10 % • tree 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 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) (m^3 ha^{-1})

BEF_{ag} = biomass expansion factor for above-ground biomass (Deleuze, et al., 2014)

WBD = wood biomass density (tonnes d.m./m^3) (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 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) (m^3 ha^{-1})

BEF_{bg} = biomass expansion factor for below-ground biomass (Vande Walle, et al., 2005)

WBD = wood biomass density (tonnes d.m./m^3) (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)

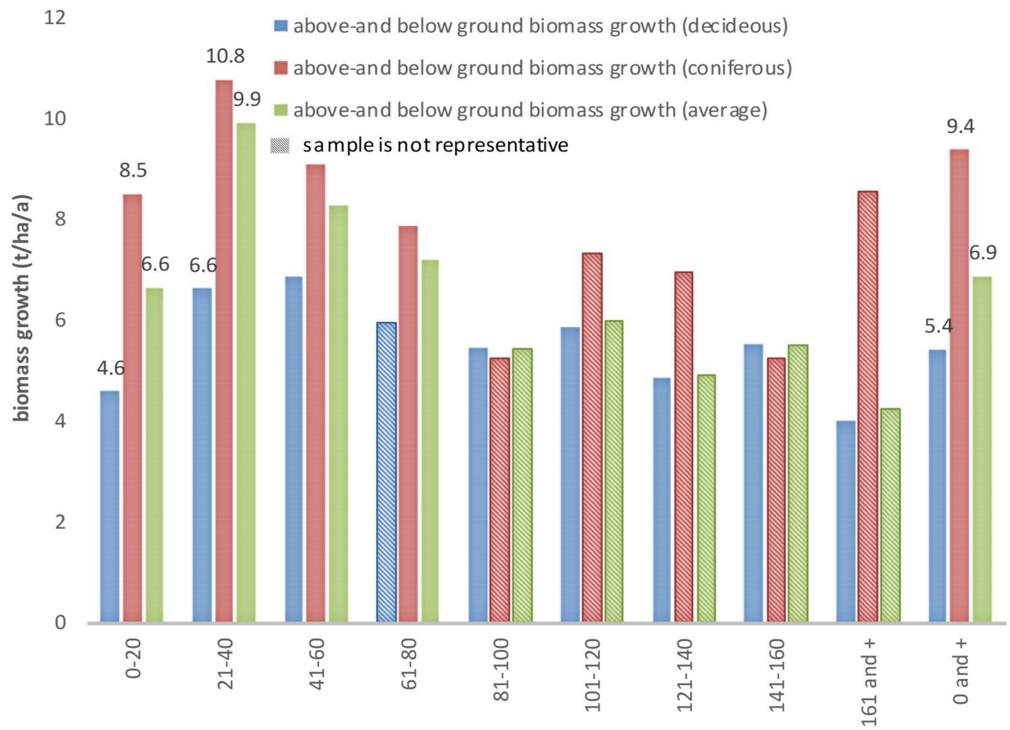


Table 6-17 – Country-specific values for above- and below ground biomass increment factors (tonnes d.m. ha^{-1} yr^{-1})

		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 extend 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

	$BCEF_R$	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 m^3/ha/a
b) Stemwood drain from private deciduous forests: 3.3 m^3/ha/a
c) Stemwood drain from public coniferous forests: 8.7 m^3/ha/a
d) Stemwood drain from private coniferous forests: 8.7 m^3/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 m^3/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

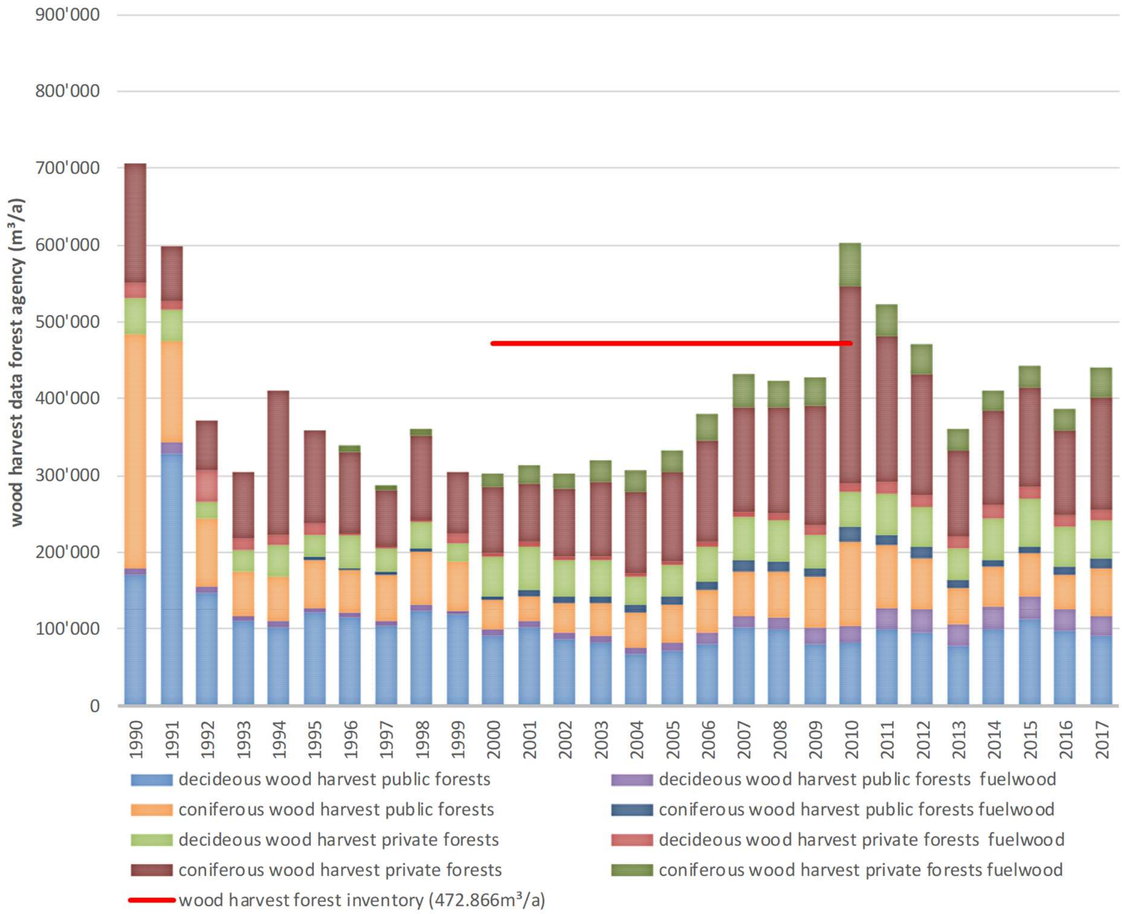


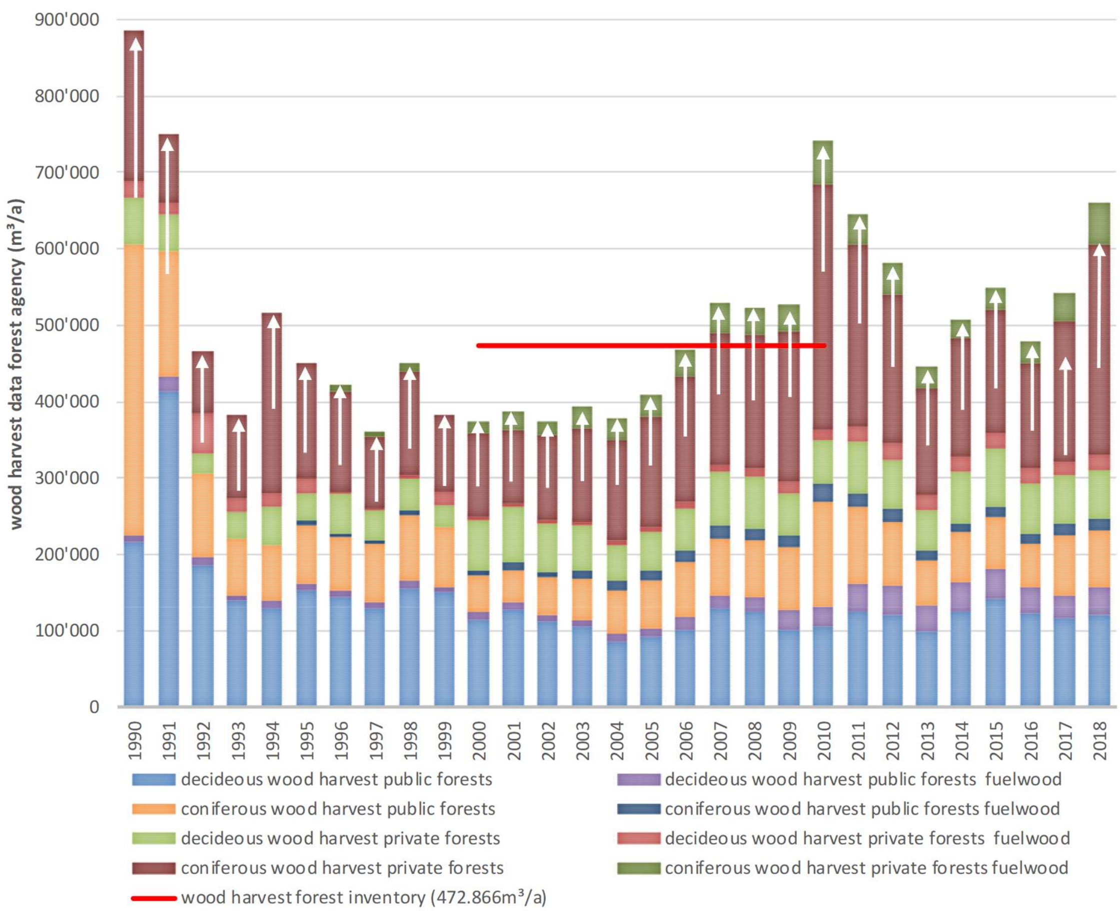
Figure 6-9 shows the yearly wood drain from public forests (yellow bars) as collected by the ANF. The green bars show the estimated wood drain from private forests estimated with the specific ratios of wood drain and forest distribution as collected during the forest inventory. The peaks 1990 and 1991 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 $m^3/h/a$).

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 m^3/a) than the average measured during the forest inventory (472 866 m^3/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:

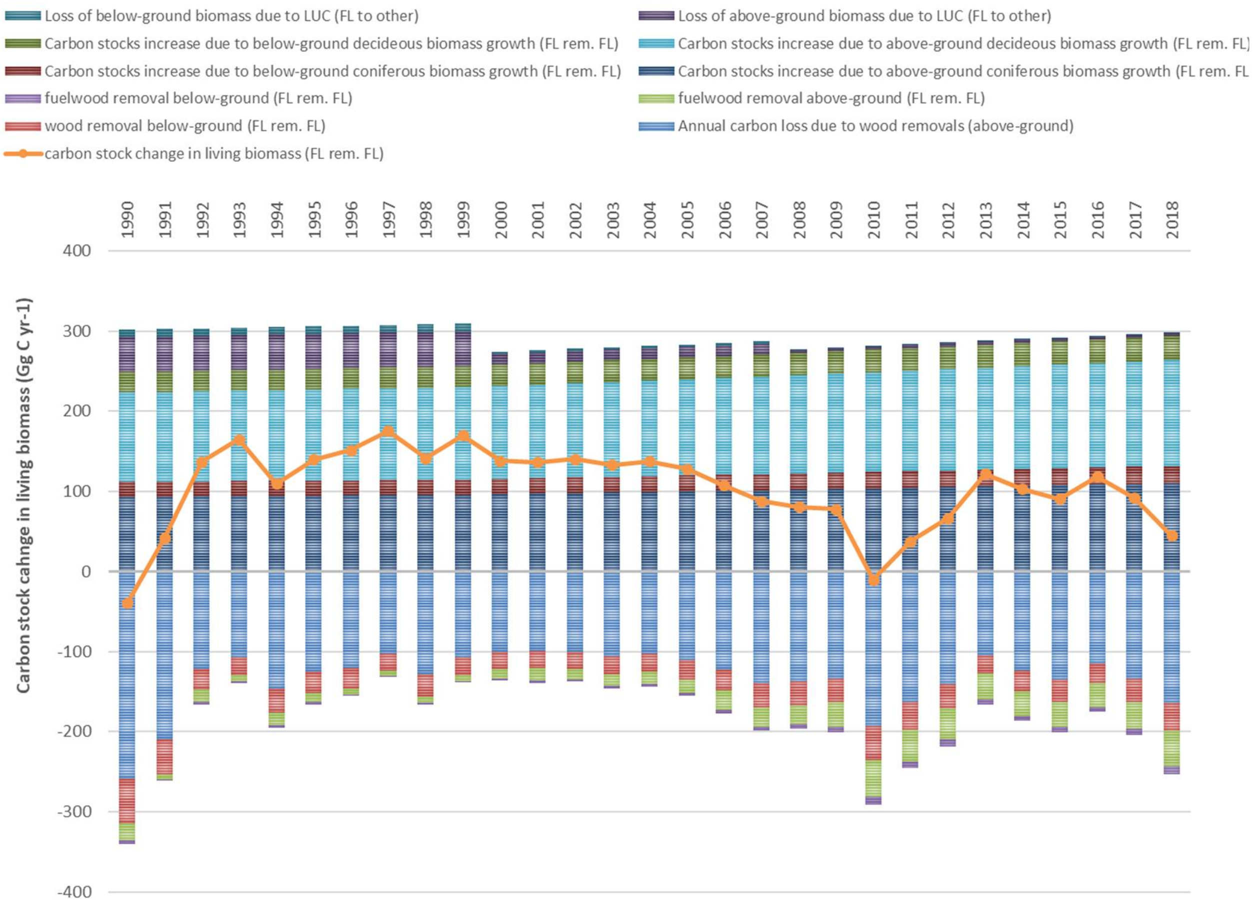
- The data collected from the inventory is more reliable as it is based on a more systematic approach
- The calculation of the total biomass removed is based on country specific biomass expansion and conversion factors (described here above) that are based on the assumption that all wood >7 cm in diameter 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 taking fuelwood as tree parts is only used marginally in Luxembourg (expert judgement) and thus it is considered that all fuelwood is removed as whole aboveground tree parts. With regards to natural disturbances it is assumed that during previous disturbances all stemwood was removed as part of salvage logging.

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 2017 GHGI a stock-difference approach was used to account for changes in dead wood. In the 2018 GHGI the results of the dead wood calculations from the FRL have been used instead. 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 moduleis 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

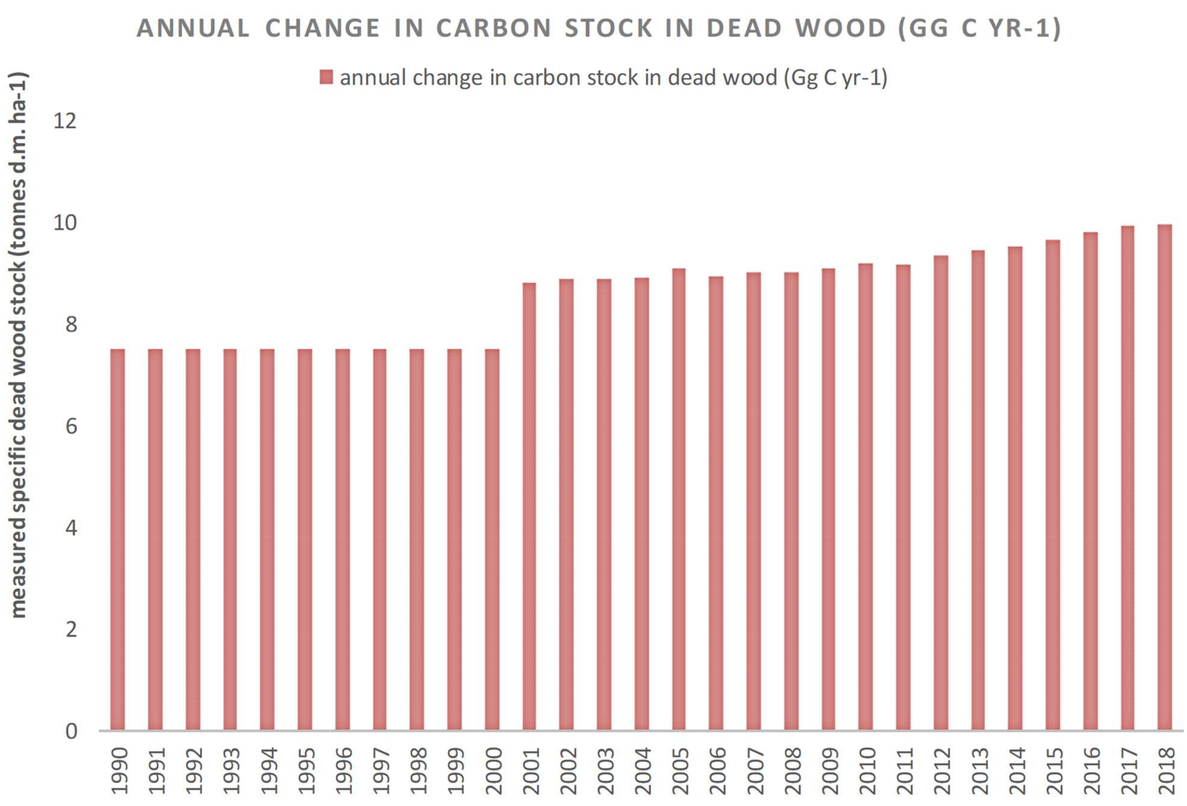
age class	NFI 2000 (td.m. ha-1)	NFI 2010 (td.m. ha-1)	CSCF (td.m. ha-1yr-1)
0-20	5.7	6.2	0.05
21-40	7.0	9.9	0.30
41-60	13.0	11.0	-0.20
61-80	11.8	13.2	0.14
80+	1.4	3.0	0.15

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:

$$\textit{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

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).

$\Delta T_{TO\_OTHERS(i)}$ = 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	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- and below ground biomass) and Switzerland – NIR 2015: 3.61 Mg C ha^{-1}(above- and below ground biomass)) 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 Luxembourgs	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:

$$\mathrm{IEF}(LUC_j) = \frac{\sum_i \mathrm{IEF}(LUC_j)_{\mathrm{st,i}} \cdot A_{st,i}}{\sum_i A_{st,i}}$$

$\mathrm{IEF}(LUC_j)$ = average yearly emission factor for carbon stock change in soil from land use change j (eg forestland in cropland)

$\mathrm{IEF}(LUC)_{st,i}$ = 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:

$$\text{IEF}(LUC_j)_{\text{st,i}} = \frac{\text{SOC}(LU_a)_{\text{st,i}} - \text{SOC}(LU_b)_{\text{st,i}}}{\text{transition}_{\text{period}}}$$

$IEF(LUC)_{st,i}$ = 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)

$$\text{IEF}_{\text{CL}\rightarrow\text{GL\_Oesling}} = \frac{\text{SOC}_{\text{CL}_{\text{Oesling}}} - \text{SOC}_{\text{GL}_{\text{Oesling}}}}{\text{transition}_{\text{period}}} = \frac{91.5 - 89.2}{20} = 0.115\ \text{tC.}\,\text{ha}^{-1}.\,yr^{-1}$$

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)

$$\text{IEF}_{\text{CL}\rightarrow\text{GL\_national}} = \frac{\text{IEF}_{\text{CL}\rightarrow\text{GL\_Oesling}} \times \text{area}_{\text{Oesling}} + \text{IEF}_{\text{CL}\rightarrow\text{GL\_Buntsandstein}} \times \text{area}_{\text{Buntsandstein}} + \cdots}{\text{area}_{\text{Oesling}} + \text{area}_{\text{Buntsandstein}} + \cdots}$$

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:

a) annual cropland converted to forestland: +1.784 t C/ha*y
b) perennial cropland converted to forestland: +1.237 t C/ha*y
c) grassland converted to forestland: +0.476 t C/ha*y
d) wetland converted to forestland: +5.554 t C/ha*y
e) settlements converted to forestland: +3.393 t C/ha*y
f) 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 2018. Some management practices (*e.g.* slash and burn, *etc.*) and organic soils do not occur and are prohibited in Luxembourg.

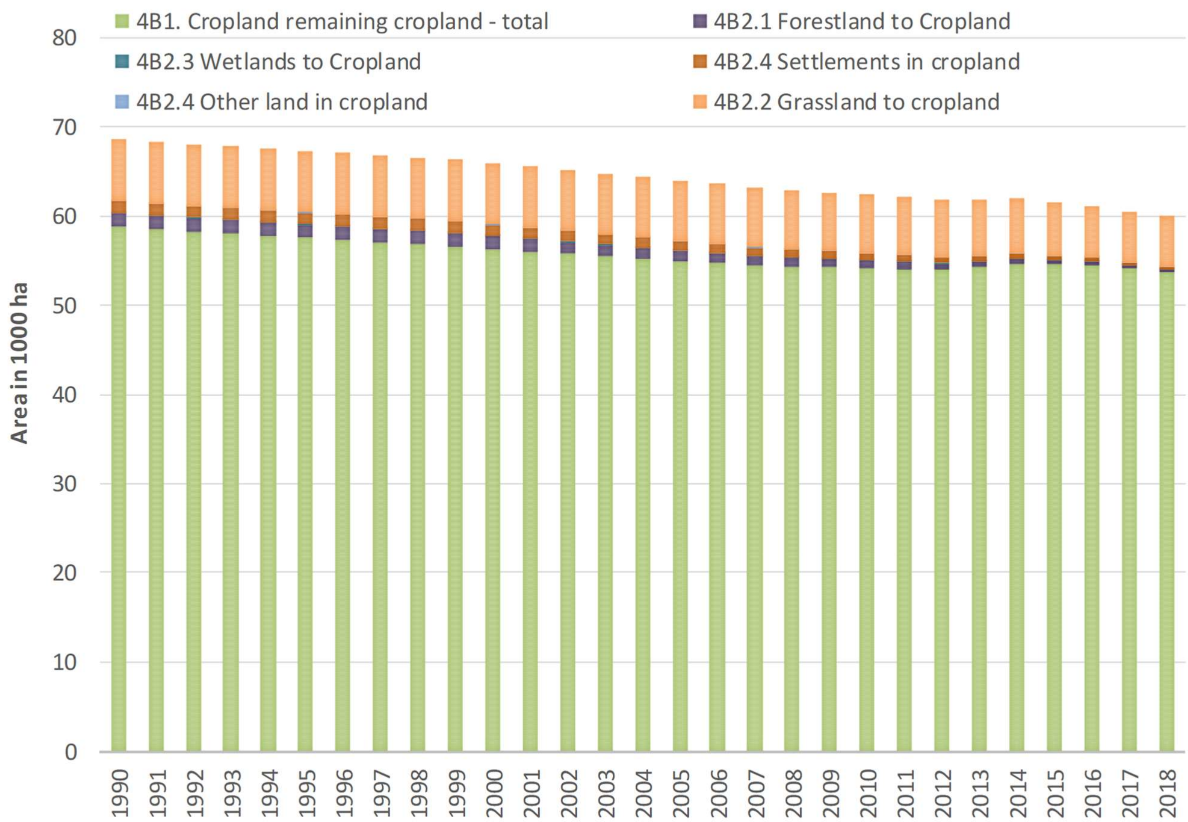
Emissions/Removals were estimated for the sub-categories and related sources/sinks as shown in Table 6-28.

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 copland
4B2 Land converted to cropland
4B2.1Forest 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 1990-2018



The annual emissions from 1990-2018 range between 77.8 Gg CO_2 equivalent and 36.0 Gg CO_2 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 – CO_2 removals/emissions from category 4B – Cropland for 1990-2018

4B - Cropland

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_2O (in CO_2 eq)	N_2O leaching (in CO_2 eq)
1990	77.80	- 1.28	47.07	36.15	- 0.75	-7.78	-0.24	4.62	1.04
1991	77.80	- 1.28	47.07	36.15	- 0.75	-7.78	-0.24	4.62	1.04
1992	77.80	- 1.28	47.07	36.15	- 0.75	-7.78	-0.24	4.62	1.04
1993	77.80	- 1.28	47.07	36.15	- 0.75	-7.78	-0.24	4.62	1.04
1994	77.80	- 1.28	47.07	36.15	- 0.75	-7.78	-0.24	4.62	1.04
1995	77.80	- 1.28	47.07	36.15	- 0.75	-7.78	-0.24	4.62	1.04
1996	77.80	- 1.28	47.07	36.15	- 0.75	-7.78	-0.24	4.62	1.04
1997	77.80	- 1.28	47.07	36.15	- 0.75	-7.78	-0.24	4.62	1.04
1998	77.80	- 1.28	47.07	36.15	- 0.75	-7.78	-0.24	4.62	1.04
1999	77.80	- 1.28	47.07	36.15	- 0.75	-7.78	-0.24	4.62	1.04
2000	52.63	3.42	17.93	35.48	- 0.68	-7.87	-0.22	4.57	1.03
2001	52.25	3.26	17.58	35.36	- 0.65	-7.62	-0.20	4.51	1.02
2002	51.87	3.09	17.24	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	51.11	2.76	16.55	35.02	- 0.56	-6.85	-0.17	4.36	0.98
2005	50.72	2.60	16.20	34.90	- 0.53	-6.60	-0.16	4.31	0.97
2006	50.34	2.43	15.85	34.79	- 0.50	-6.34	-0.15	4.25	0.96
2007	49.96	2.27	15.51	34.67	- 0.47	-6.09	-0.14	4.20	0.95
2008	42.52	2.89	8.77	33.11	- 0.42	-5.82	-0.12	4.11	0.93
2009	41.93	2.71	8.37	32.75	- 0.39	-5.41	-0.11	4.02	0.91
2010	42.17	2.53	7.96	33.17	- 0.35	-5.01	-0.10	3.98	0.89
2011	41.53	2.35	7.56	32.73	- 0.32	-4.60	-0.09	3.90	0.88
2012	41.18	2.17	7.15	32.59	- 0.28	-4.20	-0.08	3.83	0.86
2013	39.88	1.99	6.74	31.53	- 0.25	-3.79	-0.07	3.72	0.84
2014	38.66	1.81	6.34	30.58	- 0.21	-3.39	-0.06	3.59	0.81
2015	37.50	1.63	5.93	29.69	- 0.18	-2.98	-0.05	3.45	0.78
2016	36.08	1.45	5.53	28.56	- 0.14	-2.58	-0.03	3.29	0.74
2017	35.96	1.27	5.12	28.67	- 0.11	-2.17	-0.02	3.19	0.72
2018	35.28	1.09	4.72	28.23	- 0.07	-1.77	-0.01	3.10	0.70
Trend 1990-2018	-54.65%	-184.74%	-89.98%	-21.91%	-90.67%	-77.28%	-95.22%	-32.95%	-32.95%
Trend 2017-2018	-1.87%	-14.22%	-7.92%	-1.54%	-33.57%	-18.65%	-50.00%	-3.06%	-3.06%

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.e.* 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:

$$\textit{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

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 $ha^{-1}yr^{-1}$).

$B_{AFTER(i)}$ = 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 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 Laboratories de Contrôle et d'Essais, Service de Pédologie).

According to expert judgment (see calculation under Decision 529), 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 :

$$IEF(LUC_{perennial\ cropland\ ->\ annual\ cropland}) = -0.462\ t\ C/\ ha\ *yr$$

IEF(LUCj) = 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 $ha^{-1}yr^{-1}$ 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 $ha^{-1}yr^{-1}$ (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 $ha^{-1}yr^{-1}$ - 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 :

$$IEF(LUC_{annual\ cropland\ ->\ perennial\ cropland}) = +0.462\ t\ C/ha\ *yr$$

IEF(LUCj) = 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:

$$Annual\ change\ in\ carbon\ stock\ in\ biomass = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

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 $ha^{-1}yr^{-1}$).

$B_{AFTER(i)}$ = 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 before conversion is 6.4 t C ha^{-1} for perennial 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.)$^{-1}$.

<u>b) Changes of carbon stock in dead wood and litter of land converted to cropland:</u>

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 = 5,1 t C/ha*yr (average between forest inventory from 2000 and 2010) & 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.

<u>d) Changes of carbon stock in mineral soils of land converted to annual cropland:</u>

According to the methodology described in Annex 3:, annual change in carbon stock of mineral soils = IEF(LUC_j) * conversion area, where :

$$IEF(LUC_{forestland \text{ -> } annual\ cropland}) = -1.237\ t\ C/ha\ {*}yr$$

$$IEF(LUC_{grassland \text{ -> } annual\ cropland}) = -1.308\ t\ C/ha\ {*}yr$$

$$IEF(LUC_{wetland \text{ -> } annual\ cropland}) = +3.770\ t\ C/ha\ {*}yr$$

$$IEF(LUC_{settlements \text{ -> } annual\ cropland}) = +1.609\ t\ C/ha\ {*}yr$$

$$IEF(LUC_{other\ land \text{ -> } annual\ cropland}) = +3.770\ t\ C/ha\ {*}yr$$

IEF(LUCj) = 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:

$$\textit{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

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^{-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 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})

C_o = dead wood/litter stock, under the old land-use category, tonnes C ha^{-1} (value dead wood in forest = 5.1 t C/ha*yr (average between forest inventory from 2000 and 2010) & 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 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 :

$$IEF(LUC_{forestland\ ->\ perennial\ cropland}) = -1.237\ t\ C/\ ha\ *yr$$

$$IEF(LUC_{grassland\ ->\ perennial\ cropland}) = -1.517\ t\ C/\ ha\ *yr$$

$$IEF(LUC_{wetland\ ->\ perennial\ cropland}) = +5.079\ t\ C/\ ha\ *yr$$

$$IEF(LUC_{settlements\ ->\ perennial\ cropland}) = +2.917\ t\ C/\ ha\ *yr$$

$$IEF(LUC_{other\ land\ ->\ perennial\ cropland}) = +5.079\ t\ C/\ ha\ *yr$$

IEF(LUCj) = average yearly emission factor for carbon stock change in soil from land use change j (eg forestland in cropland)

6.3.4.2.3 N_2O emissions in soils of land converted to cropland

The annual release of direct N_2O 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:

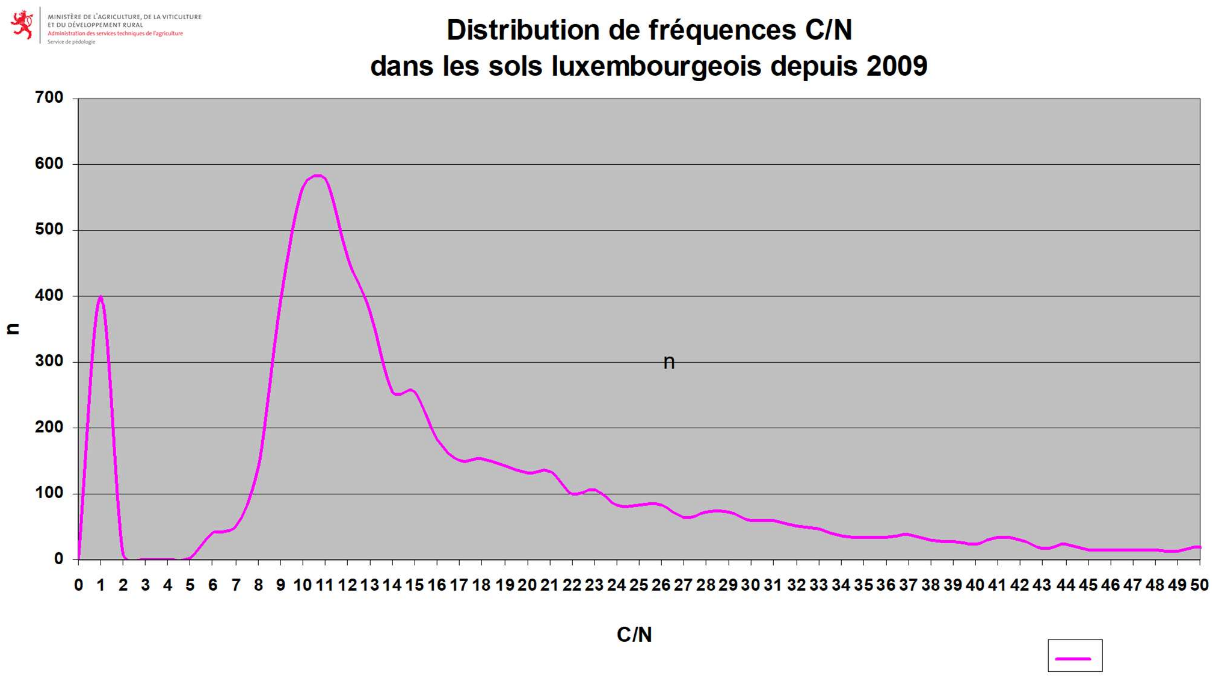
EF_1=emission factor for N mineralised as a result of loss of soil carbon (default value = 0.01)

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 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 (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 N_2O 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):

$$N_2O_{(L)} - N = F_{SOM} \cdot Frac_{LE\qquad(H)} \cdot EF_5$$

where:

$N_2O_{(L)}$-N=annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kgN_2O-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 N_2O 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.

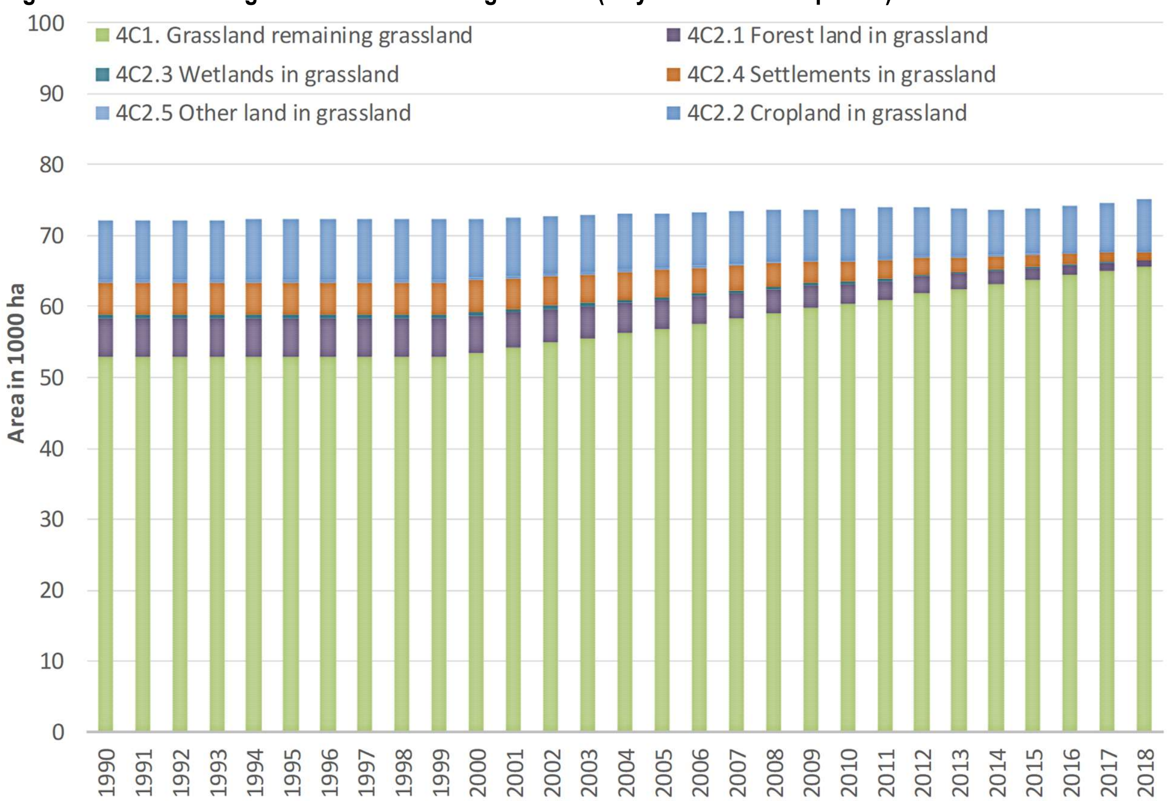
Emissions/Removals were estimated for the following IPCC sub-categories and their related sources/sinks (Table 6-30).

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
4C2Land converted to grassland
4C2.1Forest 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 2018, 74 648 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 1990-2018



The annual emissions of grassland in Luxembourg amounted to 31.45 Gg CO_2 in 1990 and – 41.52 Gg CO_2 in 2018 (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 – CO_2 removals/emissions for category 4C – Grassland for 1990-2018

4C - Grassland
Greenhouse gas emissions/removals (Gg CO_2 e)

Year	4B Total Cropland (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_2O (in CO_2 eq)	N_2O leaching (in CO_2 eq)
1990	32.52	NO	144.97	- 44.56	- 11.26	-50.18	-7.45	1.00	0.22
1991	32.52	NO	144.97	- 44.56	- 11.26	-50.18	-7.45	1.00	0.22
1992	32.52	NO	144.97	- 44.56	- 11.26	-50.18	-7.45	1.00	0.22
1993	32.52	NO	144.97	- 44.56	- 11.26	-50.18	-7.45	1.00	0.22
1994	32.52	NO	144.97	- 44.56	- 11.26	-50.18	-7.45	1.00	0.22
1995	32.52	NO	144.97	- 44.56	- 11.26	-50.18	-7.45	1.00	0.22
1996	32.52	NO	144.97	- 44.56	- 11.26	-50.18	-7.45	1.00	0.22
1997	32.52	NO	144.97	- 44.56	- 11.26	-50.18	-7.45	1.00	0.22
1998	32.52	NO	144.97	- 44.56	- 11.26	-50.18	-7.45	1.00	0.22
1999	32.52	NO	144.97	- 44.56	- 11.26	-50.18	-7.45	1.00	0.22
2000	- 72.51	NO	35.19	- 43.84	- 10.24	-47.92	-6.67	0.96	0.22
2001	- 70.04	NO	34.81	- 43.09	- 9.79	-46.58	-6.32	0.92	0.21
2002	- 67.57	NO	34.43	- 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	- 62.62	NO	33.68	- 40.84	- 8.43	-42.56	-5.27	0.80	0.18
2005	- 60.15	NO	33.30	- 40.09	- 7.97	-41.22	-4.92	0.76	0.17
2006	- 57.68	NO	32.92	- 39.34	- 7.52	-39.89	-4.57	0.72	0.16
2007	- 55.21	NO	32.54	- 38.59	- 7.06	-38.55	-4.22	0.68	0.15
2008	- 67.44	NO	15.38	- 37.73	- 6.44	-35.41	-3.87	0.63	0.14
2009	- 63.77	NO	14.95	- 36.86	- 5.91	-33.01	-3.52	0.58	0.13
2010	- 63.29	NO	14.51	- 39.18	- 5.39	-30.61	-3.17	0.54	0.12
2011	- 59.36	NO	14.07	- 38.05	- 4.86	-28.20	-2.81	0.49	0.11
2012	- 54.38	NO	13.64	- 35.87	- 4.33	-25.80	-2.46	0.44	0.10
2013	- 50.07	NO	13.20	- 34.35	- 3.80	-23.40	-2.11	0.40	0.09
2014	- 44.77	NO	12.76	- 31.85	- 3.27	-21.00	-1.76	0.35	0.08
2015	- 44.49	NO	12.33	- 34.38	- 2.74	-18.59	-1.41	0.30	0.07
2016	- 42.37	NO	11.89	- 35.05	- 2.21	-16.19	-1.06	0.26	0.06
2017	- 42.59	NO	11.45	- 38.07	- 1.69	-13.79	-0.71	0.21	0.05
2018	- 41.52	NO	11.02	- 39.80	- 1.16	-11.39	-0.36	0.17	0.04
Trend 1990-2018	-227.69%	NA	-92.40%	-10.67%	-89.72%	-77.31%	-95.17%	-83.44%	-83.44%
Trend 2017-2018	-2.51%	NA	-3.81%	4.54%	-31.35%	-17.42%	-49.34%	-21.92%	-21.92%

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 <u>Carbon stock change of grassland</u>

<u>a) Changes in carbon stock in biomass of grassland remaining grassland:</u>
As the biomass of grassland is harvested every year, there is no long term carbon storage in biomass of grassland remaining grassland.

<u>b) Changes in carbon stock in mineral soils of grassland remaining grassland:</u>
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 2018 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 IPPC 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).

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.

<u>a) Changes in carbon stock in biomass of land converted to grassland:</u>

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:

$$\text{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \left\{ \left(B_{AFTER_i} - B_{BEFORE_i} \right) \cdot \Delta A_{TO\_OTHERS_i} \right\} \cdot CF$$

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 $ha^{-1}yr^{-1}$).

$B_{AFTER(i)}$ = 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 before conversion is 6.4 t C ha^{-1} for perennial cropland, 119.7 t C ha^{-1} for forestland, 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

<u>b) Changes of carbon stock in dead wood and litter of land converted to grassland:</u>

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})

C_o = dead wood/litter stock, under the old land-use category, tonnes C ha^{-1} (value dead wood in forest = 5.1 t C/ha*yr (average between forest inventory from 2000 and 2010) & 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:

$$IEF(LUC_{forestland\ ->\ grassland}) = -0.476\ t\ C/ha\ *yr$$

$$IEF(LUC_{annual\ cropland\ ->\ grassland}) = +1.308\ t\ C/ha\ *yr$$

$$IEF(LUC_{perennial\ cropland\ ->\ grassland}) = +1.517\ t\ C/ha\ *yr$$

$$IEF(LUC_{wetland\ ->\ grassland}) = +5.079\ t\ C/ha\ *yr$$

$$IEF(LUC_{settlements\ ->\ grassland}) = +2.917\ t\ C/ha\ *yr$$

$$IEF(LUC_{other\ land\ ->\ grassland}) = +5.079\ t\ C/ha\ *yr$$

IEF(LUCj) = average yearly emission factor for carbon stock change in soil from land use change

6.4.4.2.1 N_2O emissions in soils of land converted to grassland

The annual release of direct N_2O 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):

$$N_2O_{Direct} - N = F_{SOM} \cdot EF_1$$

$$F_{SOM} = \sum\nolimits_{LU} \left[\left(\Delta C_{Mineral,LUC} \cdot \frac{1}{R} \right) \cdot 1000 \right]$$

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 N_2O 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):

$$N_2O_{(L)} - N = F_{SOM} \cdot Frac_{LEAC\ \ \ (H)} \cdot EF_5$$

where:

$N2O_{(L)}$-N=annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, $kgN_2O\text{-}Nyr^{-1}$

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 N_2O 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)

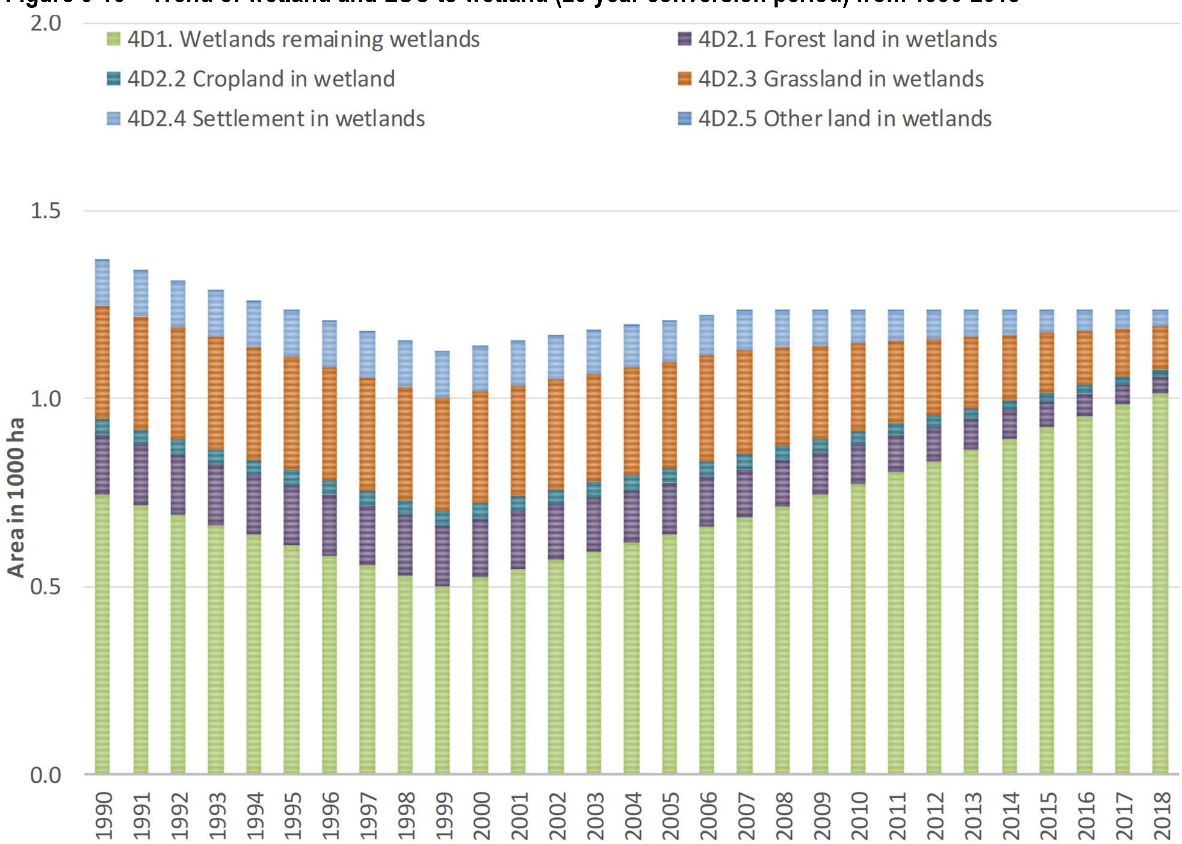
6.5.1 Category description

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 1990-2018



The annual emissions from wetland in Luxembourg amounted to 16.2 Gg CO_2 in 1990 and 4.16 Gg CO_2 in 2018 (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 – CO_2 removals/emissions for category 4D – Wetland for 1990-2018

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_2O (in CO_2 eq)	N_2O leaching (in CO_2 eq)
1990	16.20	NE	7.52	0.59	5.94	1.05	0.00	1.10	0.25
1991	16.20	NE	7.52	0.59	5.94	1.05	0.00	1.10	0.25
1992	16.20	NE	7.52	0.59	5.94	1.05	0.00	1.10	0.25
1993	16.20	NE	7.52	0.59	5.94	1.05	0.00	1.10	0.25
1994	16.20	NE	7.52	0.59	5.94	1.05	0.00	1.10	0.25
1995	16.20	NE	7.52	0.59	5.94	1.05	0.00	1.10	0.25
1996	16.20	NE	7.52	0.59	5.94	1.05	0.00	1.10	0.25
1997	16.20	NE	7.52	0.59	5.94	1.05	0.00	1.10	0.25
1998	16.20	NE	7.52	0.59	5.94	1.05	0.00	1.10	0.25
1999	16.20	NE	7.52	0.59	5.94	1.05	0.00	1.10	0.25
2000	13.85	NE	5.35	0.59	5.82	1.00	0.00	1.09	0.24
2001	13.68	NE	5.27	0.59	5.77	0.98	0.00	1.07	0.24
2002	13.52	NE	5.19	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	13.18	NE	5.03	0.59	5.61	0.93	0.00	1.02	0.23
2005	13.02	NE	4.95	0.59	5.55	0.91	0.00	1.01	0.23
2006	12.85	NE	4.87	0.60	5.50	0.89	0.00	0.99	0.22
2007	12.68	NE	4.79	0.60	5.45	0.88	0.00	0.98	0.22
2008	9.76	NE	2.64	0.53	4.89	0.78	0.00	0.92	0.21
2009	9.20	NE	2.48	0.51	4.61	0.73	0.00	0.87	0.20
2010	8.64	NE	2.32	0.48	4.34	0.68	0.00	0.81	0.18
2011	8.08	NE	2.16	0.45	4.06	0.64	0.00	0.76	0.17
2012	7.52	NE	2.01	0.43	3.78	0.59	0.00	0.71	0.16
2013	6.96	NE	1.85	0.40	3.51	0.55	0.00	0.65	0.15
2014	6.40	NE	1.69	0.38	3.23	0.50	0.00	0.60	0.13
2015	5.84	NE	1.53	0.35	2.95	0.46	0.00	0.55	0.12
2016	5.28	NE	1.38	0.32	2.67	0.41	0.00	0.49	0.11
2017	4.72	NE	1.22	0.30	2.40	0.37	0.00	0.44	0.10
2018	4.16	NE	1.06	0.27	2.12	0.32	0.00	0.38	0.09
Trend 1990-2018	-74.34%	NA	-85.89%	-54.09%	-64.30%	-69.35%	NA	-65.27%	-65.27%
Trend 2017-2018	-11.87%	NA	-12.93%	-8.79%	-11.56%	-12.35%	NA	-12.32%	-12.32%

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 (*e.g.* 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:

$$\textit{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

where :

ΔC_G = annual change in carbon stocks in biomass due to growth on land converted to another land-use category (default value for carbon accumulation rate is 0.0 t C $ha^{-1}yr^{-1}$).

