National Inventory Document for 1985-2022

Hungary

Compiled by:

HungaroMet
Magyar Meteorológiai Szolgáltató Nonprofit Zrt.

with contributions by:

Agrárközgazdasági Intézet

ERTI

NFK NEMZETI FÖLDÜGYI KÖZPONT

nébih Termőföldtől az asztalig

2024

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EXECUTIVE SUMMARY

ES.1 Background information

Pursuant to the United Nations Framework Convention on Climate Change (UNFCCC), Hungary, as a Party of the Convention, has been preparing annual inventories of greenhouse gas emissions using the IPCC methodology since 1994. The aim of a greenhouse gas (GHG) inventory is to give an as complete and accurate as possible state of the art estimation of anthropogenic emissions by sources and removal by sinks of greenhouse gases not controlled by the Montreal Protocol. In accordance with the Kyoto Protocol, the following direct greenhouse gases are taken into account: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), Sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). The quality of the inventory is controlled by Hungarian and international experts regularly.

The GHG inventory is compiled by **HungaroMet** Hungarian Meteorological Service as laid down by a government decree. The participation of National Land Centre (NLC) together with the Forest Research Institute of the University of Sopron and National Food Chain Safety Office (NFCSO) as compilers of the whole LULUCF sector is formalized by the same governmental decree. As a recent development, Institute of Agricultural Economics Nonprofit Kft. (AKI) prepares the agriculture part of the inventory also following the regulations of the above (recently amended) governmental decree. Also, other institutions and external experts are involved in the process of inventory preparation, e.g., Hungarian Central Statistical Office, Hungarian Energy and Public Utility Regulatory Authority, KTI Hungarian Institute for Transport Sciences and Logistics Non Profit Limited Liability Company, just to name a few.

The main purpose of this National Inventory Document is to describe the input data and calculation methodologies on which the emissions estimates are based thus increasing the transparency of the inventory. The present report refers to the inventory time series for the years 1985-2022. The NIR provides relevant background information on institutional arrangements, QA/QC procedures and other information underlying the inventory compilation in Chapter 1. In Chapter 2 the trends for aggregated greenhouse gas emissions are discussed. The chapters following provide detailed information on each of the main source categories. Chapter 10 discusses details of recalculations and planned improvements. In the Annexes key category analysis and complementary methodological information can be found.

ES.2 Summary of National Emissions and Removal Related Trends

In 2022, total emissions of greenhouse gases in Hungary were ***59.5 million tonnes*** carbon dioxide equivalents (CO_2-eq) excluding the LULUCF sector. Taking into account also the mostly carbon absorbing processes in the LULUCF sector, the net emissions of Hungary were 52.7 million tonnes CO_2-eq in 2022. Being about 6 tonnes, the Hungarian per capita emissions are below the European average.

Compared to the base year (average of 1985-87), 1990, and 2005, our current emissions are lower by 46%, 37%, and 23%, respectively.

This significant reduction was partly a consequence of the regime change in Hungary (1989-90) which brought in its train radical decline in the output of the national economy. The production decreased in almost every economic sector including also the GHG relevant sectors like energy, industry and agriculture. Then, between 2005 and 2013, after a period of about 14 years of relatively stagnant emission level (1992-2005), GHG emissions fell again quite significantly by 24 per cent. The global financial and economic crisis exerted a major impact on the output of the Hungarian economy, consequently on the level of GHG emissions as well resulting in a quite significant drop of 8% between 2008 and 2009. Then, after a smaller increase in 2010, emissions decreased further in the following four years. In contrast, the decline in economic output stopped in the first quarter of 2010, and Hungary not only reached the pre-crisis level of GDP again in 2014 but exceeded it even in 2015.

After 2013, emissions started growing again. Up to 2017, the overall increase reached 11%. After four years of increase, emissions have remained more or less at the same level between 2017 and 2019. In 2020, however, emissions fell by 3% to around 2016 levels, mainly due to a significant reduction in transport emissions as a consequence of COVID-19. This decrease, however, proved to be temporary, in line with global trends emissions increased again by 2 per cent in 2021.

Then in 2022, emissions fell by almost 7% due to decreasing production and consumption levels driven by rising energy prices, and especially due to a 15% drop in natural gas consumption, but we have not yet reached the previous low point of 2013-14.

The most important greenhouse gas is carbon dioxide accounting for 76% of total GHG emissions. The main source of CO_2 emissions is burning of fossil fuels for energy purposes, including transport. CO_2 emissions have decreased by 47% since the middle of the 80's, and by 38% since 1990. Methane represents 15% in the GHG inventory. Methane is generated mainly at waste disposal sites and in animal farms, but the fugitive emissions of natural gas systems (i.e., transmission, storage, and distribution) are also important sources. In 2022, CH_4 emissions were 40% and 37% lower than in the base year and 1990, respectively. Nitrous oxide contributes 6% to the total GHG emissions. Its main sources are agricultural soils, and manure management. N_2O emissions are 63% and 51% lower compared to the base year and 1990, respectively. The total emissions of fluorinated gases amount to 3%.

Table ES.1 *Trend of emissions by GHGs, excluding LULUCF (Gg CO_2-eq)*

GHG	BY	1990	1995	2000	2005	2010	2015	2020	2021	2022
CO_2	85,975	73,427	61,464	58,244	60,142	51,993	46,567	47,107	48,331	45,280
CH_4	14,621	13,850	11,716	11,870	11,045	9,861	9,493	9,173	9,001	8,730
N_2O	9,897	7,429	4,198	4,789	4,967	3,289	4,004	4,445	4,474	3,668
HFCs	NO	0	33	204	749	1,258	1,887	1,839	1,830	1,746
PFCs	333	338	200	254	252	4	4	2	2	2
SF_6	8	18	58	92	100	103	117	116	107	110
NF_3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
TOTAL	**110,834**	**95,062**	**77,670**	**75,453**	**77,255**	**66,509**	**62,072**	**62,683**	**63,745**	**59,535**

Base year (BY)=average of 1985-87

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

By far, the biggest emitting sector was the energy sector contributing 73% to the total GHG emission in 2022. Industrial processes and product use (IPPU), and Agriculture had a similar share of 10% each. The waste sector contributed 6%. Compared to the base year, and even to 1990, emissions significantly decreased in the energy (-37%), industrial processes and product use (-48%), and agriculture (-38%) sectors. Emissions in the waste sector have also declined after an initial increase (-10%). (Values in brackets indicate changes between 1990 and 2022.) The land use, land-use change and forestry (LULUCF) sector shows fluctuating behavior. Looking at the most recent trends since 2005, emissions significantly dropped in the energy, industrial processes and waste sectors by 24%, 33%, and 22% respectively. Emissions in the agriculture sector were more or less at the same level in 2022 as in 2005.

Table ES.2 *Trend of emissions and removals by sector (including LULUCF, Gg CO2-eq)*

SECTOR	BY	1990	1995	2000	2005	2010	2015	2020	2021	2022
ENERGY	80,634	69,481	59,089	56,594	57,515	49,860	44,442	44,340	45,642	43,572
IPPU	14,563	11,387	8,077	7,986	8,874	6,435	7,008	7,369	7,144	5,927
AGRICULTURE	11,971	9,968	5,961	6,053	5,985	5,519	6,550	7,099	7,115	6,213
LULUCF	-2,373	-3,300	-6,273	-1,087	-5,992	-4,795	-5,675	-7,092	-7,182	-6,787
WASTE	3,666	4,226	4,543	4,819	4,881	4,694	4,073	3,875	3,843	3,823
TOTAL	**108,461**	**91,762**	**71,397**	**74,366**	**71,263**	**61,714**	**56,397**	**55,591**	**56,563**	**52,749**

Base year (BY)=average of 1985-87

The ***energy sector*** was responsible for 73% of total GHG emissions in 2022. Production and use of energy generate most greenhouse gases, largely CO_2. Currently, 16% of domestic primary energy supply is nuclear, 13% is renewable which means that the remaining - overwhelming - part of primary energy demand has to be met by fossil fuels. Natural gas accounts for the largest share (43%) of incinerated, largely fossil fuels, followed by petroleum products (34%). Emissions have been positively influenced by the fact that the proportion of coal with higher specific emissions has fallen from 31% to 6% in the last 35 years, which is well below the current share of biomass in fuel consumption (15%).