$B_{AFTER(i)}$ = 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 before conversion is 6.4 t C ha^{-1} for perennial 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, 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})

C_o = dead wood/litter stock, under the old land-use category, tonnes C ha^{-1} (value dead wood in forest = 5.1 t C/ha*yr (average between forest inventory from 2000 and 2010) & 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 :

$$IEF(LUC_{forestland \rightarrow wetland}) = -5.554\ t\ C/ha*yr$$

$$IEF(LUC_{perennial\ cropland \rightarrow wetland}) = -3.778\ t\ C/ha*yr$$

$$IEF(LUC_{annual\ cropland \rightarrow wetland}) = -3.770\ t\ C/ha*yr$$

$$IEF(LUC_{grassland \rightarrow wetland}) = -5.079\ t\ C/ha*yr$$

$$IEF(LUC_{settlements \rightarrow wetland}) = -2.917\ t\ C/ha*yr$$

$$IEF(LUC_{other\ land \rightarrow wetland}) = 2.162\ t\ C/ha*yr$$

IEF(LUCj) = average yearly emission factor for carbon stock change in soil from land use change

6.5.4.2.1 N_2O emissions in soils of land converted to wetland

The annual release of direct N_2O 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:

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 N_2O 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 N_2O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, $kgN_2O\text{-}Nyr^{-1}$

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 N_2O 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 2018, 25 943 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 155.69 Gg $CO_2$to 60.06 Gg CO_2 (**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 1990-2018

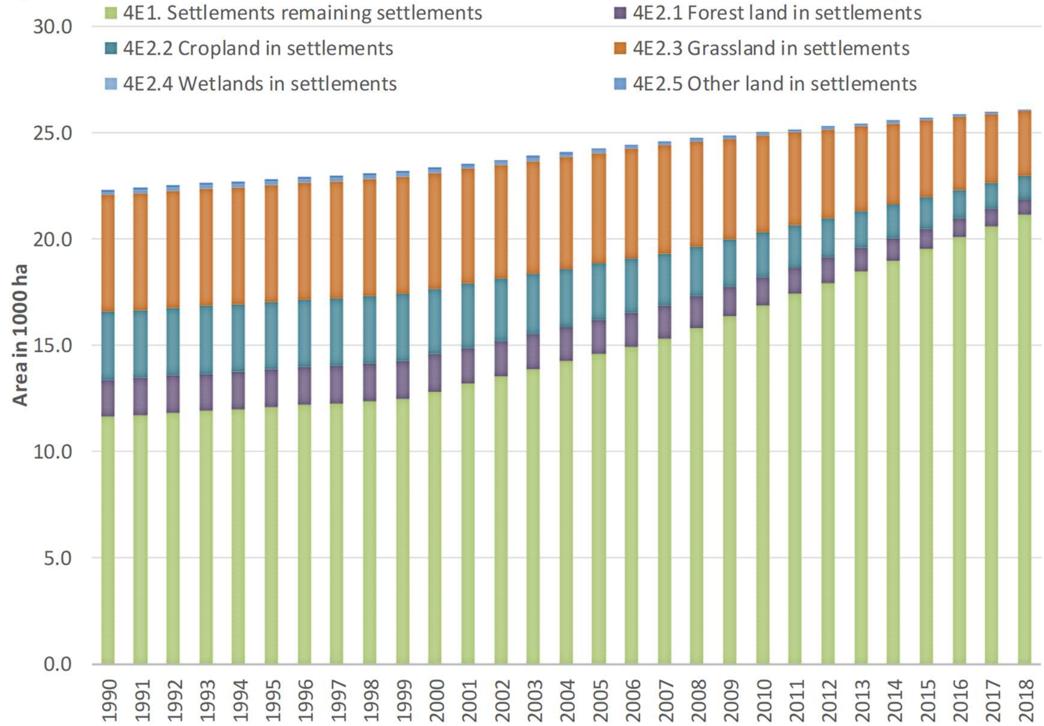


Table 6-33 – CO_2 removals/emissions for category 5E – Settlement from 1990-2018

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_2O (in CO_2 eq)	N_2O leaching (in CO_2 eq)
1990	155.69	NE	67.28	19.40	60.80	-1.43	-0.96	10.60	2.38
1991	155.69	NE	67.28	19.40	60.80	-1.43	-0.96	10.60	2.38
1992	155.69	NE	67.28	19.40	60.80	-1.43	-0.96	10.60	2.38
1993	155.69	NE	67.28	19.40	60.80	-1.43	-0.96	10.60	2.38
1994	155.69	NE	67.28	19.40	60.80	-1.43	-0.96	10.60	2.38
1995	155.69	NE	67.28	19.40	60.80	-1.43	-0.96	10.60	2.38
1996	155.69	NE	67.28	19.40	60.80	-1.43	-0.96	10.60	2.38
1997	155.69	NE	67.28	19.40	60.80	-1.43	-0.96	10.60	2.38
1998	155.69	NE	67.28	19.40	60.80	-1.43	-0.96	10.60	2.38
1999	155.69	NE	67.28	19.40	60.80	-1.43	-0.96	10.60	2.38
2000	138.28	NE	53.10	17.61	59.37	-1.35	-0.89	10.45	2.35
2001	136.95	NE	52.79	17.15	58.86	-1.30	-0.84	10.30	2.32
2002	135.61	NE	52.47	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	132.94	NE	51.84	15.76	57.34	-1.15	-0.71	9.86	2.22
2005	131.61	NE	51.53	15.30	56.83	-1.10	-0.66	9.72	2.19
2006	130.28	NE	51.21	14.84	56.33	-1.05	-0.62	9.57	2.15
2007	128.94	NE	50.89	14.38	55.82	-1.00	-0.57	9.43	2.12
2008	97.14	NE	25.02	13.09	51.45	-0.93	-0.52	9.04	2.03
2009	93.43	NE	24.14	12.41	49.58	-0.87	-0.48	8.65	1.95
2010	89.72	NE	23.25	11.74	47.70	-0.80	-0.43	8.26	1.86
2011	86.02	NE	22.37	11.07	45.83	-0.74	-0.38	7.87	1.77
2012	82.31	NE	21.49	10.39	43.96	-0.68	-0.34	7.49	1.68
2013	78.60	NE	20.60	9.72	42.09	-0.61	-0.29	7.10	1.60
2014	74.89	NE	19.72	9.04	40.21	-0.55	-0.24	6.71	1.51
2015	71.19	NE	18.84	8.37	38.34	-0.48	-0.20	6.32	1.42
2016	67.48	NE	17.95	7.69	36.47	-0.42	-0.15	5.93	1.34
2017	63.77	NE	17.07	7.02	34.60	-0.36	-0.10	5.55	1.25
2018	60.06	NE	16.19	6.35	32.72	-0.29	-0.06	5.16	1.16
Trend 1990-2018	-61.42%	NA	-75.94%	-67.29%	-46.18%	-79.52%	-94.06%	-51.33%	-51.33%
Trend 2016-2018	-5.81%	NA	-5.18%	-9.61%	-5.41%	-17.86%	-45.01%	-7.00%	-7.00%

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)

<u>a) Changes in carbon stock in biomass of land converted to settlements:</u>
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:

$$\textit{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

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 $ha^{-1}yr^{-1}$ for perennial plants for a period of 20 years and 1.29 t C $ha^{-1}yr^{-1}$ 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, 119.7 t C ha^{-1} for forestland, 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})

C_o = dead wood/litter stock, under the old land-use category, tonnes C ha^{-1} (value dead wood in forest = 5.1 t C/ha*yr (average between forest inventory from 2000 and 2010) & 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 :

$$IEF(LUC_{forestland \rightarrow settlements}) = -3.393\ t\ C/ha\ {*}yr$$

$$IEF(LUC_{annual\ cropland \rightarrow settlements}) = -1.609\ t\ C/ha\ {*}yr$$

$$IEF(LUC_{perennial\ cropland \rightarrow settlements}) = -1.616\ t\ C/ha\ {*}yr$$

$$IEF(LUC_{grassland \rightarrow settlements}) = -2.917\ t\ C/ha\ {*}yr$$

$$IEF(LUC_{wetland \rightarrow settlements}) = +2.162\ t\ C/ha\ {*}yr$$

$$IEF(LUC_{other\ land \rightarrow settlements}) = +2.162\ t\ C/ha\ {*}yr$$

EF(LUCj) = average yearly emission factor for carbon stock change in soil from land use change j

6.6.4.2.1 N_2O emissions in soils of land converted to settlements

The annual release of direct N_2O 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:

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 N_2O 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 N_2O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, $kgN_2O\text{-}Nyr^{-1}$

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 N_2O 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 2018, causing annual emission rates due to C stock changes of biomass and soils from 1.8 Gg CO_2 to 0.2 Gg CO_2 (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 1990-2018

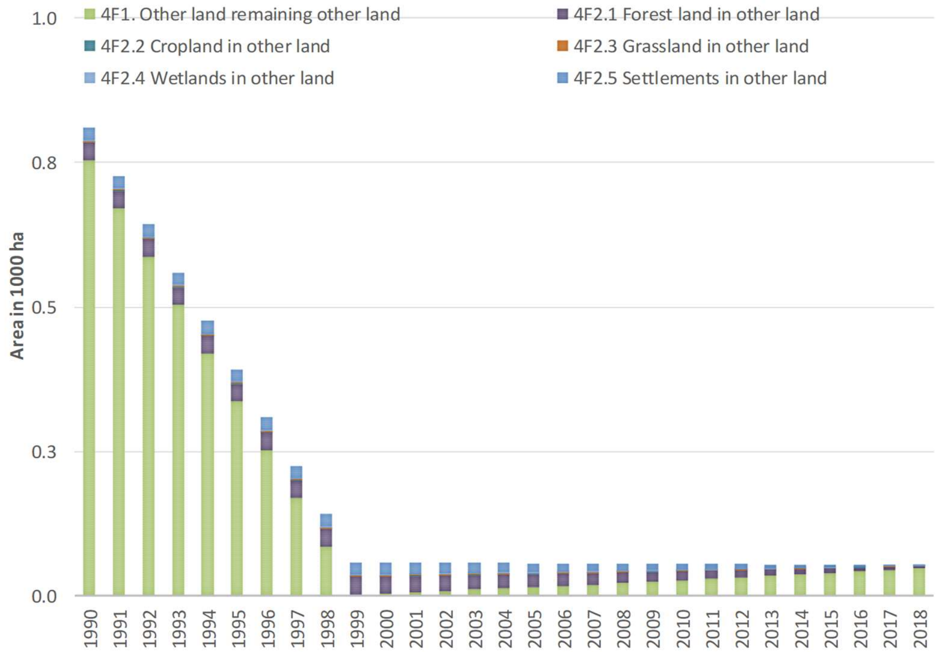


Table 6-34– CO_2 removals/emissions for category 4F – Other land from 1990-2018

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_2O (in CO_2 eq)	N_2O leaching (in CO_2 eq)
1990	1.76	NE	1.44	0.01	0.04	0.00	0.19	0.09	0.02
1991	1.76	NE	1.44	0.01	0.04	0.00	0.19	0.09	0.02
1992	1.76	NE	1.44	0.01	0.04	0.00	0.19	0.09	0.02
1993	1.76	NE	1.44	0.01	0.04	0.00	0.19	0.09	0.02
1994	1.76	NE	1.44	0.01	0.04	0.00	0.19	0.09	0.02
1995	1.76	NE	1.44	0.01	0.04	0.00	0.19	0.09	0.02
1996	1.76	NE	1.44	0.01	0.04	0.00	0.19	0.09	0.02
1997	1.76	NE	1.44	0.01	0.04	0.00	0.19	0.09	0.02
1998	1.76	NE	1.44	0.01	0.04	0.00	0.19	0.09	0.02
1999	1.76	NE	1.44	0.01	0.04	0.00	0.19	0.09	0.02
2000	0.98	NE	0.70	0.01	0.03	0.00	0.16	0.09	0.02
2001	0.94	NE	0.67	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	0.82	NE	0.58	0.01	0.03	0.00	0.13	0.07	0.02
2005	0.78	NE	0.56	0.01	0.03	0.00	0.12	0.07	0.01
2006	0.74	NE	0.53	0.01	0.03	0.00	0.11	0.06	0.01
2007	0.70	NE	0.50	0.01	0.03	0.00	0.11	0.06	0.01
2008	0.59	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	0.50	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
Trend 1990-2018	-91.65%	NA	-92.31%	-71.20%	-70.89%	NA	-93.20%	-87.91%	-87.91%
Trend 2017-2018	-23.41%	NA	-21.34%	-13.98%	-13.92%	NA	-40.05%	-28.59%	-28.59%

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:

$$\textit{Annual change in carbon stock in biomass} = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO\_OTHERS_i}\} \cdot CF$$

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 $ha^{-1}yr^{-1}$).

$B_{AFTER(i)}$ = 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 before conversion is 6.4 t C ha^{-1} for perennial 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, 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})

C_o = dead wood/litter stock, under the old land-use category, tonnes C ha^{-1} (value dead wood in forest = 5.1 t C/ha*yr (average between forest inventory from 2000 and 2010) & 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 :

$$IEF(LUC_{forestland \rightarrow other\ land}) = -5.554\ t\ C/ha*yr$$

$$IEF(LUC_{perennial\ cropland \rightarrow other\ land}) = -3.778\ t\ C/ha*yr$$

$$IEF(LUC_{annual\ cropland \rightarrow other\ land}) = -3.770\ t\ C/ha*yr$$

$$IEF(LUC_{grassland \rightarrow other\ land}) = -5.079\ t\ C/ha*yr$$

$$IEF(LUC_{settlements \rightarrow other\ land}) = -2.162\ t\ C/ha*yr$$

$$IEF(LUC_{wetland \rightarrow other\ land}) = 0.0\ t\ C/ha*yr$$

IEF(LUCj) = average yearly emission factor for carbon stock change in soil from land use change j

6.7.4.2.2 N_2O emissions in soils of land converted to other land

The annual release of direct N_2O 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):

$$N_2O_{Direct} - N = F_{SOM} \cdot EF_1$$

$$F_{SOM} = \sum_{LU}\left[\left(\Delta C_{Mineral,LUC} \cdot \frac{1}{R}\right) \cdot 1000\right]$$

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 N_2O 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 N_2O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, $kgN_2O\text{-}Nyr^{-1}$

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 N_2O 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)

6.8 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 IPPC 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 α of 5 % as recommended by IPCCC 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 rations (R). The biomass expansion factors are based on a detailed study by (Dagnelies, Palm, & Rondeux, 2013) and according to expert judgement the error linked to these factors is estimated at ±15%. The below-ground to above-ground biomass rations (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 ±93% for coniferous wood (value R=0.2 [0.12-0.49]) and ±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). Her 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 ±25%. The uncertainty on the carbon factor is also based on the default value of ±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	value	error
Above ground biomass growth coniferous trees	7.83 tC/ha^{-1}	±30%
Above ground biomass growth deciduous trees	4.40 tC/ha^{-1}	±30%
Below ground biomass growth coniferous trees	1.54 tC/ha^{-1}	±97.3%
Below ground biomass growth deciduous trees	1.01 tC/ha^{-1}	±63.8%
Above ground biomass growth trees 0-20y	5.53 tC/ha^{-1}	±32.7%
Below ground biomass growth trees 0-20y	1.12 tC/ha^{-1}	±81.2%
Dead wood	11.96 tC/ha^{-1}	±36.6%
Litter	19.20 tC/ha^{-1}	±77.2%
Biomass carbon stocks in forests (above-and below ground)	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 m^2. 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 her 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 ± 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 ± 27%	89.2 ± 13%	132.2 ± 20%	71.0 ± 0%
Buntsandstein	66.7 ± 29%	82.8 ± 26%	112.1 ± 41%	73.5 ± 0%
Dolomies du Muschelkalk	85.5 ± 35%	112.1 ± 28%	117.0 ± 20%	77.9 ± 0%
Calcaires du Bajocien	75.2 ± 33%	122.0 ± 16%	111.5 ± 21%	77.7 ± 0%
Grès de Luxembourgs	50.7 ± 25%	83.3 ± 31%	80.6 ± 23%	76.2 ± 0%
Dépôts limoneux sur Grès	58.6 ± 36%	99.4 ± 35%	95.7 ± 25%	75.1 ± 0%
Argiles du Lias inf. et moyen	69.8 ± 35%	121.6 ± 21%	95.2 ± 21%	75.7 ± 0%
Argiles lourdes du Keuper	67.7 ± 40%	121.3 ± 23%	102.6 ± 22%	76.0 ± 0%
Argiles lourdes des schistes bitumineux	88.2 ± 46%	145.7 ± 14%	104.8 ± 17%	NA
Others	80.7 ± 61%	110.8 ± 28%	126.6 ± 55%	74.9 ± 0%
ALL	**76.8 ± 48%**	**107.4 ± 37%**	**110.7 ± 42%**	**73.5 ± 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^{-1}[1]	±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%	expert judgement
biomass carbon stock for other land	0,0 tC/ha^{-1}	±0%	

The error for N_2O emissions is a combination of the error on the C/N ratio (±40%) and the error of the linked calculation of carbon emission.

6.8.5 Overall uncertainty assessment

Compared to the other sectors the LULUCF sector is particular as it does not only cover CO_2 emission but also CO_2 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

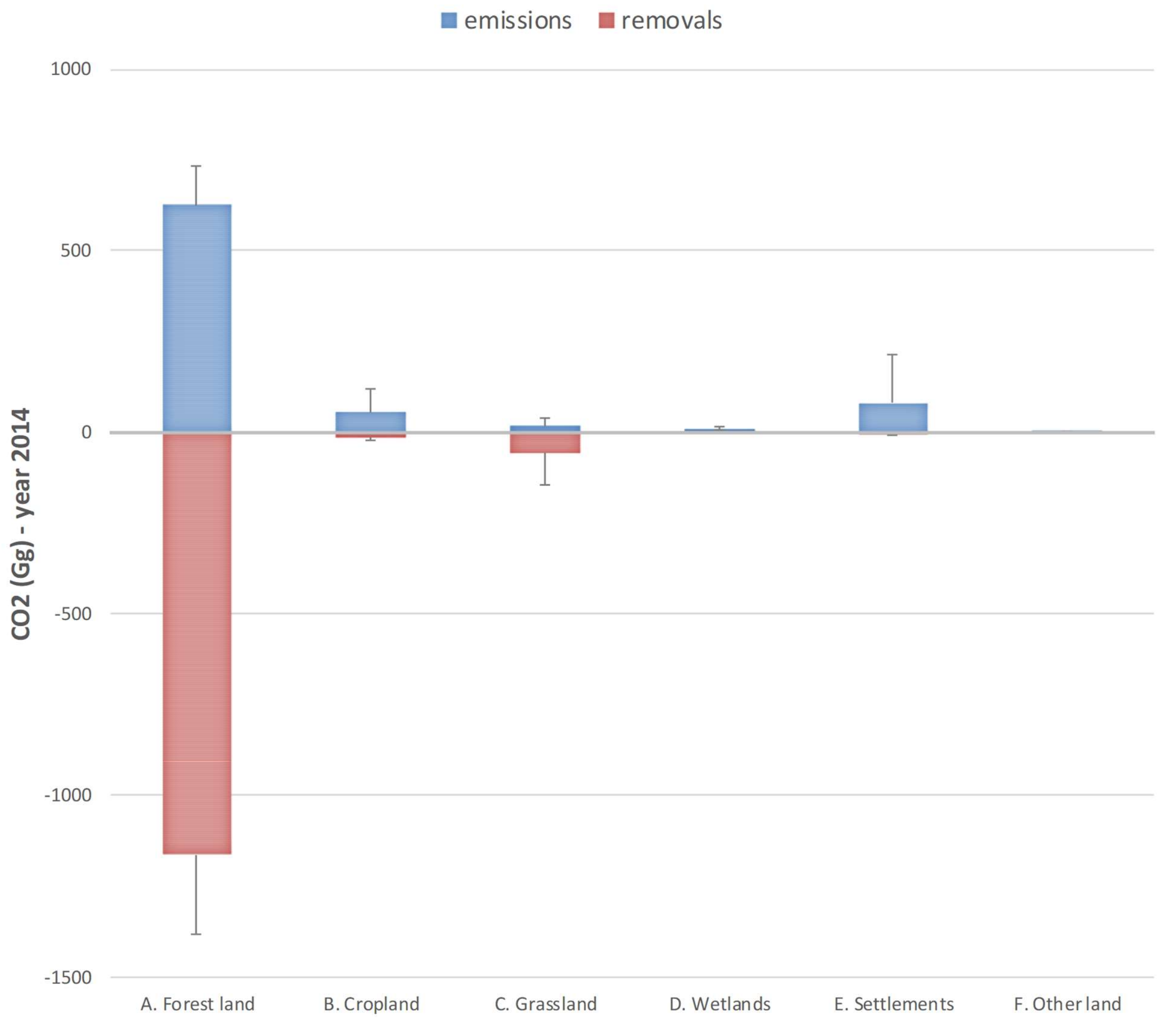
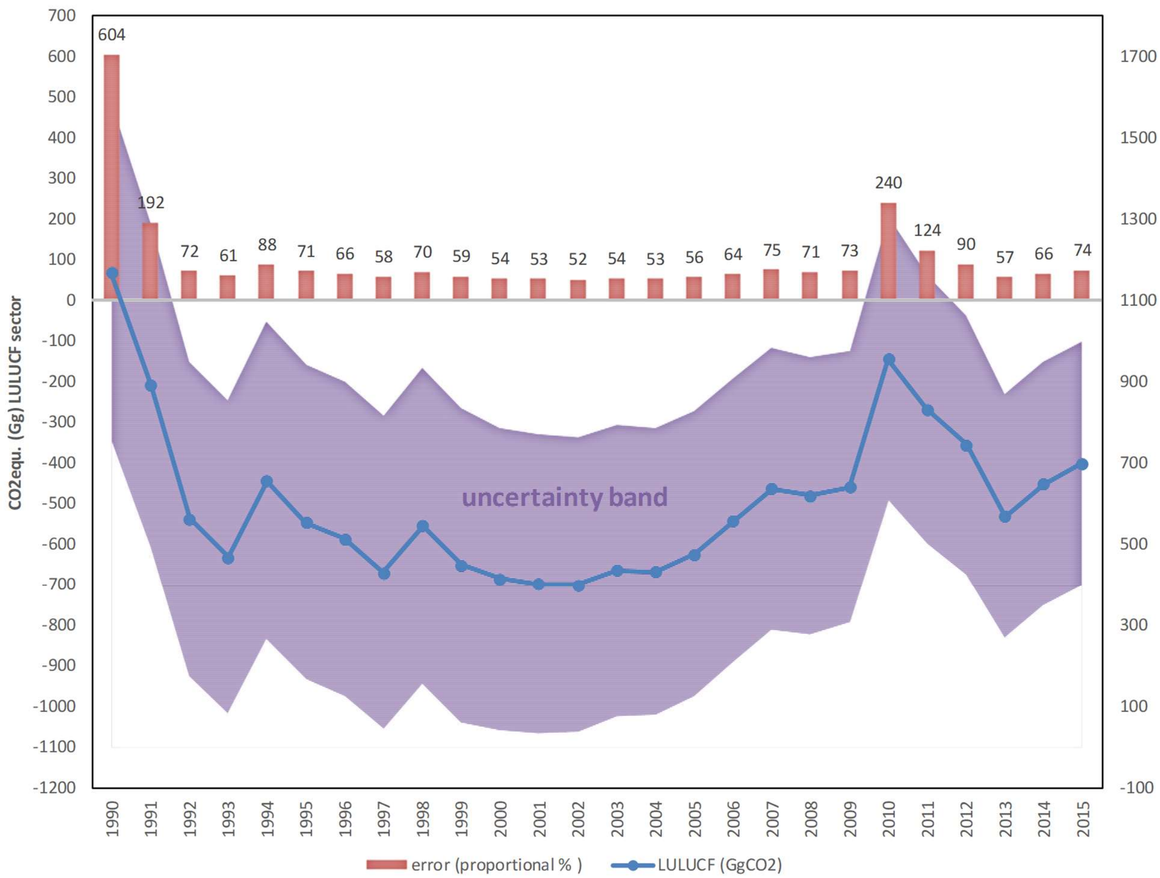


Figure 6-19 highlights how the overall LULUCF sector is mainly influenced by emissions and removals in the forest sector. The error on emissions and removals for the forest sector are ±17 % and ±19 %. The other land use categories contribute a lot less to the overall emissions and removals of the LULUCF 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



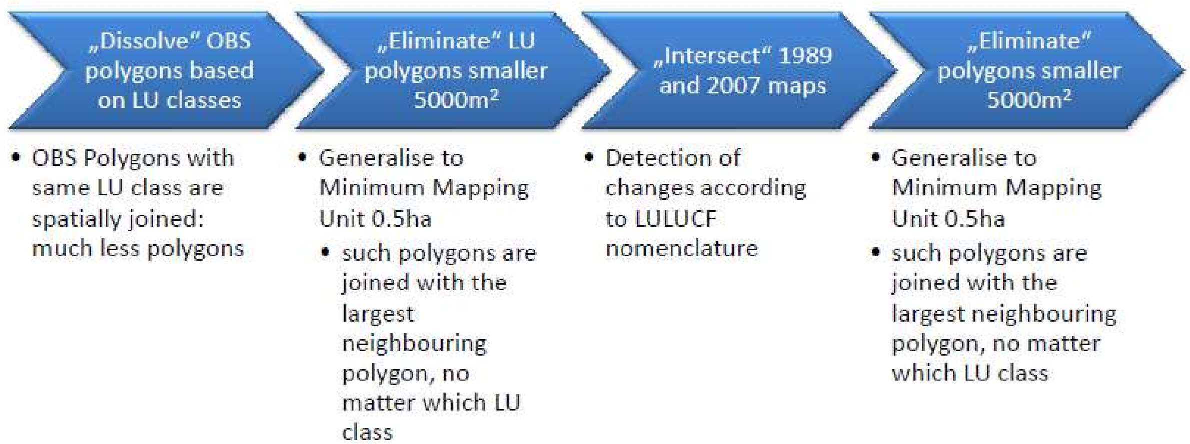
For the year 2015 the proportional error is 74 %. This value is however strongly dependant on the proportion of removals and emissions and tends towards infinity as the sum of removals and emissions tends to zero. This is very striking when comparing the year 1990 with any of the years between 1999 and 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 caped 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:

$$C(i+1) = e^{-k} \cdot C(i) + \left[\frac{1-e^{-k}}{k}\right] \cdot Inflow\ (i) \quad \textbf{(Equation 6-1)}$$

$$\Delta C(i) = C(i+1) - C(i) \quad \textbf{(Equation 6-2)}$$

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):

$$f_{IRW}(i) = \frac{IRW_P(i) - IRW_{EX}(i)}{IRW_P(i) + IRW_{IM}(i) - IRW_{EX}(i)} \quad \textbf{(Equation 6-3)}$$

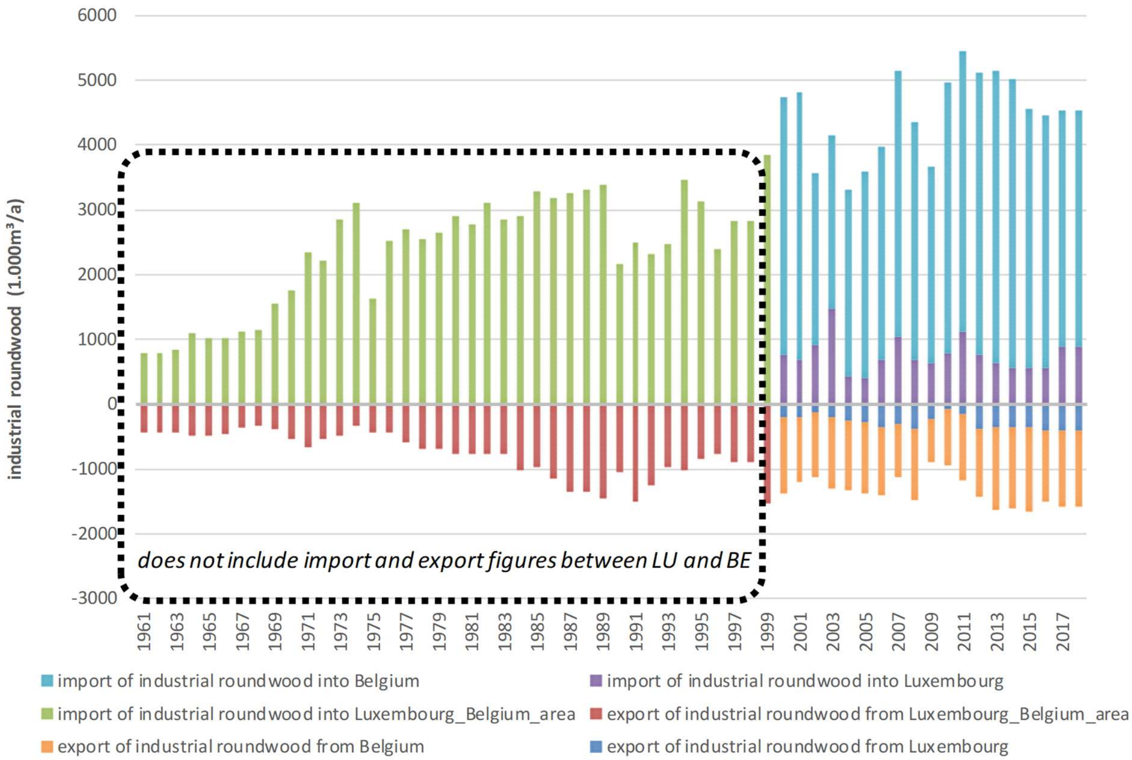
6.9.1.1 Data available in the FAO database

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

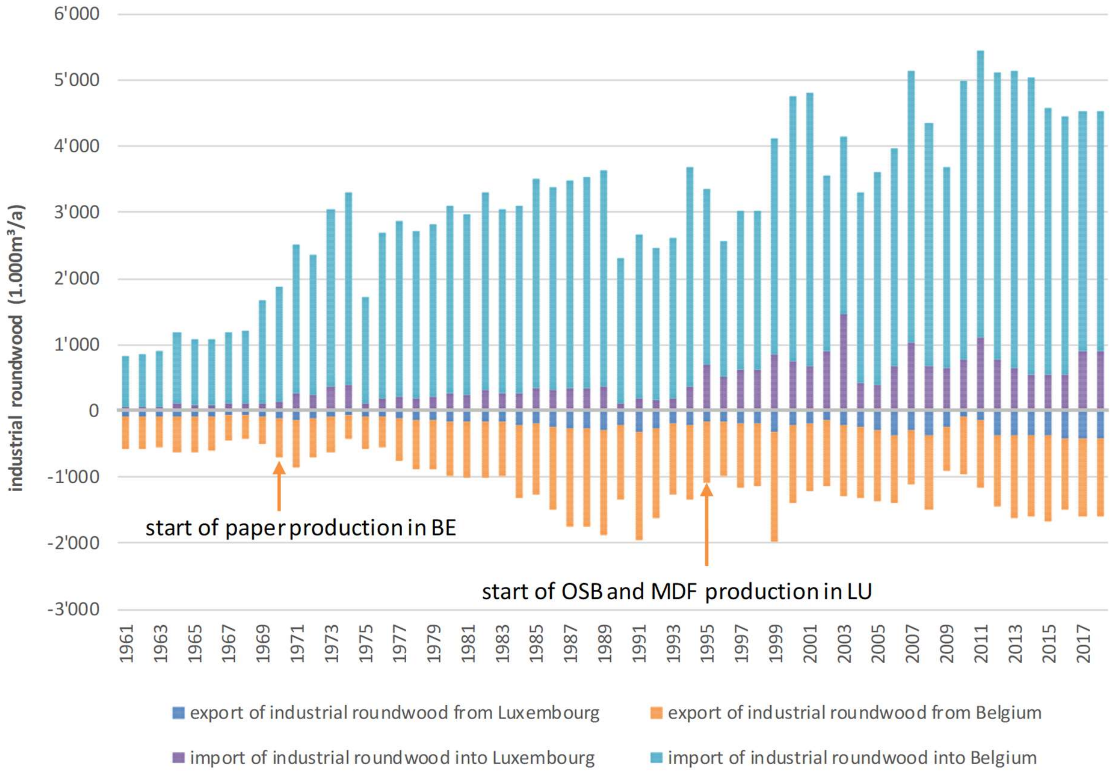
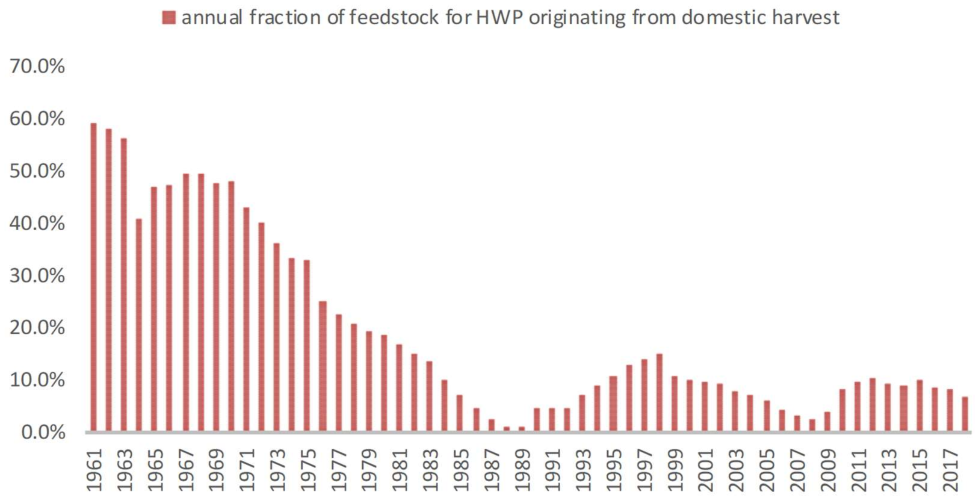


Figure 6-23 illustrates how the import and export of industrial roundwood was amended to take into account import and export figures between LU and BE:

- 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



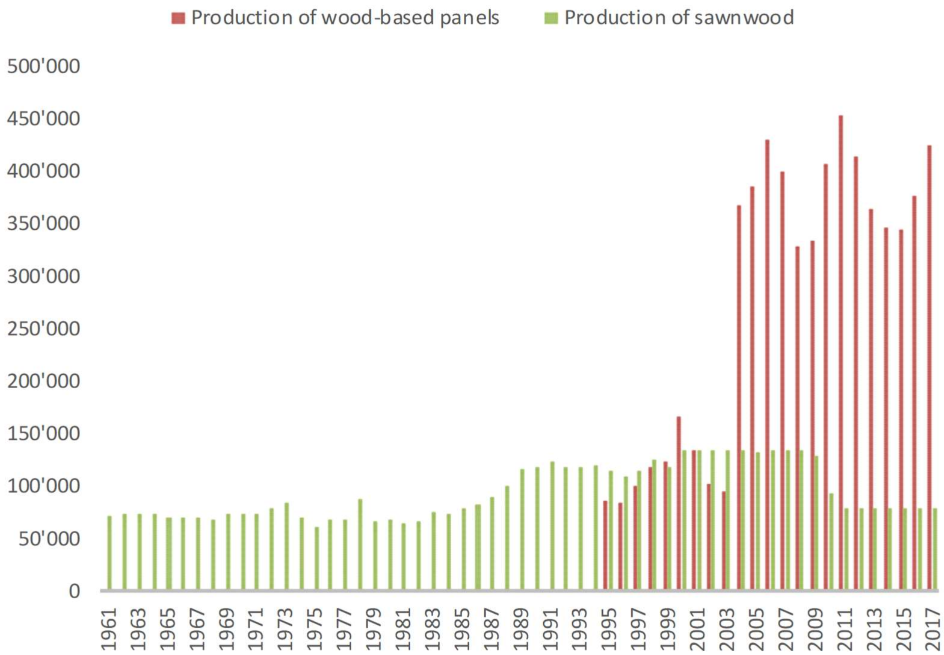
Import and export of industrial roundwood are very high and show strong yearly fluctuations. Those fluctuations can partly be explained by stock changes and bulk purchases by the wood processing industry. Unfortunately, yearly fluctuations of import and export can, on an annual basis, lead to inconsistent 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 is 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

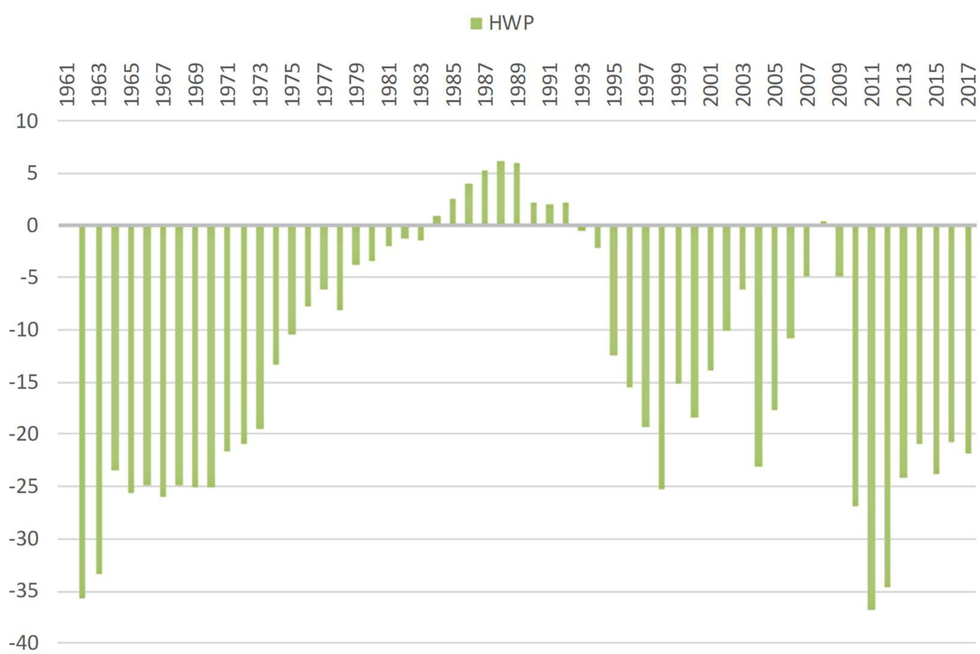


6.9.1.4 Data available on production, imports and exports of pulpwood

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.

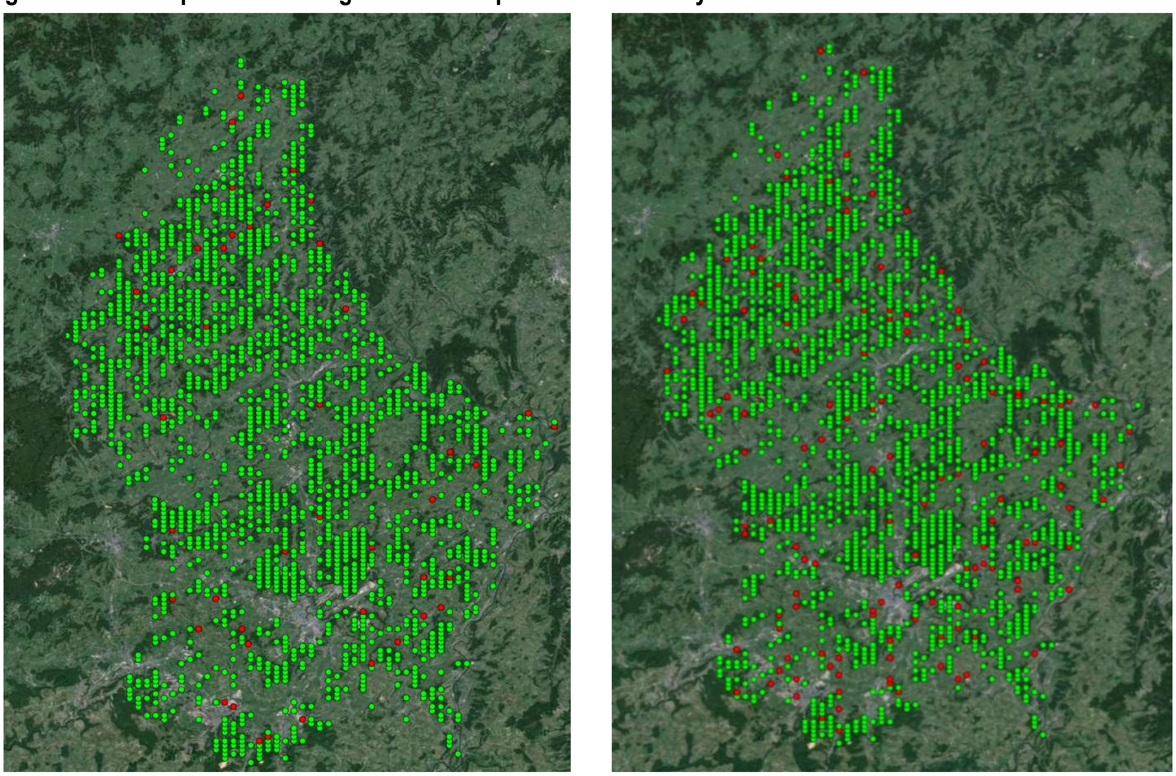
6.10 Category-specific QA/QC and verification

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 anaylsis (total: 45)

Red points are defined as forest in the in the LUC anaylsis but not in the forest inventory (total: 114)

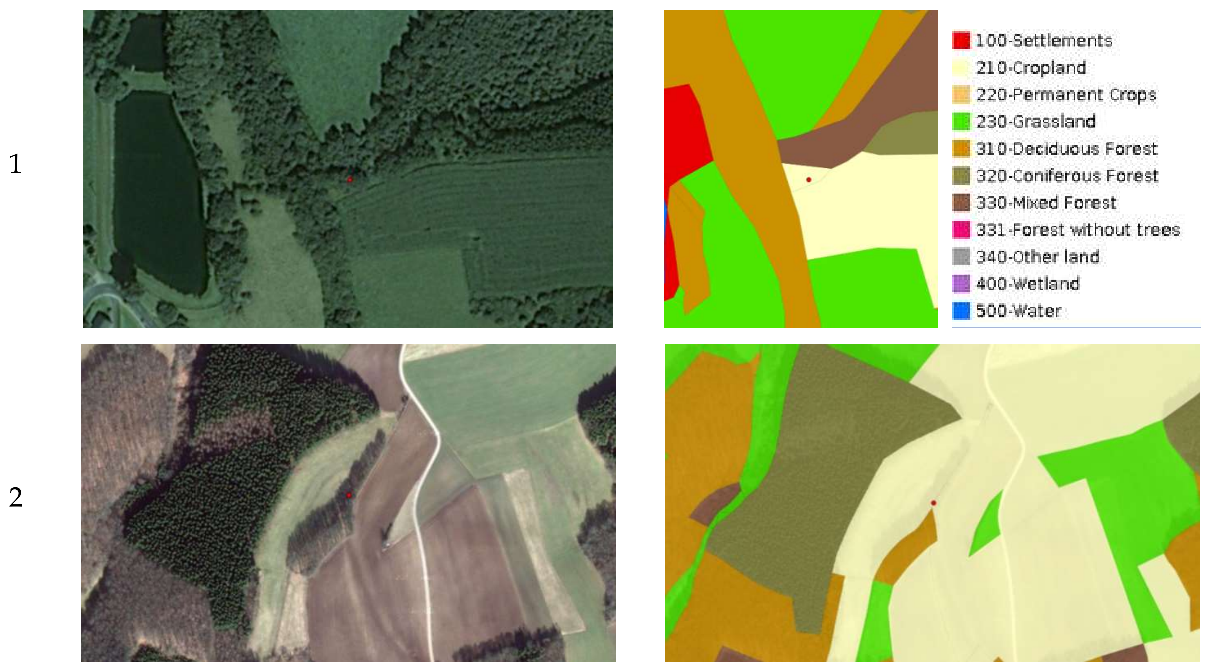
In order to compare the results of total forest area obtained via land use maps (based on aerial and satellite pictures) and the total forest area obtained via the NFI a detailed analysis has been conducted via a GIS program. For this exercise the layer of grid points of the NFI have been put in comparison 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:

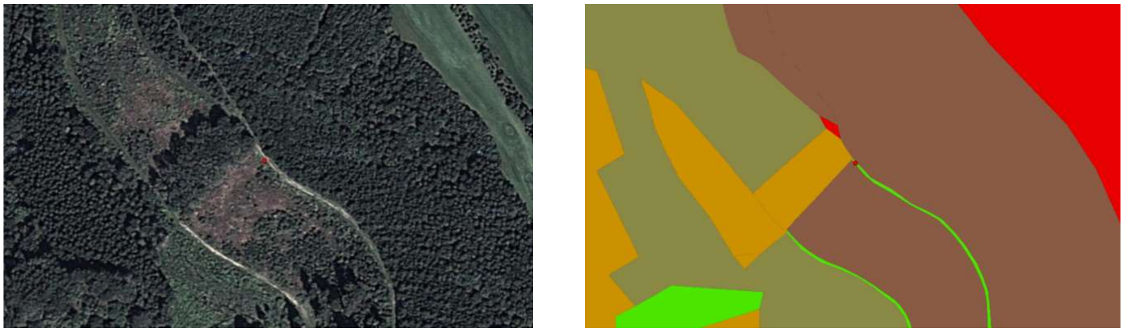
As can be seen in Figure 6-27 the difference in numbers of red points is in line with the difference in total surface area (114-45 = 69 -> 3 450 ha (according to NFI calculation with 50 ha/point), compared to 3 957 ha calculated above).

The figures here below show a sample of red points in order to highlight the type of differences or errors between both methodologies.

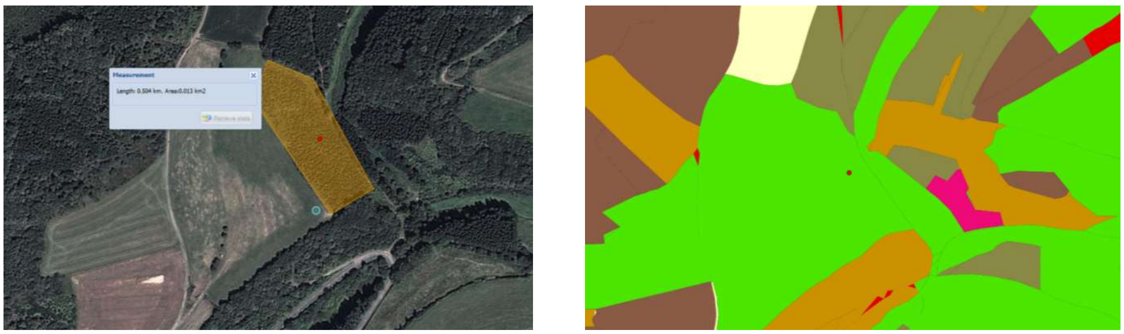
Figure 6-28 – points defined as forest in NFI but not in LUC method



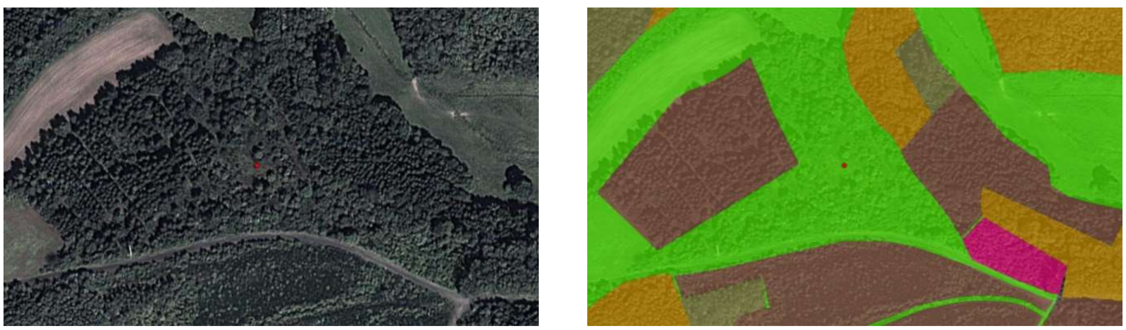
3



4



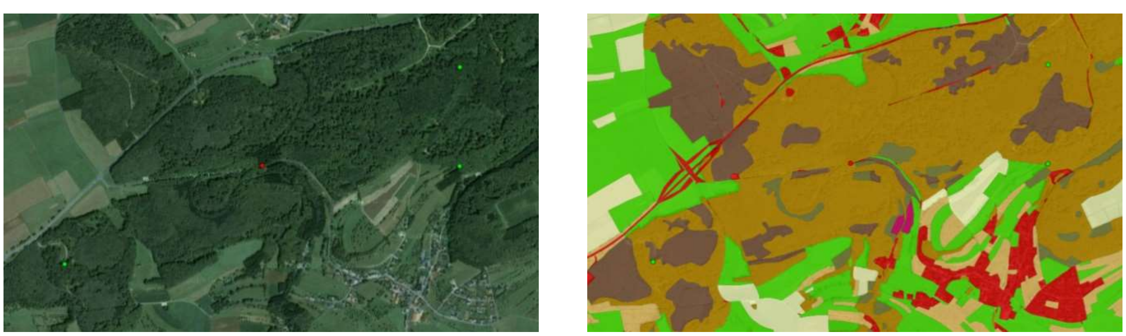
5



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

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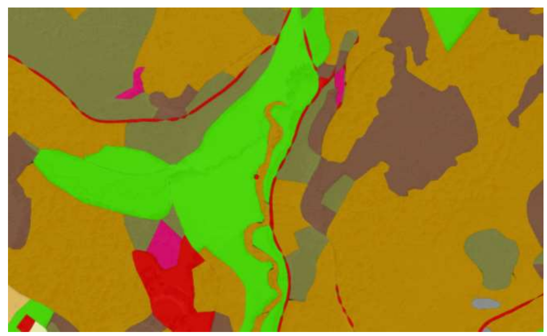


10

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.

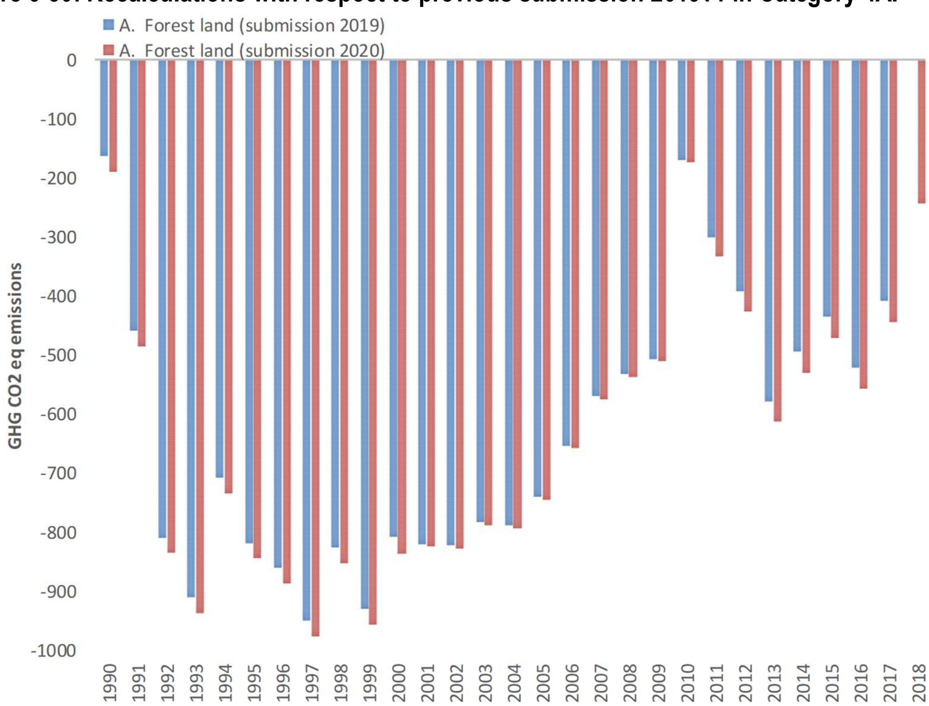
6.11 Category-specific recalculations including changes made in response to the review process

The following changes have led to the revision of the data series for the LULUCF sector:

4.A Forestland:

In order to be in line with the new calculations, under Regulation (EU) 2018/841, of the Forest Reference Level (FRL) the calculation for dead wood was changed. Instead of using a stock change approach, a carbon pool variation module, that takes account of the dynamic age-related characteristics, is used to estimate the evolution of this carbon pool.

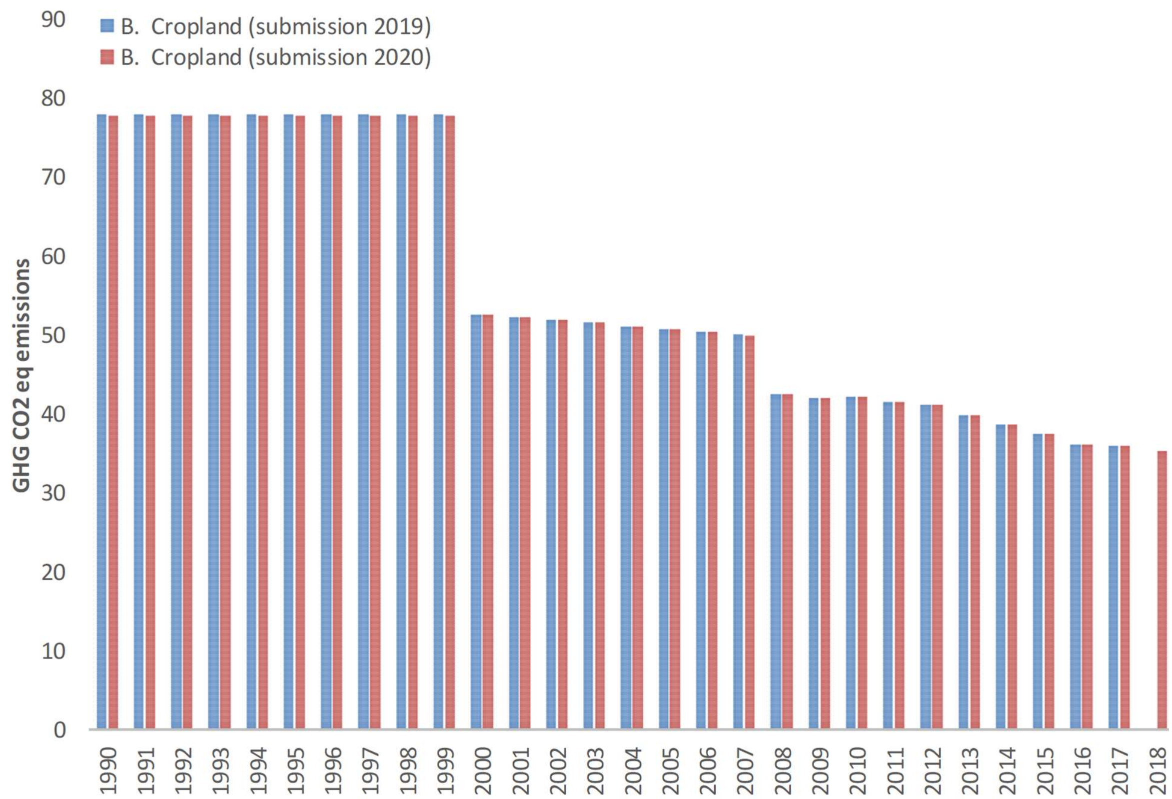
Figure 6-30: Recalculations with respect to previous submission 2019v1 in Category 4A.



4.B Cropland:

In order to be in line with the new calculations, under Regulation (EU) 2018/841, of the Forest Reference Level (FRL) the calculation for dead wood was changed. Instead of using a stock change approach, a carbon pool variation module, that takes account of the dynamic age-related characteristics, is used to estimate the evolution of this carbon pool.

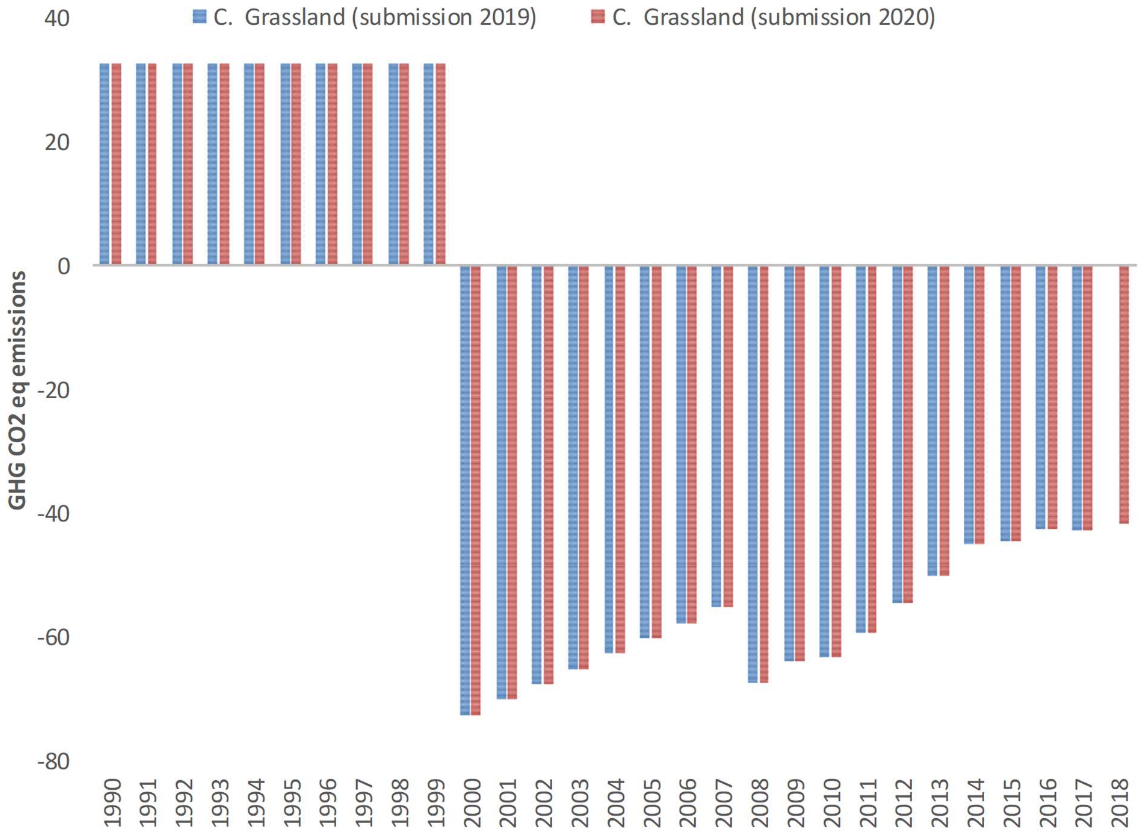
Figure 6-31: Recalculations with respect to previous submission 2019v1 in category 4B.



4.C Grassland:

In order to be in line with the new calculations, under Regulation (EU) 2018/841, of the Forest Reference Level (FRL) the calculation for dead wood was changed. Instead of using a stock change approach, a carbon pool variation module, that takes account of the dynamic age-related characteristics, is used to estimate the evolution of this carbon pool.

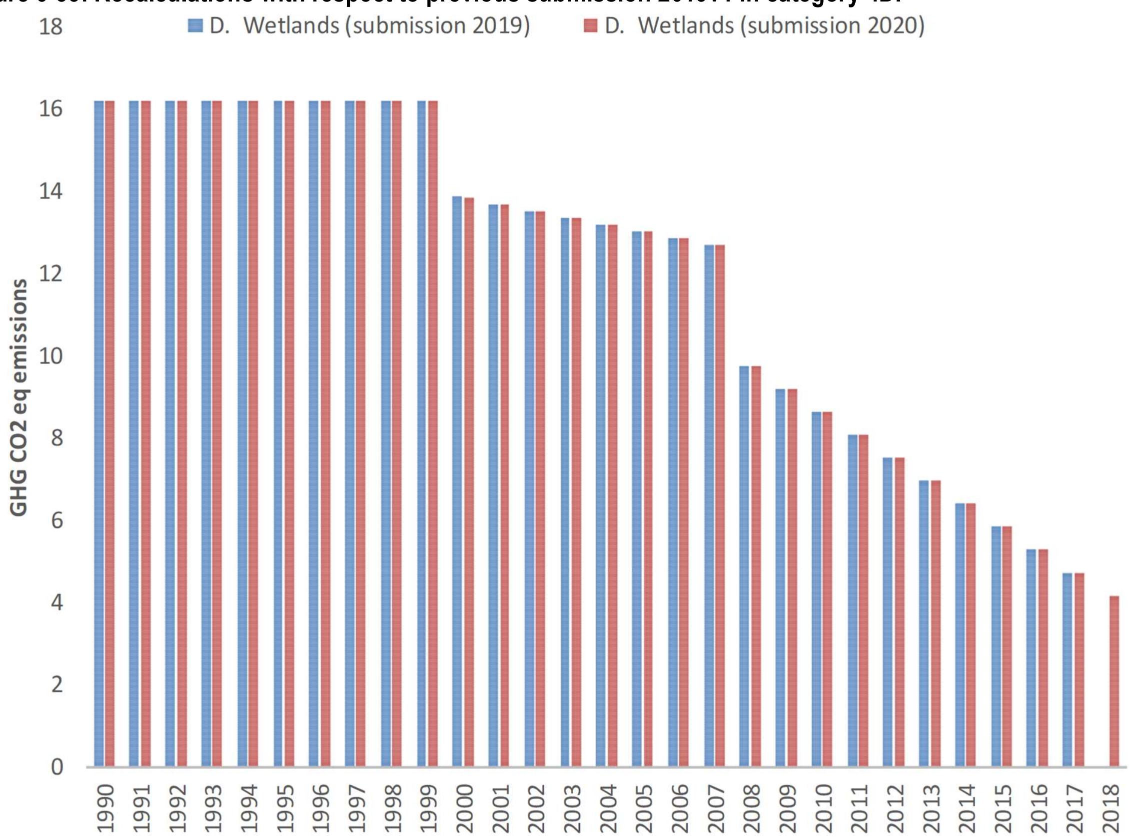
Figure 6-32: Recalculations with respect to previous submission 2019v1 in category 4C.



4.D Wetlands:

In order to be in line with the new calculations, under Regulation (EU) 2018/841, of the Forest Reference Level (FRL) the calculation for dead wood was changed. Instead of using a stock change approach, a carbon pool variation module, that takes account of the dynamic age-related characteristics, is used to estimate the evolution of this carbon pool.

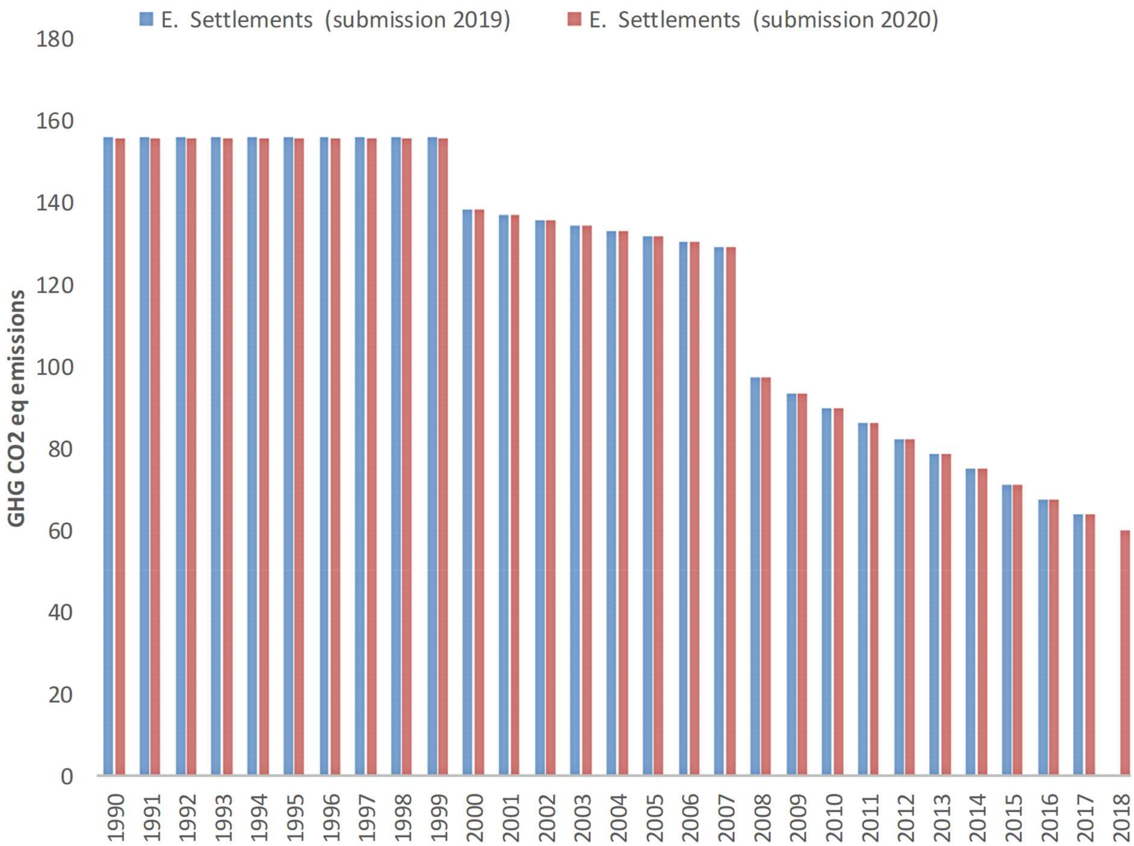
Figure 6-33: Recalculations with respect to previous submission 2019v1 in category 4D.



4.E Settlements:

In order to be in line with the new calculations, under Regulation (EU) 2018/841, of the Forest Reference Level (FRL) the calculation for dead wood was changed. Instead of using a stock change approach, a carbon pool variation module, that takes account of the dynamic age-related characteristics, is used to estimate the evolution of this carbon pool.

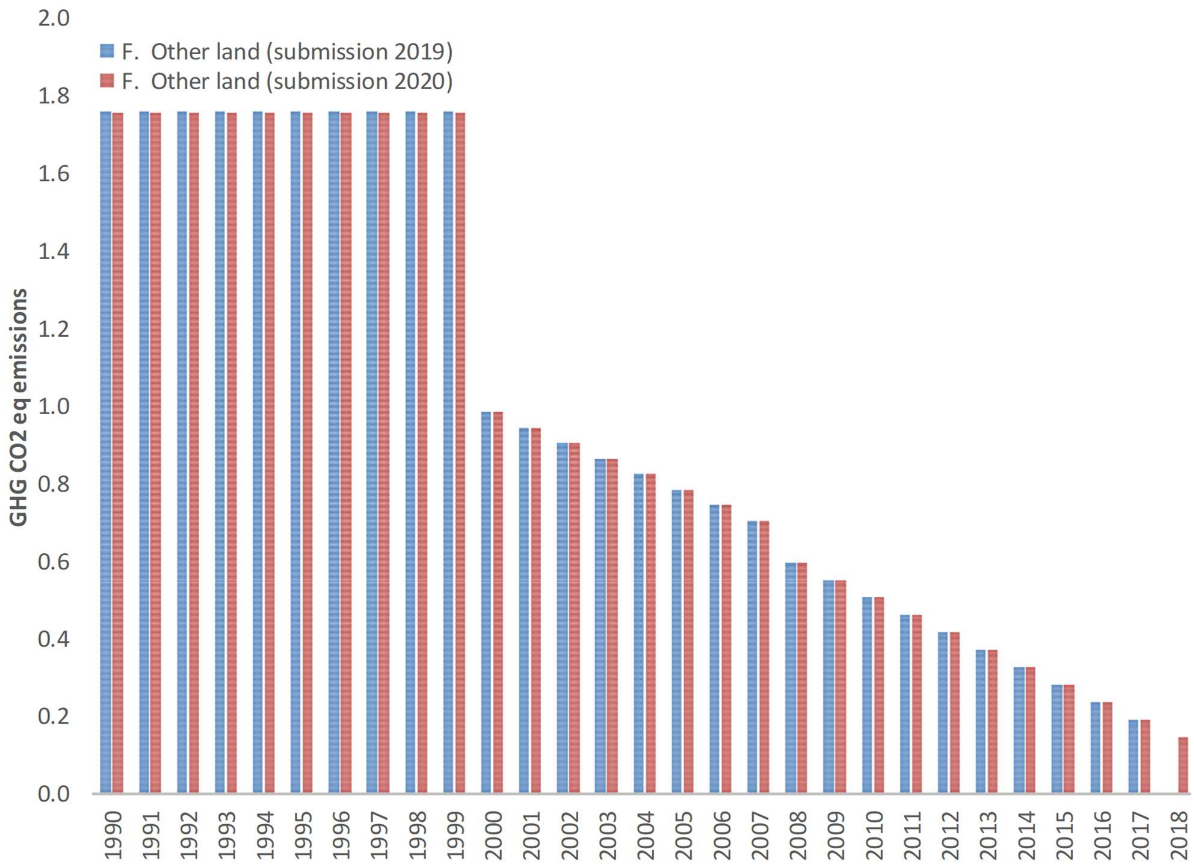
Figure 6-34: Recalculations with respect to previous submission 2019v1 in category 4E.



4.F Other land:

In order to be in line with the new calculations, under Regulation (EU) 2018/841, of the Forest Reference Level (FRL) the calculation for dead wood was changed. Instead of using a stock change approach, a carbon pool variation module, that takes account of the dynamic age-related characteristics, is used to estimate the evolution of this carbon pool.

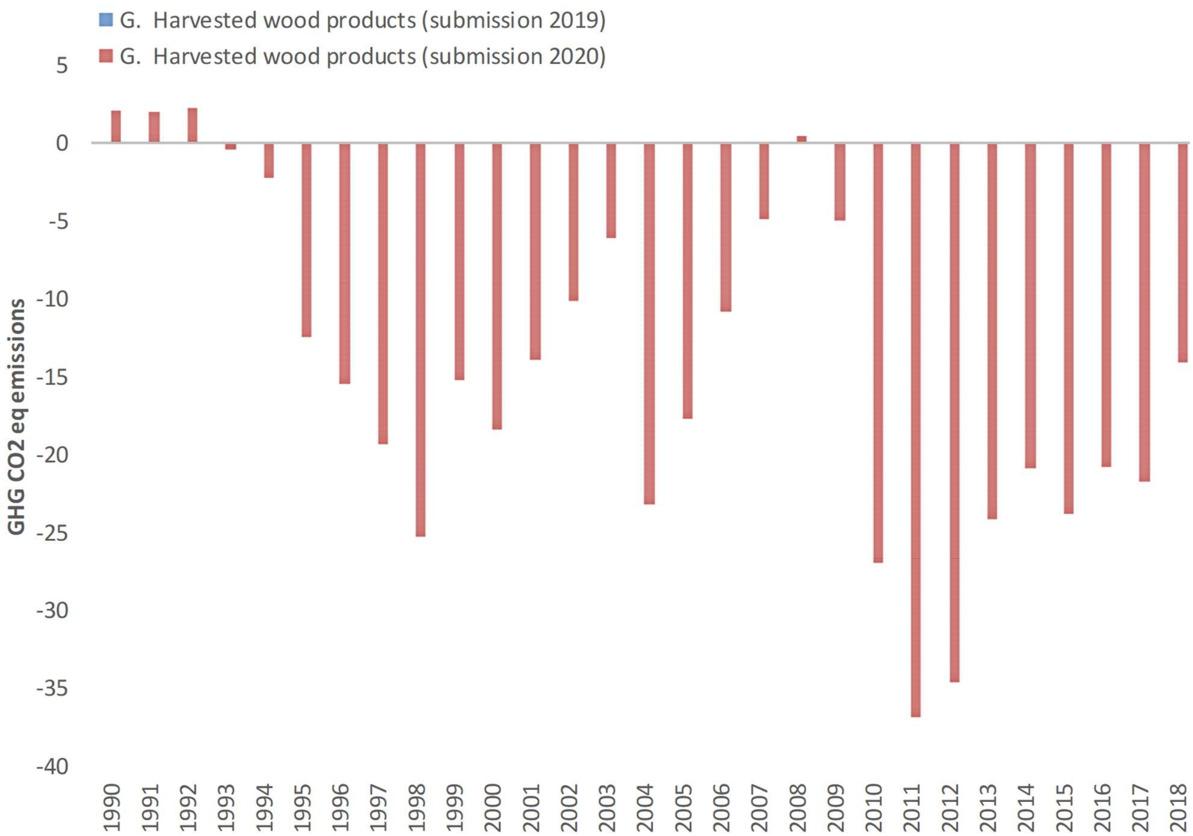
Figure 6-35: Recalculations with respect to previous submission 2019v1 in category 4F.



4.G Harvested Wood Products

In order to be in line with the new calculations of the Forest Reference Level (FRL), under Regulation (EU) 2018/841, the emissions and removals from HWP were estimated. In the 2019 submission HWP were not estimated but have been introduced with the 2020 submission.

Figure 6-36: Recalculations with respect to previous submission 2019v1 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 conduct 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 2018. 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 2018, and Table 7-2 depicting the shares of each IPCC category under CRF Sector *5* for both the years 1990 and 2018, total waste related GHG emissions have decreased by 22.07% from 1990 to 2018, and decreased by 2.46% between 2017 and 2018.

Figure 7-1 – GHG Emission Trends for category 5 – Waste: 1990-2018

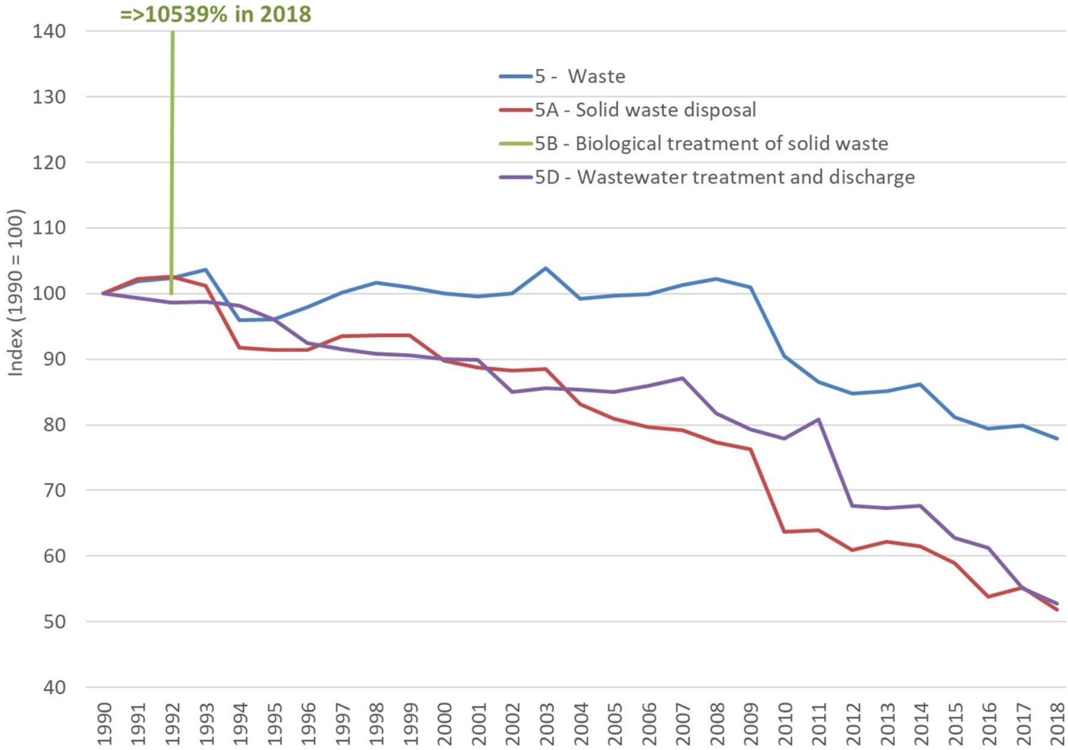
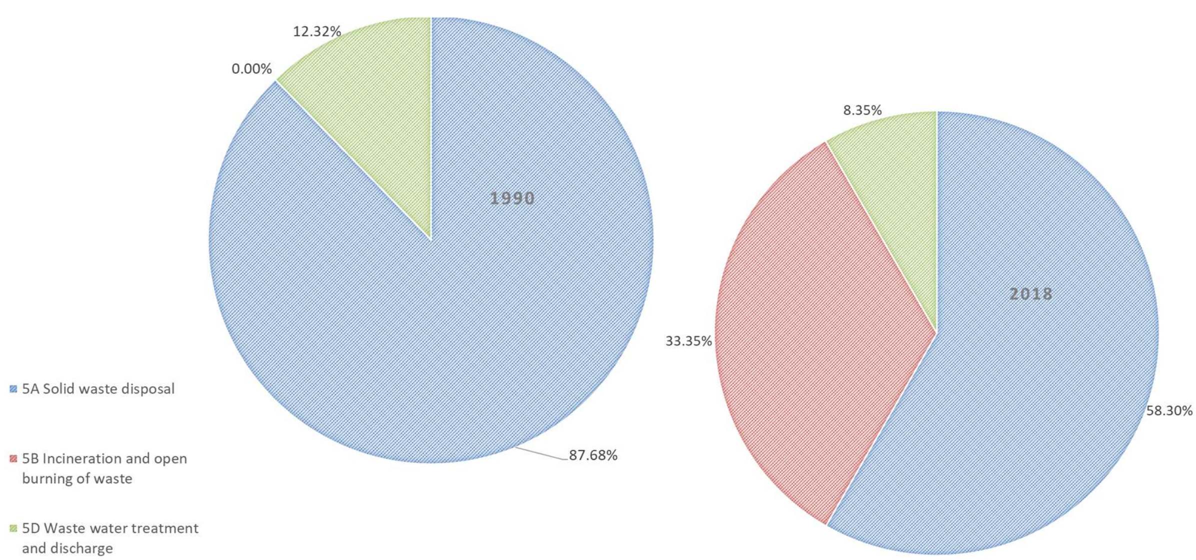


Figure 7-2 – Shares for category 5 – Waste: 1990 and 2018



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 48.18% between 1990 and 2018 due to:

- an increase in aerobic treatment[117] 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 CO_2 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 2018 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 CH_4 and N_2O. 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 CH_4 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).

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117 Aerobic treatment refers to the cold treatment at SIGRE, and the mechanical-biological treatment at SIDEC.

Table 7-1 – GHG Emission Trends in CO_2e for category *5* – Waste: 1990-2018

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_2O	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O	Total	CO_2	CH_4	N_2O
1990	92.18	NA	92.18	NA	0.00	NO	NO	NO	12.95	NA	7.30	5.65	105.14	NA	99.49	5.65
1991	94.22	NA	94.22	NA	0.00	NO	NO	NO	12.86	NA	7.12	5.74	107.09	NA	101.34	5.74
1992	94.59	NA	94.59	NA	0.26	NO	0.26	NO	12.78	NA	6.94	5.84	107.62	NA	101.78	5.84
1993	93.32	NA	93.32	NA	2.90	NO	1.80	1.10	12.80	NA	6.76	6.04	109.02	NA	101.87	7.14
1994	84.56	NA	84.56	NA	3.64	NO	2.23	1.41	12.71	NA	6.57	6.14	100.92	NA	93.36	7.55
1995	84.29	NA	84.29	NA	4.29	NO	2.62	1.67	12.45	NA	6.39	6.06	101.03	NA	93.31	7.73
1996	84.22	NA	84.22	NA	6.72	NO	4.04	2.68	11.98	NA	6.17	5.81	102.92	NA	94.43	8.49
1997	86.19	NA	86.19	NA	7.19	NO	4.29	2.90	11.86	NA	5.95	5.91	105.24	NA	96.43	8.81
1998	86.31	NA	86.31	NA	8.82	NO	5.21	3.60	11.76	NA	5.73	6.03	106.88	NA	97.25	9.63
1999	86.34	NA	86.34	NA	8.05	NO	4.74	3.31	11.73	NA	5.51	6.23	106.13	NA	96.59	9.54
2000	82.73	NA	82.73	NA	10.82	NO	6.56	4.26	11.66	NA	5.28	6.37	105.21	NA	94.57	10.63
2001	81.78	NA	81.78	NA	11.20	NO	6.99	4.22	11.64	NA	5.13	6.51	104.63	NA	93.90	10.73
2002	81.38	NA	81.38	NA	12.73	NO	7.93	4.80	11.02	NA	4.98	6.04	105.13	NA	94.29	10.84
2003	81.58	NA	81.58	NA	16.56	NO	10.50	6.06	11.09	NA	4.83	6.26	109.24	NA	96.91	12.33
2004	76.70	NA	76.70	NA	16.56	NO	10.79	5.77	11.06	NA	4.68	6.38	104.32	NA	92.16	12.15
2005	74.65	NA	74.65	NA	19.16	NO	12.69	6.47	11.01	NA	4.49	6.51	104.82	NA	91.83	12.99
2006	73.45	NA	73.45	NA	20.45	NO	13.74	6.71	11.14	NA	4.43	6.71	105.04	NA	91.61	13.42
2007	72.97	NA	72.97	NA	22.21	NO	14.99	7.22	11.28	NA	4.41	6.87	106.46	NA	92.36	14.10
2008	71.30	NA	71.30	NA	25.59	NO	17.36	8.23	10.58	NA	4.11	6.47	107.47	NA	92.76	14.70
2009	70.31	NA	70.31	NA	25.60	NO	17.88	7.72	10.27	NA	3.77	6.50	106.17	NA	91.96	14.21
2010	58.78	NA	58.78	NA	26.21	NO	18.37	7.84	10.09	NA	3.69	6.40	95.07	NA	80.84	14.24
2011	58.94	NA	58.94	NA	21.56	NO	15.79	5.77	10.47	NA	4.13	6.34	90.97	NA	78.86	12.11
2012	56.11	NA	56.11	NA	24.21	NO	18.27	5.94	8.77	NA	4.06	4.71	89.10	NA	78.45	10.65
2013	57.31	NA	57.31	NA	23.47	NO	17.81	5.66	8.72	NA	3.93	4.78	89.50	NA	79.05	10.45
2014	56.66	NA	56.66	NA	25.21	NO	19.13	6.08	8.77	NA	3.85	4.92	90.64	NA	79.64	11.00
2015	54.33	NA	54.33	NA	22.92	NO	18.05	4.87	8.13	NA	3.50	4.62	85.38	NA	75.88	9.50
2016	49.65	NA	49.65	NA	25.97	NO	20.43	5.54	7.93	NA	3.26	4.67	83.55	NA	73.33	10.21
2017	50.90	NA	50.90	NA	25.98	NO	20.65	5.33	7.13	NA	2.85	4.28	84.00	NA	74.39	9.61
2018	47.77	NA	47.77	NA	27.32	NO	21.77	5.55	6.84	NA	2.69	4.15	81.93	NA	72.23	9.70
Trend 1990-2018	-48.18%	NA	-48.18%	NA	NA	NA	NA	NA	-47.19%	NA	-63.22%	-26.45%	-22.07%	NA	-27.40%	71.79%
Trend 2017-2018	-6.15%	NA	-6.15%	NA	5.19%	NA	5.44%	4.19%	-4.04%	NA	-5.66%	-2.96%	-2.46%	NA	-2.91%	1.01%

Source: Environment Agency

For IPCC category ***5D – Wastewater Treatment and Discharge***, emissions decreased by 47.19% in 2018 compared to the base year 1990, and decreased by 4.04% compared to 2017. Wastewater treatment plant (WWTP) capacities expressed in population-equivalents have steadily grown (Section 7.6) over the period 1990 to 2018[118], whereas nitrous oxide emissions (Table 7-1) decreased by 26.45%. With regard to wastewater treatment, technical changes therefore have an unquestionable role, as the evolution of methane emissions (-63.22% from 1990 to 2018) confirms.

7.1.2 Key categories

The methodology and results of the key source analysis are presented in Chapter 1. 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	95-03, 07-09	95-09, 12-13		

Source: Environment Agency

Notes: LA = Level Assessement (Tier 1) including respectively exluding LULUCF
TA = Trend Assessement 2018 (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.

118 This increase is notably explained by *(i)* the significant population growth between 1990 and 2018, 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 N_2O emissions from WWTP.

Table 7-3 – Status of Emission Estimates for CO_2, CH_4 and N_2O in category *5 – Waste*

GHG source & sink category	Description	Status		
		CO_2	CH_4	N_2O
***5A* - Solid Waste Disposal**				
5A1	Managed waste disposal sites	NA	X	
5A2	Unmanaged waste disposal sites	NO	NO	
5A3	Uncategorized waste disposal sites	NO	NO	
***5B* - Biological Treatment of Solid Waste**				
5B1	Composting		X (1993-2018)	X (1993-2017)
5B1	Pre-treatment of solid waste		X (1993-2018)	X (1993-2018)
5B2	Anaerobic digestion at biogas facilities		X (1992-2018)	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).

* = 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 [119] (Total MSW).

According to the modified Luxembourgish Law of March 21, 2012 [120], the collection of MSW falls within the competence of municipalities. As a result municipalities joined together in different

119 For details on municipal waste collection, see: http://www.environnement.public.lu/dechets/statistiques_indicateurs/LUXUS_Daten/index.html (in German) http://www.environnement.public.lu/dechets/statistiques_indicateurs/index.html, line "*Activité des parcs à conteneurs (recycling centres)*" (in French).

120 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

municipal waste management syndicates. There are four inter-municipal syndicates responsible for the management of municipal solid waste:

- SIDA regrouping the municipalities of Wiltz and others in the north of the country (integrated in SIDEC since 1994);
- SIDEC regrouping the municipalities of Diekirch, Ettelbruck and Colmar-Berg;
- SIDOR regrouping the municipalities of Luxembourg, Esch-sur-Alzette and Capellen;
- SIGRE regrouping the municipalities of Grevenmacher, Remich and Echternach.

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 m^3 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*	*2002-2018*
	+ *Biological treatment*	*2007-2018*
SIDOR	Incineration	1976-2018
SIGRE	Landfill	1979-2018
	+ *Aerobic treatment*	*1993-2014*
	+ *Methane recovery system*	*2000-2018*

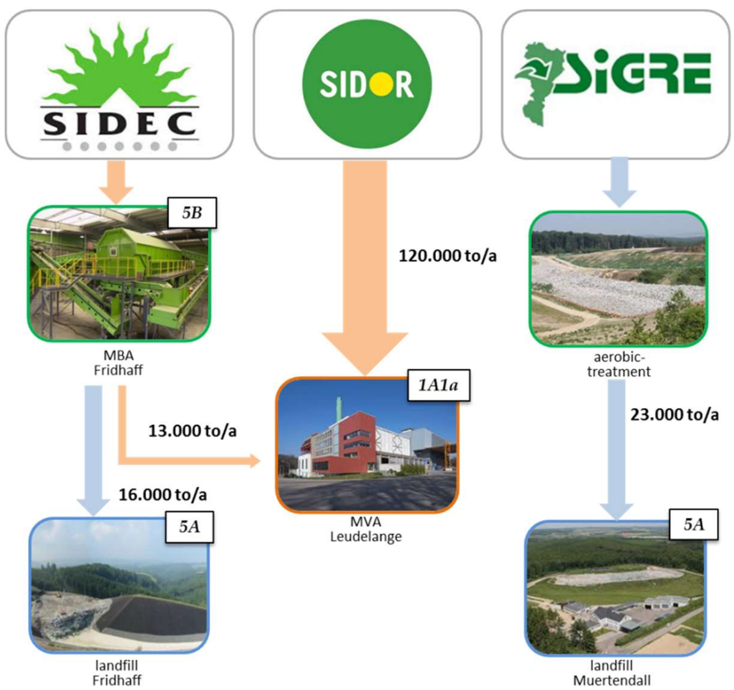
Source: Environment Agency.

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 [121]. The landfill site managed by SIDEC was subsequently closed.

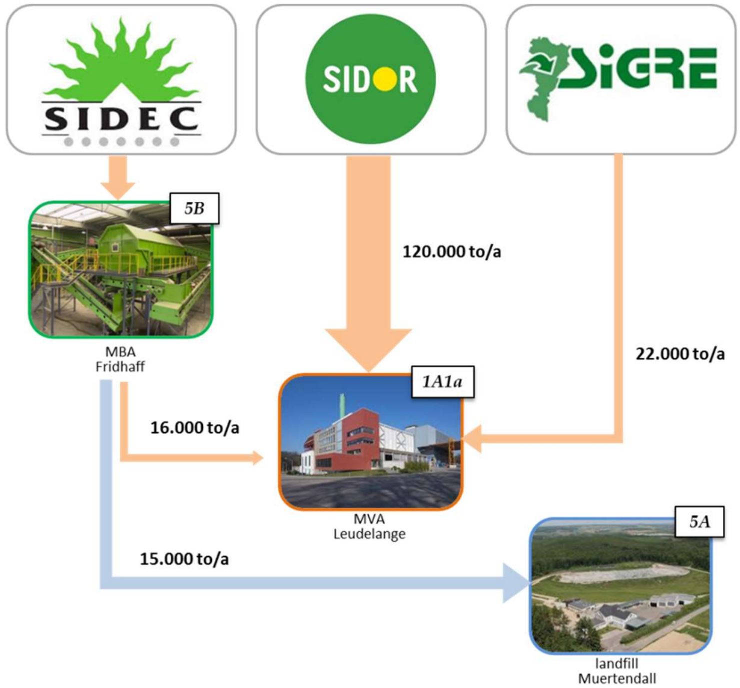
A **methane recovery system** has been in operation at the SIGRE site since 2000, and at the SIDEC site since 2002. The **aerobic treatment** in heaps has been performed at SIGRE since 1993. Also, pre-treatment of solid waste prior landfilling of waste in tunnels has been fully operational since 2007 at SIDEC.

Figure 7-3 – Waste Flow in Luxembourg before 2015



121 http://www.beaufort.lu/Collaboration_DE.pdf?FileID=publications%2Fcollaboration_de.pdf

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 (Figure 7-4 is – upon collection – partly:

- **landfilled** – accounted under IPCC category *5A* either directly[122] 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) Waste Incineration Directive 2000/76/EC, and

(iv) *Loi du 18 décembre 2015 modifiant la loi modifiée du 21 mars 2012 relative aux déchets*,

[122] Direct landfilling of waste concerns waste with or without mechanical sorting. Direct landfilling was completely abandoned in 2015. Indirect landfilling of waste is referring to waste that is pre-treated.

(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 [123].

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 [124], subsequently amended and rectified by the Grand-Ducal Regulation of February 17, 2006 [125].

The aim of the **Waste Incineration Directive**, transposed by the Grand-Ducal Regulation of May 9, 2014[126], 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 2015**[127] states clearly 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

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123 *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

124 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

125 Règlement grand-ducal du 17 février 2006 modifiant le règlement grand-ducal du 24 février 2003 concernant la mise en décharge des déchets, http://www.legilux.public.lu/leg/a/archives/2006/0036/2006A0696A.html http://www.legilux.public.lu/leg/a/archives/2006/0051/2006A1124B.html

126 Règlement grand-ducal du 9 mai 2014 abrogeant: 1) le règlement grand-ducal modifié du 9 mai 2003 portant application de la directive 2001/80/CE du Parlement européen et du Conseil du 23 octobre 2001 relative à la limitation des émissions de certains polluants dans l'atmosphère en provenance des grandes installations de combustion; 2) 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 classés; 3) le règlement grand-ducal du 19 décembre 1989 relatif aux déchets provenant de l'industrie du dioxyde de titane; 4) le règlement grand-ducal modifié du 19 décembre 2002 concernant l'incinération des déchets. http://legilux.public.lu/eli/etat/leg/rgd/2014/05/09/n1/jo

127 Loi du 18 décembre 2015 modifiant la loi du 21 mars 2012 relative aux déchets

imposed for non-compliance with this provision are fixed in the Grand-Ducal Regulation of 18 December 2015 [128]. 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 either directly landfilled or 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* (Figure 7-3 and Figure 7-4).

In 2018, the source category *5A* was responsible for 58.30% of emissions related to waste treatment under Section *5*, and for 8.13% of the total **methane** emissions estimated for Luxembourg (15.89% in 1990). It represented 0.45% of the total **GHG** emissions (excluding LULUCF) (0.72% in 1990). Neither CO_2 (biogenic origin), nor N_2O 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 CH_4 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 both landfill sites is either estimated or based on measurements.

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 Ronnebierg (Box "*Industrial Waste Disposal*

[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

Site Ronnebierg"). Today, Muertendall (managed by SIGRE in the Eastern district) is the only active landfill site.

Industrial Waste Disposal Site Ronnebierg

The deposit of industrial waste in Ronnebierg 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)	Ronnebierg I	Monticule	Ronnebierg 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 a 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, Ronnebierg, 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 syndicats

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*
Trend 1990-2018	*-13.00%*	*-2.11%*	*-34.75%*	*27.42%*	*-100.00%*	*58.71%*	*-45.18%*
Trend 2017-2018	*2.83%*	*1.89%*	*0.32%*	*13.35%*	*NA*	*1.91%*	*0.90%*

Sources: STATEC, *Statistical Yearbook*, Table A.3301, adjusted to the quantities of the annual reports (Table A 3301 will also be adapted in the near future to reflect certain inconsistences highlighted during the compilation of the NIR).

http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=13939&IF_Language=fra&MainTheme=1&FldrName=3&RFPath=65

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 captia (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

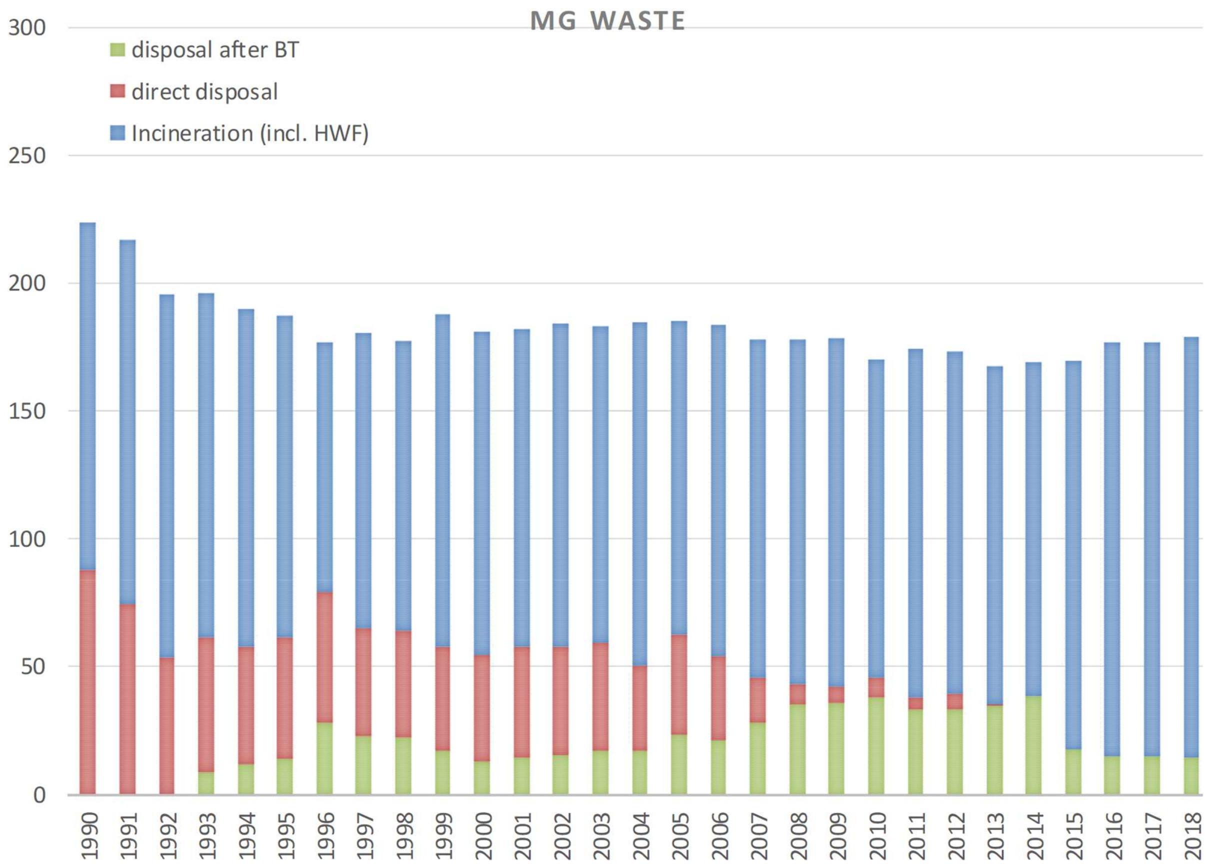
			SIGRE - Muertendall					SIDEC - Fridhaff											
Year	Incineration (incl. HWF)	SIDA total	Total	const. waste	rotting losses	to SIDOR	disposal after BT	Total	inert. Waste & metal	disposal before MS	disposal after MS	HWF	disposal before BT	rotting losses	disposal to SIGRE	disposal after BT	direct disposal	direct disposal	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
Trend 1990-2018	20.94%		100.66%				NA	-34.75%									-100.00%	-100.00%	NA
Trend 2016-2018	-1.83%		5.27%				-3.16%	0.32%									NA	NA	-3.16%

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 and 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 - 2018)



From 2014 onwards no more waste has been landfilled without pre-treatment (due to the Landfill Ordinance, see Section 7.5.1).

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 estimated (Table 7-7).

Table 7-7 – Waste Fractions and Estimated Degradable Organic Carbon for directly deposited waste

CED	*Description*	*Estimated DOC*
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, Straßenkehrricht Mai 2010

E**missions** 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 CH_4 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 of waste at the SWDS site Muertendall (managed by SIGRE) is 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 (SIDEC) 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 **AT_4 parameter** indicates the amount of O_2 consumed during the decomposition of the organic fraction of waste. SIDEC reported that AT_4 was reduced from 100 mg O_2/g TS (untreated waste) to 20 mg O_2/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). 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 and 1975**. The first available data on waste generation is the year **1990** (590 kg MSW produced *per* capita (Table 7-4), 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 **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 (SIDEC)

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%
2014 – 2018	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.

7.2.2.3.2 Deposited Waste after Biological Treatment (SIGRE and SIDEC)

During **mechanical sorting**, the high calorific fraction[129] and metals are separated from the waste:

- The separated **high calorific fraction** of in average 10.0 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 up to to 8000 tons of remaining lixiviate collected from the landfill site. Pre-treatment of waste induces a reduction of the organic pollution of lixiviate in total organic carbon (TOC) from 3000 mg/L (untreated waste) to < 250 mg/L (pre-treated waste). The remaining weight of waste after biological treatment is measured and hence the reduction of waste (rotting losses) is known.
- The aerobic treatment at the **SIGRE** landfill Muertendall is performed using forced aerated windrows of 36 tons in which large streams of waste undergo a systematic six-month-rotting process. The resulting waste is 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).

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*.

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129 The deriving high calorific (combustible) fraction (> 150mm) is incinerated (addressed under CRF subcategory *1A1a*) at the municipal waste incinerator SIDOR. Energy generation from 9000 tons of high calorific fraction accounts for electronic power supply for 1600 households.

130 De Journal, N.200, p.7, "SIDOR: Feiern in der Zeit des Umbruchs"

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 – CH_4 emissions from *5A1 - Managed Waste Disposal Sites*

CH_4 emissions from 5A1 - Managed Waste Disposal Sites

Year	Total	SIDEC, SIGRE, SIDA		Ronnebierg	IEF
	Gg	direct	indirect	Gg	kg / t MSW
1990	3.69	3.53	NO	0.15	42.08
1991	3.77	3.63	NO	0.14	50.56
1992	3.78	3.65	NO	0.13	70.49
1993	3.73	3.61	0.00	0.12	56.53
1994	3.38	3.23	0.04	0.11	52.79
1995	3.37	3.18	0.09	0.10	49.10
1996	3.37	3.13	0.14	0.09	35.81
1997	3.45	3.11	0.25	0.08	44.76
1998	3.45	3.04	0.34	0.07	45.58
1999	3.45	2.98	0.41	0.06	51.46
2000	3.31	2.78	0.45	0.07	53.61
2001	3.27	2.73	0.48	0.06	49.85
2002	3.26	2.70	0.51	0.04	49.31
2003	3.26	2.69	0.54	0.03	47.77
2004	3.07	2.47	0.57	0.03	45.21
2005	2.99	2.35	0.60	0.03	39.86
2006	2.94	2.25	0.66	0.03	42.90
2007	2.92	2.20	0.70	0.02	44.36
2008	2.85	2.08	0.76	0.01	43.03
2009	2.81	1.95	0.86	0.01	41.78
2010	2.35	1.40	0.94	0.01	31.73
2011	2.36	1.32	1.03	0.01	35.33
2012	2.24	1.14	1.10	0.01	33.11
2013	2.29	1.13	1.16	0.01	34.51
2014	2.27	1.04	1.22	0.01	32.61
2015	2.17	0.86	1.30	0.01	36.87
2016	1.99	0.71	1.27	0.01	33.51
2017	2.04	0.79	1.24	0.01	34.77
2018	1.91	0.70	1.20	0.01	31.15
Trend 1990-2018	-48%	-80%	NA	-96%	-26%
Trend 2016-2018	-6%	-11%	-3%	-21%	-10%

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

	Directly Deposited Waste	*Deposited Waste after Biological Treatment*
DOC (Degradable Organic Carbon) ***(weight fraction, wet basis)***	*"waste by composition"*	*"bulk waste data only"*
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 CH_4	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.

7.2.2.4.1 Methane Correction Factor (MCF)

From **1950** till the opening of SIDEC 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 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 at SIGRE (since 1993) or SIDEC (since 2007), 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

	Methane Correction Factor				
	Un-managed, shallow	***Un-managed, deep***	***Managed***	***Managed, semi-aerobic***	***Uncategorized***
Year	**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, SIGRE aerobic treatment					
1993-2018	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**, landfill sites of SIGRE and SIDEC 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). As the MBT residues are in many cases *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 CH_4 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 CH_4 recovered.

7.2.2.5 CH_4 Recovery

The methane recovery systems have been installed at the individual landfills Muertendall (managed by SIGRE) and Fridhaff (managed by SIDEC) in the years 2000 and 2002, respectively. Since then[131], 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. These detected quantities are included in the reported CH_4 recovery in the GHG inventory, which is taken from official waste statistics.

Table 7-12 – CH_4 Recovery from *5A1 – Managed Waste Disposal Sites*

CH_4 Recovery from 5A1 - Managed Waste Disposal Sites

Year	Total *Gg*	SIDEC, SIGRE, SID/ *Gg*	Ronnebierg *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*
Trend 1990-2018	*NA*	*NA*	*NA*
Trend 2017-2018	*9%*	*9%*	*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.*

131 For the year 2000, no data is available for the landfill Muertendall, so that the IPCC default for non-monitored data was used.

While the recovered CH_4 was used for the production of electricity at the SIGRE landfill Muertendall (> 50% methane), recovered gas was flared at the SIDEC 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.

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 for the submission 2018:

- 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 plan[132].
- 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 ± 8%.