The three most important sources of emissions in the energy sector are transport, energy industries, and "other sector" (mostly including residential and other buildings), representing respectively 25%, 18% and 19% of total national emissions in 2022. Energy use and emissions from manufacturing industries and construction contributed 8% to domestic total emissions. Fugitive (mostly methane) emissions from the domestic natural gas system represent 3% of total emissions

In recent years, the transport sector became the largest emitter, not only within the energy sector but also across all sectors. Although emissions from the road transport-dominated sector fell sharply by 14% in 2020 as a result of preventative measures for COVID-19, transport emissions increased significantly both in 2021 and 2022, and now transport accounts for a quarter of total domestic emissions. In 2022, transport emissions were 50% higher than in 2013, the previous low point. (However, preliminary fuel sales data suggest that the growth stopped in 2022, and a decline of emissions is expected for 2023 in this sector.)

As far as energy industries are concerned, domestic electricity production decreased somewhat (-1%), within which natural gas-based production fell more significantly (-8%). A welcome development is the rapid increase in the utilization of solar energy: now 13% of gross electricity production (150% of the production of coal power plants!) comes from solar energy. The share of nuclear power generation was 44%. Electricity imports are still relatively significant (a quarter of consumption). As a result of all this, total emissions from energy industries decreased by 7% in 2022.

In 2022, the winter was milder than average with lower heating demand. In addition, higher energy prices also contributed to a 10% drop in household heating energy consumption. The use of natural gas decreased the most (-14%), the use of firewood less so (-3%). The energy consumption of buildings in the service sector also dropped significantly (-15%), as did that of industrial plants (-10%).

As a result of all this, the emissions of the energy sector decreased by 5% (2.1 million tons of carbon dioxide equivalent) between 2021 and 2022.

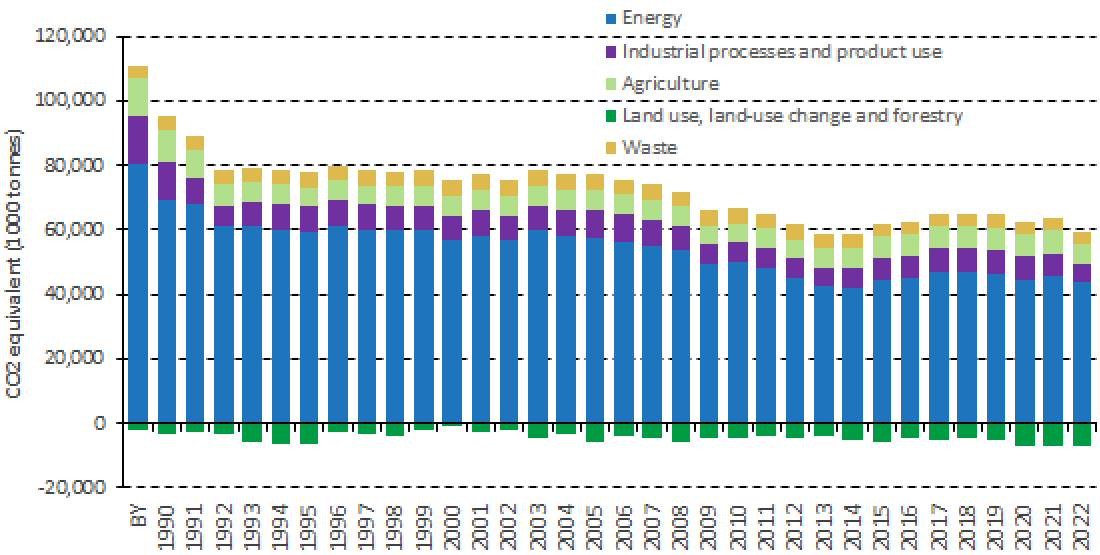


Figure ES. 1 *Change in greenhouse gas emissions from base year (BY, 1990-2022)*

The ***industrial processes and product use sector*** contributed 10% to total GHG emissions in 2022. The most important greenhouse gas was CO_2, contributing 63% to total sectoral GHG emissions, followed by F-gases with 31%. In 2022, 33% of the emissions came from chemical industry, followed by 29% from product uses as ODS substitutes. Mineral industry has 19%, metal (namely iron and steel) industry has 11% contribution to sectoral GHG emissions, respectively. Other product uses (containing SF_6 and N_2O) and non-energy products from fuels and solvent use have the smallest influence on the 2022 IPPU inventory with 6% and 2%, respectively. Process related industrial emissions decreased by 59% between the base year and 2022, and by 33% between 2005 and 2022.

In 2022, the downward flight of pig iron production continued due to problems in the operation of Hungary's only pig iron manufacturer, therefore the output of iron and steel production decreased by 24%. The growth of chemical industry emissions stopped in 2021 and started to decrease in 2022: due to the sharp fall of ammonia and urea based fertilizers production, the emissions of this sector decreased by 28%. Emissions from mineral industry (mainly from cement production) started to decrease again, it was 16% less in 2022 than in the previous year. Emissions from the non-energy use of fuels and solvent use increased by just 1% after the stronger growth in 2020.

Almost a third of industrial emissions come from the operation of equipment containing F-gases and from use of F-gas containing products. Category 2.F.1. (Refrigeration and air-conditioning) accounts for 84% of total F-gas emissions, emissions growth has stopped in recent years. Use of fluorinated and perfluorinated compounds (HFCs, PFCs) has been significant in Hungary since the early 1990s, but these gases became a commonly used refrigerant in the second half of the decade. Most of the equipment with F-gas installed after this period is now coming to the end of its lifetime. Disposal and regeneration of increasing quantities of gases from equipment end-of-life helps to stop emissions growth.

In 2022, the ***agriculture sector*** accounted for 10% of total emissions. The contribution of agriculture to total emissions was similar also in 1990. Emissions from agriculture include CH4 and N2O gases. 81 per cent of total N_2O emissions were generated in agriculture in 2022. Emissions from agriculture have decreased by 48% over the period of 1985-2022. The bulk of this reduction occurred in the years between 1985 and 1995, when agricultural production fell by more than 30 per cent, and livestock numbers underwent a drastic decline.

Between 1996 and 2008, agricultural emissions had stagnated around 6.1 Mt with fluctuations up to 3.5%. Behind this trend there were compensatory processes. While the number of livestock decreased further leading to lower emission, the use of fertilizers increased by 68% in the period 1995-2007 which caused growing nitrous oxide emissions from agricultural soils. In 2008 the significantly rising fertilizer prices led to lower fertilizer use, which resulted in some reduction in the emission levels.

Agricultural emissions decreased both in 2009 and 2010. A major reduction in emissions occurred in 2009, when 11 per cent decline in swine population also contributed to the downward trend. Agricultural emissions, after hitting the lowest point in 2010, had increased until 2018, mainly because of the increase in the inorganic fertilizer use, cattle livestock, and milk production per cow.

The GHG-emissions reflect the restructuring in the agricultural production has taken place since 2004, namely the increased ratio of crop to livestock production. Share of CH_4 emissions, which derive mainly from the animal husbandry, has decreased, while the N_2O emissions, originating primarily from the crop production has grown, since 2004.

Certain types of inorganic fertilizers as urea containing fertilizers and calcium ammonium nitrate (CAN) fertilizers contribute to the agricultural GHG-emissions not only with their nitrogen, but also their carbon content. In Hungary CAN fertilizers have become increasingly popular in the recent years, as a result N_2O and CO_2 emissions has tripled from this source since 2005.

In 2019, emissions growth temporarily slowed down, mainly due to the decreasing swine livestock and synthetic fertilizer use, but emissions increased again in 2020. The significant decrease in emissions from agricultural soils in 2022 compared to 2021 is mainly due to the decrease in nitrogen fertilizers use, and the yields of major crops were also lower than in 2021.

With an average annual net sink of above 4 million tCO2 equivalent, the ***Land Use Land-Use Change and Forestry sector*** has been a net carbon sink over the entire inventory time series. In 2022, the net sink (including that from the harvested wood product carbon pool) reached 6.8 million tCO_2 equivalent/year. Forests removed 6.2 million tCO2 from the air in 2022. Of the factors explaining these processes in the long-term, this was a result of a rather intensive afforestation for decades as well as the sustainable management of the existing forests. The carbon balance of the harvested wood product pool varies but considerably increased in the last five years, with a net sink of over 900 ktCO_2/year both in 2021 and in 2022. The non-forestry land-use sectors used to be small net sinks before 2016 but they have turned small sources since then. The net emission of these sectors has been estimated as 319 kt CO2-eq/year in 2022. Due to its complex dynamics, the variation of the annual greenhouse gas balance of the LULUCF sector is relatively high, with no trend in the years since 2005, i.e., for those with reliable data.

The ***waste sector*** was responsible for 6% of total national GHG emissions in 2022 amounting to 3.8 million tons of CO2 equivalent. The largest category was solid waste disposal on land, representing 87% in 2022, followed by wastewater treatment and discharge (9%), biological treatment of solid waste (4%), and incineration of waste without energy recovery (less than 1%). In contrast with other sectors, emissions from the waste sector are by 4% higher now than in the base year. However, the growth in emissions stopped in the last decade, and a reduction of 22% could be observed between 2005 and 2022. The degradation process in solid waste disposal sites is quite slow which means that waste that were disposed many years earlier have still an influence on current emission levels. However, the amount of disposed waste had dropped significantly since 2005 (e.g., landfilled municipal waste decreased by more than 50%) consequently methane emissions started to decrease as well. GHG emissions from wastewater handling have a pronounced decreasing trend due to a growing number of dwellings connected to the public sewerage network.

ES.4 Precursors

NO_X, CO and NMVOC gases are referred to as indirect gases because they (together with SO_2) influence atmospheric warming indirectly, via secondary effects. Nitrogen oxides, carbon monoxide and (non-methane) volatile organic compounds are precursor of ozone which is itself a naturally occurring greenhouse gas. Sulphur dioxide can contribute to formation of aerosols that scatter some of the solar radiation back into space. Calculation of the emissions of these gases is required by the UNFCCC reporting guidelines. It should be noted that Hungary (as well as the other European countries) has calculated the emissions of such gases for several decades and the Geneva Convention of 1979 (CLRTAP) also laid down such obligations. Emissions are reported consistently in the above two reporting regimes. The following table shows the main trends in emissions:

Table ES. 3 *Emissions of indirect gases, excluding LULUCF (Gg) (Source: CLRTAP reporting)*

GASES	1990	1995	2000	2005	2010	2015	2020	2021	2022
NOX	244	191	189	180	148	128	108	110	101
CO	1416	981	857	698	546	460	334	337	327
NMVOC	314	227	202	183	142	135	122	121	118
SO2	832	615	427	42	30	24	17	14	14

(Source: CLRTAP/NECD reporting)

The substantial reduction in sulphur dioxide emissions is attributable to the decreased use of fossil fuels in general and the decreasing share of coal with higher sulphur content. After 2000, further reductions were observed due to the introduction of SO_2 precipitators in coal-fired power stations. Reduced carbon monoxide emissions are obviously a consequence of decreased fuel uses. The decrease in NO_X emissions is relatively moderate due to the increasing significance of transport.

1 INTRODUCTION

1.1 Background information and climate change

Hungary submitted the First National Communication in 1994 when the country joined the UN Framework Convention on Climate Change (hereinafter referred to as the Convention). In conjunction with this, the greenhouse gas inventories of the preceding years were prepared. Since then, inventories have been compiled annually as required. According to the Convention, year 1990 considered as the general reference level was not adequate for Hungary as a base year because the economic output of the country was already on the descending course as a result of the ongoing transition to market economy. Instead of 1990, the average of years 1985, 1986 and 1987 (hereinafter referred to as ”base year”) was selected because these three years represented a certain level of stability in the fluctuating economic output. This request was accepted by the COP.

With the introduction of additional greenhouse gases, it was necessary to select the corresponding base years. (This was particularly important for HFCs because such gases had been used increasingly as replacements for ozone depleting chlorofluorocarbons since the early 1990’s.) Hungary has chosen 1995 as the base year for fluoride gases. The process of inventory preparation has been improved year by year. The inventory teams did their best to meet the changing and growing requirements. Particular emphasis was placed on determining the specific emission factors for Hungary.

The regional effects of the global climate change can clearly be seen on the Hungarian observations. The annual averages of temperature in Hungary are very similar to the well-known wave of the global temperature since the beginning of the 20th century.

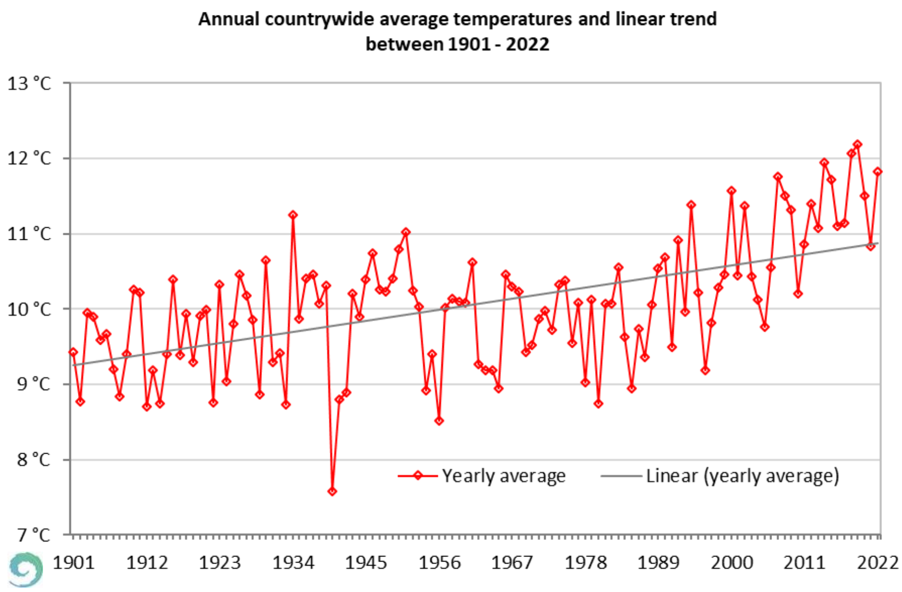


Figure 1.1. *Linear trends in annual mean temperature (°C) over the period 1901-2022 in Hungary, based on the homogenized, interpolated dataset of HungaroMet*

The yearly average temperature was 11.83 °C in 2022 in Hungary. 2022 was the third warmest in the last 122 years, closing the hottest decade since 1901, based on controlled, homogenized and interpolated data of HungaroMet Hungarian Meteorological Service. The year 2022 fits in well with the global warming trend in terms of temperature. The national average annual average temperature rises significantly at a 90% confidence level based on a linear trend estimate from a long time series beginning in 1901. The change in the national average annual temperature over the last 122 years (1901 to 2022) has averaged +1.45°C while within Hungary, there has been a temperature change of at least +1.09 °C to a maximum of +1.81 °C.

According to the homogenized data, the countrywide average of yearly total precipitation was 497 mm in 2022, which is the seventieth driest year since 1901. Over the last 122 years, between 1901 and 2022, we have seen a moderate decline, averaging 4.1%, based on the exponential trend adjusted to annual precipitation amounts.