132 *Plan national de gestion des déchets 2017*, http://www.environnement.public.lu/dechets/dossiers/pngd/index.html

Uncertainties from EFs and Methodology Applied

Under the uncertainty of the model methodology are considered:

- Uncertainty of DOC: ± 20% (Table 3.5, IPCC 2006)
- Uncertainty for MCF : −10% to 0%
- Uncertainty for fraction of CH_4 in generated landfill gas:
  ± 5% (Table 3.5, IPCC 2006)
- Uncertainty for CH_4 recovery known for SIDEC and SIGRE:
  (Uncertainty of oxidation factor included) ± 10%
- Uncertainty for half-time $t_{1/2}$: ± 15% (Table 3.4, IPCC 2006)
- Uncertainty for delay period over 50 years: ± 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 CH_4 generation rate as well as the delay time) sums up to approximatively 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.

- 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.

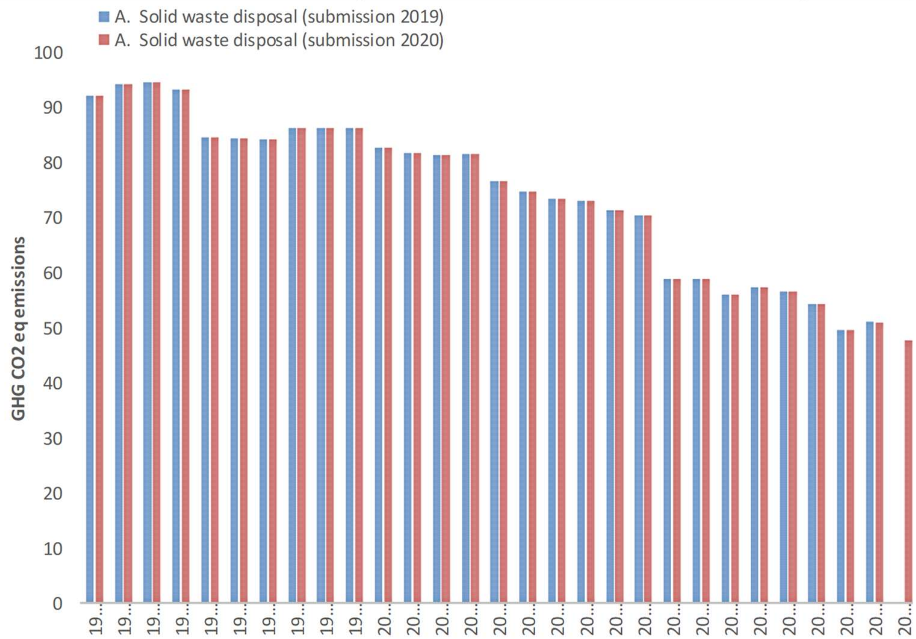
7.2.5 Category-Specific Recalculations Including Changes Made in Response to the Review Process

The emissions for 2017 were updated as the methane recovery was corrected for that year.

[133] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32002R2150&from=EN

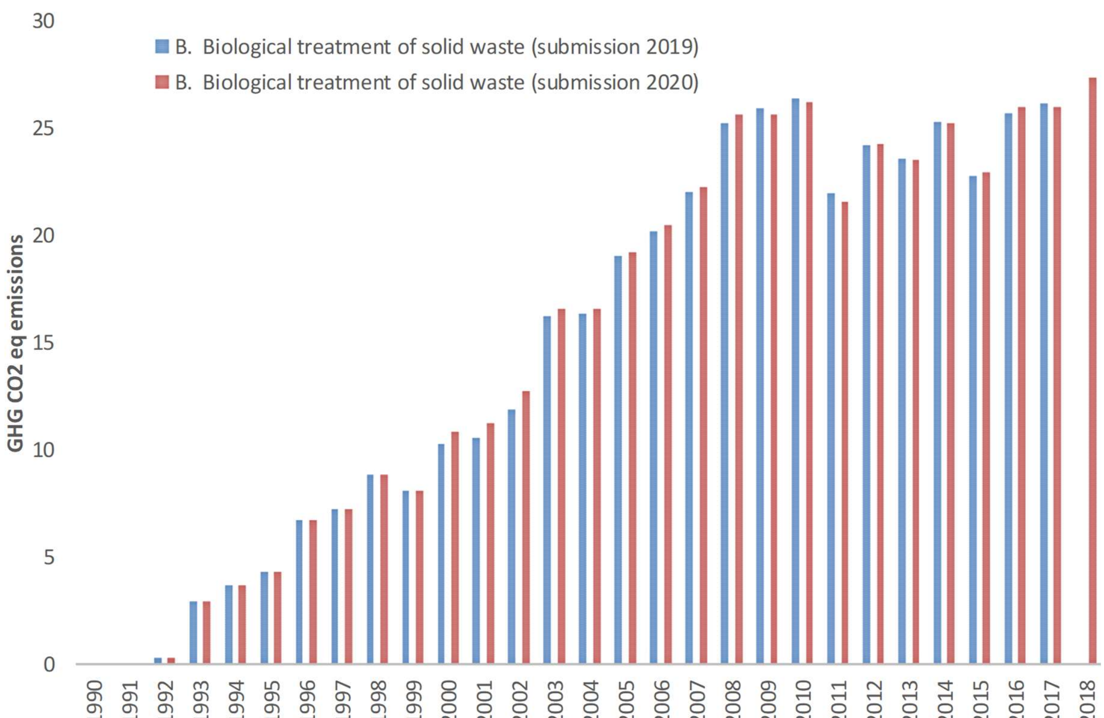
Figure 7-6: Recalculations with respect to previous submission 2019v1 in category 5A.

5B – Biological Treatment of Solid Waste



The timeseries from 2000-2018 for N_2O emissions was corrected due to an error in one of the calculation spreadsheets.

Figure 7-7: Recalculations with respect to previous submission 2019v1 in category 5B.



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.

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 2018, this source category was responsible for 33.35% of the total GHG emissions from the waste sector and it represented 0.26% of the total GHG emissions in CO_2e (excluding LULUCF). For each of the gases reported in 2018:

- CH_4 represented 30.14% of waste treatment methane related emissions and 3.71% of the total methane emissions estimated for Luxembourg;
- N_2O represented 57.19% of waste treatment nitrous oxide related emissions and 1.77% of the total nitrous oxide emissions estimated for Luxembourg.

Neither CO_2 (biogenic origin), nor N_2O 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 <u>*not*</u> 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 CO_2, water and heat. CH_4 is only formed in oxygen-deprived sections of the compost, and can be oxidized during aerobic treatment. Composting also produces N_2O 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. At SIDEC, a mechanical-biological treatment (MBT) plant has been installed treating mixed waste since 2007 (Table 7-13). Disposal of waste and its residues after treatment are reported under CRF category *5A*, while the CH_4 and N_2O 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 CH_4 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 CH_4 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 CH_4 generated (Volume 5, Chapter 4, Paragraph 4.1, IPCC 2006). N_2O emissions from *5B2 – Biogenic Waste Treated in Biogas Plants* are assumed negligible.

Table 7-13 – CH_4 & N_2O Emission Trends for Category *5B – Biological Treatment of Solid Waste*:

***5B* - Biological Treatment of Solid Waste**

Year	Emissions (Gg) CO_2	CH_4	N_2O	Total in CO_2e
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	27.32
Trend 1992-2018	NA	8298.50%	NA	10439.30%
Trend 2017-2018	NA	5.44%	-3.87%	5.19%

Source: Environment Agency.

Table 7-13 shows that CH_4 and N_2O 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 CH_4 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 seven composting installations that exist in Luxembourg, plus one that co-composts sewage sludge[134]:

- Various local municipalities (*e.g.* Mondercange, Mamer, Hesperange, Ville de Luxembourg) 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 7-14 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 Waste Division of the Environment Agency based on annual reports from 1993-2015) for the composting installations;
- Annual reports transmitted to the Waste Division of the Environment Agency for the Soil-Concept installation (Box *"Soil Concept"*).

Soil-Concept [135]

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 15 Gg of sludge and 22.5 Gg of green waste. Associated emissions are recorded in IPCC category *5B1* since these are "process" and not "spreading" emissions.

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134 Sewage sludge is allocated to the CRF Sector *3D - Agriculture*.

135 http://www.soil-concept.lu

__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 CH_4 and N_2O emissions generated during the rotting process from waste 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 at SIDEC and SIGRE 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. CH_4 and N_2O emissions are estimated using the default method given in the following equations:

$$\boldsymbol{CH_4 emissions} = \sum_i (\boldsymbol{M_i} \bullet \boldsymbol{EF_i}) \bullet 10^{-3} - \boldsymbol{R}$$

$$\boldsymbol{N_2Oemissions} = \sum_i (\boldsymbol{M_i} \bullet \boldsymbol{EF_i}) \bullet 10^{-3}$$

Where:

CH_4 emissions	=	Total CH_4 emissions in inventory year [Gg CH_4]
N_2O emissions	=	Total N_2O emissions in inventory year [Gg N_2O]
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 19 of the waste legislation of 17 June 1994 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 by means of the green waste bin (currently up to 65.4%) and the majority of municipalities also collect green waste through door-to-door pick-up (currently up to 72.2%). 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.

136 So far, emission estimates for composting are *__not__* taking CH_4 recovery into account.

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 7-14 lists the amount of compostable waste collected from households and commercial activities in Luxembourg, *i.a.* the three main waste syndicates SICA, SIDEC and SIGRE

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

Table 7-14 – 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
	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**
kg/habitant	*32*	*36*	*45*	*41*	*89*	*99*	*102*	*135*	*121*	*134*	*141*	*135*	*124*	*127*	*128*	*129*	*135*	*130*	*78*	*82*	*74*	*78*	*72*	*86*	*87*	*88*
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
kg/habitant	*20*	*25*	*31*	*25*	*78*	*114*	*133*	*154*	*146*	*156*	*148*	*165*	*170*	*168*	*174*	*175*	*182*	*172*	*112*	*106*	*100*	*107*	*94*	*102*	*93*	*90*
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
kg/habitant	*91*	*91*	*117*	*123*	*146*	*106*	*124*	*161*	*154*	*153*	*151*	*157*	*167*	*158*	*159*	*155*	*157*	*156*						*100*	*244*	*241*
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
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
kg/habitant						*72*	*39*	*91*	*67*	*89*	*89*	*96*	*95*	*91*	*88*	*75*	*80*	*69*	*67*	*81*	*76*	*81*	*72*	*82*	*52*	*51*
Hespérange											611	742	786	743	786	830	743	682	836	862			1'443	1'188	1'298	1'681
kg/habitant											*58*	*69*	*70*	*64*	*66*	*69*	*60*	*53*	*64*	*65*			*102*	*83*	*89*	*112*
Ville de Luxembourg											15'297	9'439	8'083	11'108	9'733	11'921	12'187	13'767								
kg/habitant											*195*	*119*	*101*	*135*	*116*	*139*	*138*	*152*								
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
kg/habitant													*52*	*49*	*64*	*63*	*91*	*76*	*166*	*197*	*178*	*179*	*163*	*195*	*185*	*198*
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

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 7-8).

Figure 7-8 – Emissions from Biological Treatment of Solid Waste in *5B1*

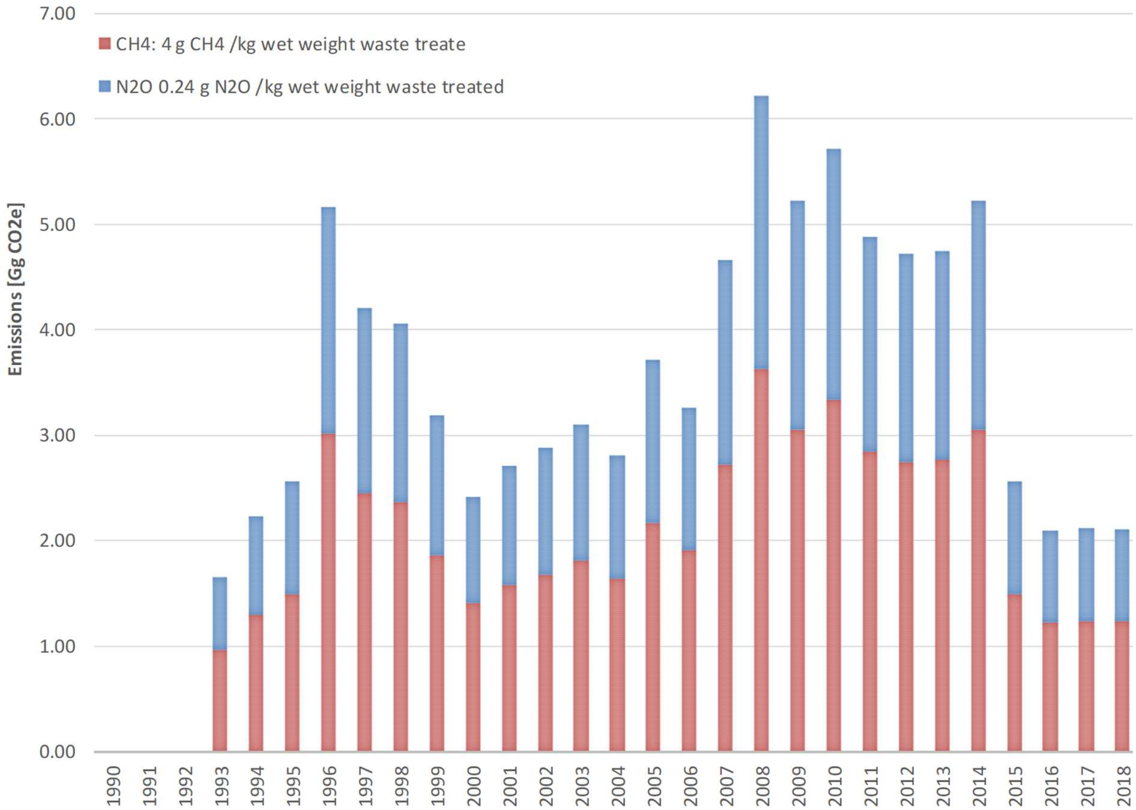


Table 7-15 lists the total emissions from *5B1 – Biogenic Waste Composted at Centralized Composting Plants.*

Table 7-15– Emissions from *5B1 – Biogenic Waste Composted at Centralized Composting Plants*

5B1 - Biogenic waste composted at centralised composting plants

Year	Emissions (Gg) CO_2	CH_4	N_2O	Total in CO_2e
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*	13.37
Trend 1993-2018	*NA*	*407.89%*	*403.79%*	*406.18%*
Trend 2017-2018	*NA*	*5.04%*	*4.19%*	*4.69%*

7.3.2.1.5 Parameters

Emission factors for **compost production** and **biological pre-treatment of solid waste prior landfilling** (Table 7-16) are actually default emission factors for CH_4 and N_2O emissions taken from Table 4.1 in IPCC 2006 Guidelines.

Table 7-16 – Default EFs for CH_4 and N_2O emissions from *5B - Biological Treatment of Waste*

Type of Biological Treatment	CH_4 EF *g CH_4/kg waste treated*	N_2O EF *g N_2O/kg waste treated*	Comment
	on a wet basis		Assumptions on the waste treated: 25-50% DOC in dry matter, 2% N in dry matter, moisture content 60%. EFs for dry waste are estimated from those for wet waste assuming moisture content of 60% in wet waste.
Composting (excluding Soil-Concept project)	4 (0.03 – 8)	0.24 (0.06 - 0.6)	
	on a dry basis		
Soil-Concept project	10 (0.08-20)	0.6 (0.2-1.6)	

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 21 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 21 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 (biogas 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*.

7.3.3.1.3 Methodology

The IPCC methodology has been followed to estimate **CH_4 emissions** from biogas plants due to unintentional leakages, which are assumed to be between 0 and 10% of the amount of CH_4 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 (biogas amounts in Joule, heating value of biogas and CH_4 content in the biogas) available for the category *1 - Energy* to derive a level of CH_4 emissions for the subcategory *5B2 - Biogenic Waste Treated in Biogas Plants* and adapts the method to the collected activity data which derives primarily from agricultural waste and energy plants.

In addition, the average fugitive emission rate has been adapted to 3.1% of the CH_4 gas production rate according to Flesch *et al.* (Flesch et al., October 2011). Comparably, the value of 3% of the CH_4 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), **N_2O emissions** for *5B2 - Biogenic Waste Treated in Biogas Plants* are assumed to be negligible.

7.3.3.1.4 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 23 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 Regulation[137] that CH_4 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.

137 https://web.ilr.lu

- 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 (biogas production).

The majority of the biogas plants in Luxembourg are modern, *i.e.* 20 out of 21 plants are producing biogas since the year 2000. 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 18.9% municipal waste, 59.8% agricultural waste, and 21.3% energy plants (Figure 7-9). 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.

Figure 7-9 – Average Feedstock Distribution of Anaerobic Digesters

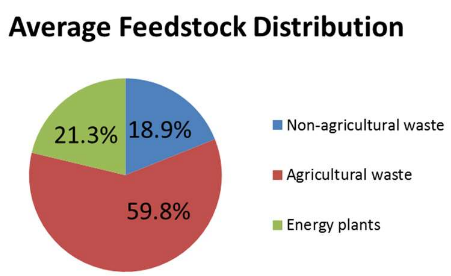


Table 7-17 shows the CH_4 leakage emissions obtained by applying the method adapted to the feedstock distribution as described under *Section 7.3.3.1.2 Methodology*. Annual CH_4 leakage emissions obtained with the IPCC methodology adapted to the national feedstock distribution range from 0.15 Gg CO_2e in 1999 to 11.22 Gg CO_2e in 2018.

Table 7-17 – CH_4 and N_2O emissions from *5B2 – Biogenic Waste Treated in Biogas Plants*

5B2 - Biogenic Waste Treated in Biogas Plants

Year	Biogas Production (GJ)	Methane Production (m^3)	Methane Production (Gg)	CH_4 leakage (Gg)	N_2O (Gg)	Total in CO_2e (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
Trend 1992-2018	5280.9%	5280.9%	5280.9%	5280.9%	NA	5280.9%
Trend 2017-2018	5.67%	5.67%	5.67%	5.67%	NA	5.67%

7.3.3.1.5 Parameters

The following parameters have been used for the estimation of CH_4 leakages based on the IPCC method adapted to national circumstances:

Table 7-18 – Parameters for Estimation of CH_4 Leakages

Parameter	Value	Source
CH_4 calorific value	0.0363 GJ / m^3CH_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. For biological pre-treatment of solid waste prior landfilling, the type, amount and composition of waste are the same as described under CRF *5A*.

The uncertainties for the solid waste quantities undergoing biological treatment are considered the same as in *5A*. 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. The uncertainties from the literature and from other countries vary between -30 % and +60 % for the CH_4 emission factor (IPCC Guidelines), and at least -50 % and +100 % for the N_2O emission factor (see Table 7-21).

7.3.4.2 Biogenic Waste Treated in Biogas Plants (*5B2*)

The uncertainty from the energy sector for the activity data is mainly influenced by the methane content in the generated biogas which is assumed at ± 6% (Agriculture, Ecosystems & Environment, 2007). In addition, the uncertainties depend on the type of facility in question, on the type of process used at the relevant time and on the precautions taken to avoid fugitive emissions. All these information are not available at the moment, thus the uncertainties for the *5B2* subsector are assumed to be high (see Table 7-19).

Table 7-19 – Uncertainties with regard to Activity Data and Emission Factors for category *5B*

Uncertainties	Activity data	Emission factor CH_4 [g CH_4 / kg waste treated *]	Emission factor N_2O [g N_2O / kg waste treated *]
5B1 **-** *Biogenic waste composted at centralised composting plants*	± 6.5 % for composting and pretreated solid waste	-30 % to +60 %	-50 % to +100 %
5B2 **-** *Biogenic waste treated in biogas plants*	see CRF Sector *1 - Energy*	NE	NE

Note: * on a wet weight basis

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

No changes have occurred since the last submission

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

IPCC Category *5D* covers waste water and related sludge handling, whether these have been generated by households or by industrial enterprises. For the moment, Luxembourg's GHG inventory covers domestic, commercial (Sub-category *5D1*) and industrial (Sub-category *5D2*) waste water handling (WWH), excluding sludge. In addition, it is assumed that domestic and commercial WWH corresponds to municipal waste water treatment carried out in waste water treatment plants (*WWTPs*). CO_2 emissions from municipal WWTP are not included in Luxembourg's GHG inventory for the reason that carbon emissions derive from biomass/biogenic raw materials.

To summarize:

- IPCC Category *5D2* covers nitrous oxide emissions from waste water treatment in industry, thus, emissions from IPCC Category *5D* correspond to emissions deriving from IPCC Sub-category *5D2*; emissions related to methane are not applicable;
- IPCC Category *5D1* covers methane and nitrous oxide emissions from waste water treatment in residential and commercial sectors and septic tanks. No CO_2 emissions deriving from non-biological or inorganic WWH residuals have been identified so far;
- Emissions related to the sludge residues of domestic and commercial WWH 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*), Thus, emissions from IPCC Category *5B* correspond to emissions deriving from IPCC Sub-category *5B2*, excluding sludge.

In 2018, this source category 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 CO_2e (excluding LULUCF). For each of the two gases reported, in 2018:

- CH_4 from WWH represented 3.7% of waste treatment methane related emissions – excluding waste incineration – and 0.46% of the total methane emissions estimated for Luxembourg;
- N_2O from WWH 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.

None of the source categories under WWH is a key category.

7.5.2 Methodological Issues – Methane Emissions

Municipal waste water treatment in Luxembourg uses mainly aerobic processes (see Table 7-20) 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 these plants, 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 of methane gas. The gas produced is usually used for energy recovery in combined heat/power generating systems or may be flared.

Table 7-20 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 7-20 – Municipal WWTP capacities and aerobic procedures: 1990-2018

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%
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%
Trend 1990-2018	**80.2%**	**NA**

Source: Water Management Agency

Treatment of human sewage from inhabitants connected to small mechanical treatment facilities or septic tanks represents an exception. The percentage of organic loads discharged to these small treatment units has been reduced consequently since 1990. In this emission inventory, methane emissions from these small anaerobic sludge treatments have been taken into account as there is no gas reuse and therefore methane emissions have been assumed. The methodology for these septic tanks is based on the IPCC method in which the relevant population (individual septic tanks) or population equivalents (for the small mechanical treatment plants) is multiplied by the average organic load *per* person.

The 2006 IPCC default value of 0.6 kg CH_4/kg BOD is used. Each habitant produces 60 g BOD/day, and a MCF of 0.27 is assumed (Steinlechner *et al*. 1994). According to national expert judgment and based on the study of Steinlechner *et al.*, 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 organic load:

*BODsep [kg/year] = inhabitants connected to septic tanks * 60 g BOD (person/day) * 365 (days) / 1000*

*BODmec [kg/year] = inhab. connected to mechanical WWTP * 60 g BOD (person/day) * 365 (days) / 1000*

Calculation of the methane emissions:

CH_4 *sep [t/year] = BODsep * B0 * MCF / 1000 ; where : sep = septic tanks*

CH_4 *mec [t/year] = BODmec * B0 * MCF / 1000*

Where:

mec = mechanical treatment plants

B0 = 0.6 kg CH4/ kg BOD 2006 IPCC Good Practice Guidance (page 6.12)

60 g BOD/person per day: 2006 IPCC Good Practice Guidance (page 6.14) and European Directive 91/271/CEE on the treatment of urbane waste water, Article 2.6

MCF: Methane Conversion Factor (Steinlechner *et al.* (1994): 0.35 * 2/3 + 0.1 * 1/3 = 0.27)

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 treatment plant is based on the last national detailed population inventories. As these censuses take place every ten years, with the most recent one in 2011 the evaluation is based on these population numbers for the years 2011-2013. The new census took place at the beginning of 2011, so that for submission 2014 a recalculation has been done.

<u>Total methane emission from waste water handling:</u>

$$CH_4\ tot = CH_4\ sep + CH_4\ mec\ [t/year)]$$

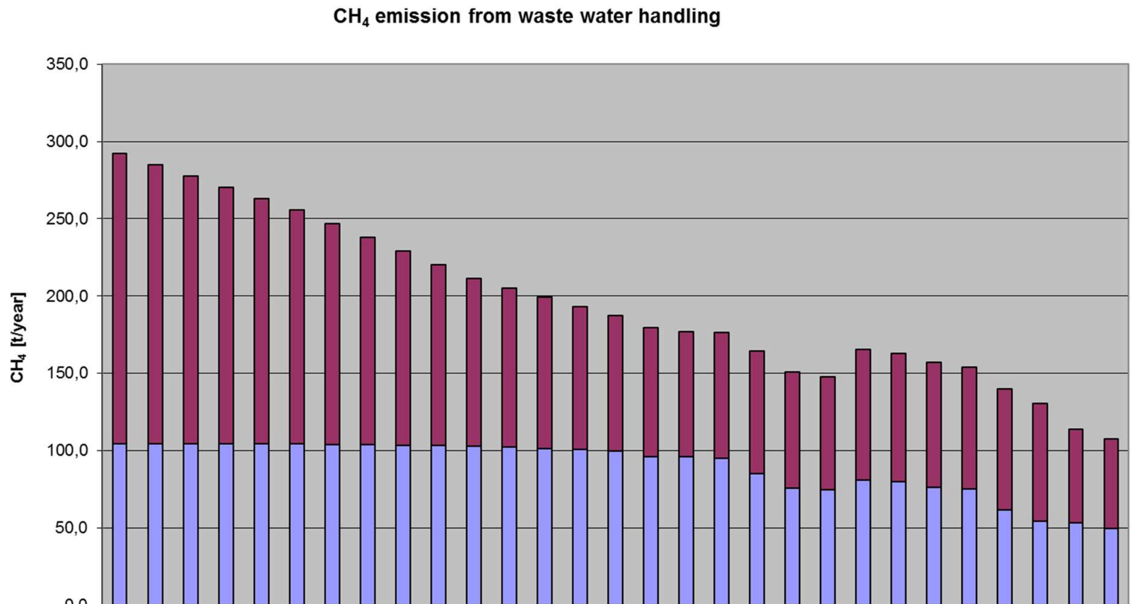
The estimated emissions, obtained following the method described above, are presented in Table 7-21 and Figure 7-10.

Table 7-21 – CH_4 emission trends for category *5D1 – Domestic & Commercial WWH*: 1990-2018

	CH4 emissions (tonnes) 5.D.1 Domestic Wastewater		
Year	**Mechanical**	**Septic Tanks**	**Total**
1990	187.94	104.20	292.14
1991	180.63	104.20	284.83
1992	173.33	104.20	277.53
1993	166.02	104.20	270.22
1994	158.72	104.20	262.92
1995	151.41	104.20	255.61
1996	142.83	103.94	246.77
1997	134.25	103.67	237.92
1998	125.66	103.41	229.08
1999	117.08	103.15	220.23
2000	108.50	102.88	211.38
2001	103.18	102.13	205.31
2002	97.86	101.38	199.24
2003	92.54	100.62	193.17
2004	87.23	99.87	187.10
2005	83.98	95.79	179.77
2006	81.27	95.79	177.06
2007	81.27	95.03	176.30
2008	79.25	85.07	164.32
2009	75.20	75.68	150.88
2010	73.00	74.47	147.47
2011	84.46	80.88	165.33
2012	82.96	79.64	162.60
2013	80.96	76.32	157.28
2014	78.81	75.13	153.94
2015	78.37	61.70	140.07
2016	76.06	54.26	130.32
2017	60.55	53.34	113.89
2018	57.95	49.50	107.44
Trend 1990-2018	-69.17%	-52.50%	-63.22%
2005-2018	-31.00%	-48.33%	-40.23%
2017-2018	-4.31%	-7.21%	-5.66%

<u>Source:</u> Water Management Agency.

Figure 7-10 – CH_4 emission trends for category *5D1 – Domestic & Commercial WWH*: 1990-2018



	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
CH4 mechanical WWTP	187,9	180,6	173,3	166,0	158,7	151,4	142,8	134,2	125,7	117,1	108,5	103,2	97,9	92,5	87,2	84,0	81,3	81,3	79,3	75,2	73,00	84,5	83,0	81,0	78,8	78,4	76,1	60,6	57,9
CH4 septic tanks	104,2	104,2	104,2	104,2	104,2	104,2	103,9	103,7	103,4	103,1	102,9	102,1	101,4	100,6	99,9	95,8	95,8	95,0	85,1	75,7	74,5	80,9	79,6	76,3	75,1	61,7	54,3	53,3	49,5

<u>Source:</u> Water Management Agency.

<u>Methane emissions from industrial waste water treatment:</u>

Industrial waste water treatment and sewage sludge treatment is carried out under aerobic conditions (activated sludge process). As for the municipal facilities, there are no methane emissions.

7.5.3 Methodological Issues – Nitrous Oxide

7.5.3.1 Nitrous Oxide Emissions from Municipal Waste Water

Pursuant to the 2006 IPCC Guidelines, nitrous oxide emissions from household waste water can be evaluated by taking into account the average per capita protein intake. The IPCC default values are used in each case for the nitrous oxide emission factor per kg of nitrogen in waste water and for the nitrogen fraction in protein.

N_2O emissions from urban waste water handling are calculated by distinguishing waste water arising from populations:

a) not connected to a waste water treatment plant (WWTP)
a) connected to a WWTP without denitrification
b) connected to a WWTP with denitrification

After comments during several UNFCCC-reviews and consultation with experts abroad (a.o. reviewers from the EU ESD-review), Luxembourg decided to strictly apply the Tier 1 method described in the 2006-GL (Volume 5, Chapter 6.3). We do realise that this methodology is at discussion (e.g. the method assumes no N_2O-emissions from treatment of the older generation WWTP; the EF for advanced WWTP is very low). However, we have 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 N_2O 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-GL. So, applying these GL makes our estimate more comparable to the estimate in other member states;
- IPCC is currently working on a 2019-Refinement. In the most recent draft our concerns on the 2006-GL are addressed. Rather than developing our own CS-methodology we prefer to wait for the new refinement to be finalised and then align our methodology with the new guidelines.

In our estimate, Luxembourg calculated emissions per discharge pathway (septic tanks, older WWTP without denitrification, advanced waste water treatment plants with nitrification). For septic tanks and older WWTP without denitrification indirect emissions of N_2O are calculated using equation 6.7 and 6.8 in the 2006 GL:

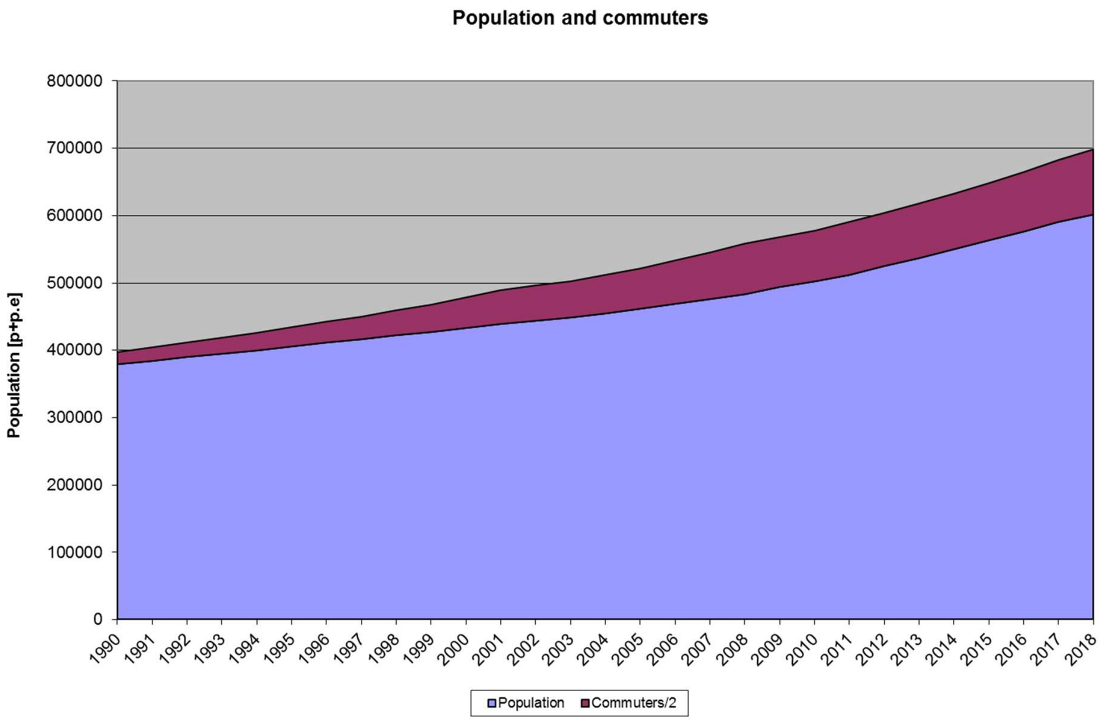
- For septic tanks, no correction is made for N removed with sludge, because no data are available on sludge removal or N-removal from septic tanks. In line with the 2006 guidelines a default value of N_{sludge} of 0 is applied;
- For older WWTP it is assumed that 35% of $N_{effluent}$ is removed as 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 older WWTP. Calculations of sludge production at these WWTP reveal that the majority of this 35% will be removed by sludge and this does not result in *direct* N_2O-emissions at the WWTP. 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 WWTP 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 (an additional 1000 tons CO_2-eq, with a ToS of about 5000 tons CO_2-eq.). Therefore, direct N_2O-emissions from these older WWTP can be neglected.
- For advanced WWTP we apply the guidance as provided in Box 6.1 in the PCC-guidelines and *direct* emissions are calculated using the EF provided. The note in this box indicates that the amount of nitrogen associated with these emissions (N_{wwt}) must be back calculated and subtracted from $N_{effluent}$. The term 'associated' is open to multiple interpretations. In our interpretation 'associated' refers to all N that is fed to WWTP. As a result, $N_{effluent}$-N_{wwt}-is 0 and no indirect emissions are calculated due to discharge of effluent from advanced WWTP.

A sensitivity analysis reveals that the impact on *indirect* N_2O-emissions of a more conservative interpretation of 'associated' (e.g. associated refers to $N_{removed}$ and a N-removal efficiency of 85%) results in additional N_2O-emissions below the threshold of significance for Luxembourg (an additional 950 tons CO_2-eq, with a ToS of about 5000 tons CO_2-eq.). Therefore, *indirect* N_2O-emissions from these advanced WWTP can be neglected.

The N_2O emissions resulting from the population not connected to a WWTP were calculated according the 2006 IPCC default approach. For the nitrous oxide calculation, daily commuters have also been taken into account, in addition to the residents of the country. As these commuters spend only their working hours in the country, their impact was calculated using only half of their nitrous oxide load. The numbers of inhabitants and the commuters are provided by the STATEC.

Figure 7-11 illustrates the population and cross-border commuters' growth between 1990 and 2018. The latter is divided by 2 in the figure below (so that only a half load of nitrogen is counted for by commuting individual).

Figure 7-11 – Resident population and cross-border commuters: 1990-2018



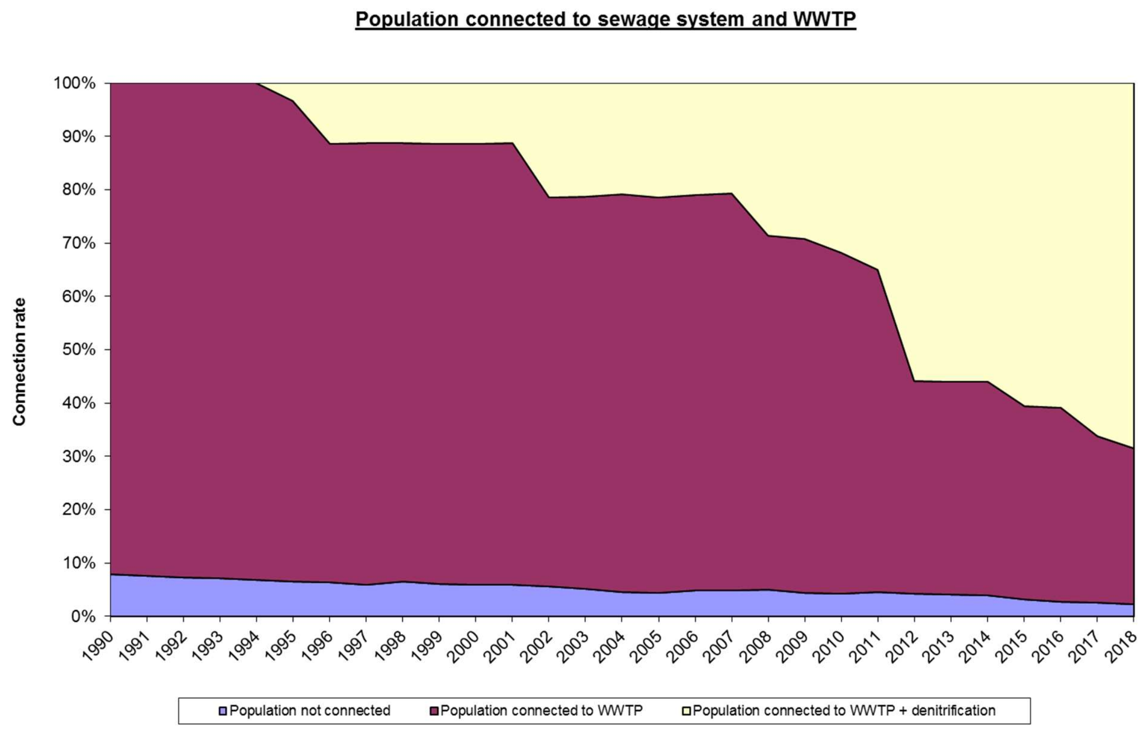
Sources: Le Portail des Statistiques au Luxembourg, *Statistical Yearbook*,
http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12928&IF_Language=fra&MainTheme=2&FldrName=3&RFPath=92
http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=12861&IF_Language=fra&MainTheme=2&FldrName=1

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. WWTP 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.

For the current evaluation of the N_2O emissions the methodology of the 2006 IPCC Guidelines has been applied with a default value 3.2 g N_2O per capita per year (for biological waste water treatment plant with denitrification processes) as well a factor of Find-com of 1.25 based on data in Metcalf & Eddy (2003) and expert judgment.

Figure 7-12 provides an overview of the population of Luxembourg connected to WWTPs (with or without denitrification) or not. In 2014, the number of the population connected to WWTPs with denitrification increased considerably due to the fact that 3 new WTTPs with denitrification went online. Consequently, N_2O emissions were reduced accordingly.

Figure 7-12 – Population connected to sewage system and biological WWTP: 1990-2018



Source: Water Management Agency.

Following the in-country review 2018, Luxembourg:

- added "non consumed protein fraction" factor ($F_{non-con}$) at 1.1 (2006 IPCC Guidelines default value, page 6.27), since garbage disposal installations on sinks are not allowed in Luxembourg;
- adapted protein intake parameters based on the latest activity report data with extrapolation for missing years (FAO Statistical Yearbook 2010[138]).

[138] http://www.fao.org/3/am081m/PDF/am081m00d.pdf (consulted 07-12-2018)

Determination of N_2O from waste water not connected to a biological WWTP (2006 IPCC Guidelines):

$$N_2O\ nc\ [t/year] = N\ effluent * F\ ind\text{-}com * F\ non\text{-}con * EF\ effluent / 1000 * 44/28$$

Where:

nc = not connected

N effluent = P * Protein * F NPR with P = inhabitants (p. e.) not connected

Protein = protein intake per person (kg/year) (http://www.fao.org)

EF effluent = Emission Factor 0.005 (2006 IPCC Guidelines default value, page 6.25)

F ind-com = fraction of industrial and commercial co-discharged protein (default = 1.25, based on data in Metcalf & Eddy (2003) and expert judgment; IPCC Guidelines, page 6.26)

F NPR = 0.16 kg N/kg protein (2006 IPCC Guidelines, page 6.25)

F non-con = factor to adjust for non-consumed protein 1,1 (2006 IPCC Guidelines default value, page 6.27)

44/28 = 1.57: conversion of N_2O-N to N_2O (44/28, N_2O/N))

Determination of N_2O from waste water connected to a biological WWTP without denitrification:

$$N_2Owwtp\ [t/year] = N\ effluent * F\ ind\text{-}com * F\ non\text{-}con * EF\ effluent / 1000 * \%\ FRAC\ denitri * 44/28$$

Where:

WWTP = waste water treatment plant

N effluent = P * Protein * F NPR with P = population connected

Protein = protein intake per person (kg/year) (http://www.fao.org)

F NPR = 0.16 kg N/kg protein (2006 IPCC Guidelines, page 6.25)

EF effluent = Emission Factor 0.005 (2006 IPCC Guidelines default value, page 6.25)

% FRAC denitri = 35 % denitrification rate (% of waste water which is denitrified)

F ind-com = fraction of industrial and commercial co-discharged protein (default = 1.25, based on data in Metcalf & Eddy (2003) and expert judgment, IPCC Guidelines, page 6.26)

F non-con = factor to adjust for non-consumed protein 1,1 (2006 IPCC Guidelines default value, page 6.27)

44/28 = 1.57, conversion of N_2O-N to N_2O (44/28, N_2O/N)

Determination of N_2O from waste water connected to a biological WWTP with denitrification:

$$N_2Owwtp\text{-}de = P * F\ ind\text{-}com * EF\ plant / 1.000.000 \qquad [t/year]$$

Where:

wwtp-de = waste water treatment plant with denitrification

P = inhabitants connected

F ind-com = fraction of industrial and commercial co-discharged protein (default = 1.25, based on data in Metcalf & Eddy (2003) and expert judgment; IPCC Guidelines, page 6.26)

EF plant = emission factor, 3.2 g N_2O / person / year

Determination of N_2O total emission from waste water handling:

N_2Omun tot [t/year] = N_2O not connected + N_2O connected to WWTP without denitrification + N_2O connected to WWTP with denitrification

Where:

mun = municipal waste water

The estimated emissions obtained following the method described above are presented in

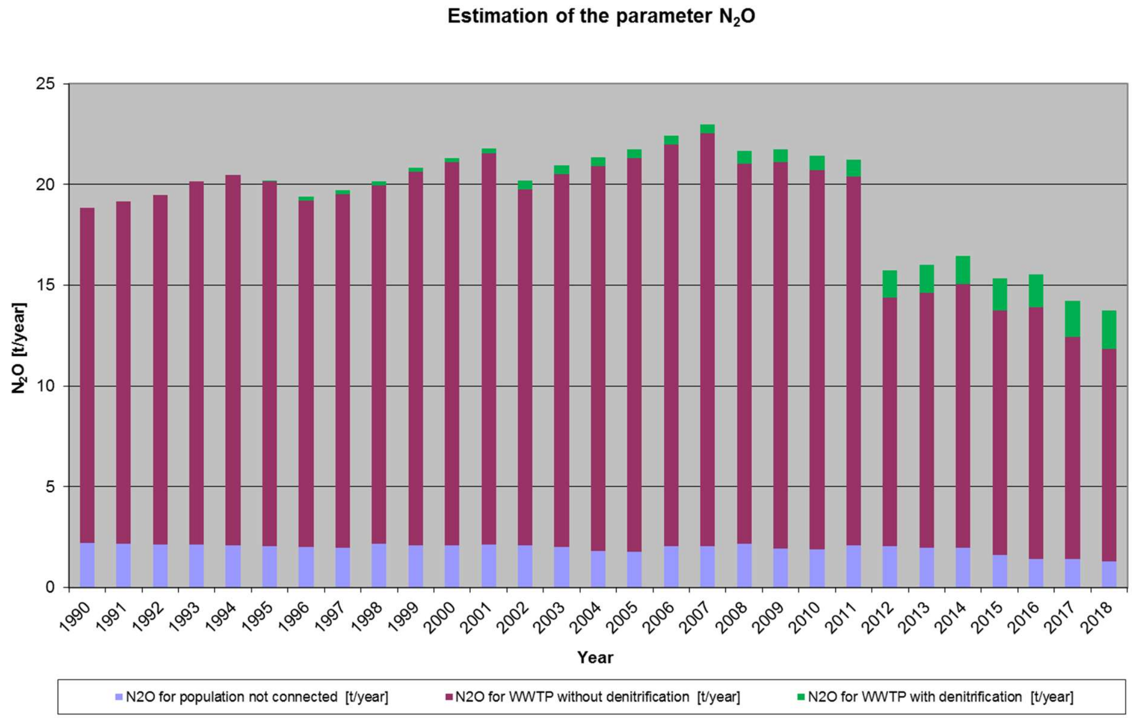
Table 7-22 and Figure 7-13.

Table 7-22 – N_2O emission trends for category *5D1 – Domestic & Commercial WWH*: 1990-2018

	N_2O emissions (tonnes) 5.D.1 Domestic Wastewater			
Year	**N_2O nc**	**N_2O wwtp**	**N_2O wwtp-de**	**Total**
1990	2.20	16.64	NO	18.84
1991	2.16	17.00	NO	19.16
1992	2.12	17.36	NO	19.48
1993	2.12	18.04	NO	20.16
1994	2.08	18.41	NO	20.49
1995	2.03	18.12	NO	20.15
1996	2.03	17.16	NO	19.19
1997	1.96	17.56	0.20	19.72
1998	2.16	17.80	0.21	20.17
1999	2.09	18.53	0.21	20.83
2000	2.11	18.99	0.22	21.32
2001	2.12	19.44	0.22	21.78
2002	2.10	17.67	0.43	20.19
2003	2.02	18.50	0.43	20.94
2004	1.82	19.08	0.43	21.33
2005	1.78	19.53	0.45	21.76
2006	2.04	19.92	0.45	22.42
2007	2.06	20.49	0.45	23.00
2008	2.19	18.83	0.64	21.67
2009	1.94	19.15	0.66	21.76
2010	1.91	18.78	0.74	21.43
2011	2.10	18.32	0.83	21.24
2012	2.06	12.34	1.35	15.75
2013	1.98	12.65	1.39	16.01
2014	1.96	13.10	1.42	16.47
2015	1.61	12.14	1.57	15.33
2016	1.42	12.50	1.62	15.54
2017	1.40	11.03	1.81	14.23
2018	1.30	10.54	1.91	13.75
Trend 1990-2018	-40.78%	-36.65%	838%	-26.99%
2005-2018	-26.82%	-46.03%	328%	-36.78%
2017-2018	-6.87%	-4.39%	6%	-3.34%

Source: Water Management Agency.

Figure 7-13 – N_2O emission trends for category *5D1 – Domestic & Commercial WWH*: 1990-2018



Source: Water Management Agency.

7.5.3.2 Nitrous Oxide Emissions from Industrial WWTP

N_2O 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 products. Both release N to aquatic environments. These industrial waste water treatment plants (WWTP) are equipped with a biological treatment with denitrification. N_2O emissions are based on the measured inflow data in the WWTP. The data available since the year 2002 are the flow as well as the mean annual nitrogen concentration in the WWTP.

The determination of N_2O from waste water connected to an industrial waste water treatment plant with denitrification is calculated as follows:

*N_2O ind = N cc [mg/l] * Inflow [m3/a] /1000 * % FRAC denitri * 0.01 *44/28 [t/year]*

Where:

ind = industrial

N cc = N concentration in mg/l (measured data)

Inflow = flow in m^3/year (measured data)

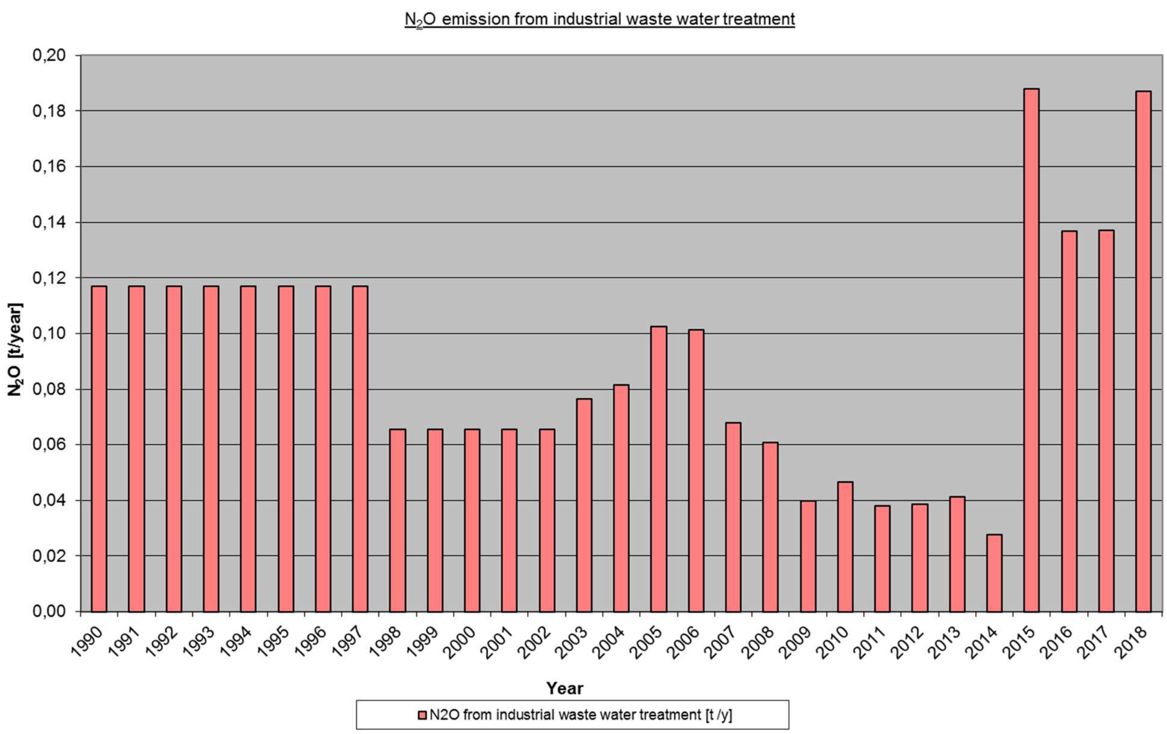
% FRAC denitri = 70% denitrification rate in % (% of waste water which is denitrified)

0.01 = 1% of the denitrified N is emitted as N_2O (ORTHOFER *et al*. 1995)

44/28 = 1.57, conversion of N_2O-N to N_2O (44/28, N_2O/N)

The estimated emissions obtained following the method described above are presented in Figure 7-14.

Figure 7-14 – N_2O emission trends for category *5D2 – Industrial Waste Water WWH*: 1990-2018



Source: Water Management Agency.