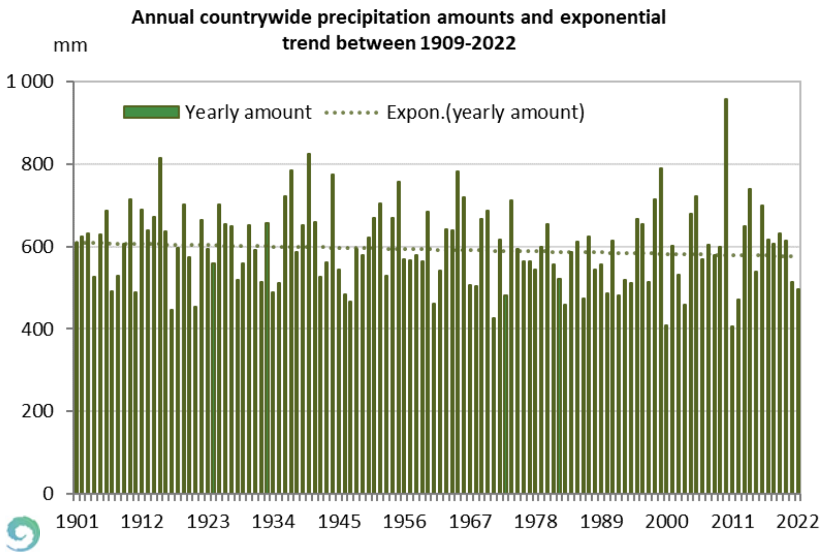


Figure 1.2 *Exponential trends in annual precipitation sum (mm) over the period 1901-2022 in Hungary, based on the homogenized, interpolated dataset of HungaroMet*

1.2 Institutional arrangements

The minister responsible for the environment has overall responsibility for the Hungarian Greenhouse Gas Inventory and the Hungarian National System for Climate Reporting. He/she is responsible for the institutional, legal and procedural arrangements for the national system and the strategic development of the national inventory. The Ministry of Environment and Water had been abolished after the elections in spring 2010, and its tasks have been taken over by the Ministry of Rural Development. The structure and duties of the ministries changed again somewhat after the elections in 2014, and the Ministry of Rural Development turned to Ministry of Agriculture which nevertheless had the same responsibilities as regards environmental matters. Following the 2022 elections, the Ministry for Technology and Industry took over the environmental issues until December 1, when the new Ministry for Energy Affairs was established with responsibilities for climate policy and environment, among others. Therefore, the designated single national entity is now the **Ministry for Energy Affairs**.

Contact details of the single national entity are as follows:

Ministry for Energy Affairs

Head office:	1011 Budapest, Fő u. 44-50.
Postal address:	1440 Budapest, Pf. 1.
Phone:	+36-1- 795-67-66
Fax:	+36-1- 550-39-44
E-mail:	ugyfelszolgalat@tim.gov.hu, sajto@tim.gov.hu

Csaba Lantos, Minister of Energy Affairs

Postal address:	1011 Budapest, Fő u. 44-50.

The national system has to be operated by the minister responsible for the environment but, as prescribed by legislation, in consent and cooperation with the ministers responsible for energy policy, forest management, agricultural policy, and national budget. Within the Ministry for Energy Affairs, a Climate Policy Department has been established that plays a coordinating and supervisory role in the national system. The head of this department is Hungary's current UNFCCC Focal Point.

Currently, Government Decree 278/2014 of 14 November 2014 regulates the preparation of the national GHG reports and the procedure of the obligatory data provision necessary for the inventories. This decree designates **HungaroMet** Hungarian Meteorological Service (thereinafter: HungaroMet) as the main compiler institute. In addition, it formalizes the participation of the University of Sopron (that incorporates the former Forest Research Institute), Hungarian National Land Centre (that has a Forestry Department), and National Food Chain Safety Office in the inventory preparation process. The latter three institutes are responsible for the LULUCF sector. As a recent development, Institute of Agricultural Economics Nonprofit Kft. (AKI) became responsible by legislation for the agriculture sector of the inventory.

Pursuant to Article 13 (1)-(5) of Government Decree 547/2023 of 12 December 2023 on the National meteorological service provider and meteorological activities in Hungary, the related rights and obligations of the Hungarian Meteorological Service (OMSZ) have been transferred to HungaroMet from 1st January 2024. On the basis of these provisions, all duties of OMSZ have been taken over by HungaroMet, a state-owned limited company, also from 1st January 2024. HungaroMet performs the tasks of the legal predecessor OMSZ without interruption and without change.

The duties of HungaroMet are also specified in the above mentioned Government Decree 547/2023. These duties include also the preparation of emission inventories of greenhouse gases and air pollutants for the fulfillment of reporting obligations arising from international treaties.

A greenhouse gas inventory division was already established in 2006 within the Met. Service for the preparation and development of the GHG inventory. The name of the division was changed to Unit of National Emissions Inventories in 2015 to reflect the fact that this unit was also responsible for the compilation of air pollutant emission reports. From 2024 on, the emission inventories are compiled in the newly established **Air Quality Modelling & Emissions Unit**. This unit is responsible for most inventory related tasks, compiles the greenhouse gas inventories and other reports with the involvement of external institutions and experts, partly on a contractual basis. Many parts of the inventory (energy, industrial processes, and waste) are prepared by the experts of the unit themselves. The agriculture sector is prepared by the Institute of Agricultural Economics Nonprofit Kft. (AKI), and the whole LULUCF sector is compiled by the institutes listed in the above-mentioned Government Decree 278/2014. Within the Air Quality Modelling & Emissions Unit, there is a core expert team of three people dealing with emissions. The division of labor and the sectoral responsibilities within the team are laid down in the QA/QC plan and other official documents of HungaroMet. The Head of Unit coordinates the teamwork and organizes the cooperation with other institutions involved in inventory preparations. He is responsible for the compilation of CRF tables and NIR. Within the team the experts are responsible for different sectors. Besides, a QA/QC coordinator and an archive manager have been nominated.

The following table summarizes the institutional arrangements:

Function	***Institution***	***Responsibilities***
Single national entity	Ministry for Energy Affairs (in consent and cooperation with the Ministry of Agriculture)	• Supervision of national system • Official consideration and approval of inventory
Inventory coordination and compilation	HungaroMet *Air Quality Modelling & Emissions Unit*	• Provision of work plan • Contracting consultants • Inventory preparation of Energy, IPPU, and Waste sectors • Compilation of the CRF and NIR • Archiving • Coordinating QA/QC activities • Reporting to UNFCCC secretariat
Inventory preparation of the LULUCF sector (by law)	Hungarian National Land Centre (NLC) Forest Research Institute of the University of Sopron National Food Chain Safety Office (NFCSO)	• Data collection, choice of methods and EFs, inventory preparation • Compilation of the relevant parts of the CRF and NIR
Inventory preparation of the agriculture sector	Agricultural Economics Nonprofit Kft. (AKI)	• Data collection, choice of methods and Efs, inventory preparation • Compilation of the relevant parts of the CRF and NIR

1.3 Inventory preparation

The annual inventory cycle is carried out in accordance with the principles and procedures set out in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. As a general method of preparing the inventory, the procedures described in the IPCC Guidelines are applied and the latest CRF Reporter software is used. Usually, the sectoral experts are responsible for the choice of methods and emission factors in consultation with the head of Air Quality Modelling & Emissions Unit. According to the recommendations of the IPCC Guidelines, the calculation methods are chosen by taking into account the technologies available in Hungary whenever possible. The calculation of emissions occurs basically by using the formula: AD x EF, where the activity data (AD) can be raw material or product or energy use etc. Part of the available data (e.g., production data) can directly be entered into the IPCC tables; others require previous processing and conversion. For example, energy data are not always available in the required depth and resolution. The default emission factors (EF) are being gradually replaced by country-specific emission factors characteristic of domestic technologies. Efforts are made to use the highest possible Tier method, especially in case of key categories. After preliminary quality control of the basic data, the necessary calculations are carried out with the coordination of the core team. The sectoral data are compiled and – after repeated checks – unified by using the CRF Reporter software. QA/QC activities are described in more detail in chapter 1.7 and the full, updated QA/QC Plan (synthesizing the former QA/QC Plan, the old ISO Procedure and the old archiving manual) is included in Annex 5.