Determination of N concentration:

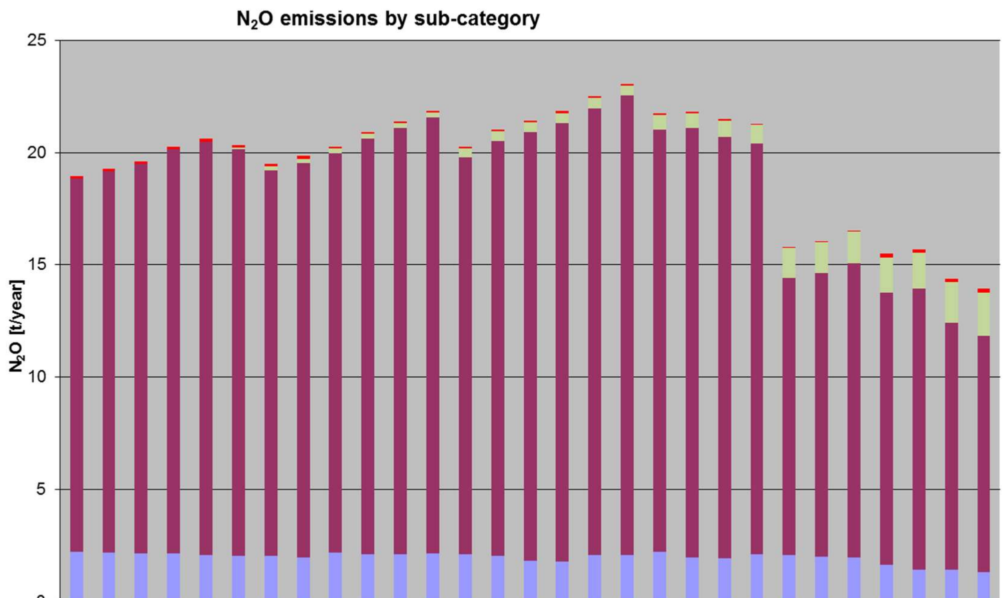
Year 1990 - 1997	Year 1998 - 2002	Year 2002 – 2014	Since 2015
N concentration extrapolated by expert judgment of the water management administration	N concentration extrapolated by expert judgment of the water management administration. In 1998 the WWTP has been upgraded allowing also denitrification	N concentration based on monitoring analyses	N concentration based on monitoring analyses (for both industrial plants)

7.5.3.4 Determination of the Total Nitrous Oxide Emissions

$$N_2O\ tot = N_2O\ mun\ tot + N_2O\ ind$$

The estimated emissions obtained following the formula described above are presented in Figure 7-15 and Table 7-23.

Figure 7-15 - N_2O emission trends for category 5D1 and category 5D2 WWH: 1990-2018



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
N2O from industrial waste water treatment [t /y]	0,12	0,12	0,12	0,12	0,12	0,12	0,12	0,12	0,07	0,07	0,07	0,07	0,07	0,08	0,08
N2O for WWTP with denitrification [t/year]	0,00	0,00	0,00	0,00	0,00	0,06	0,20	0,20	0,21	0,21	0,22	0,22	0,43	0,43	0,43
N2O for WWTP without denitrification [t/year]	16,6	17,0	17,4	18,0	18,4	18,1	17,2	17,6	17,8	18,5	19,0	19,4	17,7	18,5	19,1
N2O for population not connected [t/year]	2,2	2,2	2,1	2,1	2,1	2,0	2,0	2,0	2,2	2,1	2,1	2,1	2,1	2,0	1,8

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
N2O from industrial waste water treatment [t /y]	0,10	0,10	0,07	0,06	0,04	0,05	0,04	0,04	0,04	0,03	0,19	0,14	0,14	0,19
N2O for WWTP with denitrification [t/year]	0,45	0,45	0,45	0,64	0,66	0,74	0,83	1,35	1,39	1,42	1,57	1,62	1,81	1,91
N2O for WWTP without denitrification [t/year]	19,5	19,9	20,5	18,8	19,2	18,8	18,3	12,3	12,7	13,1	12,1	12,5	11,0	10,5
N2O for population not connected [t/year]	1,8	2,0	2,1	2,2	1,9	1,9	2,1	2,1	2,0	2,0	1,6	1,4	1,4	1,3

Year

Source: Water Management Agency.

Table 7-23 – N_2O emission trends for category *5D1* and category *5D2* WWH: 1990-2018

Year	N2O emissions (tonnes) 5.D.1 Domestic Wastewater & 5.D.2 Industrial Wastewater				
	N_2O nc	N_2O wwtp	N_2O wwtp-de	N_2O ind	Total
1990	2.20	16.64	NO	0.12	18.96
1991	2.16	17.00	NO	0.12	19.27
1992	2.12	17.36	NO	0.12	19.59
1993	2.12	18.04	NO	0.12	20.27
1994	2.08	18.41	NO	0.12	20.61
1995	2.03	18.12	0.06	0.12	20.33
1996	2.03	17.16	0.20	0.12	19.51
1997	1.96	17.56	0.20	0.12	19.84
1998	2.16	17.80	0.21	0.07	20.24
1999	2.09	18.53	0.21	0.07	20.90
2000	2.11	18.99	0.22	0.07	21.38
2001	2.12	19.44	0.22	0.07	21.85
2002	2.10	17.67	0.43	0.07	20.26
2003	2.02	18.50	0.43	0.08	21.02
2004	1.82	19.08	0.43	0.08	21.41
2005	1.78	19.53	0.45	0.10	21.86
2006	2.04	19.92	0.45	0.10	22.52
2007	2.06	20.49	0.45	0.07	23.07
2008	2.19	18.83	0.64	0.06	21.73
2009	1.94	19.15	0.66	0.04	21.80
2010	1.91	18.78	0.74	0.05	21.48
2011	2.10	18.32	0.83	0.04	21.28
2012	2.06	12.34	1.35	0.04	15.79
2013	1.98	12.65	1.39	0.04	16.05
2014	1.96	13.10	1.42	0.03	16.50
2015	1.61	12.14	1.57	0.19	15.52
2016	1.42	12.50	1.62	0.14	15.68
2017	1.40	11.03	1.81	0.14	14.37
2018	1.30	10.54	1.91	0.19	13.94
Trend 1990-2018	-40.78%	-36.65%	3151%	60%	-26.45%
2005-2018	-26.82%	-46.03%	328%	82%	-36.23%
2017-2018	-6.87%	-4.39%	6%	36%	-2.96%

Source: Water Management Agency.

7.5.4 Uncertainties and Time-Series Consistency

- Waste water quantity: 10 % not connected to waste water treatment plants
- Emission factor for N_2O: 50% (IPCC 2006 - Guidelines)
- Emission factor for CH_4: 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 1.7.

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 Luxemburg);
- 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

Table 7-24 presents the main revisions and recalculations done relevant to category *5D*.

Table 7-24 - Changes in GHG inventory since submission 2019v1

GHG source & sink category	Revisions 2019v1 → 2020v1	Type of revision
5D	No recalculations were operated	

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 7-25 will be explored.

Table 7-25 – Planned improvements for category 5D – WWH

GHG source & sink category	Planned improvement
5D1 – Domestic & Commercial WWH – CH_4	List of WWTPs which produce methane gas for energy reuse in combined heat/power generating systems
5D1 – Domestic & Commercial WWH	Reassessment of the EF_{plant} for WWTP with and without denitrification following comments from ERT. Ongoing second study with the Umweltbundesamt Austria
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 CO_2 and nitrous oxide emissions[139]

No indirect CO_2 and nitrous oxide emissions have been reported.

[139] Content of this chapter should be consistent with paragraph 29. In addition, Annex I Parties should provide information on the following precursor gases: carbon monoxide (CO), nitrogen oxides (NO_X) and non-methane volatile organic compounds (NMVOCs), as well as sulphur oxides (SO_X). Annex I Parties may report indirect CO_2 from the atmospheric oxidation of CH_4, CO and NMVOCs. Annex I Parties may report as a memo item indirect N_2O emissions from other than the agriculture and LULUCF sources. These estimates of indirect N_2O should not be included in national totals. For Parties that decide to report indirect CO_2 the national totals shall be presented with and without indirect CO_2.

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 2019v1

GHG source & sink category	Revisions 2019v1 ➔ 2020v1	Type of revision
1A1a – liquid fuels	The country-specific CO_2 emission factor for gasoil was revised for the entire timeseries because the emission factors of the importing countries have changed (Table 3-73).	CO_2 EF
1A1a - biomass	Activity data for wood and wood products from 2013-2017 was revised according to the national energy balance.	AD
1A1a – liquid fuels	Activity data for heating gasoil from 2000-2017 was revised according to the national energy balance.	AD
1A2	Fuel consumption data for natural gas and heating gasoil for the years 2015-2017 was revised due to revised energy balance from the national statistics institute	AD
1A2	The country-specific CO_2 EFs for gasoil/diesel oil and gasoline were revised for the entire timeseries due to changes of the emission factors of the importing countries (Table 3-74)	CO_2 EF
1A2gvii	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. For submission 2019v1, these models used emission factors from HBEFA3.3. For submission 2020v1, the newer version HBEFA4.1 was implemented. Due to this methodological change, the allocation of fuel quantities to the different road and offroad subsectors was also revised.	AD
1A2gvii	CH_4 and N_2O EFs for offroad machinery were modified from HBEFA3.3 to HBEFA4.1	EF
1A3b/c/d	Country-specific CO_2 emission factors for gasoline and diesel changed for the entire time-series because the Netherlands changed their national emission factors (see Table 3-74).	updated EF
1A3b/c/d	CH_4 and N_2O emission factors were updated from HBEFA 3.3 to HBEFA4.1	Updated EF
1A3b/c/d	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. For submission 2019v1, these models used emission factors from HBEFA3.3. For submission 2020v1, the newer version HBEFA4.1 was implemented. Due to this methodological change, the allocation of fuel quantities to the different road and offroad subsectors was also revised.	Updated AD
1A4	Fuel consumption data for natural gas for 2017 was revised due to revised energy balance from the national statistics institute	AD
1A4bii/cii	The country-specific CO_2 EF for gas/diesel oil and gasoline was revised for the entire timeseries due to changes of the emission factors of the importing countries (Table 3-74)	CO_2 EF
1A4bii/cii	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. For submission 2019v1, these models used emission factors from HBEFA3.3. For submission	AD

GHG source & sink category	Revisions 2019v1 ➔ 2020v1	Type of revision
	2020v1, the newer version HBEFA4.1 was implemented. Due to this methodological change, the allocation of fuel quantities to the different road and offroad subsectors was also revised.	
1A4bii/cii	CH4 and N2O EFs for offroad machinery were modified from HBEFA3.3 to HBEFA4.1	CH_4 / N_2O EF
1A5b	The country-specific CO_2 EF for gas/diesel oil was revised for the entire timeseries due to changes of the emission factors of the importing countries (Table 3-74)	CO_2 EF
1A5b	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. For submission 2019v1, these models used emission factors from HBEFA3.3. For submission 2020v1, the newer version HBEFA4.1 was implemented. Due to this methodological change, the allocation of fuel quantities to the different road and offroad subsectors was also revised.	AD
1A5b	CH4 and N2O EFs for offroad machinery were modified from HBEFA3.3 to HBEFA4.1	EF
1D - Reference approach – jet kerosene	Error correction for the years 2010, 2014, and 2015	Error correction
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".	AD, EF
2.D.3.2	The activity data for the years 2005 to 2017 was updated due to updates of fleet parameters and emission factors in the NEMO model.	AD
2.F.2	Foam blowing: data has been revised for the years 2009-2017.2F1 - Mobile refrigeration and air conditioning in passenger vehicles: new data regarding the population of cars using alternatives to R134a, such as R1234yf, has been obtained and implemented for the years 2016-2018.	AD
2.F.4	Aerosols/Metered dose inhalers: data for the year 2017 has been revised and updated.	AD
2.G.2.b	Particle accelerators: the category was created following the suggestion made during the UNFCCC in-country review of 2018.	New category
2.G.3.b	Propellant for pressure and aerosol products: data for the years 2016 and 2017 have been revised.	AD
3.	A detailed description of the recalculations made in the agriculture sector is given in Annex 3A.	
4.	Please refer to section 0	
5.A	The emissions for 2017 were updated as the methane recovery was corrected for that year.	Error correction
5.A	The timeseries from 2000-2018 for N_2O emissions was corrected due to an error in one of the calculation spreadsheets.	Error correction
5D1	Recalculation following UNFCCC reviews	
5D1	Added $F_{non\text{-}con}$ for N_2O calculations	
5D1	Adapted protein intake	
5D1	Adapted denitrification % in tables	

10.1.2 KP-LULUCF inventory

The same modifications were made as described in section 0.

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

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Base year (1990 (Gg)	2000 (Gg)	2010 (Gg)	2015 (Gg)	2016 (Gg)	2017 (Gg)
Emissions of HFCs - (kt CO2 equivalent)	-	-	-0.01	0.11	0.41	-2.06
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)	0.41	0.43	0.42	0.48	0.49	0.50
Emissions of NF3 - (kt CO2 equivalent)	NO	NO	NO	NO	NO	NO

Table 10-6 present the recalculations of CO_2, CH_4, N_2O, F-gases and total GHG emissions for the years 1990, 2000, 2010 and 2015-2017.

Table 10-2 – CO_2 emissions: recalculations done since submission 2019v1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	2000	2010	2015	2016	2017
	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
1. Energy	**1.18**	**3.07**	**2.36**	**2.63**	**3.96**	**6.25**
A. Fuel Combustion (Sectoral Approach)	1.18	3.07	2.36	2.63	3.96	6.25
1. Energy Industries	-	-1.17	-1.01	-0.23	-0.30	-0.61
2. Manufacturing Industries and Construction	-0.08	-0.03	-0.30	7.24	13.80	3.09
3. Transport	2.11	4.48	4.49	-9.55	-8.94	-1.94
4. Other Sectors	-0.84	-0.20	-0.82	5.17	-0.60	5.71
5. Other	0.00	0.00	0.00	0.00	0.00	0.00
B. Fugitive Emissions from Fuels	-	-	-	-	-	-
1. Solid Fuels	NO	NO	NO	NO	NO	NO
2. Oil and natural gas and other emissions from energy	-	-	-	-	-	-
C. CO2 transport and storage	NO	NO	NO	NO	NO	NO
2. Industrial Processes	**-1.28**	**-0.11**	**-0.42**	**-0.96**	**-0.54**	**-0.72**
A. Mineral industry	-	-	-	-	-	-
B. Chemical industry	NO	NO	NO	NO	NO	NO
C. Metal industry	-	-	-	-	-	-
D. Non-energy products from fuels and solvent use	-1.28	-0.11	-0.42	-0.96	-0.54	-0.72
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	**-**	**-**	**-**	**0.59**	**0.84**	**1.41**
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	-	-	-	0.59	0.84	1.41
H. Urea application	NE	NE	NE	NE	NE	NE
I. Other carbon-containing fertilizers	NO	NO	NO	NO	NO	NO
J. Other	NO	NO	NO	NO	NO	NO
4. Land use, land-use change and forestry (2)	**-23.31**	**-46.04**	**-31.07**	**-59.62**	**-57.26**	**-58.60**
A. Forest land	-25.15	-27.55	-4.09	-35.82	-36.43	-36.82
B. Cropland	-0.04	-0.01	0.00	0.00	0.00	0.00
C. Grassland	-0.16	-0.03	-0.01	-0.01	-0.01	-0.01
D. Wetlands	0.00	0.00	0.00	0.00	0.00	0.00
E. Settlements	-0.05	-0.04	-0.01	-0.01	-0.01	-0.01
F. Other land	0.00	0.00	0.00	0.00	0.00	0.00
G. Harvested wood products	2.11	-18.40	-26.95	-23.78	-20.81	-21.75
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	0.00	0.00	4.71	-0.01	0.00	0.00
Aviation	0.00	0.00	4.71	-0.01	-	0.00
Navigation	0.00	0.00	0.00	0.00	0.00	0.00
Multilateral operations	NO	NO	NO	NO	NO	NO
CO_2 emissions from biomass	-	-	0.00	-0.09	-0.09	-33.31
CO_2 captured	NO	NO	NO	NO	NO	NO
Long-term storage of C in waste disposal sites	NE	NE	NE	NE	NE	NE
Indirect N_2O						
Total CO_2 equivalent emissions without LULUCF	-0.10	2.96	1.94	2.25	4.26	6.94
Total CO_2 equivalent emissions with LULUCF	-23.41	-43.07	-29.12	-57.37	-53.00	-51.66
Total CO_2 equivalent emissions, including indirect CO_2,	NA	NA	NA	NA	NA	NA
Total CO_2 equivalent emissions, including indirect CO_2, with	NA	NA	NA	NA	NA	NA

Table 10-3 – CH_4 emissions: recalculations done since submission 2019v1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	2000	2010	2015	2016	2017
	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
1. Energy	**0.05**	**0.03**	**0.04**	**0.07**	**0.08**	**0.04**
A. Fuel combustion (sectoral approach)	0.05	0.03	0.04	0.07	0.08	0.04
1. Energy industries	-	0.00	0.00	0.00	0.00	-0.01
2. Manufacturing industries and construction	-	-	0.00	0.00	0.00	0.00
3. Transport	0.05	0.03	0.04	0.07	0.08	0.09
4. Other sectors	-	-	-	0.00	0.00	-0.04
5. Other	-	-	-	-	-	0.00
B. Fugitive emissions from fuels	-	-	-	-	-	-
1. Solid fuels	NO	NO	NO	NO	NO	NO
2. Oil and natural gas and other emissions from energy	-	-	-	-	-	-
C. CO2 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	**0.01**	**0.04**	**-0.01**	**-0.03**	**-0.04**	**-0.03**
A. Enteric fermentation	0.00	0.00	0.00	0.00	0.00	0.01
B. Manure management	0.01	0.05	-0.01	-0.03	-0.04	-0.04
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**	**NO**	**NO**	**NO**	**NO**	**NO**
A. Forest land	NO	NO	NO	NO	NO	NO
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	**-**	**-**	**-**	**0.00**	**0.00**	**-0.01**
A. Solid waste disposal	-	-	-	-	-	-0.01
B. Biological treatment of solid waste	NO,IE	-	-	0.00	0.00	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	-	-	-	-	-	-
E. Other	NO	NO	NO	NO	NO	NO
6. Other (as specified in summary 1.A)	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
Total CH_4 emissions without CH_4 from LULUCF	**0.06**	**0.07**	**0.03**	**0.04**	**0.03**	**0.00**
Total CH_4 emissions with CH_4 from LULUCF	**0.06**	**0.07**	**0.03**	**0.04**	**0.03**	**0.00**
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	-	-	-	-	-	-
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 – N_2O emissions: recalculations done since submission 2019v1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990 (Gg)	2000 (Gg)	2010 (Gg)	2015 (Gg)	2016 (Gg)	2017 (Gg)
1. Energy	-0.01	-0.01	-0.01	0.02	0.03	0.03
A. Fuel combustion (sectoral approach)	-0.01	-0.01	-0.01	0.02	0.03	0.03
1. Energy industries	-	0.00	0.00	0.00	0.00	0.00
2. Manufacturing industries and construction	-	-	0.00	0.00	0.00	0.00
3. Transport	-0.01	-0.01	-0.01	0.02	0.03	0.03
4. Other sectors	-	-	-	0.00	0.00	0.00
5. Other	-	-	-	-	-	0.00
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	NO	NO	NO	NO	NO	NO
C. CO2 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	**-0.05**	**-0.04**	**-0.04**	**-0.05**	**-0.05**	**-0.05**
A. Enteric fermentation						
B. Manure management	-0.03	-0.03	-0.02	-0.02	-0.03	-0.03
C. Rice cultivation						
D. Agricultural soils	-0.02	-0.01	-0.02	-0.03	-0.03	-0.02
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	NO	NO	NO	NO	NO
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**
A. Solid waste disposal						
B. Biological treatment of solid waste	NA,NO	0.00	0.00	0.00	0.00	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	-	-	-	-	-	-
E. Other	NO	NO	NO	NO	NO	NO
6. Other (as specified in summary 1.A)	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
Total direct N_2O emissions without N_2O from LULUCF	**-0.06**	**-0.05**	**-0.05**	**-0.03**	**-0.02**	**-0.02**
Total direct N_2O emissions with N_2O from LULUCF	**-0.06**	**-0.05**	**-0.05**	**-0.03**	**-0.02**	**-0.02**
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	-	-
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 2019v1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Base year (1990	2000	2010	2015	2016	2017
	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
Emissions of HFCs - (kt CO2 equivalent)	-	-	-0.01	0.11	0.41	-2.06
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)	0.41	0.43	0.42	0.48	0.49	0.50
Emissions of NF3 - (kt CO2 equivalent)	NO	NO	NO	NO	NO	NO

Table 10-6 – Total GHG emissions: recalculations done since submission 2019v1

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	1990	2000	2010	2015	2016	2017
CO_2 equivalents	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
1. Energy	**-0.26**	**1.31**	**1.68**	**10.86**	**14.04**	**16.24**
A. Fuel combustion (sectoral approach)	-0.26	1.31	1.68	10.86	14.04	16.24
1. Energy industries	-	-1.18	-1.02	-0.23	-0.31	-0.92
2. Manufacturing industries and construction	-0.08	-0.03	-0.30	7.64	14.16	3.32
3. Transport	0.66	2.71	3.82	-1.75	0.79	9.42
4. Other sectors	-0.84	-0.20	-0.82	5.21	-0.60	4.42
5. Other	0.00	0.00	0.00	0.00	0.00	0.00
B. Fugitive emissions from fuels	-	-	-	-	-	-
1. Solid fuels	NO	NO	NO	NO	NO	NO
2. Oil and natural gas and other emissions from energy	-	-	-	-	-	-
C. CO2 transport and storage	NO	NO	NO	NO	NO	NO
2. Industrial processes	**-0.88**	**0.32**	**-0.01**	**-0.37**	**0.36**	**-2.28**
A. Mineral industry	-	-	-	-	-	-
B. Chemical industry	NO	NO	NO	NO	NO	NO
C. Metal industry	-	-	-	-	-	-
D. Non-energy products from fuels and solvent use	-1.28	-0.11	-0.42	-0.96	-0.54	-0.72
E. Electronic industry	NO	NO	NO	NO	NO	NO
F. Product uses as ODS substitutes	-	-	-0.01	0.11	0.41	-2.06
G. Other product manufacture and use	0.41	0.43	0.42	0.48	0.49	0.50
H. Other	NO	NO	NO	NO	NO	NO
3. Agriculture	**-14.18**	**-11.26**	**-12.57**	**-15.51**	**-15.98**	**-14.03**
A. Enteric fermentation	-0.04	-0.05	-0.06	-0.07	-0.06	0.21
B. Manure management	-7.63	-9.08	-7.17	-8.02	-8.57	-8.45
C. Rice cultivation	NO	NO	NO	NO	NO	NO
D. Agricultural soils	-6.50	-2.13	-5.33	-8.02	-8.19	-7.20
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	-	-	-	0.59	0.84	1.41
H. Urea application	NE	NE	NE	NE	NE	NE
I. Other carbon-containing fertilizers	NO	NO	NO	NO	NO	NO
J. Other	NO	NO	NO	NO	NO	NO
4. Land use, land-use change and forestry (2)	**-23.31**	**-46.04**	**-31.07**	**-59.62**	**-57.26**	**-58.60**
A. Forest land	-25.15	-27.55	-4.09	-35.82	-36.43	-36.82
B. Cropland	-0.04	-0.01	0.00	0.00	0.00	0.00
C. Grassland	-0.16	-0.03	-0.01	-0.01	-0.01	-0.01
D. Wetlands	0.00	0.00	0.00	0.00	0.00	0.00
E. Settlements	-0.05	-0.04	-0.01	-0.01	-0.01	-0.01
F. Other land	0.00	0.00	0.00	0.00	0.00	0.00
G. Harvested wood products	2.11	-18.40	-26.95	-23.78	-20.81	-21.75
H. Other	NO	NO	NO	NO	NO	NO
5. Waste	**-**	**0.59**	**-0.12**	**0.19**	**0.32**	**-0.32**
A. Solid waste disposal	-	-	-	-	-	-0.14
B. Biological treatment of solid waste	NA,NO,IE	0.59	-0.12	0.19	0.32	-0.18
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:						
International bunkers	0.00	0.00	4.75	-0.01	0.00	0.00
Aviation	0.00	0.00	4.75	-0.01	-	-
Navigation	0.00	0.00	0.00	0.00	0.00	0.00
Multilateral operations	NO	NO	NO	NO	NO	NO
CO_2 emissions from biomass	-	-	0.00	-0.09	-0.09	-33.31
CO_2 captured						
Long-term storage of C in waste disposal sites						
Indirect N_2O						
Total CO_2 equivalent emissions without land use, land-use	**-15.31**	**-9.03**	**-11.01**	**-4.84**	**-1.27**	**-0.39**
Total CO_2 equivalent emissions with land use, land-use	**-38.62**	**-55.07**	**-42.08**	**-64.46**	**-58.53**	**-58.98**
Total CO_2 equivalent emissions, including indirect CO_2,	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
Total CO_2 equivalent emissions, including indirect CO_2, 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 1990-2017 (in Gg CO_2eq 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).

	total GHG emissions excl. LULUCF			
	submission 2019v1	submission 2020v1	recalculation difference	recalculation difference
year	Gg CO_2eq	Gg CO_2eq	Gg CO_2eq	%
1990	12756.38	12741.06	-15.31	-0.12%
1991	13404.09	13382.78	-21.31	-0.16%
1992	13132.85	13146.80	13.94	0.11%
1993	13287.47	13293.45	5.97	0.04%
1994	12466.21	12468.53	2.32	0.02%
1995	10093.18	10091.81	-1.37	-0.01%
1996	10154.56	10155.26	0.70	0.01%
1997	9504.71	9503.14	-1.57	-0.02%
1998	8626.68	8622.18	-4.50	-0.05%
1999	9092.59	9087.98	-4.61	-0.05%
2000	9678.14	9669.11	-9.03	-0.09%
2001	10165.43	10158.18	-7.24	-0.07%
2002	10941.89	10934.88	-7.01	-0.06%
2003	11380.84	11376.30	-4.54	-0.04%
2004	12783.08	12766.97	-16.11	-0.13%
2005	13024.76	13009.12	-15.65	-0.12%
2006	12852.45	12838.07	-14.38	-0.11%
2007	12267.33	12253.93	-13.40	-0.11%
2008	12153.88	12135.10	-18.78	-0.15%
2009	11607.67	11587.58	-20.09	-0.17%
2010	12180.08	12169.06	-11.01	-0.09%
2011	12061.97	12046.25	-15.72	-0.13%
2012	11781.30	11773.25	-8.05	-0.07%
2013	11238.61	11234.48	-4.13	-0.04%
2014	10786.88	10776.85	-10.03	-0.09%
2015	10294.94	10290.10	-4.84	-0.05%
2016	10051.96	10050.69	-1.27	-0.01%
2017	10236.08	10235.70	-0.39	0.00%

Table 10-8 - Recalculation differences of national emissions by gas (without LULUCF) and by sector.

recalculation difference (2020v1 vs. 2019v1)					recalculation difference (2020v1 vs. 2019v1)					
total GHG emissions excl. LULUCF (Gg CO_2eq)					Gg CO_2eq (sum of all GHGs)					
year	CO_2	CH_4	N_2O	F-gases	year	1 - Energy	2 - IPPU	3 - Agriculture	4 - LULUCF	5 - Waste
1990	-0.10	1.50	-17.12	0.41	1990	-0.26	-0.88	-14.18	-23.31	-
1991	-0.28	1.81	-23.23	0.39	1991	-0.46	-0.84	-20.01	-23.69	-
1992	14.21	1.66	-2.31	0.39	1992	13.76	-0.78	0.96	-23.69	-
1993	11.48	1.51	-7.39	0.38	1993	9.93	0.00	-3.96	-26.60	-
1994	11.78	1.44	-11.28	0.38	1994	10.02	0.03	-7.72	-28.62	-
1995	10.45	1.39	-13.57	0.36	1995	8.81	0.18	-10.37	-39.07	-
1996	11.25	1.45	-12.39	0.39	1996	9.20	0.27	-8.78	-42.33	-
1997	7.54	1.47	-10.97	0.40	1997	5.85	0.12	-7.53	-46.40	-
1998	8.44	1.49	-14.85	0.42	1998	6.61	0.29	-11.40	-52.61	-
1999	7.52	1.65	-14.20	0.42	1999	5.71	0.31	-10.64	-42.74	-
2000	2.96	1.83	-14.26	0.43	2000	1.31	0.32	-11.26	-46.04	0.59
2001	4.29	1.98	-13.95	0.43	2001	2.77	0.20	-10.86	-18.56	0.65
2002	4.34	1.93	-13.73	0.43	2002	3.39	0.23	-11.48	-14.86	0.85
2003	6.44	1.89	-13.31	0.44	2003	6.21	0.09	-11.19	-10.65	0.36
2004	-4.38	1.88	-14.05	0.45	2004	-4.08	0.04	-12.32	-27.62	0.26
2005	-3.82	1.68	-13.95	0.46	2005	-3.14	-0.09	-12.58	-22.57	0.15
2006	-1.68	1.39	-14.56	0.46	2006	-0.87	-0.25	-13.57	-14.99	0.30
2007	1.05	1.20	-16.12	0.47	2007	1.09	-0.29	-14.41	-9.12	0.21
2008	-4.05	1.20	-16.42	0.49	2008	-4.32	-0.50	-14.33	-3.55	0.36
2009	-4.46	0.89	-17.01	0.49	2009	-4.33	-0.65	-14.83	-8.91	-0.29
2010	1.94	0.67	-14.03	0.41	2010	1.68	-0.01	-12.57	-31.07	-0.12
2011	1.45	0.71	-18.31	0.43	2011	2.74	-0.27	-17.83	-70.64	-0.36
2012	3.91	0.69	-13.09	0.44	2012	6.76	-0.30	-14.56	-69.12	0.05
2013	6.88	0.72	-12.19	0.45	2013	11.67	-1.11	-14.63	-59.17	-0.05
2014	-0.01	0.90	-11.05	0.13	2014	5.79	-0.34	-15.44	-56.20	-0.03
2015	2.25	1.00	-8.68	0.59	2015	10.86	-0.37	-15.51	-59.62	0.19
2016	4.26	0.82	-7.25	0.90	2016	14.04	0.36	-15.98	-57.26	0.32
2017	6.94	-0.05	-5.71	-1.56	2017	16.24	-2.28	-14.03	-58.60	-0.32

Figure 10-1 - Recalculation differences of national emissions by gas (without LULUCF, 2020v1 vs. 2019v1).

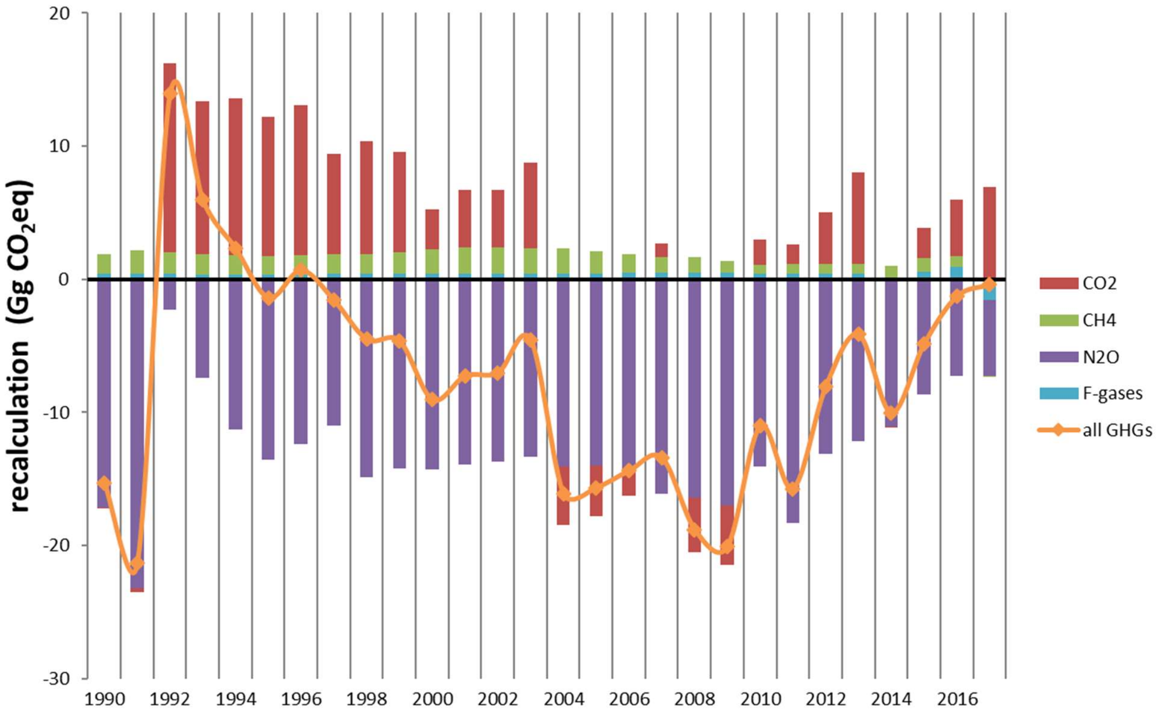
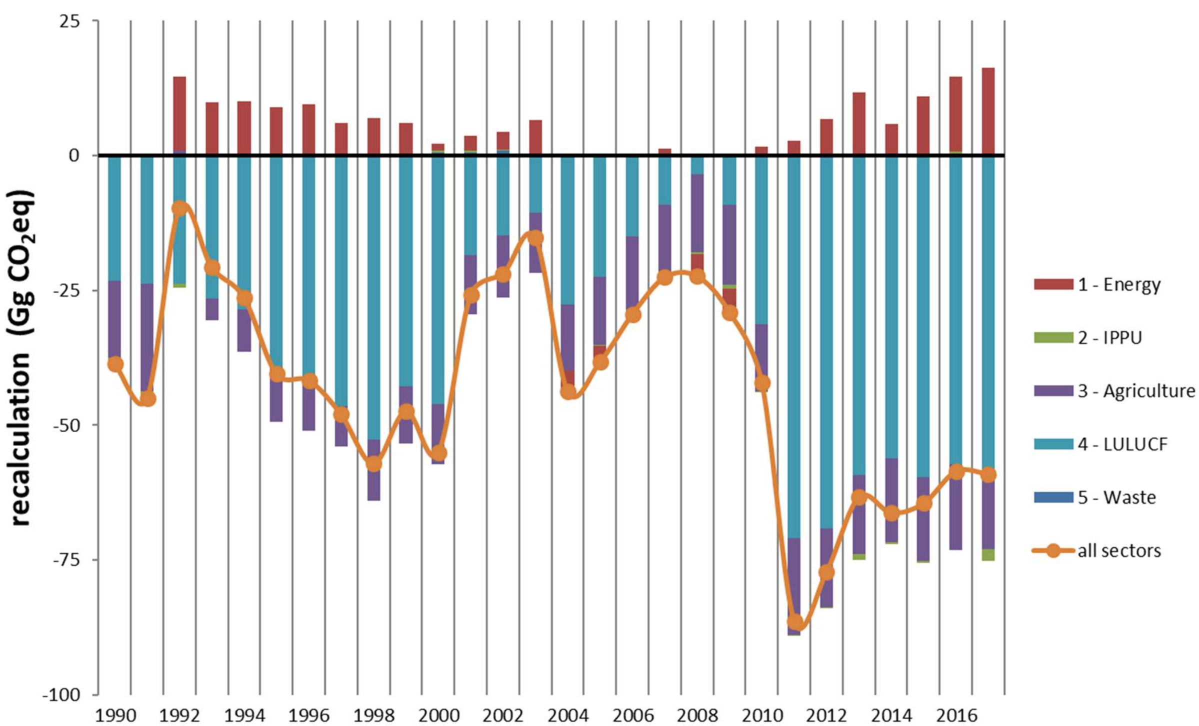


Figure 10-2 - Recalculation differences of national emissions by sector (2020v1 vs. 2019v1).



10.2.2 KP-LULUCF inventory

The same modifications were made as those under chapter 4 - LULUCF.

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 1990-2017 of the national total (including LULUCF) has changed from -2988.66 Gg CO_2eq in submission 2019v1 to -3009.03 Gg CO_2eq in submission 2020v1.

Table 10-9: Emission trends 1990-2017 in submissions 2020v1 and 2019v1.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Submission 2020 v1			Submission 2019 v1		
	1990	2017	trend 1990-2017	1990	2017	trend 1990-2017
	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)	(Gg)
1. Energy	**10300.98**	**8794.37**	**-1506.61**	**10301.24**	**8778.13**	**-1523.12**
A. Fuel combustion (sectoral approach)	10281.59	8763.06	-1518.54	10281.86	8746.81	-1535.04
1. Energy industries	35.64	242.78	207.13	35.64	243.70	208.06
2. Manufacturing industries and construction	6265.75	1144.58	-5121.17	6265.83	1141.26	-5124.57
3. Transport	2617.10	5648.16	3031.06	2616.44	5638.74	3022.30
4. Other sectors	1359.98	1727.42	367.44	1360.82	1722.99	362.17
5. Other	3.12	0.12	-3.01	3.12	0.12	-3.01
B. Fugitive emissions from fuels	19.39	31.32	11.93	19.39	31.32	11.93
1. Solid fuels	NO	NO	NO	NO	NO	NO
2. Oil and natural gas and other emissions from energy production	19.39	31.32	11.93	19.39	31.32	11.93
C. CO_2 transport and storage	NO	NO	NO	NO	NO	NO
2. Industrial processes	**1639.38**	**659.63**	**-979.74**	**1640.25**	**661.91**	**-978.34**
A. Mineral industry	623.45	436.40	-187.05	623.45	436.40	-187.05
B. Chemical industry	NO	NO	NO	NO	NO	NO
C. Metal industry	984.91	109.48	-875.43	984.91	109.48	-875.43
D. Non-energy products from fuels and solvent use	20.54	30.03	9.49	21.83	30.75	8.92
E. Electronic industry	NO	NO	NO	NO	NO	NO
F. Product uses as ODS substitutes	0.00	64.69	64.69	0.00	66.75	66.75
G. Other product manufacture and use	10.47	19.03	8.56	10.06	18.53	8.47
H. Other	NO	NO	NO	NO	NO	NO
3. Agriculture	**695.57**	**697.69**	**2.12**	**709.75**	**711.72**	**1.98**
A. Enteric fermentation	387.78	407.39	19.61	387.83	407.18	19.35
B. Manure management	78.91	88.28	9.36	86.54	96.73	10.19
C. Rice cultivation	NO	NO	NO	NO	NO	NO
D. Agricultural soils	228.62	193.23	-35.39	235.12	200.43	-34.70
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	8.80	8.54	0.26	7.39	7.13
H. Urea application	NE	NE	NE	NE	NE	NE
I. Other carbon-containing fertilizers	NO	NO	NO	NO	NO	NO
J. Other	NO	NO	NO	NO	NO	NO
4. Land use, land-use change and forestry (2)	**101.25**	**-402.41**	**-503.66**	**124.56**	**-343.82**	**-468.37**
A. Forest land	-188.74	-444.82	-256.09	-163.58	-408.00	-244.42
B. Cropland	77.80	35.96	-41.84	77.84	35.96	-41.88
C. Grassland	32.52	-42.59	-75.11	32.68	-42.58	-75.26
D. Wetlands	16.20	4.72	-11.48	16.20	4.72	-11.49
E. Settlements	155.69	63.77	-91.92	155.74	63.78	-91.96
F. Other land	1.76	0.19	-1.56	1.76	0.19	-1.57
G. Harvested wood products	2.11	-21.75	-23.86	NO	NO	NO
H. Other	NO	NO	NO	NO	NO	NO
5. Waste	**105.14**	**84.00**	**-21.13**	**105.14**	**84.32**	**-20.82**
A. Solid waste disposal	92.18	50.90	-41.29	92.18	51.04	-41.14
B. Biological treatment of solid waste	NA,NO,IE	25.98	NA	NA,NO,IE	26.15	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	12.95	7.13	-5.82	12.95	7.13	-5.82
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	**389.54**	**1697.57**	**1308.03**	**389.54**	**1697.57**	**1308.03**
Aviation	389.45	1697.40	1307.95	389.45	1697.40	1307.95
Navigation	0.09	0.17	0.08	0.09	0.17	0.08
Multilateral operations	NO	NO	NO	NO	NO	NO
CO_2 emissions from biomass	159.05	812.91	653.86	159.05	846.22	687.17
CO_2 captured	NO	NO	NO	NO	NO	NO
Long-term storage of C in waste disposal sites	NE	NE	NE	NE	NE	NE
Indirect N_2O	NE,NO	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE
Indirect CO_2 (3)	NE,NO	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE
	12756.68					
Total CO_2 equivalent emissions without land use, land-use change and	**12741.06**	**10235.70**	**-2505.37**	**12756.38**	**10236.08**	**-2520.29**
Total CO_2 equivalent emissions with land use, land-use change and	**12842.31**	**9833.28**	**-3009.03**	**12880.93**	**9892.27**	**-2988.66**
Total CO_2 equivalent emissions, including indirect CO_2, without land	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
Total CO_2 equivalent emissions, including indirect CO_2, with land use,	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**

10.3.3 KP-LULUCF inventory

The changes mentioned in 4A Forestland (section 0) also effect KP estimates for Forest Management (FM):

	2013	2014	2015	2016	2017
FM 2019v1	-399.18	-317.89	-261.49	-350.97	-240.99
FM 2020v1	-433.83	-352.82	-296.86	-386.94	-277.37

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
International Bunkers - Aviation	Analyse LTO data per aircraft type from Eurostat for Luxembourg in order to optimize split between International Bunkers – Aviation and 1A3a – Domestic aviation.
1.A.4.a – Commercial/Institutional, 1.A.4.b – 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.
1.B.2.a.5 - 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.
2.D.2	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.
2.F.2	continue the quest for country-specific data
2.F.4	continue the quest for country-specific data
3.A	Investigation on country-specific data for GE and DE%
3.B	update of the manure management system using more recent data
3.B	The flow of total ammoniacal nitrogen (TAN) through the manure management will be revised, following the 2019 EMEP/EEA guidelines
3.D	update of the manure management system using more recent data
3.D	the N flow model will be updated to comply with the 2019 EMEP/EEA guidelines
3.D	As the area cultivated by Luxemburgish farmers, i.e. the area derived from the agriculture census, is - in particularly in recent years – strongly overestimating the agriculture area in Luxemburg, alternative data sources are currently investigated.
4.A	Luxembourg plans to revise its OBS maps by 2020-2021
4.A	Luxembourg plans conduct a new NFI by 2025
5D1 – Domestic & Commercial WWH – CH_4	List of WWTPs which produce methane gas for energy reuse in combined heat/power generating systems
5D1 – Domestic & Commercial WWH	Reassessment of the EF_{plant} for WWTP with and without denitrification following comments from ERT. Ongoing second study with the Umweltbundesamt Austria
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.

10.4.3 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-LULUCG 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: • Minimum land area: 0.5 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_2O emissions from managed soil[5]	Biomass burning[9]		
					Mineral	Organic[3]		N_2O	CH_4[7]	N_2O	N_2O	N_2O	CO_2[10]	CH_4	N_2O
Article 3.3 activities															
Afforestation and reforestation	R	R	R	R	R	NO	IO	NO	NO	NO	NO	NO	NO	NO	NO
Deforestation	R	R	R	R	R	NO	IO	NO	NO	NO	R	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
Cropland management	NR	NR	NR	NR	NR	NO			NO		NA		NO	NO	NO
Grazing land management	NR	NR	NR	NR	NR	NO			NO		NA		NO	NO	NO
Revegetation	NR	NR	NR	NR	NR	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

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	0.00	0.00	79.31	14.00
1991	92.18	-0.44	0.70	79.57	14.00
1992	91.73	-0.88	1.40	79.83	14.00
1993	91.29	-1.32	2.10	80.09	14.00
1994	90.85	-1.77	2.80	80.35	14.00
1995	90.41	-2.21	3.50	80.61	14.00
1996	89.97	-2.65	4.20	80.87	14.00
1997	89.53	-3.09	4.90	81.12	14.00
1998	89.08	-3.53	5.60	81.38	14.00
1999	88.64	-3.97	6.30	81.64	14.00
2000	88.52	-4.42	7.00	82.21	13.48
2001	88.39	-4.55	7.18	82.79	12.96
2002	88.26	-4.69	7.36	83.36	12.43
2003	88.13	-4.83	7.53	83.93	11.91
2004	88.01	-4.96	7.71	84.50	11.39
2005	87.88	-5.10	7.89	85.08	10.86
2006	87.75	-5.23	8.06	85.65	10.34
2007	87.62	-5.37	8.24	86.22	9.82
2008	87.58	-5.51	8.42	86.88	9.17
2009	87.54	-5.55	8.47	87.54	8.52
2010	87.50	-5.59	8.52	88.20	7.88
2011	87.47	-5.62	8.58	88.87	7.23
2012	87.43	-5.66	8.63	89.53	6.58
2013	87.39	-5.70	8.68	90.19	5.93
2014	87.35	-5.74	8.73	90.85	5.29
2015	87.31	-5.78	8.79	91.51	4.64
2016	87.27	-5.82	8.84	92.17	3.99
2017	87.23	-5.86	8.89	92.83	3.34
2018	87.19	-5.90	8.95	93.49	2.70

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 UNFCC 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 UNFCC 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

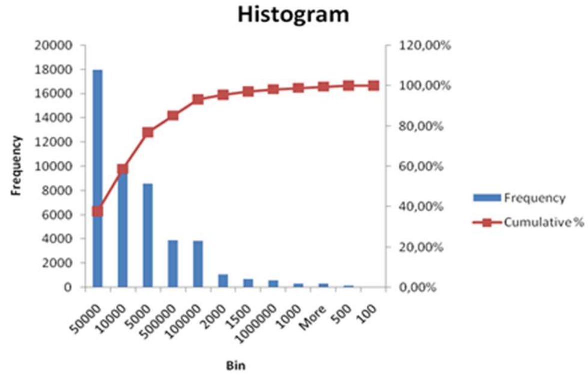
The base data used for this reporting is the so-called OBS map data "Occupation Biophysiques du Sol" that is a detailed land use/land cover map in digital format covering the entire territory of Luxembourg. Three versions of the OBS map data set exist. The first OBS data set, the OBS89, was collected 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

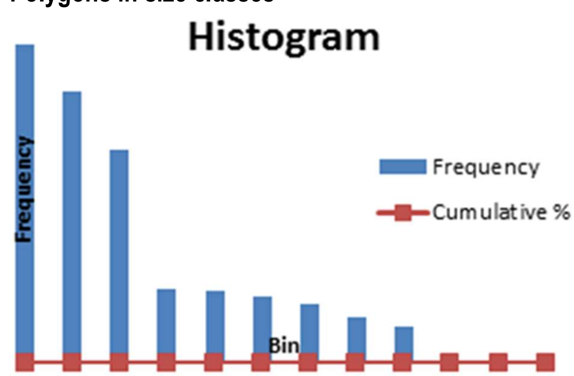


The OBS99 MMU is in principle 2 500 m² (0.25 ha) but adapted for important but small areas, i.e. wetlands and little lakes/ponds to 1 500 m² (0.15 ha). Linear structures and parts of it are mapped as areas if their width is larger than 20m, other parts (<20m) are taken from the BD-L-TC and presented 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

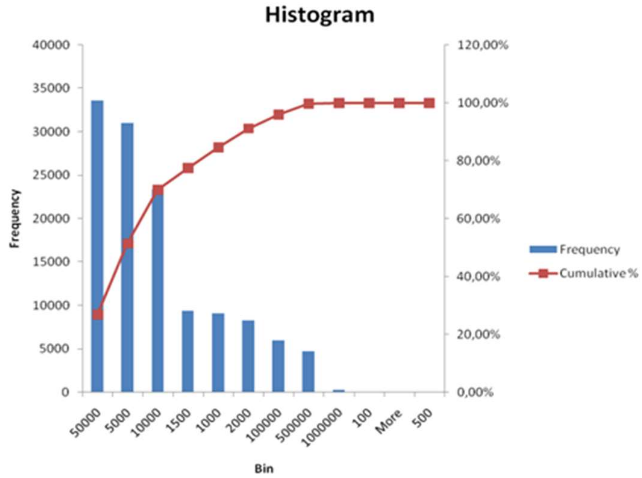


The OBS07 MMUs correspond to those of the OBS99 with changes from OBS99 to OBS07 mapped with a MMU of 500 m². Table 11-4 and Figure 11-4 provide information about the frequency distribution of polygon areas.

Table 11-4 - OBS07 data: Frequency of Polygons in size classes & cumulative percentages

Area (m²) 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

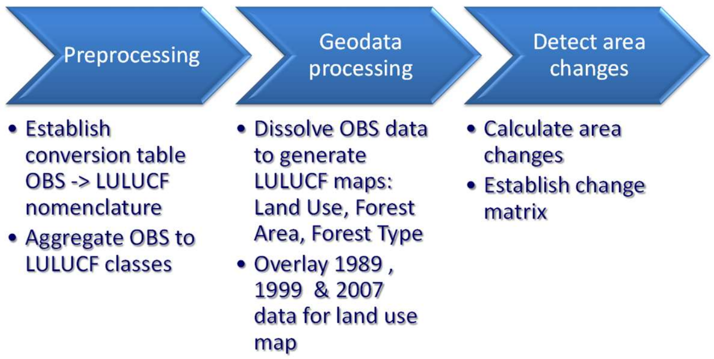
The generation of the LULUCF maps is based on the OBS and RE data. Data processing of OBS89, OBS99 and OBS07 follows the same processing scheme.

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.

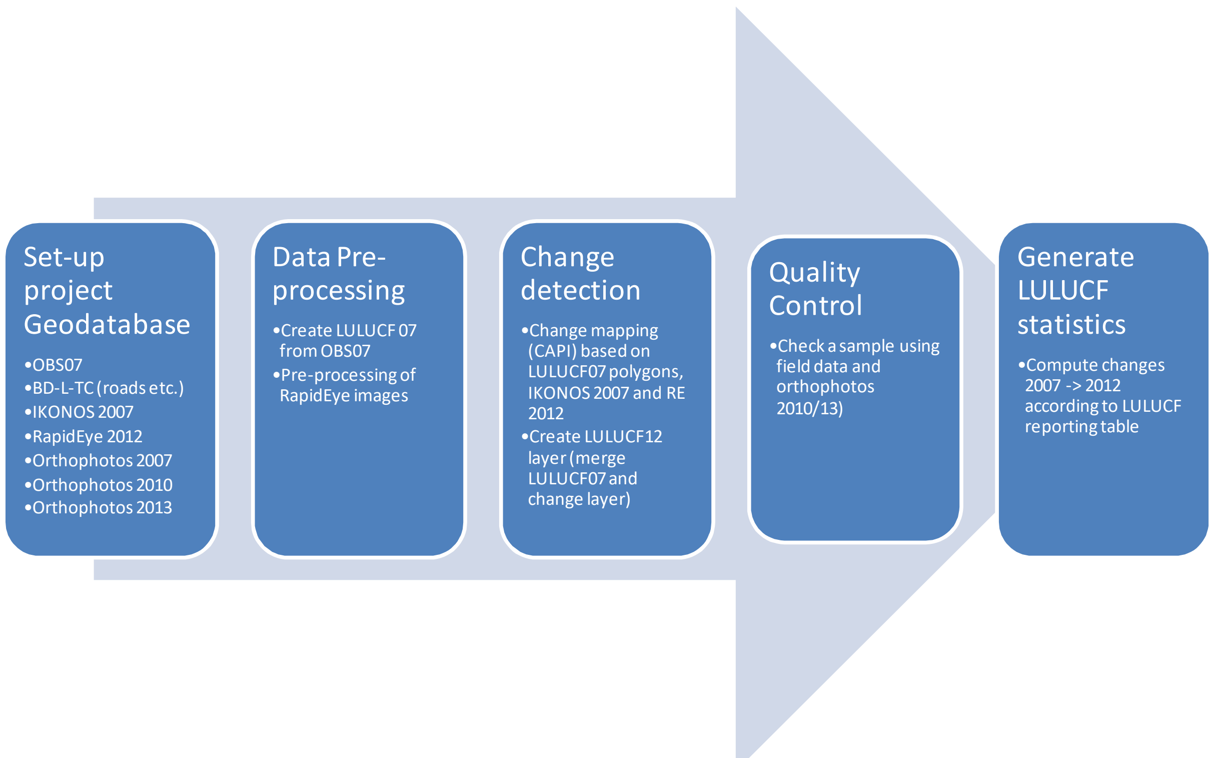
In order to preserve the detail in the data for the generation of the area statistics, no generalisation was performed before the change detection. Change detection of Land Use / Forest types between the selected reference years 1989, 1999 and 2007 has been carried out by overlay (intersect) of the Land 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 Luxemburg, and especially in the northern part of Luxemburg (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

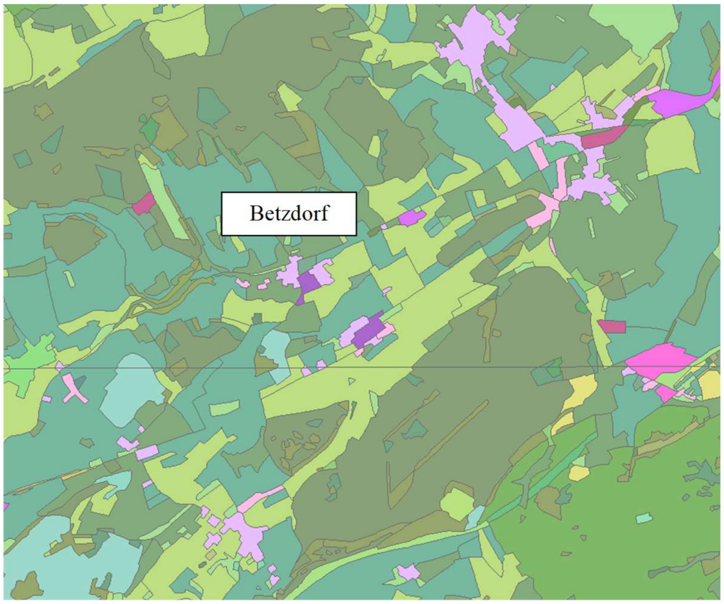
The first biophysical land cover map covering the entire Luxembourg territory consisted in a mapping and data collection in the field. Based on prepared aerial ortho photos showing delineated areas, experts from the "OekoFonds" and the association "Hellëf fir d'Natur" mapped/classified the areas during 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 m^2, 580 polygons smaller than 1000 m^2 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.

<u>Biophysical Land Cover Map 1999 – "Occupation Biophysique du Sol" OBS99</u>

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 m^2 (0.25 ha) but adapted for important but small areas, i.e. wetlands and little lakes/ponds to 1500 m^2 (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.

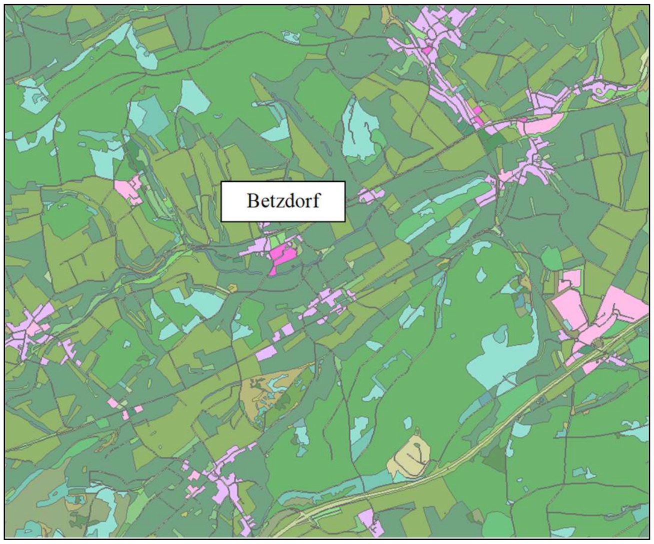
The map includes 4 landscape element categories (isolated tree, group of isolated trees, tree rows, hedges) and in total 77 land use/cover classes, divided in 5 broad categories (Table 11-6).

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

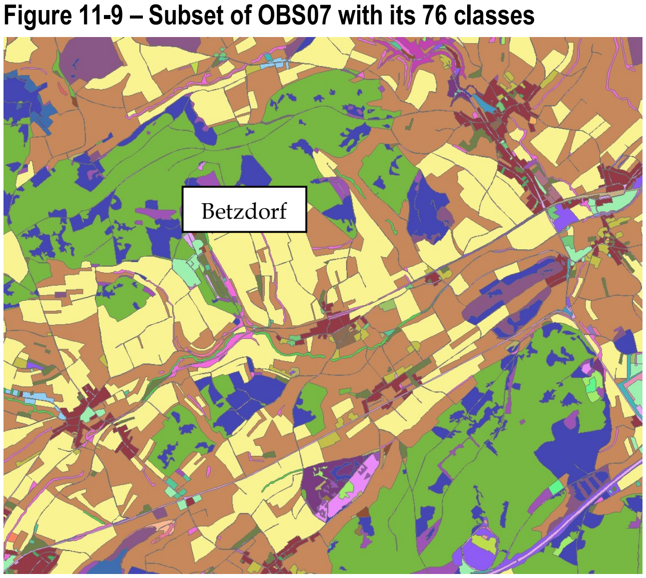


The data has been used for LULUCF mapping for the year 1999.

<u>Biophysical Land Cover Map 2007 – "Occupation Biophysique du Sol" OBS07</u>

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 500m^2. 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 km^2. 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

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.

Table 11-7 – C stock change factors in AR areas

Aforestation/Reforestation	C before LUC (t C/ha)	Biomass: ag & bg growth Age class: 0-20 years (t C/ha*y)	Biomass: ag & bg growth Age class: 20-40 years (t C/ha*y)	Soil: C stock change after 20 years of LUC (tC/ha)	Soil: annual C stock change (t C/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

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	Biomass		Dead wood & litter	Soil	
	$C_{average}$ before LUC (t C/ha)	Growth (t C/ha*y)	$C_{average}$ before LUC (t C/ha*y)	C stock change after 20 years of LUC (tC/ha)	annual C stock change (t C/ha*yr)
Forestland converted to Annual Cropland	119.70	5.00	24.26	-35.68	-1.78
Forestland converted toPerennial Cropland	119.70	0.21	24.26	-24.74	-1.24
Forestland converted to Grassland	119.70	6.35	24.26	-9.51	-0.48
Forestland converted to Wetlands	119.70	0.00	24.26	-111.09	-5.55
Forestland converted to Settlements	119.70	1.29 / 0.15	24.26	-67.85	-3.39
Forestland converted to Other land	119.70	1.29	24.26	-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_2O (Gg N_2O)
	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

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) [140]				
	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	218.19	47.03	-164.43	-35.08	0.00	0.00					

<u>**Harvested wood products**</u>

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.

[140] Carbon gain due to Land converted to forestland before 1990 and not reported under afforestation.

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, forests are not fertilised in Luxembourg (expert judgement). So, fertilisation at AR areas do not occur. The new forestry code, that will be published this year, will most likely include a paragraph forbidding the application of fertilizer in forest.

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):

	2013	2014	2015	2016	2017	2018
FM 2019v1	-399.18	-317.89	-261.49	-350.97	-240.99	
FM 2020v1	-433.83	-352.82	-296.86	-386.94	-277.37	-94.94

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

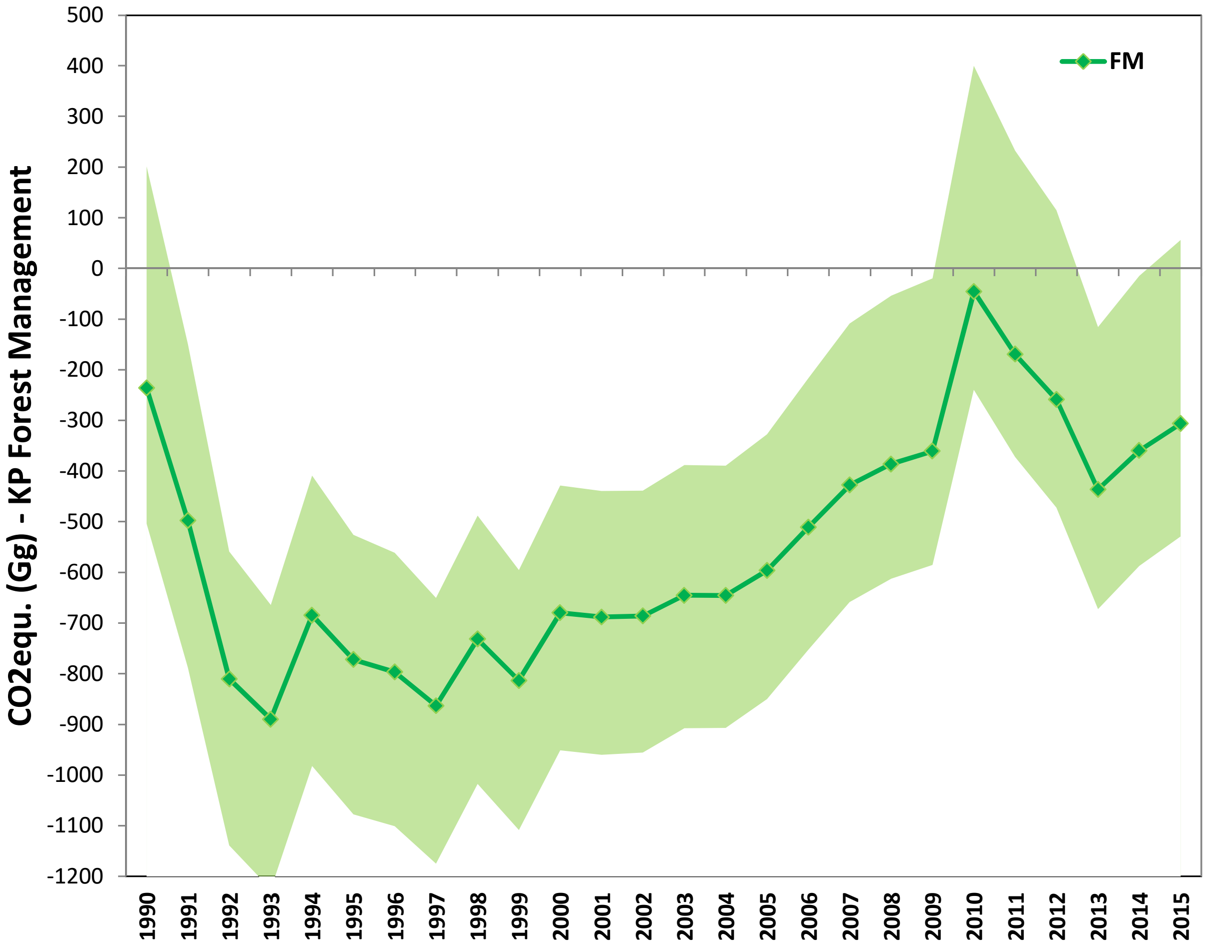


Figure 11-11 - Uncertainty analysis for D

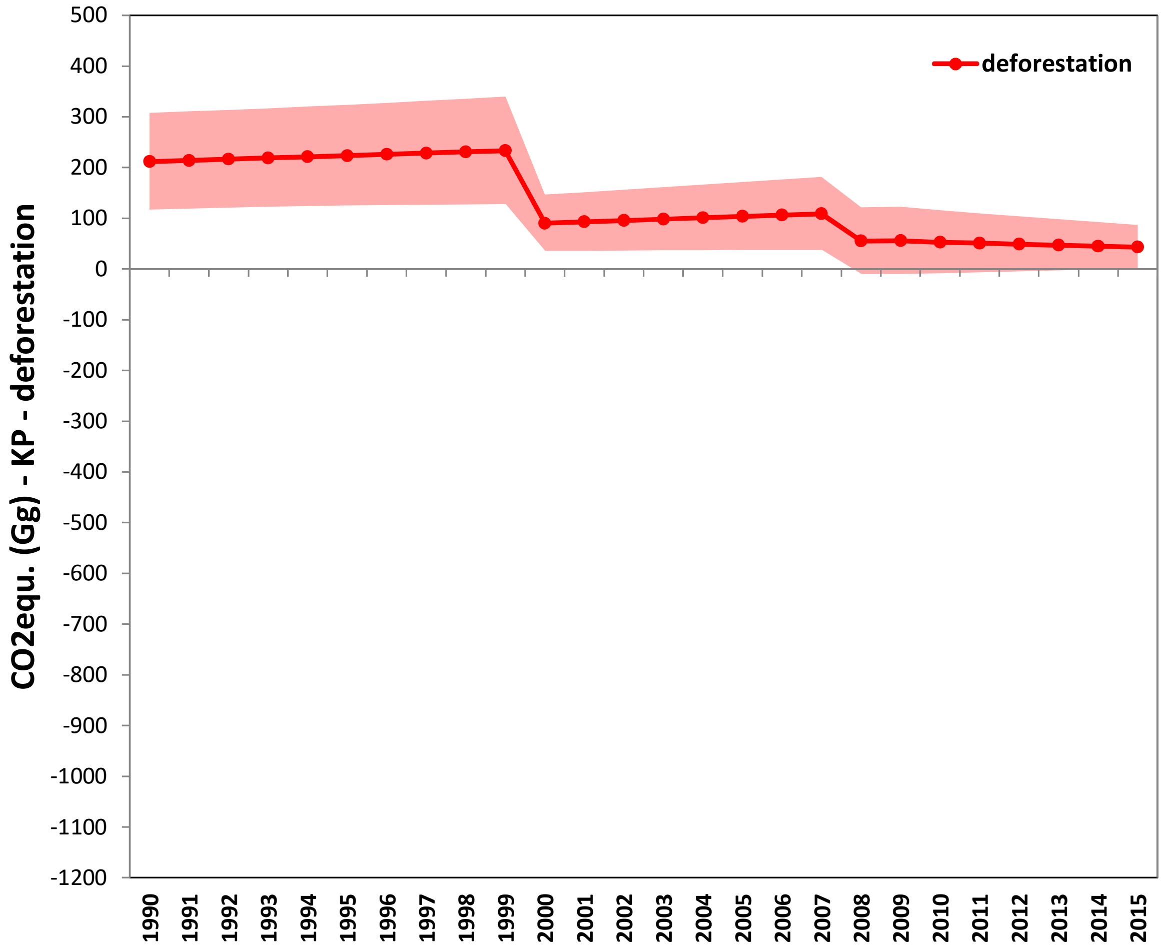
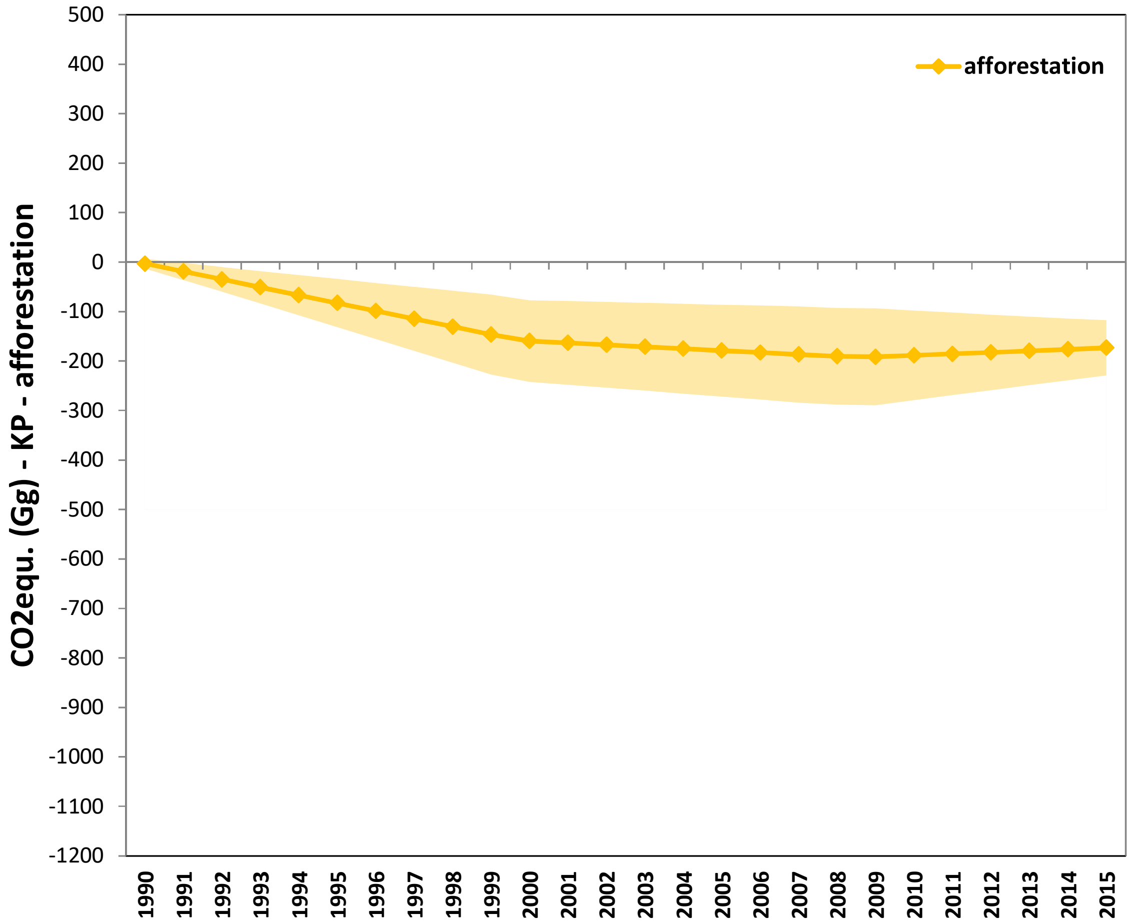


Figure 11-12 - Uncertainty analysis for AR



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).*"[141]

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.

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,

[141] 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)

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 Hansaluftbild 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 $MtCO_{2eq}$ 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

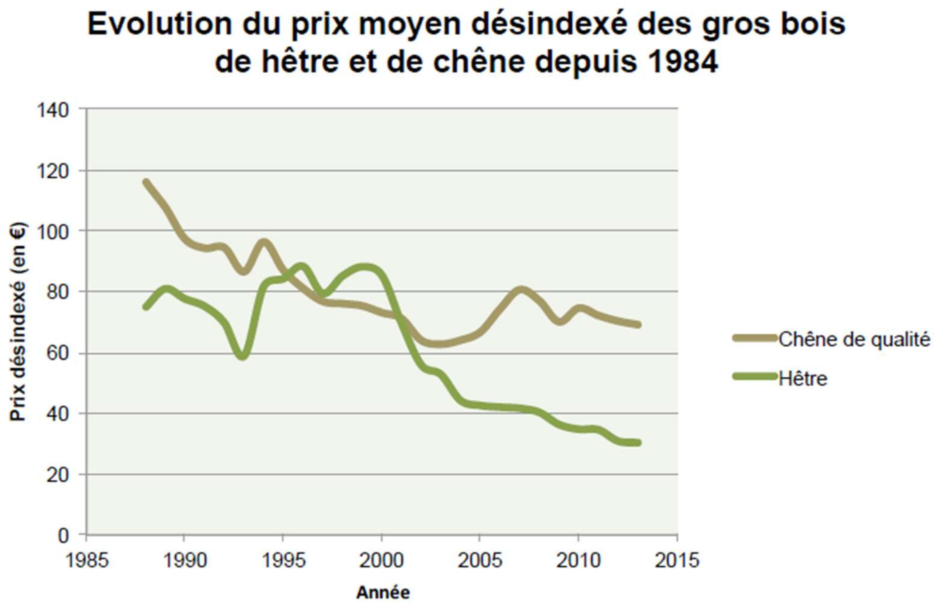
Age structure, species composition and past management practices are all known factors that change slowly and can be used for simple predictions of wood harvest. Future wood demand and management are driven by policies and market demand which are unknown and may change rapidly. Those latter factors increase 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)

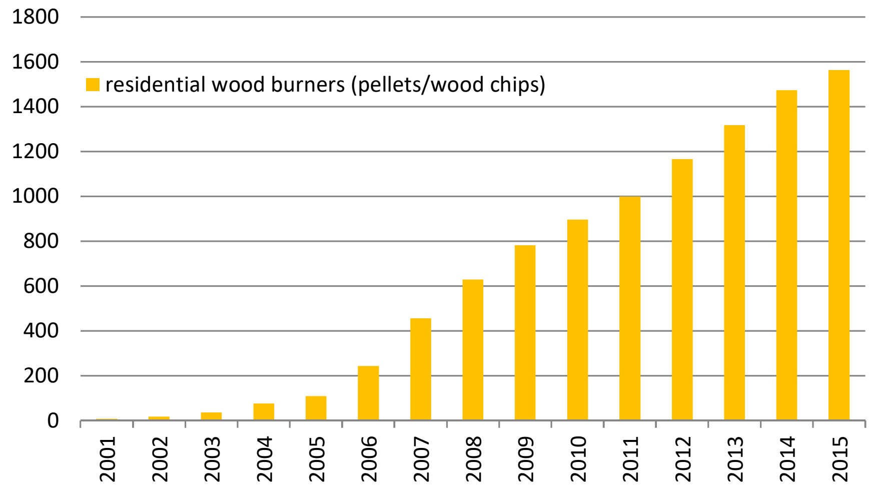


Figure 11-14 gives an overview of the evolution of the number of subsidies payed for central wood (pellets of wood chips) burners used in residential buildings. This statistic does not include wood stoves but only central burners which act as sole heating system. The figure shows a steady increase of 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

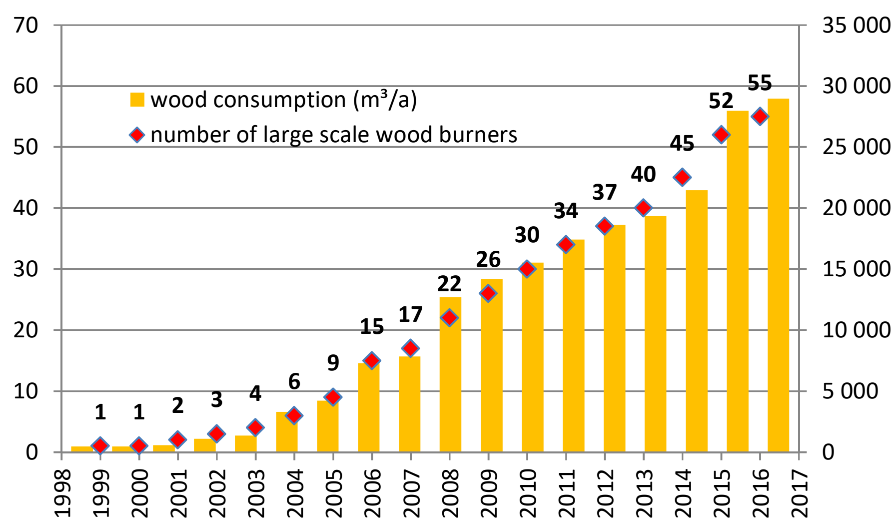


Figure 11-15 shows the evolution of the number and the consumption of large scale wood chips burners (large scale privately owned pellets burners are not included) operating in Luxembourg. Between 2010 and 2015 the installed power of those heating systems has tripled and hence the quantity of wood consumed for energy purposes has increased from an initial value of less than 5 000 m^3 in 2005 to almost 30 000 m^3 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 m^3 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.

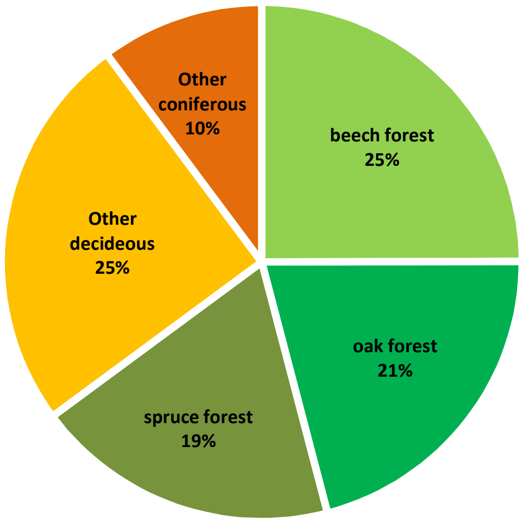
11.4.3.2.4 Projected harvest rate

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 m^3/ha/a) are lower compared to public forests (4,8 m^3/ha/a) but are essentially the same in coniferous forests (8,7 m^3/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:

$$P_{élargi} = {}^{V_s}/_{d} + Z * s * bo + K * {}^{V'}/_{d} + (S - s) * b'o$$

where :

$P_{élargi}$ = 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

bo 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

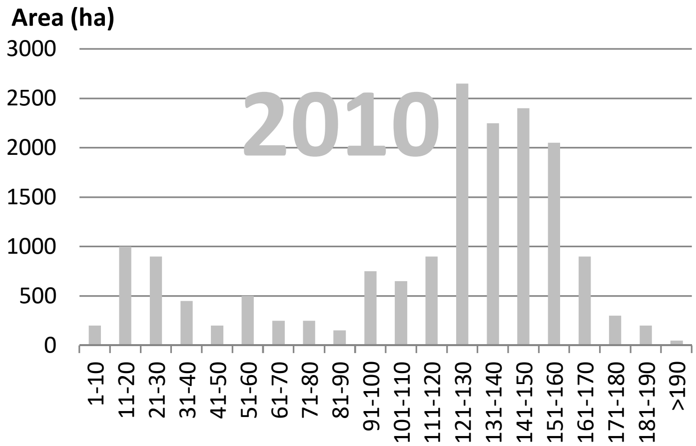
	Rotation age (years)
Beech (Fagus sylvatica) L.)	160
Oak	200
Norway spruce (Picea abies (L.)	70
Other deciduous	80
Other coniferous	80

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



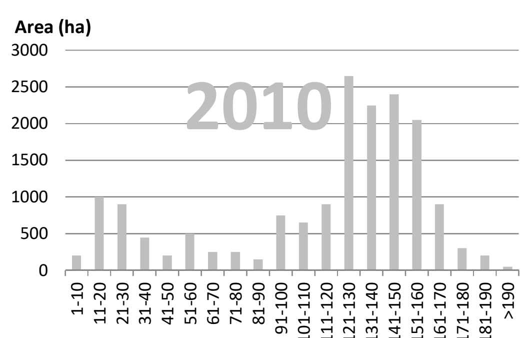
Analysing the age structure in Figure 11-17 of beech forests in Luxembourg it becomes apparent that the proportion of mature forests (120–180 years) is very high and the proportion of middle aged forests (41–80 years) is very low. Considering the uneven age structure in beech forest it would be necessary 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

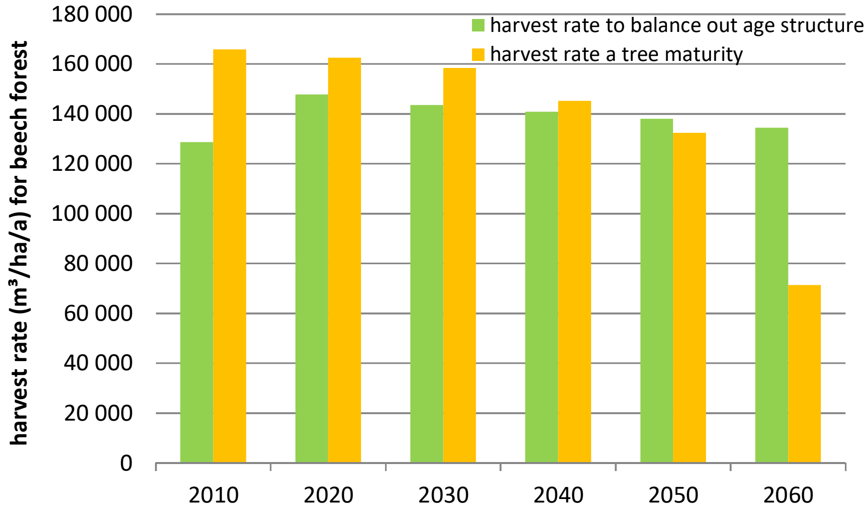


Harvest at tree maturity (160 years)

Harvest in order to even out age class structure


(ha)
3000
2500
2000
1500
1000
500
0
1-10
11-20
21-30
31-40
41-50
51-60
61-70
71-80
81-90
91-100
101-110
111-120
121-130
131-140
141-150
151-160
161-170
171-180
181-190
>190
2020
2030
2040
2050
2060
2070
2080

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 m^3/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

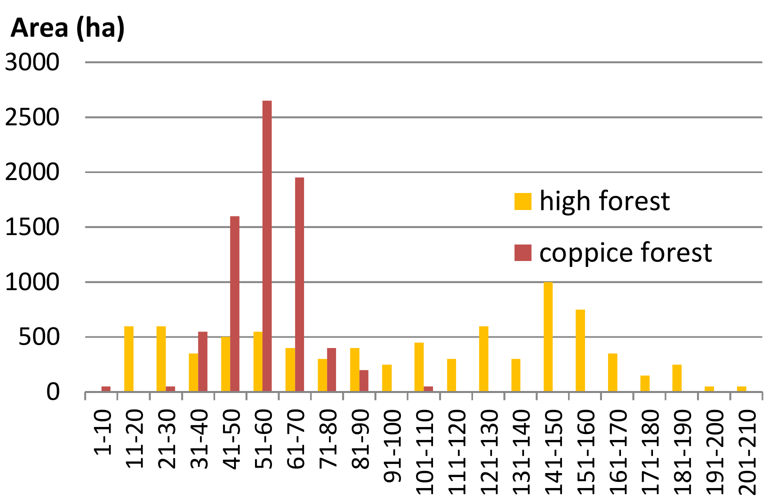
In Luxembourg there are two types of oak forest. On the one hand there are common high oak forest for timber production but on the other hand there are also coppice oak forests ("Lohhecken").

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, 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 nutriments from the forest soil.

Figure 11-20 - Illustration of coppice oak forests (Lohhecken) in Luxembourg (Hermes, 2006)

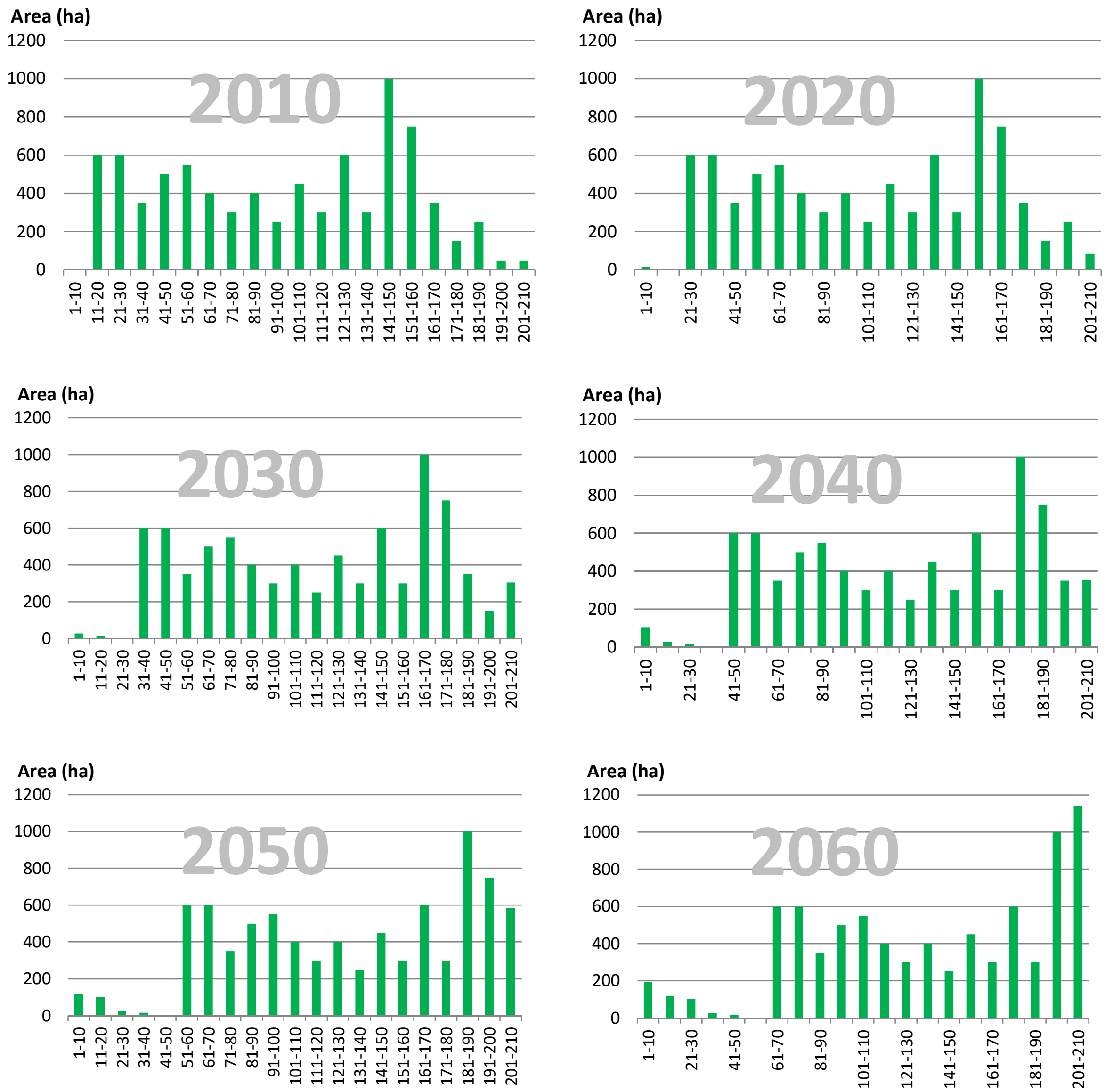
Wood growth in coppice oak forest can be estimated at around 4,1 – 4,6 m³/ha/a, but according to the results of the NFI harvest rates is estimated at about 1 m³/ha/a which highlights the fact that these forest are very underutilised. This harvest rate will be used for further calculations and will be 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

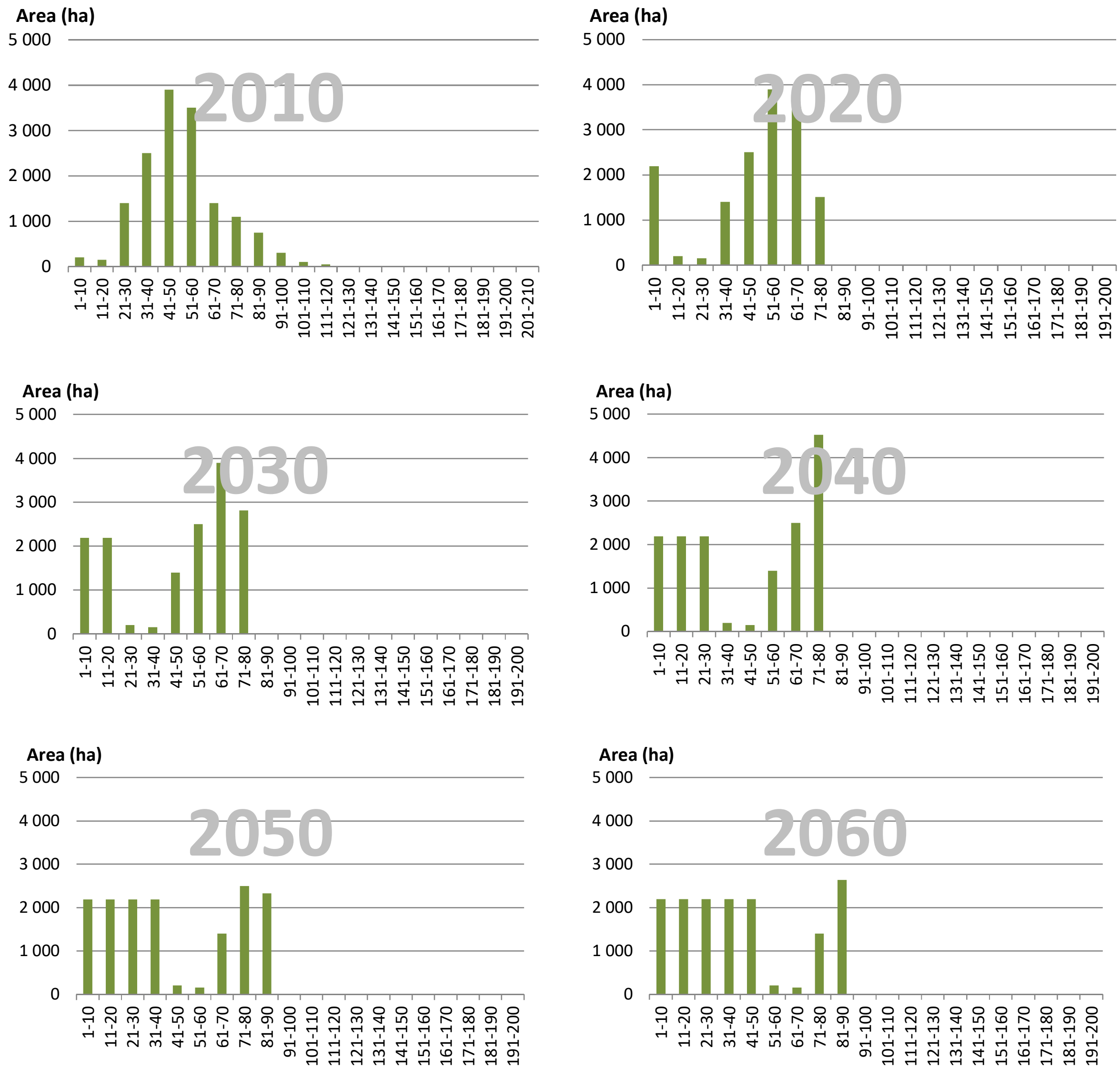


11.4.3.2.4.5 Spruce forests

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.

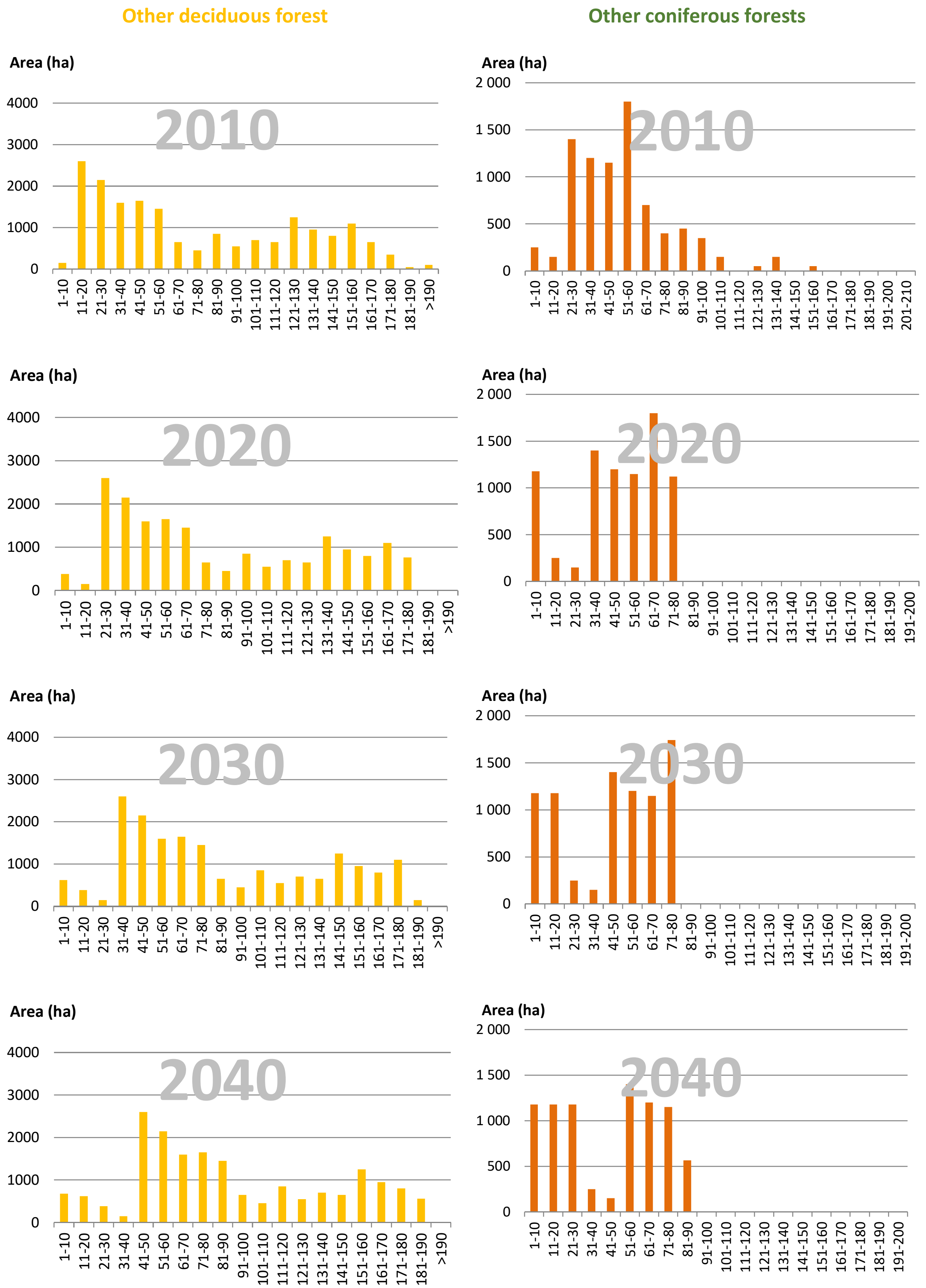
Figure 11-23 - Evolution of age structure of high stand oak forests

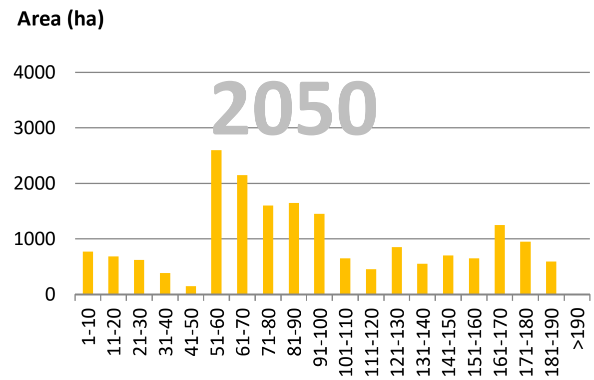


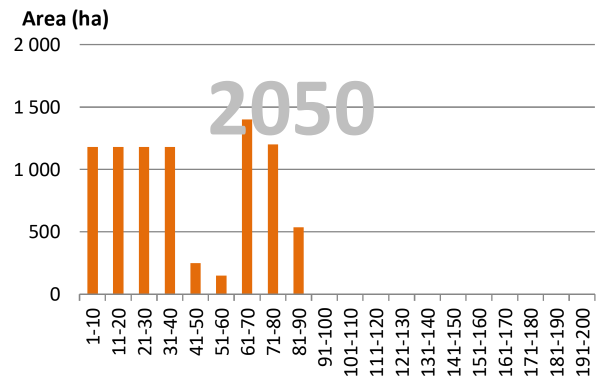
11.4.3.2.4.6 Other forests

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).

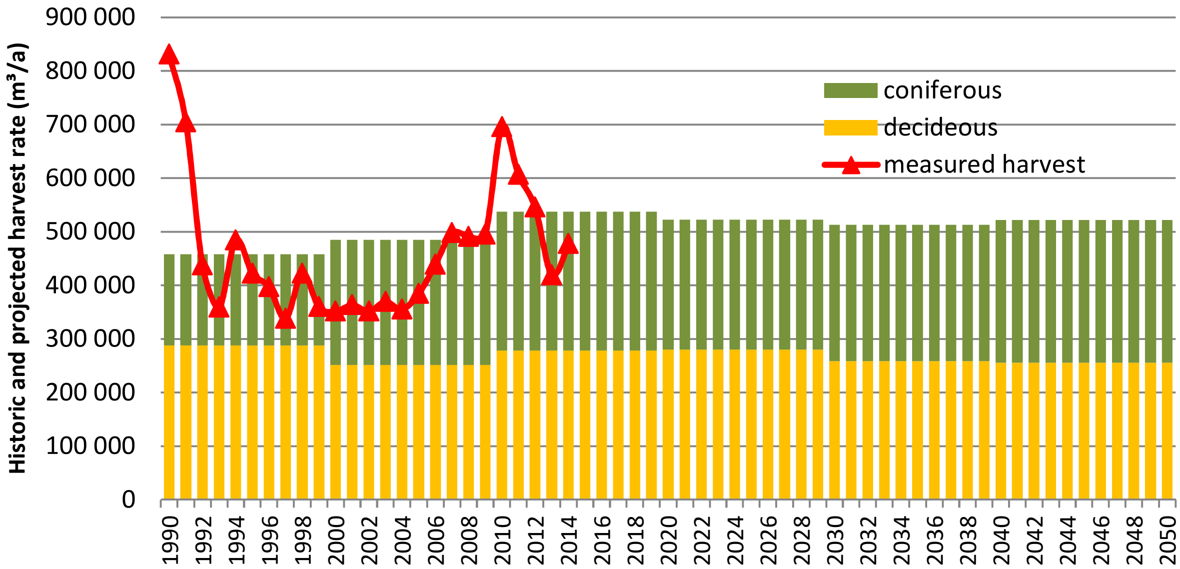
According to the same study a further 4 640 ha are situated on a slope > 60 % and can hence only be exploited with great difficulty. The conservative approach is taken that those forest areas are considered unmanaged and the assumption is taken that carbon emission and removals are in balance. This is 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)

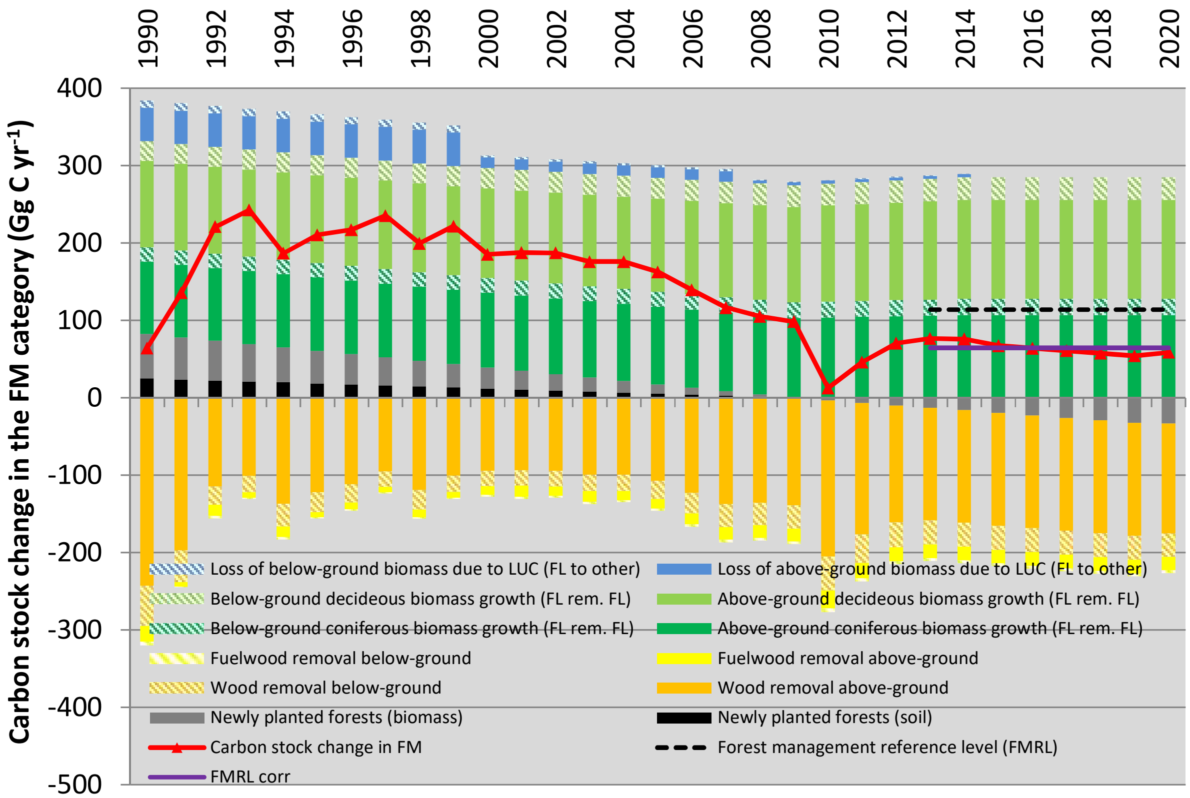
The definition of forest management according to KP comprises all forest minus the forest areas which have been afforested or reforested since 1990 (Luxembourg has not elected carbon equivalent forests). The calculation for biomass gain and loss as well as carbon gain and loss in soils according to GPG 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.

11.4.3.2.6 Projected emissions for Forest Management (activity-based approach)

Figure 11-26 - Projected emissions in FM and FMRL corr.