Recalculation of some data-series of the inventory can be justified by several reasons. Just to name a few, QA/QC procedures, ERT recommendations, changing for higher Tier methodologies can lead to a recalculation. As a basic rule, whenever new information emerges that improves the quality or accuracy of the emission data, the emissions are recalculated. The Hungarian Meteorological Service funds research and development projects for the improvement of the inventory whenever possible. Recalculations are always documented in the relevant chapter of the national inventory document.

The Inventory cycle can be summarized with the following table based on our QA/QC plan:

Date/deadline	*Item*	*To*
From May to November	Overview of sectors to identify areas for possible improvements; Data collection, choice of methodologies, Start of calculations Repeated checks	
From September to December (and April)	Calculations from external expert	
From September to December (and April)	Calculations, checks, archiving	
15 January	Official submission	EU
Between January and March	QC procedures including EU internal review	
15 March	National Inventory Document, Official submission	EU
Between March and April	QC procedures in the process of finalizing the NIR and CRF tables	
08 April	National Inventory Document for approval	National Authority
15 April	Official submission	UNFCCC
31 July	Preliminary inventory of year x-1	EU
From 15th of April to October	Archiving, QA/QC and Development Plan	internal

A Figure presenting the inventory cycle is included in Annex 5.

The inventory report is approved by two ministers: (1) minister for energy affairs (responsible for energy policy but also for environment), (2) minister for agriculture (responsible for agricultural policy, land administration, and forest management) before submission to the UNFCCC.

1.4 Data collection, processing and storage

Data is collected in several ways and throughout the whole yearly cycle of the inventory preparation. All institutes, i.e., HungaroMet, AKI, NLC, NFCSO, University of Sopron, are authorized by law to collect the necessary data. Sector specialists (or external experts on contractual basis) are making the data inquiry and collection in addition to the data arriving based on the reporting obligation set up by Govt. Decree 278/2014 as described below in more detail). Plant specific data are collected if possible (especially in case of power stations, heating stations and industrial technologies) but statistical databases are also heavily used as source of information. The most important statistical publications are the Statistical Yearbook of Hungary, the Environmental Statistical Yearbook of Hungary and the Environmental Report of Hungary published by the Hungarian Central Statistical Office (HCSO) and the Energy Statistical Yearbook published earlier by the Energy Efficiency, Environment and Energy Information Agency. As regards energy statistics, the practice changed in a way that the compiler institute relies less to classic statistical publication and more to databases sent by the Hungarian Energy and Public Utility Regulatory Authority to the IEA and Eurostat. The compiler institute receives the same completed joint questionnaires that are sent to the international organizations which ensure the consistency with data reported under Regulation (EC) No 1099/2008.

Since the use of ETS data has several advantages, the inventory team was granted access (by the same Govt. Decree) to the verified emissions database held earlier by the National Inspectorate for Environment and Nature (now: National Climate Protection Authority).

In addition to statistical data, contacts were established with the representatives of a number of major emitting sectors. Moreover, information from the websites of international associations (e.g., International Iron and Steel Institute, IISI) is used as well.

For the calculation of F-gas emissions, import data from the Customs Office and Police were used together with data obtained directly from companies importing and using fluorinated gases and information from cooling industry associations, the Hungarian Monitoring and Certification Body (OMKT-HMBC), the Hungarian Electrotechnical Association (MEE) and the National Directorate General for Disaster Management, Ministry of the Interior (NDGDM).

Data reported pursuant to Article 6(1) of Regulation (EC) No 842/2006 on F-gases (for the consistency check required by the Regulation (EU) 2018/1999) is received from Hungarian contact point responsible for the reporting under 842/2006/EC. This data provision is also included in Govt. Decree 278/2014.

The Act LX of 2007 on the implementation framework of the UN Framework Convention on Climate Change and the Kyoto Protocol thereof aims to give direct data collection authorization to the minister responsible for the environment in order to collect data for the national system for climate reporting and gives a permanent status to the system. Relevant paragraphs for data collection are the following: "The state authorities having disposal of the data necessary to operate the National Registration System and the organizations emitting at least 100 tons of carbon dioxide equivalent per year shall provide these data for the National Registration System in accordance with the provisions of a separate legal instrument." "The data (…) necessary to fulfill international data supply shall be provided for the

National Registration System irrespective of the fact that they are qualified as individual data pursuant to the relevant provision of Act XLVI of 1993 on statistics." This separate legal instrument, the above-mentioned Government Decree 278/2014 on data provision relating to GHG emissions prescribes compulsory data provision for GHG inventory purposes for numerous governmental bodies and emitters. QA/QC Activities connected to data collection are regulated by the updated QA/QC Plan included in Annex 5.

Govt. Decree 278/2014 has two annexes with quite long lists of data providers and data to be submitted. The first annex relates to information that are to be submitted by government institutions, Annex II relates to data provision obligation by firms. Information contained in these two annexes cover the basic data needs for inventory compilation. In addition to what is included in the above annexes, paragraph 5 states that:

In addition to the regular data provision as specified in the annexes, the inventory compiler institutes are entitled to request additional data in order to supplement or refine the available information, or to make the corrections required during reviews.

To facilitate exchange of information, Hungarian Meteorological Service (now HungaroMet) became "VIP customer" of the statistical office recently, which means we have a dedicated VIP contact person within the statistical office in case of additional data needs.

All the collected data, where relevant, are also used for the elaboration of the air pollutant emission inventories (NFR). Therefore, the consistency with the reporting of air pollutant emission inventories under Directive 81/2001 and the Convention on Long-range, Transboundary Air Pollution (CLRTAP) is ensured.

A copy of all data, information necessary for the compilation of the given annual inventory is stored in printed or electronic form either by the Air Quality Modelling & Emissions Unit in HungaroMet or by the institutions involved in inventory preparations. Significant steps were taken earlier to create a central archive in the premises of Hungarian Meteorological Service (now HungaroMet) where all background data would be stored.

The most important paper information archived already in the Service is the following:

- Statistical Yearbooks of Hungary from the year 1961
- Environmental Statistical Yearbook of Hungary from 1996
- Energy Statistical Yearbook published by the Energy Efficiency, Environment and Energy Information Agency from 1985.
- Hungarian Statistics on Road Vehicles (in electronic format since 2000)
- National, regional and local emission survey of the Hungarian road, rail, water-borne and air transport (1995-2004) made yearly by the Institute of Transport Sciences

Lots of background data are stored by contracted expert institutions as well, which increases the security of data availability. Nevertheless, at least a copy of all important information has been transferred to the building of HungaroMet. The following information is stored elsewhere:

- Data from individual industrial plants – Ministry for Energy Affairs;
- ETS data, registry - National Climate Protection Authority;
- Forestry statistics – Hungarian National Land Centre;

- Wastewater data – General Directorate of Water Management, Ministry of Agriculture, Ministry of Interior, HCSO.

Electronic information is stored on disks on a fileserver with a regular backup. The whole data files are backed up once a week, while the implements (those files that have been modified since the last saving) are saved two times a week. The data are stored on tape storage system. The cassettes of the data storage system are stored far from the recording system, in another room, which is air conditioned and equipped with an up-to-date fire service system. All events connected with the data saving are logged in accordance with the documents of the Quality Management System of HungaroMet.

For HungaroMet, as a successor of OMSZ, same strict record management, documentation and archiving rules apply in general. OMSZ's general record management, documentation and archiving regulation have been amended in 2011. The new regulation had been supplemented with a new chapter relating to the Unit of National Emissions Inventories. The main elements of the former proposal of the 'manual for the maintenance and management of the archiving system' as the procedures of documents and data handling had been formalized in this regulation.

A particular issue of this regulation is to ensure the integrity of the data handling in relation to the GHG inventory. The regulation has specific rules on handling confidential data as well. These rules are as follows:

Confidential data are

- accessible only for members of the Air Quality Modelling & Emissions Unit. They are not allowed to be forwarded to other institute or persons, except for the ERT
- it is not allowed to make hard copies of these documents, only one electronic copy can be made, which is stored on the server of Air Quality Modelling & Emissions Unit ;
- data stored on the server of GHG are protected by password;
- it is not allowed to take out any confidential information from the building of HungaroMet, not even their copies;
- the original hard copies are not allowed to be forwarded to the Hungarian Environmental Archives; they are stored in the records of HungaroMet's Air Quality Modelling & Emissions Unit.

The new regulation has been endorsed by the Minister of Public Administration and Justice and has been in force since January of 2012.

The directories of the server, where the data of the Unit of National Emissions Inventories are stored have access protection, so they are available only for the staff of the Unit in charge of the different sectors of the GHG inventory. It is important to note that there are different directories for all the calculations and drafts (working folder) and for the submitted reports and incoming data which cannot be modified. Within the Air Quality Modelling & Emissions Unit of HungaroMet, the nominated archive manager is responsible for the maintenance of the archiving system in close cooperation with the IT Department of the Service.

The most important elements of the previously planned procedural manual for management and maintenance of the archiving system (archiving manual) have been included formally into the general record management, documentation and archiving regulation of HungaroMet and the new QA/QC Plan of the Air Quality Modelling & Emissions Unit. (Instead of the introduction of a new regulation the already existing regulations have been amended and supplemented with the issues of the draft manual.). So, these two regulations define the QA/QC activities connected to data collection, processing, storage and the documentation and archiving activities of the Air Quality Modelling & Emissions Unit. Further development of the system may include the incorporation of other emission data, which are relevant to air pollution.

1.5 Brief general description of methodologies and data sources used

The IPCC Guidelines provide methodologies for estimating emissions and removals of greenhouse gases. However, the basic idea is not greenhouse gas specific, the same approach is used for other pollutants, and other emission inventories, as well (e.g. see the EMEP/EEA air pollutant emission inventory guidebook). The basic equation is as simple as this:

Emission = AD x EF,

where AD stands for activity data which represents some human activity (e.g. fuel use, industrial production, animal population, dwellings supplied with public sewerage, area of vineyard abandonment), whereas EF is the emission factor that quantifies the emission (or removal) per unit of activity. For example, in energy industry, which is the most important source category, emission factors for combusting natural gas or lignite are 56.1 t CO_2/TJ and 107.9 t CO_2/TJ, respectively; the importance of the mix of fuels used to produce energy becomes apparent at a glance.

Emission factors are usually dependent on several other factors, used technologies etc. which leads us to the concept of tiers. A tier represents a level of methodological complexity. In the Guidelines, usually three tiers are provided. Tier 1 is the basic method, where activity data are usually aggregated national statistics and the emission factors are default values representing typical process conditions. Higher tier methodologies are more demanding in terms of complexity and data requirements as they require country-specific information on the used technologies, facility level data whenever possible, or use of complex models. For key categories, i.e., categories that have a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level of emissions and removals, the trend in emissions and removals, or uncertainty in emissions and removals, it is required to apply higher tier methods. Accordingly, the compilers of the Hungarian inventory aim at taking into account the technologies available in Hungary to the extent possible. For example, the emission trading system of the European Union makes possible to have access to facility level activity and verified emission data.

Although this basic equation can widely be used, in some source categories other approaches are used. For example, mass balance method is used for estimating the change in carbon content of living biomass in forests, or in case of solid waste disposal sites, a calculation method is applied which assumes that the degradable organic component in waste decays slowly throughout a few decades.

To ensure that the national inventory fulfils its main purpose, namely monitoring the country's compliance with its commitments, it has to meet certain quality standards, in other words it has to be accurate, complete, consistent, comparable and transparent (ACCCT). The first two requirements need no special explanation: an inventory is accurate, if it has no systematic bias towards under- or overestimations, whereas a complete inventory covers all relevant sources and sinks, and gases within the borders of the country. The next two criterions are closely linked to the requirements of the UNFCCC. Consistency ensures that the trends in the times-series of the inventory reflect real differences in emissions, and not caused by any methodological changes. National greenhouse gas inventories of all countries shall be comparable; therefore, the submitted information shall be compiled in accordance with the UNFCCC reporting guidelines and the 2006 IPCC guidelines.

More detailed source specific information on used data and methodologies can be found in Chapters 3-9 in this inventory document.

1.6 Key source categories

Based on the IPCC Tier 1 methodology, 40 key categories have been identified. One category (4.B.1 4.C.2 Land Converted to Grassland – CO_2) was dropped out in this submission compared to the last submission. On the other hand, four categories (1.A.3.d Domestic Navigation - Liquid Fuels – CO_2, 1.A.4 Other Sectors - Other Fossil Fuels – CO_2, 1.A.5 Other Sectors - Other (Not specified elsewhere) - Liquid Fuels – CO_2 and 1.B.2.c Fugitive Emissions from Fuels - Venting and flaring – CO_2) became key.

Table.1.6.1 *Key category analysis summary*

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Level	Trend	excL	incL
1.	1.A.1 Fuel combustion - Energy *Industries - Liquid* Fuels	CO2	X	X	X	X
2.	1.A.1 Fuel combustion - Energy Industries - Solid Fuels	CO2	X	X	X	X
3.	1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CO2	X	X	X	X
4.	1.A.1 Fuel combustion - Energy Industries - Other Fossil Fuels	CO2	X	X	X	X
5.	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO2	X	X	X	X
6.	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Solid Fuels	CO2	X	X	X	X
7.	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO2	X	X	X	X
8.	1.A.2 Fuel combustion - Manufacturing Industries and Construction - Other Fossil Fuels	CO2	X	X	X	X
9.	1.A.3.b Road Transportation	CO2	X	X	X	X
10.	1.A.3.c Railways	CO2		X	X	X
11.	1.A.3.d Domestic Navigation - Liquid Fuels	CO2		X	X	
12.	1.A.4 Other Sectors - Liquid Fuels	CO2	X	X	X	X
13.	1.A.4 Other Sectors - Solid Fuels	CO2	X	X	X	X
14.	1.A.4 Other Sectors - Solid Fuels	CH4		X	X	X
15.	1.A.4 Other Sectors - Gaseous Fuels	CO2	X	X	X	X
16.	1.A.4 Other Sectors - Other Fossil Fuels	CO2		X		X
17.	1.A.4 Other Sectors - Biomass	CH4	X	X	X	X
18.	1.A.5 Other Sectors - Other (Not specified elsewhere) - Liquid Fuels	CO2		X	X	X
19.	1.B.1 Fugitive emissions from Solid Fuels	CH4		X	X	X
20.	1.B.2.b Fugitive Emissions from Fuels - Oil and Natural Gas - Natural Gas	CH4	X	X	X	X
21.	1.B.2.c Fugitive Emissions from Fuels - Venting and flaring	CO2		X	X	

	KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	Level	Trend	excL	incL
22.	2.A.1 Cement Production	CO2	X		X	X
23.	2.A.2 Lime Production	CO2		X	X	X
24.	2.B.1 Ammonia Production	CO2	X		X	X
25.	2.B.2 Nitric Acid Production	N2O		X	X	X
26.	2.B.8 Petrochemical and Carbon Black Production	CO2	X	X	X	X
27.	2.C.1 Iron and Steel Production	CO2	X	X	X	X
28.	2.C.3 Aluminium Production	PFCs		X	X	
29.	2.F.1 Refrigeration and Air conditioning	F-gases	X	X	X	X
30.	2.G Other Product Manufacture and Use	N2O	X	X	X	X
31.	3.A Enteric Fermentation	CH4	X	X	X	X
32.	3.B Manure Management	CH4	X		X	X
33.	3.B Manure Management	N2O	X		X	X
34.	3.D.1 Direct N2O Emissions From Managed Soils	N2O	X	X	X	X
35.	3.D.2 Indirect N2O Emissions From Managed Soils	N2O	X			X
36.	4.A.1 Forest Land Remaining Forest Land	CO2	X	X		X
37.	4.A.2 Land Converted to Forest Land	CO2	X	X		X
38.	4.B.2 Land Converted to Cropland	CO2		X		X
39.	4.G Harvested Wood Products	CO2	X	X		X
40.	5.A Solid Waste Disposal	CH4	X	X	X	X
41.	5.D Wastewater Treatment and Discharge	CH4	X	X	X	X

Note: L = Level assessment; T = Trend assessment, incL = including LULUCF, excL = excluding LULUCF.