The following points are important when analysing Figure 11-26:

a. 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.
b. The emissions are based on the assumption that there is no afforestation or deforestation after 2013.
c. 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.
d. 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.
e. 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).

f. 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 $GgCO_2eq.yr^{-1}$
$FMRL_{corr}$	- 236 $GgCO_2eq.yr^{-1}$
Difference in % = 100*[(FMRLcorr-FMRL)/FMRL]%	- 43%
Technical Correction = $FMRL_{corr}$-FMRL	182 $GgCO_2eq.yr^{-1}$
FM reported during the commitment period (2018)	- 241 $GgCO_2e$
Accounting Parameter = reported FM – (FMRL + Technical Correction)	-5 $GgCO_2e$

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):

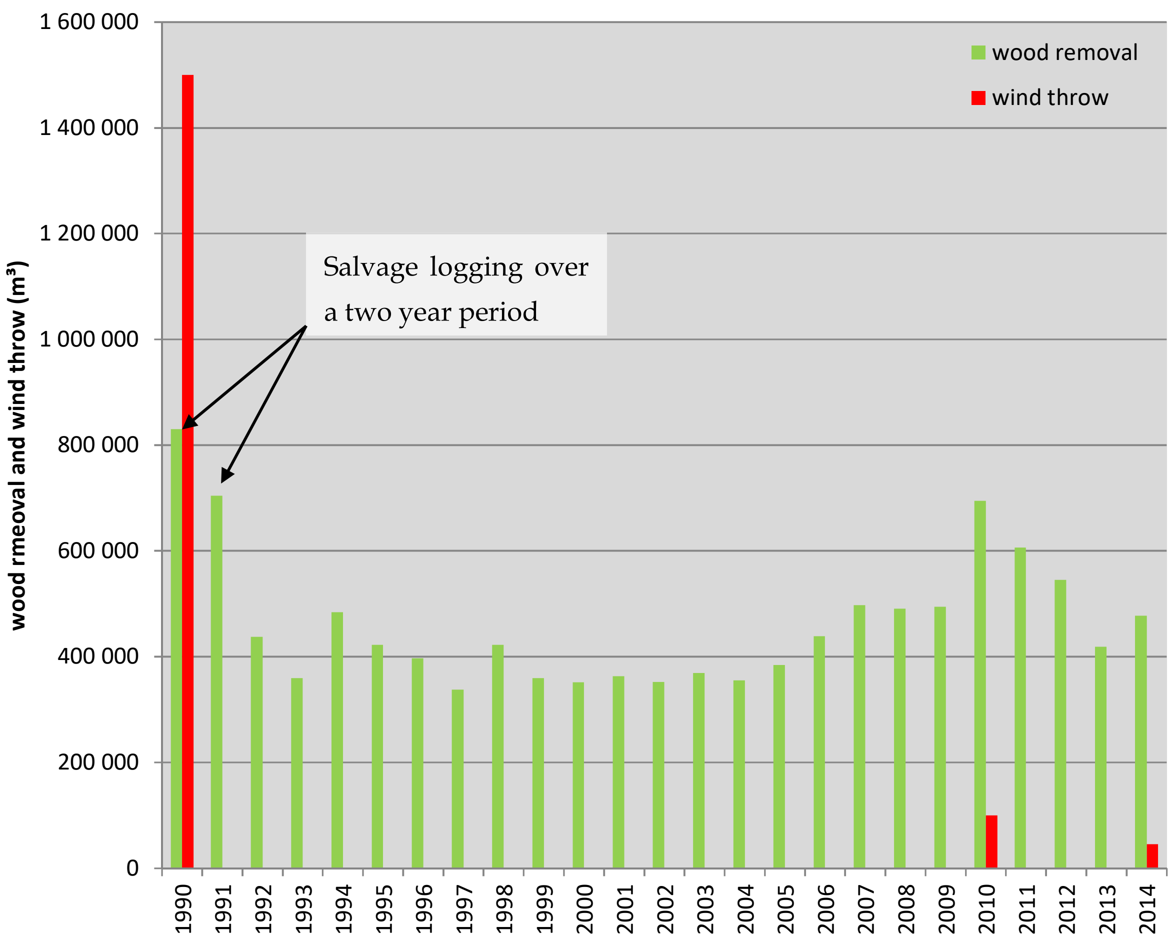
Step 1: Define the type of natural disturbances that the Party wishes to exclude from accounting:

Wildfires have occurred on some occasions but are very rare and the extent of wildfires have always been very limited. Insect attacks (eg bark beetle) do occur in Luxembourg but forest owners have an obligation to remove infected trees (salvage logging) in order to stem its propagation. The same principle applies to disease infestations (mainly fungal infestation like Fomes fomentarius and ash tree infestation). Ash tree infestation with Hymenoscyphus fraxineus is, as in many European countries, widespread in Luxembourg. Luxembourg does, however, not have a big ash tree population (+/- 1,3 %) and infestations are generally act on by removing trees (salvage logging).

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 outliners. 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. 2019, 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, lCERs, AAUs and RMUs for the year 2019 will be submitted to the UNFCCC on April 15th, 2020 (RREG1_LU_2019_1_1.xlsx and RREG1_LU_2019_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 2019.
- Paragraph 13: No CDM notification occurred in 2019.
- Paragraph 14: No CDM notification occurred in 2019.
- Paragraph 15: No non-replacements occurred in 2019.
- Paragraph 16: No invalid units exist as of 31 December 2019.
- 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 2018, as submitted to the UNFCCC on 15th April 2020.

Therefore Luxembourg's commitment period reserve is calculated as follows[142]:

Either:

Luxembourg's Adjusted Assigned Amount x 90%

72 454 473 x 0.90 = 65 209 026 assigned amount units

Or:

2018 Total Emissions x Total years of the second commitment period

10 333 875 x 8 = 82 671 000 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 *65 209 026 tonnes CO_2 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.

[142] https://unfccc.int/files/national_reports/annex_i_ghg_inventories/national_inventories_submissions/application/zip/lux-2016-ir-15mar17.zip

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 SF_6 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)	12741.06 ktCO_2eq
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 SF6 - 1990	1.2834 kt CO_2 eq
Emissions of SF6 - 1995	1.7503 kt CO_2 eq
FM cap = 0.035*(12741.06-0.0000715-1.2834+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 2019. Note that the 2019 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	There have been no new EUCR releases after version 8.2.2 (the production version at the time of the last Chapter 14 submission). No change was therefore required to the database and application backup plan or to the disaster recovery plan. The database model is provided in Annex A. No change to the capacity of the national registry occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(d) Change regarding conformance to technical standards	No changes have been introduced since version 8.2.2 of the national registry (Annex B). 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). No other change in the registry's conformance to the technical standards occurred for the reported period.

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(e) Change to discrepancies procedures	No change of discrepancies procedures occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(f) Change regarding security	No changes regarding security occurred during the reported period.
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

-> No changes occurred since the last submission (NIR 2019) - ARR 2013, §88.

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:

<u>Adverse effects of climate change</u>
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.

<u>Social, environmental and economic impacts on developing countries</u>
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.

(http://ec.europa.eu/environment/climat/pdf/lux_nap_final.pdf/)

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 CO_2 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.

<u>Subsidies:</u>

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 5th national communication, p.236-240.

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 (CO_2, CH_4, N_2O, HFC, and SF_6). 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 CO_2 emissions from fossil fuel combustion

Please refer to sections 3.2.5 to 3.2.10 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:

- The 2017 provisional livestock activity data were revised and updated, where necessary.
- When calculating the net energy for maintenance for sheep, the used Cf_i for adult sheep and lamb had been mixed-up. This was corrected.
- CH_4-emissions associated with manure management for cattle and swine were revised and updated, whereby taking into account country-specific frequency of the distribution of slurry storage, region-specific methane conversion factors and maximum methane producing capacity for manure (B_o) produced by cattle and pigs, respectively.
- Following the request from the review in 2018, the used N excretion (N.ex) were for all livestock categories explained in full detail, resulting in additional request in 2019, namely to review all N.ex, except for dairy cows, as the used fertilizer units were considered to be inadequate.
- However, also the N.ex for dairy cows had to be updated, as there had been an error in the calculation for the weighted average of milk urea.
- Direct N_2O-emissions from manure management were revised and updated, due to new N.ex values and adapted livestock activity data, but by taking also into account country-specific frequencies of slurry storage systems, and corresponding emission factors.
- Furthermore for indirect N_2O-emissions from manure management, a Tier 2 approach was taken.
- The activity data for crops were revised and updated, with consequently also a revision of the annual amount of synthetic fertilizer used, and the estimated N associated with crop residuals.
- The annual amount of animal manure N applied to soils (kg N per year) were revised and updated following an N-flow model. The same was applied for N in urine and dung deposited during grazing.
- Also was the activity data for compost revised as erroneously the fresh quantities were used, rather than the dry matter quantities, when estimating the N quantities of the applied compost to soils.
- Further was a Tier 2 approach taken for indirect N_2O-emissions from soil management.
- The activity data for liming for the last five years had to be updated, as the share of the two main suppliers had decreased from approximately 100% to now-a-days 80%.

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

	Agriculture emissions (excluding LULUCF) Gg CO2 eq.		Impact of recalculation	Agriculture emissions (including LULUCF) Gg CO2 eq.		Impact of recalculation
Year	New	Old	%	New	Old	%
1990	696.9	709.7	-1.8	696.9	709.75	-1.8
1991	710.9	729.3	-2.5	711.0	729.27	-2.5
1992	700.1	697.4	0.4	700.2	697.43	0.4
1993	695.9	698.2	-0.3	696.0	698.22	-0.3
1994	686.4	692.5	-0.9	686.4	692.46	-0.9
1995	703.8	712.5	-1.2	703.9	712.47	-1.2
1996	711.5	718.6	-1.0	711.6	718.56	-1.0
1997	701.5	707.3	-0.8	701.6	707.29	-0.8
1998	696.2	705.9	-1.4	696.3	705.88	-1.4
1999	704.0	712.8	-1.2	704.1	712.76	-1.2
2000	696.4	705.8	-1.3	696.5	705.82	-1.3
2001	680.3	689.3	-1.3	680.3	689.33	-1.3
2002	663.2	673.0	-1.5	663.2	672.98	-1.4
2003	626.3	635.9	-1.5	626.3	635.86	-1.5
2004	646.1	656.8	-1.6	646.2	656.83	-1.6
2005	630.5	641.5	-1.7	630.6	641.47	-1.7
2006	621.9	633.8	-1.9	621.9	633.83	-1.9
2007	636.2	648.9	-2.0	636.3	648.94	-2.0
2008	650.0	662.7	-1.9	650.0	662.67	-1.9
2009	652.1	665.3	-2.0	652.2	665.30	-2.0
2010	661.6	672.5	-1.6	661.6	672.47	-1.6
2011	649.4	665.6	-2.4	649.5	665.63	-2.4
2012	636.0	649.0	-2.0	636.1	648.98	-2.0
2013	646.5	659.5	-2.0	646.5	659.52	-2.0
2014	661.3	675.0	-2.0	661.4	675.02	-2.0
2015	674.6	688.3	-2.0	674.6	688.26	-2.0
2016	690.0	704.1	-2.0	690.0	704.14	-2.0
2017	699.6	711.7	-1.7	699.6	711.72	-1.7
2018	692.5			692.5		

Source: SER

Revision of livestock categories

There was no revision of the livestock categories since last submission. Although when estimating the N.ex. per animal per year (see further down), more detailed data were necessary for the livestock category “calves” and the livestock category “horses”.

Revision of livestock numbers (i.e. average animal population (AAP))

The 2017 livestock numbers were provisional, and had to be updated.

Revision of N.ex and recalculations

Revision of N.ex values for all livestock categories others than dairy cows

General

Based on the reviewers request N.ex values for the different livestock categories, other than dairy cows, were revised.

The old N.ex estimates were based on “fertilization units” (in German “Dungeinheit” (DE)), as published in Luxemburgish agro-environmental legislation (Règlement_grand-ducal 2015), multiplied by 85 (i.e. 85 kg N per UF (Règlement_grand-ducal 2015)) to obtain country-specific N.ex per head/place per year. According to the reviewer, the so-obtained country-specific N.ex might have be an underestimation of the true N.ex per head/animal place per year as N losses that might occur previous to the application of the manure to the soil, might not have been considered in these estimates. The N.ex for the different livestock categories were, except for dairy cows and cervidae therefore revised.

Having no own measurements, and having no information on feed ratio for the different livestock categories, which would allowing to estimate the N.ex based on an N-balance, the revised N.ex data were taken from the technical literature from Germany, Belgium, the Netherlands and France and are summarized in Table A3-2. Recalculations for N.ex in kg N for other cattle than dairy cows per year, for all other livestock categories and for the total livestock is summarized in Table A3-3, Table A3-4 and Table A3-5, respectively.

Detailed information for the different livestock species, others than dairy cows, are provided hereafter. To a large extent the literature cited herein dates the period that is covered by the inventory. Hence it is assumed that the details provided are representative of the time series from 1990 onwards and that the methodology based can be applied to all years since 1990.

Belgium, Germany and France (here in particular the Northern part) have direct borders with Luxembourg (Figure A3-1), 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.

Figure A3-1: - Geographic Location of Luxembourg

<u>Source</u>: Google Maps.

Table A3-2: The old and the revised N excretion per head/place per year for the different livestock categories

	N excretion (kg N per head/animal place per year) Old values	Revised values	Notes/Sources
Calves (female calves) < 1 year	29.75*	33	(CBS 2018, VLM 2017, 2016, 2015, 2014, 2013, 2012)
Calves (male calves) < 1 year	29.75*	31.5	(CBS 2018)
Female young female cattle 1-2 years	42.50*	58	(VLM 2017, 2016, 2015, 2014, 2013, 2012)
Heifers > 2 years	68.00*	77	"Other cattle older than 2 years" (VLM 2017, 2016, 2015, 2014, 2013, 2012)
Fattening bulls 1-2 years	42.50*	58	(VLM 2017, 2016, 2015, 2014, 2013, 2012)
Mature male cattle > 2 years	68.00*	77	"Other cattle older than 2 years" (VLM 2017, 2016, 2015, 2014, 2013, 2012)
Suckler cows	68.00*	82	(KTBL 2006) page 490
Sows	12.75*	23.5	(VLM 2017, 2016, 2015, 2014, 2013, 2012)
Weaners	2.55*	3.6	(Horlacher 2018) page 488-489
Fattening pigs	7.65*	11.1	(Horlacher 2018) page 488-489
Mature sheep	5.60*	10.5	(VLM 2017, 2016, 2015, 2014, 2013, 2012)
Sheep lambs < 1 year	-	4.36	(VLM 2017, 2016, 2015, 2014, 2013, 2012)
Mature goats	5.60*	18.7	(CBS 2018)
Goat kids < 1 year	-	-	Considered with does
Horses (including anes & mules)	68.00*	calculated	
Agr. Horses > 6 months		65	Horses > 600 kg; (VLM 2017, 2016, 2015, 2014, 2013, 2012)
Riding horses > 6 months		50	Horses 200-600 kg; (VLM 2017, 2016, 2015, 2014, 2013, 2012)
Horses < 200 kg		35	Ponys; horses < 6 months; mules & anes; (VLM 2017, 2016, 2015, 2014, 2013, 2012)
Broilers	0.255*	0.3	(CITEPA 2019)
Laying hens	0.595*	0.81	(VLM 2017, 2016, 2015, 2014, 2013, 2012)
Other poultry	0.85*	0.38	(CITEPA 2019)#
Ostriches	2.975*	15.6	(Rösemann et al. 2019)
Rabbits - Breeding female animals	3.6125*	3.16	Breeding female animal, including raising of young stock (but no fattening); (VLM 2017, 2016, 2015, 2014, 2013, 2012)
Other rabbits	0.34*	0.658	Fattening rabbits; (VLM 2017, 2016, 2015, 2014, 2013, 2012)
Cervidae	16.00	16	(Haenel et al. 2018, Rösemann et al. 2019)

Note:

* Using the fertilizer units as published in the (Règlement_grand-ducal 2015) and assuming 85 kg N per fertilizer unit (Règlement_grand-ducal 2015);

Using the French N extraction 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), N.ex for "other poultry" was calculated to be 0.38 kg N/bird place/year.

Table A3-3: Recalculation of N.ex in kg N per year for dairy cows, for other cattle than dairy cows and for the total cattle population for 1990-2018

years	N.ex in kg N for dairy cows per year New	N.ex in kg N for dairy cows per year Old	Impact of recalculation (%)	N.ex in kg N for other cattle than dairy cows per year New	N.ex in kg N for other cattle than dairy cows per year Old	Impact of recalculation (%)	N.ex in kg N for total cattle population per year New	N.ex in kg N for total cattle population per year Old	Impact of recalculation (%)
1990	6 484 139	6 508 237	-0.4	8 782 434	7 310 140	20.1	15 266 573	13 818 377	10.5
1991	6 179 745	6 202 313	-0.4	9 200 999	7 656 282	20.2	15 380 744	13 858 594	11.0
1992	5 737 933	5 758 676	-0.4	8 925 887	7 421 707	20.3	14 663 819	13 180 383	11.3
1993	5 676 762	5 696 971	-0.4	9 002 184	7 487 408	20.2	14 678 946	13 184 378	11.3
1994	5 532 452	5 552 330	-0.4	8 989 447	7 470 829	20.3	14 521 899	13 023 158	11.5
1995	5 531 048	5 550 670	-0.4	9 400 519	7 805 346	20.4	14 931 566	13 356 016	11.8
1996	5 477 847	5 497 082	-0.3	9 683 278	8 043 771	20.4	15 161 125	13 540 853	12.0
1997	5 298 977	5 317 600	-0.4	9 463 158	7 850 065	20.5	14 762 135	13 167 664	12.1
1998	5 269 824	5 288 256	-0.3	9 305 647	7 717 724	20.6	14 575 471	13 005 980	12.1
1999	5 203 193	5 221 403	-0.3	9 326 685	7 740 160	20.5	14 529 878	12 961 563	12.1
2000	5 014 528	5 032 052	-0.3	9 283 128	7 702 105	20.5	14 297 656	12 734 157	12.3
2001	4 850 635	4 884 114	-0.7	9 354 342	7 762 162	20.5	14 204 977	12 646 276	12.3
2002	4 807 497	4 832 432	-0.5	8 900 932	7 398 328	20.3	13 708 428	12 230 760	12.1
2003	4 788 712	4 805 786	-0.4	8 546 894	7 095 396	20.5	13 335 605	11 901 183	12.1
2004	4 923 480	4 932 677	-0.2	8 411 148	6 984 063	20.4	13 334 627	11 916 741	11.9
2005	4 684 969	4 684 841	0.0	8 410 506	6 973 192	20.6	13 095 475	11 658 033	12.3
2006	4 706 224	4 708 905	-0.1	8 328 232	6 903 551	20.6	13 034 456	11 612 457	12.2
2007	4 936 068	4 932 909	0.1	8 684 680	7 202 802	20.6	13 620 748	12 135 711	12.2
2008	4 868 207	4 825 910	0.9	9 010 733	7 453 149	20.9	13 878 940	12 279 059	13.0
2009	4 750 010	4 709 508	0.9	9 026 642	7 475 015	20.8	13 776 651	12 184 523	13.1
2010	4 988 464	4 887 183	2.1	9 129 676	7 549 077	20.9	14 118 140	12 436 260	13.5
2011	4 917 549	4 835 262	1.7	8 755 702	7 246 495	20.8	13 673 251	12 081 756	13.2
2012	4 730 299	4 645 293	1.8	8 492 185	7 029 428	20.8	13 222 484	11 674 721	13.3
2013	4 871 608	4 819 230	1.1	8 631 968	7 140 366	20.9	13 503 576	11 959 596	12.9
2014	4 924 131	4 903 514	0.4	8 990 099	7 445 647	20.7	13 914 230	12 349 161	12.7
2015	5 001 082	4 978 205	0.5	9 090 279	7 536 925	20.6	14 091 360	12 515 130	12.6
2016	5 522 615	5 445 477	1.4	8 838 543	7 331 933	20.5	14 361 159	12 777 410	12.4
2017	5 803 871	5 624 300	3.2	8 848 705	7 317 992	20.9	14 652 576	12 942 292	13.2
2018	5 943 281			8 577 549			14 520 831		

Source: SER

Note: In the previous submission only provisional data were available for the 2017 livestock numbers. Those were, where applicable, updated.

Table A3-4: Recalculation of N.ex in kg N per year for swine, poultry, small ruminants, horses and for others for 1990-2018

	N.ex N in kg for swine per year		Impact of recalculation (%)	N.ex in kg N for poultry per year		Impact of recalculation (%)	N.ex in kg N for small ruminants (sheep & goats) per year		Impact of recalculation (%)	N.ex in kg N for horses, including mules and anes per year		Impact of recalculation (%)	N.ex in kg N for "others" (i.e. ostriches, rabbits, cervidae)		Impact of recalculation (%)
years	New	Old		New	Old		New	Old		New	Old		New	Old	
1990	648 621	455 568	42.4	51 045	39 175	30.3	53 975	51 255	5.3	92 205	117 096	-21.3	16 102	13 597	18.4
1991	576 006	404 975	42.2	46 710	35 865	30.2	56 943	53 563	6.3	97 435	124 372	-21.7	15 988	13 087	22.2
1992	600 831	422 147	42.3	44 689	34 196	30.7	52 755	51 281	2.9	96 295	124 780	-22.8	14 089	11 536	22.1
1993	637 131	447 219	42.5	46 977	35 774	31.3	49 010	45 365	8.0	101 560	130 900	-22.4	11 325	9 740	16.3
1994	605 872	425 621	42.4	44 778	34 086	31.4	57 464	55 514	3.5	111 295	144 364	-22.9	11 372	9 944	14.4
1995	640 509	449 847	42.4	41 382	31 720	30.5	56 492	55 616	1.6	113 165	147 152	-23.1	11 084	9 879	12.2
1996	621 311	436 440	42.4	45 459	34 659	31.2	51 781	50 541	2.5	114 865	149 464	-23.1	8 879	7 874	12.8
1997	671 048	470 741	42.6	44 420	34 415	29.1	56 361	53 537	5.3	120 015	156 060	-23.1	10 725	9 402	14.1
1998	682 401	478 660	42.6	45 042	34 617	30.1	60 493	59 938	0.9	121 900	159 256	-23.5	11 668	10 335	12.9
1999	709 728	497 327	42.7	43 775	33 182	31.9	58 000	56 419	2.8	145 355	191 624	-24.1	11 785	10 581	11.4
2000	675 780	473 180	42.8	51 249	38 621	32.7	58 299	57 426	1.5	163 070	214 472	-24.0	14 091	13 088	7.7
2001	678 559	475 262	42.8	59 678	45 019	32.6	63 275	63 074	0.3	160 560	212 568	-24.5	12 238	10 931	12.0
2002	687 110	480 954	42.9	55 339	41 753	32.5	70 930	66 657	6.4	159 915	211 956	-24.6	12 504	11 147	12.2
2003	733 746	512 915	43.1	56 809	42 836	32.6	87 924	84 456	4.1	176 140	234 532	-24.9	13 737	9 837	39.6
2004	837 211	583 951	43.4	53 424	40 283	32.6	94 435	88 154	7.1	189 265	250 648	-24.5	15 401	10 501	46.7
2005	886 195	618 022	43.4	57 611	43 664	31.9	95 255	84 928	12.2	205 420	285 124	-28.0	13 845	9 805	41.2
2006	834 803	582 216	43.4	56 425	42 774	31.9	95 745	90 512	5.8	205 995	294 848	-30.1	13 423	9 756	37.6
2007	825 176	575 419	43.4	57 751	43 491	32.8	95 954	87 350	9.9	204 270	294 712	-30.7	10 998	7 772	41.5
2008	813 000	566 740	43.5	62 033	46 208	34.2	99 271	89 518	10.9	210 910	308 448	-31.6	13 156	9 746	35.0
2009	814 398	567 699	43.5	70 390	52 781	33.4	103 535	92 501	11.9	214 155	310 216	-31.0	13 673	10 075	35.7
2010	745 075	520 237	43.2	64 009	47 924	33.6	120 068	103 390	16.1	212 615	312 868	-32.0	12 338	9 223	33.8
2011	783 941	546 621	43.4	73 614	55 068	33.7	123 945	106 832	16.0	212 805	312 392	-31.9	15 463	10 881	42.1
2012	805 199	560 841	43.6	82 867	62 369	32.9	129 214	109 510	18.0	226 670	332 316	-31.8	13 563	10 274	32.0
2013	785 968	547 233	43.6	82 548	61 663	33.9	123 746	107 368	15.3	213 530	318 376	-32.9	13 701	8 849	54.8
2014	794 995	553 336	43.7	86 120	64 373	33.8	120 201	104 894	14.6	216 360	321 232	-32.6	11 033	8 333	32.4
2015	852 942	593 149	43.8	83 080	62 214	33.5	132 145	114 189	15.7	214 290	320 756	-33.2	11 617	8 020	44.9
2016	847 359	589 201	43.8	83 172	62 245	33.6	127 998	109 676	16.7	205 860	308 720	-33.3	9 914	6 393	55.1
2017	882 783	603 804	46.2	89 119	66 908	33.2	127 084	108 872	16.7	213 625	321 776	-33.6	7 870	5 062	55.5
2018	824 217			89 032			129 248			210 335			8 923		

Source: SER

Note: In the previous submission only provisional data were available for the 2017 livestock numbers. Those were, where applicable, updated.

Table A3-5: Recalculation of N.ex in kg N per year for all livestock for 1990-2018

years	N.ex in kg N for total livestock population		Impact of recalculation (%)
	New	Old	
1990	16 128 520	14 495 068	11.3
1991	16 173 826	14 490 456	11.6
1992	15 472 478	13 824 323	11.9
1993	15 524 949	13 853 377	12.1
1994	15 352 680	13 692 686	12.1
1995	15 794 198	14 050 229	12.4
1996	16 003 420	14 219 831	12.5
1997	15 664 704	13 891 819	12.8
1998	15 496 975	13 748 786	12.7
1999	15 498 521	13 750 695	12.7
2000	15 260 146	13 530 943	12.8
2001	15 179 286	13 453 130	12.8
2002	14 694 227	13 043 227	12.7
2003	14 403 962	12 785 758	12.7
2004	14 524 364	12 890 277	12.7
2005	14 353 801	12 699 576	13.0
2006	14 240 846	12 632 562	12.7
2007	14 814 897	13 144 455	12.7
2008	15 077 309	13 299 718	13.4
2009	14 992 802	13 217 796	13.4
2010	15 272 246	13 429 901	13.7
2011	14 883 019	13 113 551	13.5
2012	14 479 997	12 750 032	13.6
2013	14 723 069	13 003 084	13.2
2014	15 142 940	13 401 328	13.0
2015	15 385 433	13 613 457	13.0
2016	15 635 462	13 853 645	12.9
2017	15 973 057	14 048 715	13.7
2018	15 782 585		

Source: SER

Note: The 2017 livestock numbers were provisional data, and were updated where applicable.

Revised N.ex for cattle categories other than dairy cows

Calves

We made, similar as the Netherlands and France, the distinction between male and female calves.(Lagerwerf et al. 2019, CITEPA 2019)

The N.ex for female calves < 1 year were based on the N.ex for dairy calves < 1 year as published for the years 2012-2017 for the region Flandern in Belgium (VLM 2017, 2016, 2015, 2014, 2013, 2012) and for female dairy calves < 1 year for South-east Netherlands for 2017,(CBS 2018) namely 33 kg N/animal/year (see Table A3-2).

The assumed N.ex for male calves < 1 year was based on the value from the Netherlands, (CBS 2018) namely 31.7 kg N/animal/year (see Table A3-2).

The applied N.ex for calves are similar to Belgium and the Netherlands, and are slightly higher than the N.ex values used in the French emission calculations (i.e. 26.8 kg N/animal/year and 27.6 kg N/animal/year for female and male calves respectively).(CITEPA 2019)

Female young cattle 1-2 years

The N.ex for female young cattle 1-2 years was assumed to be 58 kg N/animal/year (see Table A3-2)), based on the N.ex as published for the years 2012-2017 for the region Flandern in Belgium (VLM 2017, 2016, 2015, 2014, 2013, 2012).

The applied N.ex for female young cattle 1-2 years is higher than the values used by the Wallonia region in Belgium (i.e. 48 kg N/animal/year)(Protect'eau 2017) and France (i.e. 51.1 kg N/animal/year and 53.5-53.3 kg N/animal/year for beef breed female heifers 1-2 years and for dairy breed female heifers 1-2 years, respectively),(CITEPA 2019) but lower than the values used in the Dutch emission calculations (93.2 kg N/animal/year in 1990 decreasing over time to 67.9 kg N/animal/year in 2017). (Lagerwerf et al. 2019, CBS 2018, 2009).

Fattening bulls 1-2 years

The N.ex for fattening bulls 1-2 years was assumed to be 58 kg N/animal/year (see Table A3-2), based on the N.ex as published for the years 2012-2017 for the region Flandern in Belgium (VLM 2017, 2016, 2015, 2014, 2013, 2012).

The applied N.ex for female young cattle 1-2 years is higher than the values used by the Wallonia region in Belgium (i.e. 40 kg N/animal/year)(Protect'eau 2017), but in the same range as used in French emissions calculations (i.e. 57.8-57.6 kg N/animal/year and 56.4-56.2 kg N/animal/year for beef breed young bulls 1-2 years and for dairy breed young bulls 1-2 years, respectively),(CITEPA 2019) and Dutch emission calculations (72.6 kg N/animal/year in 1990 decreasing to 50.3 kg N/animal/year in 2017).(CBS 2009, 2018)

Heifers > 2 years

The N.ex for heifers > 2 years was assumed to be 77 kg N/animal/year (see Table A3-2), based on the N.ex as published for the years 2012-2017 for the region Flandern in Belgium (VLM 2017, 2016, 2015, 2014, 2013, 2012) for other cattle older than 2 years (in Dutch “andere runderen”), the only value provided by VLM for other cattle than suckler cows or dairy cows.

This is slightly higher than the values used by the Wallonia region in Belgium (i.e. 66 kg N/animal/year)(Protect'eau 2017) and France (i.e. 69.7 kg N/animal/year in 1990 and 69.1 kg N/animal/year in 2017 for dairy heifers > 2 years, respectively 67 kg N/animal/year in 1990 and 66.9 kg N/animal/year in 2017 for beef heifers >2 years),(CITEPA 2019) but similar to the Dutch emission calculations (94.2 kg N/animal/year in 1990 and decreasing to 69.3 kg N/animal/year for heifers > 2 years).(CBS 2009, 2018)

Male bulls > 2 years

The N.ex for heifers > 2 years was assumed to be 77 kg N/animal/year (see Table A3-2), based on the N.ex as published for the years 2012-2017 for the region Flandern in Belgium (VLM 2017, 2016, 2015, 2014, 2013, 2012) for other cattle older than 2 years (in Dutch "andere runderen"), the only value provided by VLM for other cattle than suckler cows or dairy cows.

This is slightly higher than the values used by the Wallonia region in Belgium (i.e. 66 kg N/animal/year)(Protect'eau 2017) and in the Dutch emission calculations (72.6 kg N/animal/year in 1990 decreasing to 50.3 kg N/animal/year in 2017).(CBS 2009, 2018) But this value is in the same range as used in French emissions calculations (i.e. 77.8-77.7 kg N and 79.1-78.4 kg N for beef breed young bulls 1-2 years and for dairy breed young bulls 1-2 years, respectively),(CITEPA 2019) and lower than the value used in German emission calculations (84 kg N/animal/year).(Rösemann et al. 2019, KTBL 2006)

Suckler cows

The N.ex for heifers > 2 years was assumed to be 82 kg N/animal/year (see Table A3-2), based on the N.ex used in the German emission calculations.(Rösemann et al. 2019, KTBL 2006)

Although all other cattle N extraction were derived from the Flandern region emission calculations, the 65 kg N/suckler cow/year used in their emissions seems too low,(VLM 2017, 2016, 2015, 2014, 2013, 2012) although that value is similar to the N.ex used for suckler cows in the Wallonia region (i.e. 66 kg N/suckler cow/year).(Protect'eau 2017) But with Limousin being the main breed in Luxembourg, opposite to the Belgian White and Blue breed used as main breed in Belgium, the values used in the German and the Dutch emission calculations (i.e. 81.5 kg N/suckler cow/year in 2017) seems more appropriated.(KTBL 2006, Rösemann et al. 2019, CBS 2018) The used value 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, also other heavier breeds.

Revised N.ex for swine categories

The swine production in Luxemburg is in the hand of very few, but very professional farmers, and therefore more in line with the German, the Dutch or Flemish swine production.

Sows

The N.ex for sows (pregnant sows and sows with piglets < 8 kg) was assumed to be 23.5 kg N/animal place/year (see Table A3-2), based on the N.ex used for reduced N-feeding strategies for the years 2012-2017 for the region Flandern in Belgium (VLM 2017, 2016, 2015, 2014, 2013, 2012).

This value is in the same magnitude as used in the French emission calculations (CITEPA 2019), and as published by KTBL (Horlacher 2018). The used value is higher than the one used in the Wallonia (B.) emission calculations, namely 15 kg N/sow place/year,(Protect'eau 2017) and lower than the value used in the Dutch emission calculations, (33.8 kg N/sow place/year in 1990 and decreasing to 30.2 kg N/sow place/year and including piglets < 20kg). The latter value is however, not comparable, as including piglets up to 20 kg with the sow emissions.(CBS 2009, 2018)

Weaners

The N.ex for weaners (8-30 kg) was assumed to be 3.6 kg N/animal place/year (see Table A3-2), based on the N.ex provided in KTBL for reduced N-feeding strategies.(Horlacher 2018)

This value is in the same order of magnitude as used in the French emission calculations (4.1 kg N/animal place/year in 2017).(CITEPA 2019)

In the Belgium emissions calculations, weaners are only considered up to 20 kg, and therefore not suitable for our purpose (i.e. 1.9 kg N/animal place/year in the Wallonia region, and 2.18 kg N/animal place/year in the Flanders region),(Protect'eau 2017, VLM 2017) and in the Dutch emission calculations, piglets up to 20 kg are included in the sow extraction.

Fattening pigs

The N.ex for fattening pigs (>30 kg) was assumed to be 11.1 kg N/animal place/year (see Table A3-2), based on the N.ex provided in KTBL for reduced N-feeding strategies.(Horlacher 2018)

This value is slightly lower than the value used in the French emission calculations (12.9 kg N/fattening animal place/year in 2017).(CITEPA 2019) The used value seems to be more in the magnitude of N extraction of Flemish and Dutch fattening pigs. Although in both emission calculations fattening pigs are considered from 20 kg onwards, and therefore is the used N extraction per animal place by definition slightly higher, but with 11.87 kg N/animal/place and 11.7 kg N/animal/place in 2017, respectively, comparable to the used value in the Luxembourgish emission calculations.(VLM 2017, CBS 2018) The extraction value used in the Wallonia region is with 7.8 kg N/animal place/year far below any other value used in neighbouring country.

Revised N.ex for poultry categories

Laying hens

Laying hens are in the hand of a few, very professional farmers. The N.ex for laying hens was assumed to be 0.81 kg N/animal place/year (see Table A3-2), based on the N.ex used for the Flanders region in Belgium (VLM 2017, 2016, 2015, 2014, 2013, 2012).

This used value is slightly higher than the values used in the French and Dutch emission calculations, namely in 2017 0.7 kg N/animal place/year and 0.76 kg N/animal place/year, respectively.(CITEPA 2019, CBS 2018).

Broilers

The broiler production is closer to "poulet de ferme" with a 80-day production cycle as more common in France than the typical 32 to 40 day broilers as produced in Flanders, the Netherlands and Germany. The N.ex for broilers was therefore assumed to be 0.3 kg N/animal place/year (see Table A3-2), based on the N.ex used in the French emission calculations.(CITEPA 2019)

This value is similar to the more extensive broiler production found in the Wallonia region in Belgium (i.e. 0.27 kg N/animal place/year).(Protect'eau 2017)

Other poultry

Turkey, duck, goose and other poultry are considered together in one category (varying over the years between 550-1500 birds/year). There is no large-scale production of any of these birds, the majority of the birds are kept as a kind of "backyard" and within the majority just one round per year. Using the French N extraction for ducks, turkeys, geese and broilers (as proxy for all other poultry), assuming that places for ducks, turkeys and geeses' would only be occupied for half a year, and using the distribution as observed in 2005, N.ex for "other poultry" was calculated to be 0.38 kg N/animal place/year.

This value is similar to the more extensive production found in the Wallonia region in Belgium (i.e. 0.43 kg N/animal place/year).(Protect'eau 2017)

Revised N.ex for small ruminants

Sheep > 1 year

The N.ex for sheep >1 year was assumed to be 10.5 kg N/animal place/year (see Table A3-2), based on the N.ex used for the years 2012-2017 for Flanders region in Belgium (VLM 2017, 2016, 2015, 2014, 2013, 2012).

This value is in the same magnitude as used in the German emission, 11 kg N/animal place/year (Rösemann et al. 2019). The major sheep production in France is not situated in the Northern part of France, and also are the used breeds different, why these emissions cannot be compared. The Dutch emissions calculations consider emissions per ewe, including extractions from lambs why hard to compare. The used N.ex per ewe per year was decreasing from 25 kg N/ewe/year in 1990 to 13.7 kg N/ewe/year in 2017.(CBS 2009, 2018)

Sheep lambs < 1 year

The N.ex for sheep lambs <1 year was assumed to be 4.36 kg N/animal place/year (see Table A3-2), based on the N.ex used for the years 2012-2017 for Flanders region in Belgium (VLM 2017, 2016, 2015, 2014, 2013, 2012).

This value is in the same magnitude as used in the German emission, namely 4 kg N/animal place/year (Rösemann et al. 2019). The major sheep production in France is not situated in the Northern part of France, and are the used breeds different, why these emissions are hard to compare. In the Dutch emission calculations, the extraction from lambs are considered together with ewes.

Goats does > 1 year

The majority of goats are dairy goats. The initiator of this production in Luxembourg were second-generation Dutch immigrants, with good connections and relations to the Dutch dairy goat sector, which has not changed since then. Therefore the N.ex for mature goats, in the majority goat does, was based on goat does, including N.ex of raised goat kits < 1 year, and was assumed to be 18.7 kg N/animal place/year (see Table A3-2) similar to the N.ex used for the years 2017 in the Dutch emission calculations.(CBS 2018)

The major goat production in France is not situated in the Northern part of France, and are the used breeds different, why these emissions are hard to compare. The Flemish emissions calculations consider emissions per doe and per kit, whereby using the same values as for sheep. (VLM 2017, 2016, 2015, 2014, 2013, 2012).

Goat kits < 1 year

The N.ex for goat kits <1 year were included in the N.ex estimates for goat does, and therefore set at 0 kg N/animal place/year in the model (see Table A3-2).

Revised N.ex for "other animals"

Horses

The N.ex for horses was assumed to be 65 kg N/animal/year for agriculture horses >6 months (i.e. horses > 600 kg) where the major breed is Ardennes; 50 kg N/animal/year for riding horses >6 months (i.e. horses 200-600 kg); and 35 kg N/animal/year for light horses (i.e. horses < 200 kg) such as ponys and horses <6 months, but including also mules and anes (see Table A3-2), based on the N.ex used in Belgium (VLM 2017, 2016, 2015, 2014, 2013, 2012, Protect'eau 2017).

This value is in the same magnitude as used in the French emission calculations, who also distinguish between tree different horse categories. (CITEPA 2019) The German and the Netherlands, do distinguish only between two categories, with similar values for ponys/"light" horses, and 53.6 kg N/horses 500-600 kg/year and 58.6 kg N/horse/year, respectively.(Rösemann et al. 2019, CBS 2018, 2012)

Ostriches

Neither IPCC (IPCC 2006), nor (EMEP/EEA 2016) provide a default value for N.ex of ostriches. Belgium and Germany report N.ex for ostriches, whereby the German N.ex was based on Danish data.(Rösemann et al. 2019) The Flemish emission calculations used N.ex for different production stages (i.e. breeding adult bird (18 kg N/bird/year), fattening bird (8.6 kg N/bird/year), young bird 0-3 months (3.16 kg N/bird/year).(VLM 2017) But these detail information were not available in Luxembourg, and seen the low numbers (varying between 343-172 birds/year), will more than probably also not collected in the close future. The used N.ex for ostriches was therefore based on the N.ex used in the German emission calculations, namely 15.6 kg N/bird place/year (see Table A3-2).(Haenel et al. 2018, Rösemann et al. 2019)

Rabbits

The IPCC (IPCC 2006) default value for N.ex for rabbits is 8.1 kg, and in the same magnitude is the value used in the French emission calculations (8.1 kg N/animal place/year in 1990 decreasing to 7.5 kg N/animal place),(CITEPA 2019) the Dutch emission calculations (8.7 kg N/animal place/year in 1990 decreasing to 8.3 kg N/animal place/year in 2017),(CBS 2009, 2018) and in the Flemish emission calculations for female breeding animals, including raising and fattening of rabbits (i.e. 7.42 kg N/animal place/year.(VLM 2017, 2016, 2015, 2014, 2013, 2012).

The Flemish emission calculations however, foresees also N.ex for fattening rabbits (0.658 kg N/animal place/year) and for female breeding animals, including raising of young stock, ***but excluding*** the fattening of young stock (3.16 kg N/animal place/year). (VLM 2017, 2016, 2015, 2014, 2013, 2012). The German emission calculations foresees only N excretion for fattening rabbits (i.e. 0.8 kg N/animal place/year).(Rösemann et al. 2019)

The majority of rabbits are rather small-scale, often for self-consumption. To better fit the Luxemburgish conditions, N.ex were calculated for fattening places and for breeding animal, including raising of youngstock, ***but excluding*** fattening, separately, whereby using the same values as used in the Flemish emission calculations, namely 0.658 kg N/fattening place/year and 3.16 kg N/female breeding animal place including raising of youngstock/year, see Table A3-2.

Deer

The livestock categories "deer" are in the majority deer. Neither IPCC (IPCC 2006), nor (EMEP/EEA 2016) provide a default value for the N.ex of deer. So do also neither Belgium, nor France, nor the Netherlands calculate N emissions for deer. Only Germany report N excretions for deers, whereby the German N.ex was based on Danish data.(Haenel et al. 2018, Rösemann et al. 2019) Given that deer's in Luxembourg are kept under similar conditions w.r.t. climate, feeding situation and holding system (i.e. kept outdoor throughout the year) as found in Germany, the Luxemburg calculations have been based on the N excretion value used by Germany, i.e. 16 kg/animal place/year (Haenel et al. 2018, Rösemann et al. 2019), see Table A3-2.

Updating N.ex values for dairy cows

When estimating the weighted average for milk urea in November 2018, an error had occurred. This mistake was noted in November 2019 and the Administration des service technique de l'agriculture (ASTA) - Service d'analyse du lait, corrected the error and provided the updated values (Tom Engel, written communication 26th November 2019). The recalculated N.ex (in kg N per dairy cow per year) at national level for dairy cows are summarized in Table A3-3.

Revision of slurry storage systems

In earlier submissions no distinction was made between different slurry storage systems and only default values were used in the agricultural emission calculations. The updated slurry storage have an impact on the CH_4-emissions associated with manure management (for recalculations see next further down), and on the direct and indirect N_2O-emissions (for recalculations see following sections).

The following separate frequency distributions were extracted from Gargano et al. (2014) for slurry stores in cattle and pig husbandry:

- Slurry tank without cover: 10.8%;
- Slurry tank with cover (plastic film or solid cover): 14.8%;
- Slurry stored underneath slatted floor: 74.4%.

The frequencies of these categories apply to the cattle and pig categories as a whole. Slurry stored in slurry tank without cover, was assumed to have a natural crust, if originating from cattle, and was assumed to have no natural crust, if originating from pigs. The data available was collected for the year 2010. 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 agriculture census.

Methane emissions from enteric fermentation

When calculating the net energy for maintenance for sheep, the used Cf_i for adult sheep and lamb had been mixed-up. This was corrected. The recalculated methane emissions from enteric fermentation for sheep decreased on average by 4%, see Table A3-6. However, they had only a marginal impact on the total emissions associated with enteric fermentation (-0.01%), except for the year 2017, where the larger changes can be explained by the updated livestock activity data.

Table A3-6: Recalculation of methane emission from enteric fermentation in Gg (CO_2-equivalent)

	Cattle		Impact of recalculation	Sheep		Impact of recalculation	Swine		Impact of recalculation	Others		Impact of recalculation	Enteric Fermentation (CRF 3A)		Impact of recalculation
	Gg CH_4			Gg CH_4			Gg CH_4			Gg CH_4			Gg CH_4		
Year	New	Old	%	New	Old	%	New	Old	%	New	Old	%	New	Old	%
1990	15.3	15.3	0	0.04	0.05	-3.9	0.09	0.09	0	0.03	0.03	0	15.5	15.5	-0.01
1991	15.5	15.5	0	0.05	0.05	-3.8	0.08	0.08	0	0.04	0.04	0	15.6	15.62	-0.01
1992	14.9	14.9	0	0.04	0.04	-4.1	0.08	0.08	0	0.04	0.04	0	15.0	15.02	-0.01
1993	15.0	15.0	0	0.04	0.04	-3.7	0.09	0.09	0	0.04	0.04	0	15.2	15.18	-0.01
1994	14.9	14.9	0	0.05	0.05	-4.0	0.08	0.08	0	0.04	0.04	0	15.1	15.08	-0.01
1995	15.4	15.4	0	0.05	0.05	-4.1	0.09	0.09	0	0.04	0.04	0	15.6	15.59	-0.01
1996	15.6	15.6	0	0.04	0.05	-4.0	0.09	0.09	0	0.04	0.04	0	15.8	15.82	-0.01
1997	15.3	15.3	0	0.05	0.05	-3.8	0.09	0.09	0	0.05	0.05	0	15.5	15.52	-0.01
1998	15.2	15.2	0	0.05	0.05	-4.1	0.10	0.10	0	0.05	0.05	0	15.4	15.37	-0.01
1999	15.2	15.2	0	0.05	0.05	-3.9	0.10	0.10	0	0.06	0.06	0	15.4	15.36	-0.01
2000	15.0	15.0	0	0.05	0.05	-4.1	0.10	0.10	0	0.07	0.07	0	15.2	15.20	-0.01
2001	15.1	15.1	0	0.05	0.06	-4.2	0.10	0.10	0	0.06	0.06	0	15.3	15.30	-0.02
2002	14.6	14.6	0	0.05	0.06	-3.9	0.10	0.10	0	0.07	0.07	0	14.8	14.79	-0.01
2003	14.1	14.1	0	0.06	0.06	-4.3	0.11	0.11	0	0.07	0.07	0	14.3	14.34	-0.02
2004	13.9	13.9	0	0.06	0.07	-4.2	0.12	0.12	0	0.08	0.08	0	14.2	14.18	-0.02
2005	13.9	13.9	0	0.06	0.06	-3.8	0.13	0.13	0	0.09	0.09	0	14.2	14.20	-0.02
2006	13.8	13.8	0	0.06	0.07	-4.3	0.12	0.12	0	0.09	0.09	0	14.1	14.06	-0.02
2007	14.3	14.3	0	0.06	0.06	-4.2	0.12	0.12	0	0.09	0.09	0	14.5	14.6	-0.02
2008	14.8	14.8	0	0.06	0.06	-4.3	0.11	0.11	0	0.10	0.10	0	15.0	15.0	-0.02
2009	14.9	14.9	0	0.06	0.06	-4.2	0.11	0.11	0	0.10	0.10	0	15.1	15.1	-0.02
2010	15.1	15.1	0	0.06	0.06	-4.2	0.11	0.11	0	0.11	0.11	0	15.4	15.4	-0.02
2011	14.6	14.6	0	0.06	0.06	-4.3	0.12	0.12	0	0.11	0.11	0	14.9	14.9	-0.02
2012	14.3	14.3	0	0.05	0.06	-4.3	0.12	0.12	0	0.12	0.12	0	14.6	14.6	-0.02
2013	14.6	14.6	0	0.06	0.06	-4.4	0.11	0.11	0	0.11	0.11	0	14.9	14.9	-0.02
2014	15.1	15.1	0	0.06	0.06	-4.3	0.12	0.12	0	0.11	0.11	0	15.4	15.4	-0.02
2015	15.5	15.5	0	0.06	0.06	-4.3	0.13	0.13	0	0.11	0.11	0	15.8	15.8	-0.02
2016	15.8	15.8	0	0.06	0.06	-4.3	0.13	0.13	0	0.11	0.11	0	16.1	16.1	-0.02
2017	16.0	16.0	0.06	0.06	0.06	-4.3	0.13	0.13	1.56	0.11	0.11	-0.65	16.3	16.3	0.05
2018	15.9			0.06			0.12			0.11			16.1		

Source: SER.

Note 1: In the previous submission only provisional data were available for the 2017 livestock numbers. Those were, where applicable, updated.

Note 2: 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

Having no country-specific measurements, but similar systems, similar cattle breeds and similar conditions as Germany and the Netherlands, the maximum methane producing capacity for manure (Bo) produced by cattle was changed from the IPCC default values of 0.24 for dairy cattle and 0.18 for other cattle (IPCC 2006a), to 0.225 (i.e. average of Dutch and German Bo (NL: 0.22 (Lagerwerf et al., 2019)) and Germany (0.23 (Rösemann et al., 2019))). For swine, the Bo was changed from the IPCC default value of 0.45 (IPCC 2006a) to 0.305 (i.e. average of Dutch and German Bo (Germany (0.30 (Rösemann et al., 2019)) and NL: 0.31 (Lagerwerf et al., 2019))).

The default IPCC methane conversion factor (MCF) for cattle and swine, i.e. 17%, (IPCC 2006a) was adapted to better fit local conditions (i.e. slurry storage), 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. Whereas for swine, the used methane conversion factor 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).

The recalculated total methane emissions from manure management resulted in a slight increase of the emissions, on average 3.5%, see Table A3-7.