1.7 QA/QC information

The national system has to ensure high quality of the inventory, i.e. to ensure that the inventory is transparent, consistent, comparable, complete and accurate. These principles guide the internal expert team that maintains the system. QA/QC activities are performed in two levels: based on the ISO 9001 standards and following the IPCC recommendations. The updated QA/QC Plan that entered into force in 2013 aims to integrate these two sets of requirements. The QA/QC Plan is updated regularly, the last update entered into force in December 2022.

For HungaroMet, as a successor of OMSZ, same strict record management, documentation and archiving rules as well as the same QA/QC plan apply in general.

ISO activities

The Hungarian Meteorological Service (OMSZ), the legal predecessor of HungaroMet, introduced the quality management system ISO 9001:2000 in 2002 for the whole range of its activities which was quite unique among meteorological services. However, GHG inventory preparation was not among its activities in that time. Therefore, the scope of our ISO accreditation had to be modified and lots of efforts have been made to bring also the national system under the umbrella of the ISO QM system. Several regulatory ISO documents were created, among others: ISO procedure on the activities of the

GHG Division; QA/QC plan; registers and records for quality checks and documentation. Naturally, from that time on, HungaroMet level QA/QC activities apply for the Air Quality Modelling & Emissions Unit as well, such as general quality objectives, application of QA/QC Manual, QA/QC regarding contractors, etc. Further information on quality management system of HungaroMet is available in English at: http://www.met.hu/en/omsz/minosegiranyitas/

In 2012 the ISO procedure of the GHG division was reviewed, and the former QA/QC Plan with the archiving manual was integrated into it. ISO document No.: ELFO_UHG_401.01 entered into force on 4 January 2013 can be regarded as the QA/QC Plan required for inventory preparation. In addition, the records used for documentation of QA/QC and other standardized activities have also been renewed. On 21 May 2014, an update of the QA/QC Plan (No.: ELFO_UHG_401.02) entered into force in order to insert the recommendation of the review of the year before regarding the documentation of QA activities. The update of the QA/QC Plan (No.: ELFO_NELO_401.01) that entered into force in the beginning of 2016 did not contain significant changes, mainly changes of names and references to legislation and the Guidebook are reflected. Our most recent QA/QC Plan (No.: MFO_NELO_402.01) is from December 2022. The records and their functions are the following at the moment:

- NELO03: Development Plan: to be filled in every year by the end of the inventory cycle based on the outcome of all reviews and own experience;
- NELO04: Responsibility: for the specification of the sectoral responsibilities of the core team and the QA/QC coordinator

The records and the English translation of the QA/QC Plan are presented in the Annex 5 of the NIR.

The QA/QC Plan contains detailed description of the data collection, inventory preparation and reporting processes, regulates the documentation and archiving activities in order to ensure transparency and reproducibility of the inventory the same as before, especially:

- MFO_NELO_402.01 formalizes the data collection and inventory preparation procedure as it is described also in chapters 1.4 and 1.5 above. It is important to note that the authorization of HungaroMet for collecting non-public data has been raised in a legally binding level since 2009 when Govt. Decree 345/2009 of 30 December 2009 entered into force. In addition, Act LX of 2007 on the implementation framework of the UN Framework Convention on Climate Change and the Kyoto Protocol authorizes HungaroMet to collect confidential data if needed as well. MFO_NELO_402.01 prescribes that any data used by the preparation of the inventory have to be documented and archived.

- Documentation and archiving: As mentioned in chapter 1.4 above, strict documentation and archiving are a basic requirement by the institution. HungaroMet has a documentation and archiving manual valid for the whole institution, which defines that all the incoming letters and emails containing data have to be registered in the central registry system. This ensures that every document is traceable. In additional data, data sources and calculation files and background documents for every inventory submission need to be documented and archived by the sectoral experts. The exact process of documentation and archiving (naming and location) is detailed in document MFO_NELO_402.01.

- Data quality check. Besides self-checking, the entries of data providers and external experts are checked regularly. Significant changes compared to previous data shall be explained. The QA/QC plan prescribes the methods of checks mentioned before, including Development Plan, where first of all the recommendations of the last years' reviews conducted by the expert review team of the UNFCCC have to be taken into consideration as much as possible every year.

Having an ISO system in place has an advantage of being subject to regular internal and external audits. During our last external audit, the activities of the Unit of National Emissions Inventories were audited as well. Our system was audited favorably in the end of March 2007; and our ISO certification has been renewed in January 2012 and a comprehensive external audit was again performed in January 2014 2015, 2016, 2017 and 2018 as well. On 5 April 2013, 12 December 2014 and 11 October 2016 an internal audit has been performed too. In all cases the result was a few non-significant recommendations. Therefore, we can claim that the GHG inventory is subject to and our procedures are in line with ISO 9001:2008. The most recent external audit was held in December 2023.

As part of the QA and verification activities there is an ongoing QA procedure between the NFCSO and the Forest Research Institute of the University of Sopron who are involved in the LULUCF of the inventory.

Peer-reviews on the other chapters will be conducted depending on available resources.

UNFCCC reviews

Reviews conducted by expert review teams of the UNFCCC usually have important impact on the development of quality and transparency of our emission estimates. The main findings in the 2023 annual inventory review report and Hungary's response to those findings will be provided in the Annexes of the March submission of the NIR *(in case we receive the ARR by then)*.

EU review processes

In 2012 the EU carried out a comprehensive individual technical review concentrating on the years 2005, 2008, 2009 and 2010, which can be regarded as an additional QA activity. Starting with the data reported for the year 2013, the European Commission conducted annual reviews of the national inventory data submitted by Member States in accordance with the Regulation (EU) No 525/2013 (the 'Monitoring Mechanism Regulation' or MMR).

Decision No 406/2009/EC (the 'Effort Sharing Decision' or ESD) converted the annual reporting cycle into an annual commitment cycle requiring a comprehensive review of Member States' greenhouse gas (GHG) inventories within a shorter time frame than the current UNFCCC inventory review, to enable the use of flexibilities and the application of corrective action, where necessary, at the end of each relevant year.

Regulation (EU) No 525/2013 (the 'Monitoring Mechanism Regulation' or MMR) set up at Union level a review process of the greenhouse gas inventories submitted by Member States to ensure that compliance with the ESD is assessed in a credible, consistent, transparent and timely manner.

The annual ESD reviews consisted of two steps. In the first step the transparency, accuracy, consistency, completeness and comparability of Member States' inventories are checked pursuant to Articles 29 and 33 of Regulation (EU) No 749/2014 (the 'MMR Implementing Regulation').

The first step of the ESD review is performed by the European Environment Agency (EEA) European Topic Centre for Atmospheric Climate Mitigation (ETC/ACM). The main purpose of step 1 is to identify potential significant issues which are handed over to step 2 for more detailed analysis.

In the second step of the annual a Technical Expert Review Team (TERT) analyses the significant issues mainly by performing checks pursuant to Articles 32 and 33 of Regulation (EU) No 749/2014 to identify cases where inventory data are prepared in a manner that is inconsistent with the UNFCCC guidance documentation or Union rules.

The EU annual review processes contribute significantly to the quality assurance procedures. The main actions and outcomes of the annual EU review processes were as follows:

In 2015, Hungary participated in STEP 2 of the ESD trial review on a voluntary basis.

The main objectives of the trial review were to provide, through recommendations, informal feedback from a review team on emission estimates because no reviews were carried out on UN level, and to provide additional support to the improvement of the Member States GHG-inventories. During the reviews all the sectors (except LULUCF) had been thoroughly reviewed, and several recommendations have been formulated and the majority of the recommendations were implemented in subsequent submissions.

In May 2016, a comprehensive review was carried out by the EU for the compliance years 2013 and 2014, and for the years 2005, 2008, 2009 and 2010 pursuant to Monitoring Mechanism Regulation (EU) 525/2013 Article 27.