Table A3-7: Recalculation of methane emission from manure management in Gg (CO_2-equivalent) for 1990-2018

	Cattle		Impact of recalculation	Sheep		Impact of recalculation	Swine		Impact of recalculation	Others		Impact of recalculation	Manure Management (CRF 3Ba)		Impact of recalculation
	Gg CH_4			Gg CH_4			Gg CH_4			Gg CH_4			Gg CH_4		
Year	New	Old	%	New	Old	%	New	Old	%	New	Old	%	New	Old	%
1990	1.5	1.5	4.6	0.001	0.001	-2.4	0.35	0.35	-0.5	0.01	0.01	0.0	1.9	1.8	3.6
1991	1.8	1.7	5.0	0.001	0.001	-2.3	0.31	0.31	-0.5	0.01	0.01	0.0	2.1	2.0	4.1
1992	1.8	1.7	5.1	0.001	0.001	-2.7	0.32	0.32	-0.5	0.01	0.01	0.0	2.1	2.0	4.2
1993	1.8	1.7	5.1	0.001	0.001	-2.0	0.34	0.34	-0.5	0.01	0.01	0.0	2.2	2.1	4.2
1994	1.9	1.8	5.3	0.001	0.001	-2.5	0.33	0.33	-0.5	0.01	0.01	0.0	2.2	2.1	4.4
1995	2.0	1.9	5.6	0.001	0.001	-2.7	0.34	0.35	-0.5	0.01	0.01	0.0	2.3	2.2	4.6
1996	2.0	1.9	5.9	0.001	0.001	-2.6	0.34	0.34	-0.5	0.01	0.01	0.0	2.3	2.2	4.9
1997	2.0	1.9	5.9	0.001	0.001	-2.2	0.36	0.36	-0.5	0.01	0.01	0.0	2.4	2.3	4.8
1998	2.0	1.9	5.7	0.001	0.001	-2.7	0.37	0.38	-0.5	0.01	0.01	0.0	2.4	2.3	4.7
1999	2.2	2.1	5.6	0.001	0.001	-2.5	0.39	0.40	-0.5	0.01	0.01	0.0	2.6	2.5	4.6
2000	2.2	2.0	5.8	0.001	0.001	-2.7	0.37	0.37	-0.8	0.01	0.01	0.0	2.5	2.4	4.8
2001	2.2	2.0	5.9	0.001	0.001	-2.8	0.36	0.37	-1.1	0.01	0.01	0.0	2.5	2.4	4.8
2002	2.1	2.0	5.6	0.001	0.001	-2.4	0.37	0.37	-1.3	0.01	0.01	0.0	2.4	2.3	4.4
2003	2.0	1.9	5.5	0.001	0.001	-3.1	0.38	0.39	-1.6	0.01	0.01	0.0	2.4	2.3	4.2
2004	1.9	1.8	5.4	0.001	0.001	-3.0	0.42	0.43	-1.8	0.01	0.01	0.0	2.3	2.2	4.0
2005	1.9	1.8	5.2	0.001	0.001	-2.3	0.45	0.46	-2.1	0.01	0.01	0.0	2.3	2.3	3.7
2006	1.8	1.7	4.9	0.001	0.001	-3.2	0.42	0.43	-2.4	0.01	0.01	0.0	2.3	2.2	3.4
2007	1.9	1.8	4.7	0.001	0.001	-2.8	0.41	0.42	-2.7	0.01	0.01	0.0	2.3	2.2	3.3
2008	1.9	1.8	4.7	0.001	0.001	-3.1	0.40	0.41	-2.9	0.01	0.01	0.0	2.3	2.2	3.3
2009	1.9	1.8	4.2	0.001	0.001	-3.0	0.39	0.41	-3.2	0.01	0.01	0.0	2.3	2.2	2.8
2010	1.9	1.8	3.8	0.001	0.001	-2.9	0.38	0.39	-3.5	0.01	0.01	0.0	2.3	2.2	2.5
2011	1.8	1.7	3.6	0.001	0.001	-3.0	0.40	0.41	-3.5	0.01	0.01	0.0	2.2	2.2	2.2
2012	1.8	1.7	3.3	0.001	0.001	-3.2	0.40	0.41	-3.5	0.01	0.01	0.0	2.2	2.1	2.0
2013	1.8	1.8	3.2	0.001	0.001	-3.2	0.39	0.40	-3.5	0.01	0.01	0.0	2.2	2.2	2.0
2014	1.9	1.8	3.3	0.001	0.001	-3.2	0.39	0.40	-3.4	0.01	0.01	0.0	2.3	2.2	2.1
2015	1.9	1.9	2.9	0.001	0.001	-3.1	0.43	0.44	-3.4	0.01	0.01	0.0	2.4	2.3	1.7
2016	2.0	2.0	2.0	0.001	0.001	-3.0	0.42	0.43	-3.4	0.01	0.01	0.0	2.4	2.4	1.0
2017	2.0	2.0	1.9	0.001	0.001	-3.2	0.44	0.45	-2.0	0.01	0.01	-0.5	2.5	2.5	1.2
2018	2.0			0.001			0.41			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.

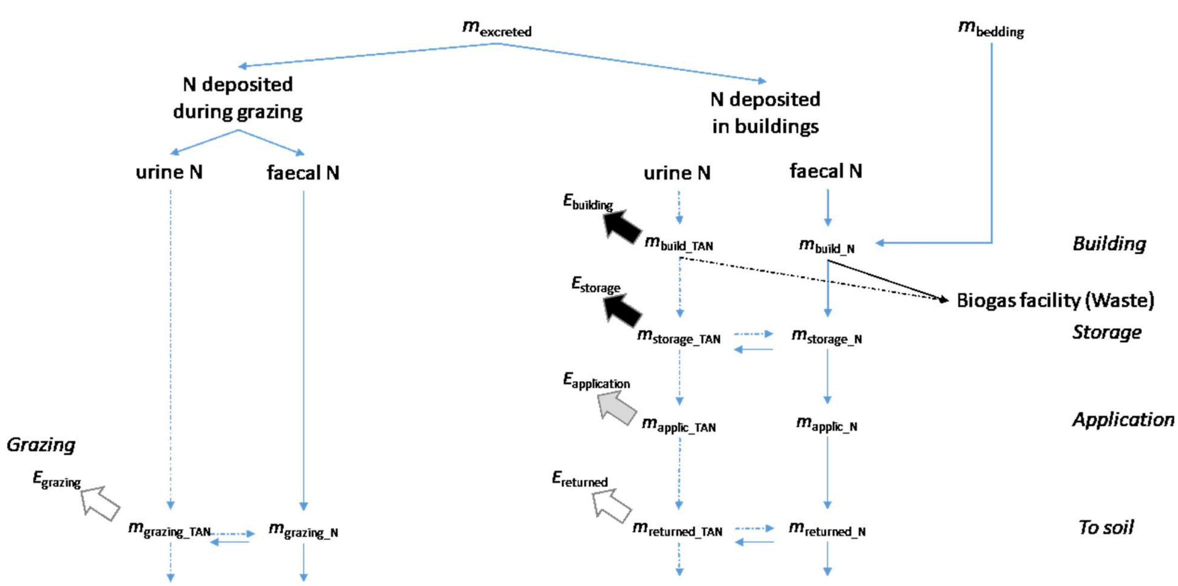
N_2O emissions from manure management

Revised livestock activity data for the year 2017 and the updated N.ex per head/place influenced the N_2O emissions from manure management, both direct and indirect.

Further, with additional information on slurry storage, were the direct N_2O emissions for liquid manure management revised. In earlier submission, the default IPCC emission factors (EF) for direct N_2O emissions from manure management (in kg N_2O-N per kg N.ex) for liquid/slurry with natural crust was used (i.e. 0.005).(IPCC, 2006a) This was adapted, whereby the assumed EF was 0.005, 0.005 and 0.002 for cattle slurry stored in open slurry tanks, in covered slurry tanks and in pits storage below animal confinements, respectively. And for swine slurry, the assumed EF was 0.00, 0.005 and 0.002 for swine slurry stored in open slurry tanks, in covered slurry tanks and in pits storage below animal confinements, respectively. The used EFs' were based on the IPCC guidelines,(IPCC, 2006a) with the exception for covered tanks. There was no EF for covered tanks in the 2006 IPCC guidelines,(IPCC, 2006a) we therefore used the same value as in the German Inventory,(Rösemann et al., 2019) given that climate, storage time, feeding system and animal breeds are similar.

The indirect N_2O-N emissions from manure management (i.e. housing, storage; without spreading), previously calculated using a Tier 1 approach, were revised and were now calculated using an N-flow model (see Figure A3-2 for a schematic representation and section 5.2.6 for additional details).

Figure A3-2: - N Flows 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* 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 arrows mark emissions from application: (E_{applic} NH_3 emissions during and after spreading). Broad white arrows mark emissions from soils: ($E_{grazing}$ NH_3, N_2O, NO_x and N_2 emissions during and after grazing; $E_{returned}$ N_2O, NO_x and N_2 emissions from soil resulting from manure input). Red arrows indicate the flow to another sector (i.e. the proportion of manure that was used as feedstock for anaerobic digestions in biogas facilities). For a full description see NIR 2020 submission.

In earlier submissions indirect N_2O-N emissions due to volatilisation of N from manure management in the country ($N_2O - N_{G(mm)}$), expressed as kg N_2O-N per year, whereby estimated following equation 10.27 of the 2006 IPCC guidelines (IPCC 2006a):

$$N_2O - N_{G(mm)} = [N_{volatilization-MMS} * EF_{GN2O}]$$

in which:

$N_{volatilization-MMS}$	= amount of manure nitrogen that is lost due to volatilisation of NH3 and NOx, kg N per year
$EF_{GN2O(j)}$	= emission factor for N2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N2O-N/ kg NH3-N +NOx-N, whereby using the default value as provided in Table 11.3, namely 0.01 of the 2006 IPCC guidelines (IPCC 2006b).

$N_{volatilization-MMS}$ was calculated following equation 10.26 of the 2006 IPCC guidelines (IPCC 2006a):

$$N_{volatilization-MMS} = \sum_j \left[\sum_i \left[\left(N_i * N.ex_{(i)} * MS_{(ij)} \right) * \left(\frac{Frac_{GasMS}}{100} \right)_{(i,j)} \right] \right]$$

in which:

$N_{(i)}$	= number of head/places of livestock category *i* in the country
$N.ex_{(i)}$	= annual average N excretion per head/place of livestock category *i*, in kg N per head/place per year
$MS_{(i,j)}$	= fraction of livestock category *i*'s manure handled using manure management system *j* in the country
$Frac_{GasMS}$	= fraction of managed manure nitrogen excretion for each livestock categories *i* that is managed in manure management system *j* in the country

In the current submission those emissions are now calculated by multiplying the total emissions of NH_3 and NO_x from animal housing, manure management and NH_3 from manure storage by an emission factor. The used formula is:

$$N_2O - N_{G(mm)} = \{[NH_3 - N\ emissions\ manure\ management + NO_x - N\ emissions\ manure\ management\ ] * EF_{iN_2O-N}\}$$

with:

NH_3-N emissions manure management = NH_3-N emissions (kg NH_3-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; Note: n_i= the number of animals in the i-th livestock category.

$$= \sum_i [\{E_{build\_slurry\_NH3-N(i)} + E_{build\_solid\_NH3-N(i)} + E_{storage\_slurry\_NH3-N(i)} + E_{storage\_solid\_NH3-N(i)}\} * n_i]$$

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; Note: n_i= the number of animals in the i-th livestock category.

$$= \sum_i [\{ E_{storage\_slurry\_NO-N(i)} + E_{storage\_solid\_NO-N(i)}\} * n_i]$$

EF_{iN2O}-N manure management indirect = Nitrous oxide emission factor for indirect emission following atmospheric deposition of NH3 and NOx, here the default IPCC value from Table 11.3 of the 2006 IPCC guidelines (IPCC 2006a) was used, namely 0.01.

The recalculated N_2O emissions from manure management, both direct and indirect together, resulted in an average reduction of 23%, see Table A3-8.

Table A3-8: Recalculation of N_2O emissions from manure management in Gg (CO_2-equivalent) for 1990-2018

	Manure management - Direct emissions		Impact of recalculation	Indirect emissions		Impact of recalculation	Total (CRF 3Bb)		Impact of recalculation
	Gg N_2O			Gg N_2O			Gg N_2O		
Year	New	Old	%	New	Old	%	New	Old	%
1990	0.07	0.08	-7	0.04	0.06	-36	0.11	0.14	-20
1991	0.07	0.08	-9	0.04	0.06	-39	0.11	0.14	-22
1992	0.06	0.07	-10	0.03	0.06	-40	0.10	0.13	-23
1993	0.07	0.07	-10	0.03	0.06	-40	0.10	0.13	-23
1994	0.06	0.07	-11	0.03	0.06	-40	0.10	0.13	-24
1995	0.07	0.07	-11	0.03	0.06	-41	0.10	0.13	-24
1996	0.07	0.07	-11	0.03	0.06	-41	0.10	0.13	-24
1997	0.06	0.07	-11	0.03	0.06	-41	0.10	0.13	-24
1998	0.06	0.07	-12	0.03	0.06	-41	0.10	0.13	-25
1999	0.06	0.07	-15	0.03	0.06	-43	0.09	0.13	-28
2000	0.06	0.07	-15	0.03	0.05	-43	0.09	0.12	-27
2001	0.06	0.07	-14	0.03	0.05	-42	0.09	0.12	-27
2002	0.06	0.07	-14	0.03	0.05	-42	0.09	0.12	-26
2003	0.06	0.06	-14	0.03	0.05	-40	0.09	0.11	-25
2004	0.06	0.06	-13	0.03	0.05	-39	0.09	0.11	-25
2005	0.05	0.06	-12	0.03	0.05	-38	0.09	0.11	-24
2006	0.05	0.06	-12	0.03	0.05	-38	0.08	0.11	-24
2007	0.06	0.06	-12	0.03	0.05	-38	0.09	0.11	-23
2008	0.06	0.06	-10	0.03	0.05	-37	0.09	0.11	-22
2009	0.06	0.06	-9	0.03	0.05	-36	0.09	0.11	-21
2010	0.06	0.06	-8	0.03	0.05	-35	0.09	0.11	-20
2011	0.06	0.06	-9	0.03	0.05	-35	0.09	0.11	-20
2012	0.05	0.06	-9	0.03	0.05	-35	0.09	0.11	-20
2013	0.06	0.06	-9	0.03	0.05	-35	0.09	0.11	-21
2014	0.06	0.06	-9	0.03	0.05	-35	0.09	0.11	-21
2015	0.06	0.06	-10	0.03	0.05	-35	0.09	0.11	-21
2016	0.06	0.06	-10	0.03	0.05	-35	0.09	0.12	-21
2017	0.06	0.07	-10	0.03	0.05	-35	0.09	0.12	-21
2018	0.06			0.03			0.09		

Source: SER.

N_2O emissions from managed soil

We noted a few errors in the crop activity data in different years for the period 1990-2017. For the current update, the last published figures were used. As a consequence,

- the estimated synthetic N-fertilizer had to be revised. In previous submission the published total was used. But as the published total was not necessary updated at the moment that the agricultural surface area was revised it was decided to work from now-onwards with the published weighted average usage of synthetic N per ha and multiply this value with the total agricultural surface area, with consequently slight changes in quantities compared to previous submission.
- the estimated N from crop residues slightly changed, due to the updated crop activity data.

The activity data for compost had to be revised as erroneously the fresh quantities were used, rather than the dry matter quantities, when estimating the N quantities applied from compost to soils, resulting in lower quantities of N, and hence lower emissions in the current submission.

N_2O emissions due to N mineralised from mineral soil as a result of loss of soil carbon were revised and adapted as requested by the reviewer. Emissions were recalculated. The used EF was 0.01, i.e. the default value given in Table 11.1 in the 2006 guidelines (IPCC, 2006b).

N_2O emissions from animal manure for category 3D has changed to previous submission, partly because the revised N.ex per head/animal place per year and partly because of the adapted calculation method for the annual amount of animal manure N applied to soils (kg N per year).

In previous submissions was the annual amount of animal manure N applied to soils (F_{AM}), in kg N per year calculated using the following formula:

$$F_{AM} = \left[\sum_i (N_{(i)} * N.ex_i)\right] - \left[NH_3 - N_{(mm)}\right] - \left[N_2O - N_{D(mm)}\right] - \left[N_2O - N_{G(mm)}\right] - \left[N_2 - N_{(mm)}\right] - \left[NO - N_{(mm)}\right]$$

$N_{(i)}$	= 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
$NH_3\text{-}N_{(mm)}$	= annual national emissions of NH_3–N occurring in stable and during storage, in kg NH_3-N per year.
$N_2O - N_{D(mm)}$	= direct N_2O-N emissions due to manure management in the country, kg N_2O-N per year.
$N_2O - N_{G(mm)}$	= indirect N_2O-N emissions due to volatilization of N from manure management in the country.
$N_2\text{-}N_{(mm)}$	= annual national emissions of N_2–N occurring in stable and during storage, in kg N_2-N per year
$NO\text{-}N_{(mm)}$	= annual national emissions of NO–N occurring in stable and during storage, in kg NO-N per year.

In the current submission we followed the N flow shown in Figure A3-2. Gross amounts are used throughout, i.e. emissions of various N substances from a given source are calculated using the same basic nitrogen amount. Gross amounts are used throughout, i.e. emissions of various N substances from a given source are calculated using the same basic nitrogen amount. Only at the end of the calculation is the combined loss subtracted in order to yield the remaining N available for application. This corresponds to step 13 described in section 5.2.6.

$$F_{AM} = \left[\sum_i \left(\left[m_{returned\_slurry\_N(i)} + m_{returned\_solid\_N(i)}\right] * n_i\right)\right]$$

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* and shown in Table 5-5;

N_2O emissions from urine and dung N deposited on pasture by grazing animals (F_{PRP}) has changed to previous submission, partly because the revised N.ex per head/animal place per year and partly because of the adapted calculation method.

In previous submissions was the annual amount of urine and dung N deposited on pasture by grazing animals (F_{PRP}), expressed in kg N per year estimated according to equation 11.5 of the 2006 IPCC Guidelines (IPCC 2006b):

$$F_{PRP} = \sum_i \left[\left(N_{(i)} * N.ex_i\right) * MS_{(i,PRP)}\right]$$

in which:

$N_{(i)}$	= 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
$MS_{(i,PRP)}$	= fraction of total annual N exrection for each livestock category *i*'s that is deposited on pasture.

In the current submission is the annual amount of urine and dung N deposited on pasture by grazing animals (F_{PRP}), expressed in kg N per year determined using a mass-flow approach 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.

$$F_{PRP} = \left[\sum_i \left(\left[m_{grazing\_N(i)} \right] * n_i \right) \right]$$

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;

In previous submission the indirect N_2O emissions occurring after 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, grazing, sewage sludge and compost (all attributed to agricultural soils) used to be calculated using a TIER 1, whereby following equation 11.10 of the 2006 IPCC guidelines (IPCC 2006b), which is an IPCC Tier 1 approach:

$$N_2O_{ATD} = \{(F_{SN} * Frac_{GASF}) + [(F_{ON} + F_{PRP}) * Frac_{GASM}] * EF_4\} * (\frac{44}{28})$$

In which:

F_{SN}	= annual amount of synthetic fertilizer N applied to soils, kg N per year, see Table 5-32
$Frac_{GASF}$	= 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. 0.1 was used.
F_{ON}	= annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils, kg per year, see Table 5-32 and for the calculations see also section 5.6.3.1
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.
$Frac_{GASM}$	= fraction of applied organic N fertiliser materials and of urine and dung N deposited by grazing animals 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. 0.2 was used.
EF_4	= emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, kg N_2O-N. For the emissions calculations the default values provided in Table 11.3 in the 2006 IPCC guidelines (IPCC 2006b), namely 0.01 was used.
44/28	= conversion of $N_2O\text{-}N_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions.

In the current submission these emissions were calculated using the N-flow model (see Figure A3-2 for a schematic representation and section 5.2.6 for additional details). Whereby the following formula was used:

$$indirect\ soil\ N_2O\ emissions = \{[E_{NH3-N} + E_{NO-N}]_{fert} + [E_{NH3-N} + E_{NO-N}]_{SAM} + [E_{NH3-N} + E_{NO-N}]_{SSS} + [E_{NH3-N} + E_{NO-N}]_{Comp} + [E_{NH3-N} + E_{NO-N}]_{graz}\} * EF_{N_2O-N\ indirect\ soil} * \left(\frac{44}{28}\right)$$

Where:

- Indirect N_2O emissions resulting from the deposition of NH_3 and NO_x emitted from agricultural soils, in Gg/year
- $[E_{NH3-N} + E_{NO-N}]_{fert}$: NH_3-N and NO-N emissions from mineral fertilizer, in Gg/year.
- $[E_{NH3-N} + E_{NO-N}]_{SAM}$: NH_3-N and NO-N emissions from spreading of animal manure, in Gg/year.
- $[E_{NH3-N} + E_{NO-N}]_{SSS}$: NH_3-N and NO-N emissions from spreading of sewage sludge, in Gg/year.
- $[E_{NH3-N} + E_{NO-N}]_{Comp}$: NH_3-N and NO-N emissions from spreading of compost, in Gg/year.
- $[E_{NH3-N} + E_{NO-N}]_{graz}$: NH_3-N and NO-N emissions from grazing, Gg/year.
- $EF_{N2O-N\ indirect\ soil}$: Default IPCC N_2O-N emission factor for indirect emissions from deposition (i.e. (0.01 (IPCC 2006b)), expressed in kg N_2O-N/kg N
- 44/28 : Conversion factor from kg N_2O-N to kg N_2O

And consequently the fraction of synthetic fertilizer N ($Frac_{GASF}$) that volatilizes as NH_3 and NO_x, was calculated by using the following formula:

$$Frac_{GASF} = {[E_{NH3-N} + E_{NO-N}]_{fert}}/{F_{SN}}$$

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 NH_3 and NO_x, calculated by using the following formula:

$$Frac_{GASM} = \left[\frac{\{[E_{NH3-N} + E_{NO-N}]_{SAM} + [E_{NH3-N} + E_{NO-N}]_{SSS} + [E_{NH3-N} + E_{NO-N}]_{Comp} + [E_{NH3-N} + E_{NO-N}]_{graz}\}}{\{F_{ON} + F_{PRP}\}}\right]$$

Where:

- F_{ON}: annual amount of managed animal manure, of sewage sludge and compost 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

The recalculated emissions for managed soils decreased on average by 2.1% (range -5% - 4%), see Table A3-9.

Table A3-9: Recalculation of N_2O emissions from managed soils (CRF 3D) in Gg (CO_2-equivalent) for 1990-2018

Year	Synthetic fertilizer	Animal manure	Sewage sludge	Compost	Grazing	Crop residues	Mineral-ization	Organic soils	Other	Atmospheric deposition	Nitrogen leaching	TOTAL
1990	0.30	0.10	0.0058	NO	0.16	0.026	0.00021	NO	NO	0.057	0.12	0.77
1991	0.31	0.10	0.0058	NO	0.17	0.027	0.00021	NO	NO	0.059	0.12	0.79
1992	0.33	0.10	0.0059	NO	0.16	0.028	0.00021	NO	NO	0.059	0.12	0.81
1993	0.30	0.10	0.0061	NO	0.16	0.030	0.00021	NO	NO	0.058	0.12	0.78
1994	0.29	0.10	0.0064	NO	0.16	0.028	0.00021	NO	NO	0.057	0.11	0.75
1995	0.28	0.10	0.0064	NO	0.16	0.030	0.00021	NO	NO	0.058	0.11	0.76
1996	0.28	0.10	0.0055	NO	0.17	0.031	0.00021	NO	NO	0.058	0.11	0.76
1997	0.28	0.10	0.0058	NO	0.16	0.034	0.00021	NO	NO	0.057	0.11	0.75
1998	0.27	0.10	0.0058	NO	0.16	0.034	0.00021	NO	NO	0.057	0.11	0.74
1999	0.28	0.10	0.0058	NO	0.16	0.035	0.00021	NO	NO	0.058	0.11	0.76
2000	0.28	0.10	0.0030	0.0015	0.16	0.039	0.00020	NO	NO	0.057	0.11	0.75
2001	0.24	0.10	0.0028	0.0007	0.16	0.036	0.00019	NO	NO	0.053	0.10	0.69
2002	0.25	0.09	0.0030	0.0008	0.15	0.029	0.00019	NO	NO	0.052	0.10	0.68
2003	0.20	0.09	0.0023	0.0004	0.15	0.024	0.00018	NO	NO	0.048	0.09	0.61
2004	0.26	0.09	0.0019	0.0005	0.15	0.034	0.00017	NO	NO	0.051	0.10	0.69
2005	0.22	0.09	0.0025	0.0013	0.15	0.026	0.00016	NO	NO	0.048	0.09	0.63
2006	0.22	0.09	0.0022	0.0012	0.15	0.028	0.00016	NO	NO	0.047	0.09	0.62
2007	0.21	0.09	0.0026	0.0012	0.15	0.031	0.00015	NO	NO	0.047	0.09	0.62
2008	0.21	0.09	0.0025	0.0014	0.15	0.032	0.00014	NO	NO	0.047	0.09	0.63
2009	0.21	0.09	0.0016	0.0013	0.15	0.032	0.00013	NO	NO	0.046	0.09	0.63
2010	0.22	0.09	0.0016	0.0016	0.16	0.029	0.00012	NO	NO	0.047	0.09	0.64
2011	0.23	0.09	0.0022	0.0011	0.15	0.025	0.00011	NO	NO	0.047	0.09	0.64
2012	0.21	0.09	0.0026	0.0008	0.15	0.036	0.00010	NO	NO	0.045	0.09	0.63
2013	0.21	0.09	0.0021	0.0007	0.15	0.035	0.00009	NO	NO	0.045	0.09	0.62
2014	0.20	0.09	0.0019	0.0008	0.16	0.037	0.00008	NO	NO	0.045	0.09	0.62
2015	0.20	0.09	0.0023	0.0009	0.16	0.027	0.00007	NO	NO	0.046	0.09	0.62
2016	0.22	0.09	0.0012	0.0009	0.16	0.033	0.00006	NO	NO	0.046	0.10	0.65
2017	0.21	0.10	0.0012	0.0011	0.16	0.030	0.00005	NO	NO	0.047	0.10	0.65
2018	0.20	0.10	0.0012	0.0009	0.16	0.030	0.00004	NO	NO	0.046	0.09	0.63
Trend 1990 - 2018	-31%	-7%	-79%		-1%	17%	-83%			-20%	-19%	-17%
Trend 2017 - 2018	-4%	-1%	0%	-19%	-1%	1%	-23%			-2%	-2%	-2%

Source: SER.

CO_2 emissions from managed soil

In the previous submission it was assumed that for the years 2013-2018 the two main suppliers would have hold 100% of the market shares. The statistics, and consequently the emissions for liming were revised as now-a-days only 80% of the liming is sold by two main suppliers (Personal Communication November-2019; Carlo Hess (Carlo Hess- Agrar Service) & Klaus Palzkill (Versis)), whereas in 2013 it used to be 100%. The estimated market share for the two were obtained, by interpolation and assuming a linear decrease from 2013 to 2018. The recalculated figures are presented in Table A3-10 and resulted in general in higher emissions than in the previous submission. In the previous submission, it was assumed that these two main suppliers would cover approximately 100%, and not only in 2013, but from 2013 onwards up to now-a-days.

Table A3-10: Recalculation of CO2 emissions from managed soil in Gg (CO2-equivalent)

	Liming		Impact of recalculation
	Gg N_2O		
Year	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	6.67	4
2015	7.36	6.77	9
2016	6.99	6.15	14
2017	8.80	7.39	19
2018	10.98		

Source: SER.

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" database[143] 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)[144]" were consulted.[145] According to these data, there was one goat kit born for two dairy goat ewes kept.[146] 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 judgement was used to determine the uncertainty.

The uncertainty of livestock numbers was simulated by multiplying the livestock numbers as obtained from the census by the uncertainty parameters presented in table A3-11.

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[143] 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).

[144] 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 (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/.

[145] Pers. Communication : Marc Schmit and Paul Jacqué, SER - Comptabilité, December 2018.

[146] 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).

Table A3-11: Uncertainty in livestock numbers

	Uncertainty			Distribution used	Notes
	Min	ML	Max		
Calves < 1 year	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[4)]	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[5)]	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	75%		125%	Uniform	[3)]; Taking the number of goat kits and assuming 0.45-0.55 (uniform) kits per dairy doe (unpublished LTBN data)
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
4) For the period 2008-2017 the percentage of culled cows (Pcull 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 2018b).
5) The percentage of fattening lambs being slaughtered was modelled as uniform distribution with minimum 75% and maximum 85% of the fattening lambs to be slaughtered at the age of 6 months.

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 is calculated by dividing the national milk production by the number of lactating dairy cows. The national milk production in itself is 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 ±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%.

[147] About 3% of the milk production in 2016 was used on farms to fed 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.

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 ($x_{grazing\ i}$) for animal category i = MMS-pasture.
- The proportion of livestock manure handled as slurry for animal category i ($x_{slurry\ i}$) = [(MMS-liquid$_{(i)}$ +MMS-feed$_{(i)}$) / (MMS-liquid$_{(i)}$ +MMS-feed$_{(i)}$+ MMS-solid$_{(i)}$)]
- The proportion of liquid livestock manure stored on the farms ($x_{slurry\_storage\ i}$) = [(MMS-liquid$_{(i)}$) / (MMS-liquid$_{(i)}$ +MMS-feed$_{(i)}$)].

The proportion of excreta deposited during grazing ($x_{grazing\ i}$) 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 80% and maximum 120%, and modelled using a pert-distribution. The proportion of excreta deposited within buildings ($x_{building\ i}$) was the remaining proportion that animals were not grazing ($x_{building\ i}$ = 100% - $x_{grazing\ i}$).

The proportion of livestock manure handled as slurry for animal category i ($x_{slurry\ i}$) 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 ($x_{solid\ i}$) was calculated using the following formula: $x_{solid\ i}$ = 100% - $x_{slurry\ i}$.

The proportion of liquid livestock manure stored on the farm for animal category i ($x_{slurry\_storage\ i}$) 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: $x_{slurry\_digester\ i}$ = 100% - $x_{slurry\_storage\ i}$.

No uncertainty was modelled for the proportion of solid manure stored on the farm ($x_{solid\_storage\ i}$) as $x_{solid\_storage\ i}$ corresponds to $x_{solid\ i}$, 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 be calculated using the following formulas:

MMS- pasture$_{(i)}$ = $x_{grazing\ i}$.

MMS-liquid$_{(i)}$ = ($x_{slurry\_storage\ i}$ / ($x_{building\ i}$)).

MMS-feed$_{(i)}$ = ($x_{slurry\_digester\ i}$ / ($x_{building\ i}$)).

MMS-solid$_{(i)}$ = ($x_{solid\ i}$ / ($x_{building\ i}$)).

Storage of slurry

There are three types of storage systems, namely slurry tank without cover ($P_{Slurry\_tank\_open}$), slurry tank with fixed cover ($P_{Slurry\_tank\_closed}$) and slurry stored underneath slatted floor ($P_{Slurry\_tank\_underneath}$).

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 A3-12.

Table A3-12: Uncertainty of the methane emission factor for swine, goats, horses and deer

	Uncertainty			Distribution used	Notes
	Min	ML	Max		
Slurry tank – open ($P_{Slurry\_tank\_open}$)	10%	10.8%	12%	Pert	Assuming -1% and +1%
Slurry tank with fixed cover($P_{Slurry\_tank\_covered}$)	13%	14.8%	16%	Pert	Assuming -1% and +1%
Slurry storage underneath slatted floor >1 month ($P_{Slurry\_tank\_underneath}$)				Calculated	$P_{Slurry\_tank\_underneath}$ = 100% - $P_{Slurry\_tank\_open}$- $P_{Slurry\_tank\_covered}$

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 ±40% for swine, goats, horses, and deer, resulting in the values presented in table A3-13.

Table A3-13: 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 ±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 ±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 6.5.

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 ±30%, which was modelled as pert-distribution with as 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 (+-15%) was used for B_o swine and cattle, whereby assuming an uniform distribution. The used values are summarized in table A3-14.

Table A3-14: Uncertainty of methane producing capacity for manure produced by livestock category *i* (Bo(*i*))

Animal category *i*	$B_{o(i)}$		Distribution used	Source: (IPCC 2006a)
	Min	Max		
Cattle	0.19125	0.25875	Uniform	+-15%
Swine	0.25925	0.0.35075	Uniform	+15%
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 A3-15.

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 ±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 ±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 ±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%.

Table A3-15: 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

And as already indicated in the previous section (Methane emissions from enteric fermentation), the digestibility energy (DE%) was assumed to vary by ±5%.

N_2O emissions from manure management (3Bb)

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 N_2O Emissions from Manure Management

The uncertainty range of the default emission factors (EF) for direct N_2O 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 NH_3 and NO_x from manure management

The uncertainty around the estimated Nitrogen loss due to volatilization of NH_3 and NO_X, as obtained from IIR 2020 (Schuman et al. 2020), was modelled by multiplying the estimated N-Emissions by an uncertainty factor that was uniformly distributed with minimum 80% and maximum 120%.

The uncertainty range used for the Emission factor – N volatilization and re-deposition for indirect soil N_2O 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.

N_2O emissions from managed soils (3D)

Activity data

Areas of cultivated crops were derived from the Agricultural census (STATEC 2019). Up to the year 2006 was the agricultural census based on self-reported data from the farmers for the 15th of May of each year[149] 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) (STATEC 2018a)[150]. Since 2007 are the data extracted from the data collected from the farms filled in by the farmers to apply for e.g. direct payments and other subsidies, respective for the

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[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/enterprises/Agriculture/agriculture/index.html accessed on 5-12-2018.

compulsory accident insurance. There are controls conducted over the year. The uncertainty of annual area for the different cultivated crops was therefore assumed to be uniformly distributed by ±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 ± 10%. For those crops, large quantities are 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; SER). For all other crops, the uncertainty of the harvest annual dry matter yield was assumed to be uniformly distributed with a range of ± 20%.

The uncertainty range of N-fertilizer is derived from the Luxemburgish LTBN data and is assumed to be uniformly distributed by ±20%. A similar uncertainty range is assumed for sewage sludge, compost and other organic fertiliser.

Direct N_2O emissions from N inputs from mineral fertilizers, sewage sludge and compost to managed soils and N mineralized from mineral soil

The uncertainty range of the emission factor (EF) for N additions from mineral fertilisers; organic amendments 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).

Direct N_2O emissions from N in crop residues

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 A3-29 and Table A3-30. No data was provided for rape, why using the values for grains as a proxy, similar to Haenele et al. 2018.

Table A3-29: 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 A3-30: 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 biosmass (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 A3-31.

Table A3-30: Uncertainty for the ratio of below-ground residues to above-ground biosmass (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).

Direct N_2O emissions from animal manure applied to soils and by grazing animals on pasture

The uncertainty range of the emission factor for N_2O emissions from urine and dung N deposited on pasture from cattle, poultry and pigs is based on Table 11.1 from the 2006 IPCC guidelines, and is assumed to be uniformly distributed with minimum 0.007 and maximum 0.06 (IPCC 2006b). The uncertainty range of the emission factor for N_2O emissions from urine and dung N deposited on pasture from sheep and "other animals" is based on Table 11.1 from the 2006 IPCC guidelines, and is assumed to be uniformly distributed with minimum 0.003 and maximum 0.03 (IPCC 2006b).

Indirect N_2O emissions from managed soils

The uncertainty range for the emissions factor for N_2O emissions from atmospheric deposition of N on soils is based on Table 11.3 from the 2006 IPCC guidelines, and is assumed to be uniformly distributed with minimum 0.002 and maximum 0.05 (IPCC 2006b).

The uncertainty around the estimated atmospheric depositions of nitrogen compounds that have evaporated in the form of NH3 and NOx from inorganic N fertilizer, the application of animal manure, grazing, sewage sludge and compost - as obtained from IIR 2020 (Schuman et al. 2020) -, was modelled by multiplying the estimated N-Emissions by an uncertainty factor that was uniformly distributed with minimum 80% and maximum 120%.

CO_2 emissions from managed soils (3D)

Activity data

The uncertainty range for the quantities of dolomite and for limestone is assumed to be uniformly distributed by ±20%. The uncertainty for the emission factor for limestone and dolomite is assumed to be -50%, as suggested by the 2006 IPCC guidelines on page 11.27 (IPCC 2006b).

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Annex 4: CO_2 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 (2000-2018). The data was submitted to AEV by Statec in October 2019.

Solid fuels (all) (tons)	2000	2005	2010	2015	2016	2017	2018
Total imports	187249	130641	113335	83873	89392	78072	72576
Total exports	2	2	1	12	11	42	40
Stock changes							
Gross inland deliveries	187248	130639	113334	83860	89381	78031	72536
Final consumption	187248	130639	113334	83860	89381	78031	72536
Total Industry	184438	129312	112266	82838	88334	77343	72118
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	69645	62820	58649
iron and steel	45778	33006	26676	11871	11758	5666	5187
machinery	0	0					
transportation equipment	0	0					
other industries	0	0					
construction	10467	6523	9535	8505	6931	8857	8282
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential	2810	1328	1068	1023	1047	687	418
Agriculture							
Non specified (others)							

Natural gas (m^3)	2000	2005	2010	2015	2016	2017	2018
Total imports	757984857	1336605223	1364362316	874777108	803881300	791802470	778526375
Total exports							
Stock changes							
Gross inland deliveries	757984857	1336605223	1364362316	874777108	803881300	791802470	778526375
Final consumption	682619208	716627094	769927158	679641776	712190250	707004070	704083278
Total Industry	338053394	373871820	352929621	312969552	315945571	301540531	312696957
other extractive industries	51175	742055	405678	571726	274469	99342	113568
food, beverages and tobacco	8538974	6042655	4345036	6892147	7903163	6566528	6953552
textiles and leather	30709656	28092391	21283224	30794000	31055783	31137293	30355867
wood and wood products	292540	502126	214565	675831	2118731	1670267	1423853
pulp, paper and printing	5471186	8365197	2390990	2580026	2508862	2226751	2545617
chemical and petro-chemical	10400534	15567451	10477927	17613655	20462029	14526384	15902776
non-metallic mineral products	95851071	90463858	87738236	79606801	80388299	75048123	76330316
iron and steel	163666827	202470750	205986749	156010777	152224754	152879550	158983674
machinery	3330984	1590720	975226	3191385	3312067	2640697	3018840
transportation equipment	113808	338426	268440	401032	570016	342661	391730
other industries	16669159	16643239	14945081	9364137	8998492	8230909	9924483
construction	2844436	2910652	2564132	4777927	5525515	5761508	6283378
Total energy sector				0	0	0	0
Total transportation sector	2862172	1145907	2836975	1845318	2128299	1418739	1599639
Commercial and public services	164827432	109884658	152657606	115025877	129217641	100588366	113414183
Residential	176848039	231695729	261466366	249800387	264897603	303269919	276162201
Agriculture	28171	28979	36589	643	1135	186515	210297
Non specified (others)							

Biogas (m^3)	2000	2005	2010	2015	2016	2017	2018
Total imports							
Total exports							
Stock changes							
Gross inland deliveries	2016273	12093349	24860513	32958691	37760706	38393351	40473569
Final consumption	1158777	6950200	10908529	12923428	15030927	15702182	15849536
Total Industry				2574914	2423406	2635346	2552611
other extractive industries				4704	2105	868	927
food, beverages and tobacco			0	56704	60620	57389	56763
textiles and leather				253353	238208	272128	247801
wood and wood products				5560	16251	14597	11623
pulp, paper and printing				21227	19244	19461	20780
chemical and petro-chemical				144914	156950	126955	129818
non-metallic mineral products				654954	616605	655891	623100
iron and steel				1283557	1167614	1336107	1297817
machinery				26257	25405	23079	24643
transportation equipment				3299	4372	2995	3198
other industries				77042	69021	71935	81016
construction				39310	42383	50353	51293
Total energy sector				0	0	0	0
Total transportation sector				15182	16325	12399	13058
Commercial and public services	777886	1152283	1417588	2878899	3817571	3109218	2884105
Residential				2055198	2031851	2650460	2254370
Agriculture	380891	5797917	9490942	5399234	6741774	7294757	8145392
Non specified (others)							

Motor gasoline (tons)	2000	2005	2010	2015	2016	2017	2018
Total imports	595007	494066	346851	275034	280905	292725	315897
Total exports	3000	1000	0	0	119	0	0
Stock changes	10203	-8073	-4467	-9506	4281	508	-3203
Gross inland deliveries	581804	501139	351318	284540	276505	292217	319100
Final consumption	581804	501139	351318	284540	276505	292217	319099
Total Industry	733	2602	2082	1914	1670	1571	1700
other extractive industries	25	41	35	65	53	8	8
food, beverages and tobacco	60	99	73	62	54	42	45
textiles and leather	3	7	6	4	4	75	82
wood and wood products	18	31	21	20	16	15	16
pulp, paper and printing	15	32	14	5	4	4	4
chemical and petro-chemical	46	128	66	14	13	23	24
non-metallic mineral products	28	9	5	122	75	72	77
iron and steel	109	166	148	72	68	60	65
machinery	21	44	37	27	21	22	24
transportation equipment	4	12	17	1	1	1	2
other industries	16	45	5	76	75	54	59
construction	386	1986	1518	1316	1173	1102	1192
Total energy sector	180	562	137	73	67	76	58
Total transportation sector	455863	384807	266371	199798	183757	193820	219302
Commercial and public services	5004	11937	14157	13840	14485	12451	13474
Residential	120025	101231	68571	68915	76525	84299	84566
Agriculture							
Non specified (others)							

Biogasoline (tons)	2000	2005	2010	2015	2016	2017	2018
Total imports	0	0	1103	10796	14026	10502	15449
Total exports	0	0	0	0	6	0	0
Stock changes	0	0	-14	-373	214	18	-157
Gross inland deliveries	0	0	1117	11169	13806	10484	15606
Final consumption	0	0	1117	11169	13806	10484	15606
Total Industry	0	0	7	75	83	56	83
other extractive industries	0	0	0	3	3	0	0
food, beverages and tobacco	0	0	0	2	3	2	2
textiles and leather	0	0	0	0	0	3	4
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	1
non-metallic mineral products	0	0	0	5	4	3	4
iron and steel	0	0	0	3	3	2	3
machinery	0	0	0	1	1	1	1
transportation equipment	0	0	0	0	0	0	0
other industries	0	0	0	3	4	2	3
construction	0	0	5	52	59	40	58
Total energy sector	0	0	0	3	3	3	3
Total transportation sector	0	0	847	7843	9175	6953	10725
Commercial and public services	0	0	45	543	723	447	659
Residential	0	0	218	2705	3821	3024	4136
Agriculture	0	0	0	0	0	0	0
Non specified (others)	0	0					

Diesel (tons)	2000	2005	2010	2015	2016	2017	2018
Total imports	997105	1839706	1748205	1562486	1520809	1535324	1626309
Total exports	2000	2000	0	593	833	580	1621
Stock changes	5409	23781	-6786	-1933	1456	-174	-5050
Gross inland deliveries	989696	1813925	1754991	1563826	1518520	1534918	1629739
Final consumption	989698	1813925	1754991	1563826	1518520	1534918	1629739
Total Industry	22183	78704	62640	57896	50513	47522	51425
other extractive industries	753	1226	1047	1959	1617	236	256
food, beverages and tobacco	1819	2994	2193	1872	1634	1270	1374
textiles and leather	104	199	172	130	123	2278	2465
wood and wood products	545	923	624	602	496	448	485
pulp, paper and printing	441	963	435	149	129	113	123
chemical and petro-chemical	1392	3859	1988	438	396	684	740
non-metallic mineral products	856	262	161	3695	2276	2165	2343
iron and steel	3287	5024	4445	2185	2062	1828	1978
machinery	649	1320	1123	811	636	665	719
transportation equipment	123	375	498	37	33	43	46
other industries	490	1376	145	2288	2281	1641	1776
construction	11673	60089	45674	39806	35496	33335	36073
Total energy sector	979	3089	4143	2195	2024	2312	1747
Total transportation sector	865100	1559012	1471167	1298517	1247378	1284450	1376303
Commercial and public services	27279	65578	76769	75450	78968	67878	73453
Residential	59907	90923	119714	111661	118425	114802	111913
Agriculture	14250	16620	20557	18107	21212	17953	14899
Non specified (others)							

Gasoil (tons)	2000	2005	2010	2015	2016	2017	2018
Total imports	336101	294331	238262	244240	241889	265002	263538
Total exports	6000	6000	1978	48	61	64	164
Stock changes	29706	-11189	-10748	-5309	-4833	-7065	-669
Gross inland deliveries	300395	299520	247032	249501	246661	272003	264043
Final consumption	298973	298947	246575	249055	245907	271451	263661
Total Industry	21818	17710	10029	7949	7571	14549	14854
other extractive industries	763	164	89	444	513	442	451
food, beverages and tobacco	2283	1412	729	1212	1285	2919	2980
textiles and leather	502	837	508	80	116	206	211
wood and wood products	336	285	133	20	28	37	38
pulp, paper and printing	470	348	93	33	29	45	46
chemical and petro-chemical	5148	4099	1768	2084	70	886	905
non-metallic mineral products	840	506	196	1122	1566	2898	2959
iron and steel	8478	2439	1782	434	461	1010	1032
machinery	1866	1695	1437	527	1004	1551	1583
transportation equipment	95	378	312	7	14	191	195
other industries	160	105	29	186	166	334	341
construction	836	5360	2684	1629	2105	3505	3578
Total energy sector	371	445	321	73	95	95	125
Total transportation sector	3584	3047	2371	3078	4207	2498	2551
Commercial and public services	56623	53940	46086	65732	61580	100595	102700
Residential	216577	223804	187768	172223	172454	153713	143431
Agriculture	0	0	0	0	0	0	0
Non specified (others)							

Biodiesel (tons)	2000	2005	2010	2015	2016	2017	2018
Total imports	0	570	45519	83539	88583	117149	123639
Total exports	0	0	0	32	49	44	123
Stock changes	0	0	-175	-103	85	-13	-384
Gross inland deliveries	0	570	45694	83610	88449	117118	123899
Final consumption	0	570	45694	83610	88449	117118	123899
Total Industry	0	0	1626	3093	2940	3625	3909
other extractive industries	0	0	27	105	94	18	19
food, beverages and tobacco	0	0	57	100	95	97	104
textiles and leather	0	0	4	7	7	174	187
wood and wood products	0	0	16	32	29	34	37
pulp, paper and printing	0	0	11	8	8	9	9
chemical and petro-chemical	0	0	52	23	23	52	56
non-metallic mineral products	0	0	4	197	132	165	178
iron and steel	0	0	115	117	120	139	150
machinery	0	0	29	43	37	51	55
transportation equipment	0	0	13	2	2	3	4
other industries	0	0	4	122	133	125	135
construction	0	0	1186	2127	2066	2543	2742
Total energy sector	0	0	107	117	118	176	133
Total transportation sector	0	570	38363	69412	72666	98014	104635
Commercial and public services	0	0	2017	4055	4597	5177	5583
Residential	0	0	3091	5966	6894	8757	8507
Agriculture	0	0	531	967	1235	1369	1132
Non specified (others)	0	0					

Residual fuel oil (tons)	2000	2005	2010	2015	2016	2017	2018
Total imports	6469	2217	2276	998	1412	2380	2740
Total exports				0	53	34	24
Stock changes	0	-1					
Gross inland deliveries	6469	2218	2276	998	1359	2346	2716
Final consumption	6469	2218	2276	998	1359	2346	2716
Total Industry	6469	2218	2276	998	1359	2346	2716
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	1359	2346	2716
construction							
Total energy sector							
Total transportation sector							
Commercial and public services							
Residential							
Agriculture							
Non specified (others)							

LPG (tons)	2000	2005	2010	2015	2016	2017	2018
Total imports	30202	16609	12800	11876	13593	10133	8041
Total exports	6025	4555	1304	2243	3210	1083	79
Stock changes			16	-40	8	-30	0
Gross inland deliveries	24177	12054	11480	9673	10375	9080	7962
Final consumption	24177	12054	11480	9673	10375	9080	7962
Total Industry	56	440	36	20	7	37	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	0	3	0
iron and steel			36	1	0	14	0
machinery	0	412					
transportation equipment							
other industries							
construction	2	14		19	7	21	0
Total energy sector				40	0	0	76
Total transportation sector	1998	1245	1352	676	731	632	336
Commercial and public services	19882	8124	8029	8546	9216	8085	7211
Residential	2241	2245	2063	431	421	326	415
Agriculture							
Non specified (others)							

Lubricants (tons)	2000	2005	2010	2015	2016	2017	2018
Total imports	7047	6194	13364	9480	10115	9037	10109
Total exports			3970	1731	1353	1129	1001
Stock changes	-55	41	-31	13	-8	-15	-23
Gross inland deliveries	7102	6153	9425	7736	8770	7923	9131
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	8770	7923	9131

Bitumen (tons)	2000	2005	2010	2015	2016	2017	2018
Total imports	33315	11784	20758	22908	23424	19802	17910
Total exports	2719	1275	114	2039	1102	17	333
Stock changes	0	0					
Gross inland deliveries	30596	10509	20644	20869	22322	19785	17577
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	22322	19785	17577

Other kerosene (tons)	2000	2005	2010	2015	2016	2017	2018
Total imports	1170	1685	642	840	475	501	448
Total exports			0	0	0	0	0
Stock changes	-13	11	-26	12	-9	3	-29
Gross inland deliveries	1183	1674	668	828	484	498	477
Final consumption	1183	1674	668	828	484	498	477
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	484	498	477
Agriculture							
Non specified (others)							

Aviation gasoline (tons)	2000	2005	2010	2015	2016	2017	2018
Total imports	266	145	352	220	222	222	235
Total exports			0	0	0	0	0
Stock changes	2	0	0	0	0	0	0
Gross inland deliveries	264	145	352	220	222	222	235
Final consumption	264	145	352	220	222	222	235
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	222	235
Commercial and public services							
Residential							
Agriculture							
Non specified (others)							

Jet kerosene (tons)	2000	2005	2010	2015	2016	2017	2018
Total imports	317804	419704	422170	443594	498036	579625	598346
Total exports			0	0	4409	22288	0
Stock changes	6169	-899	3422	-921	365	-394	1469
Gross inland deliveries	311635	420603	418748	444515	493262	557731	596877
Final consumption	311635	420603	418748	444515	493262	557731	596877
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	493262	557731	596877
Commercial and public services							
Residential							
Agriculture							
Non specified (others)							

Biomass (all wood) (GJ)	2000	2005	2010	2015	2016	2017	2018
Total imports	3626	30110	95615	1273222	1350883	1199168	879369
Total exports	5393	62162	135574	899344	1105544	920276	863981
Stock changes							
Gross inland deliveries	640646	1587606	1706714	2548326	2706396	3005875	3645710
Final consumption	635882	1541040	1611302	1756677	1893730	1678800	1461264
Total Industry		880933	863371	807701	813359	727688	442124
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products		880933	863371	807701	813359	727688	442124
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	22844	787	1087
Residential	632256	656953	742120	939001	1057527	950326	1018054
Agriculture							
Non specified (others)							

Biomass (fuel wood) (GJ)	2000	2005	2010	2015	2016	2017	2018
Total imports	3626	9245	67694	54240	81810	84793	90615
Total exports	5393	48612	69625	118418	14178	127	16132
Stock changes							
Gross inland deliveries	635882	649812	737410	644968	801367	651265	802460
Final consumption	635882	649812	737410	644968	801367	651265	802460
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	22844	787	1087
Residential	632256	646658	731599	634993	778523	650478	801373
Agriculture							
Non specified (others)							

Biomass (pellets) (GJ)	2000	2005	2010	2015	2016	2017	2018
Total imports		20865	27921	118371	102410	132244	133935
Total exports		13549	65949	213092	541189	467584	438052
Stock changes							
Gross inland deliveries		10296	15196	293303	291350	454668	657681
Final consumption		10296	10521	267069	253648	286774	210793
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	253648	286774	210793
Agriculture							
Non specified (others)							

Biomass (wood chips) (GJ)	2000	2005	2010	2015	2016	2017	2018
Total imports				1100611	1166663	982131	654819
Total exports				567834	550176	452565	409797
Stock changes							
Gross inland deliveries	4764	927498	954107	1610056	1606630	1899943	2185569
Final consumption		880933	863371	844640	831666	740761	448011
Total Industry		880933	863371	807701	813359	727688	442124
other extractive industries							
food, beverages and tobacco							
textiles and leather							
wood and wood products		880933	863371	807701	813359	727688	442124
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	18307	13073	5888
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 1-13, 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 1.7 for a detailed description of the uncertainty analysis of Luxembourg's greenhouse gas inventory.

Table 1-12 contains the information required by Table 6.1 of the IPCC good practice guidance.