In 2017, 2018, and 2019 the checks performed during the annual ESD review did not identify any significant issues, therefore Hungary was not subject to a second step of the 2017-2019 annual ESD reviews.

In 2020, all EU Member States were subject of a comprehensive review. One of the main conclusions of the review was the following: *“The reviewers raised 38 issues with Hungary during the first and the second step of the 2020 comprehensive ESD review. The TERT provided recommendations for 3 of these issues. Other issues raised during the comprehensive review were clarified and are considered non-issues for the ESD review 2020.”* All three recommendations have been addressed for this submission.

In 2021, the annual ESD review identified one significant issue, therefore, Hungary was subject to a second step. The main conclusion was the following: “*The TERT did not deem necessary any technical corrections within the meaning of Article 19(3)(c) of Regulation (EU) No 525/2013 in consultation with Hungary. Also, “The TERT did not identify any non-binding recommendations in order to improve the national inventory data of Hungary.”*

In 2022, the checks performed during the EU review did not identify any significant issues, therefore Hungary was not subject to a second step of the 2022 annual ESD review. Consequently, no revised estimates or technical corrections were deemed necessary.

From 2023 on, reviews will be conducted under Regulation (EU) 2018/1999. Two comprehensive reviews are foreseen: one in 2027 and the second in 2032.

Quattro-lateral QA/QC cooperation

Hungary joined a quattro-lateral QA/QC cooperation with the Czech Republic, Slovakia, and Poland. In 2017 some issues from the Energy and the IPPU sector were reviewed. In 2018, the focus was put on the waste sector whereas mostly LULUCF experts had fruitful discussions in the usual summer meeting in 2019. As an outcome of the meeting recommendations and good practices were shared to learn from the other Parties, to encourage the improvement and to enhance the quality of emission inventories. Unfortunately, due to COVID-19 situation, no further meetings could be held in the last three years.

Further QA and verification activities to be continuously performed and/or planned:

- Several consistency checks as detailed in chapter 1.10.
- Active participation in the support project organized by EU DG Climate for the *„Assistance of Member States for effective implementation of the reporting requirements under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC)"*

Other QA/QC activities

Besides ISO requirements, other QA/QC activities are carried out, as well. For every sector of the inventory, there is a responsible person within the core team in HungaroMet. These sectoral responsibilities are laid down in the QC record No. NELO04. Especially in case of external experts, this responsible member of our team conducts several quality checks on the provided calculations. Moreover, this exercise can be regarded as an interactive process throughout the whole inventory cycle, since the used methodologies, early results are discussed during the process of the emission/removal calculations. This QC procedure also led to a few recalculations. The used parameters and factors, the consistency of data is checked regularly. Completeness checks are undertaken, new and previous estimates are compared every time. Data entry into the database is checked many times by a second person. If possible, activity data from different data sources are compared and thus verified. Experts involved in emission forecast consulted in many areas with inventory experts of HungaroMet to reach better consistency, which in turn represented some sort of QA procedure for the inventory itself.

Nevertheless, the work continues to refine the used QA/QC procedures and implement further elements. The QA/QC Plan is under review in order to implement all changes required by the EU Monitoring Mechanism Regulation and implementation of the 2006 IPCC Guidelines.

1.8 Uncertainty

The reliability of the data for individual source categories was estimated on the basis of the 2006 IPCC Guidelines but information from the industry and expert estimates was also used. On the basis of Table 3.3 and Table 4.1 of the 2006 IPCC Guidelines we have determined the total uncertainty according to the Tier 1 method. Accordingly, the combined uncertainty as % of total national emissions (in the year 2022) is 10.9% (excluding LULUCF) and the uncertainty introduced in trend in national emissions is 2.9%.

The uncertainty values have been determined by gas as well:

	% Uncertainty excluding LULUCF
CO_2	2.7
CH_4	47.0
N_2O	134.0
F-gases	12.8

Estimation of the uncertainties including LULUCF is a planned improvement. Please find the detailed Tables presenting the whole calculation in Annex 2 of the NIR.

1.9 Completeness

GHG inventory data are provided for the base year (the average of the three years 1985–1987) and the years 1986–2022. All relevant gases, sectors and categories are included. The inventory is complete in terms of geographic coverage. The notation keys are used throughout the tables.

1.10 Consistency checks

Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action (points (i) and (j) of Part 1 of Annex V requires to report the results of the checks performed on the consistency of the emissions reported or of the data used to estimate emissions in preparation of the greenhouse gas inventories. The results of the consistency checks are summarized below.

Consistency with the verified emissions reported under Directive 2003/87/EC

ETS data is essential in inventory compilation, especially to derive country specific emission factors for several categories in the inventory. In addition, comparisons have been made between emissions reported under Directive 2003/87/EC and emissions reported to the UNFCCC. ETS emissions represent about one third of total emissions. Extending this comparison to source categories, there is no source category where the ETS emissions are higher than the reported values in the inventory. This is partly due to our practice of activity data reallocation where precedence is given to ETS data over the original IEA energy statistics. Good consistency can be found in case of several source categories, especially for 1.A.1.a Public electricity and heat production, 1.A.1.b Petroleum refining, 1.A.2.a Iron and steel, 2.A.1 Cement Production, 2.A.2 Lime production, 2.A.4 Other process uses of carbonates, and 2.B Chemical industry. Information on consistency is provided in a separate Annex submitted to the EU.

Consistency of the data used to estimate emissions in preparation of the greenhouse gas inventories with the data used to prepare inventories of air pollutants under Directive (EU) 2016/2284

As basically the same team prepares both inventories, the consistency of the used data is safeguarded. Consistently, emission estimates of carbon monoxide (CO), sulphur dioxide (SO2), nitrogen oxides (NOx) and volatile organic compounds, in inventories submitted by the Member State under Directive (EU) 2016/2284 of the European Parliament and of the Council and under the UNECE Convention on Long-range Transboundary Air Pollution are consistent with the corresponding emission estimates in greenhouse gas inventories. The difference between the total emissions of any of the above pollutants reported in both inventories is well below 5%. (Any larger difference must be due to copy-paste error.)

Consistency of the data used to estimate emissions in preparation of the greenhouse gas inventories with the data reported pursuant to Article 19 of Regulation (EC) No 517/2014

In the case of 517/2014/EC only companies importing and exporting across the EU border are required to report. However, thanks to the Hungarian F-gas regulations, data is available also on import/export of F-gases within the EU for the preparation of the inventory. Thus, the data used for the preparation of the inventory is significantly wider than the data reported based on 517/2014/EC.

Consistency of the data used to estimate emissions in preparation of the greenhouse gas inventories with the energy data reported pursuant to Article 4 of, and Annex B to, Regulation (EC) No 1099/2008

The IEA/Eurostat joint questionnaires serve as basis of emission calculation in the energy sector and as regards non-energy use of fuels partly also in the industrial processes sector. Consistency is further enhanced by our practice that emission calculation files access directly the joint questionnaires. Where ETS data are taken into account, there might, however, be some minor differences with the energy statistics (e.g., industrial waste consumption in cement production). Nevertheless, these differences are well below 2%.

2 TRENDS IN GREENHOUSE GAS EMISSIONS

2.1 Description and interpretation of emission trends for aggregated greenhouse gas emissions

Table 2.1 *Total GHG emissions (excluding LULUCF)*

	Base year	1990	2005	2022	BY-2022	1990-2022	2005-2022
ENERGY	80,634	69,481	57,515	43,572	-46%	-37%	-24%
IPPU	14,563	11,387	8,874	5,927	-59%	-48%	-33%
AGRICULTURE	11,971	9,968	5,985	6,213	-48%	-38%	4%
WASTE	3,666	4,226	4,881	3,823	4%	-10%	-22%
TOTAL	**110,834**	**95,062**	**77,255**	**59,535**	**-46%**	**-37%**	**-23%**

Base year=average of 1985-87

Since 1990, emissions have decreased in all sectors. Energy related emissions decreased by 37%, industrial processes by 48%, agriculture by 38% and waste by 10%. The land use, land-use change and forestry (LULUCF) sector shows fluctuating behavior.

(Compared to the base year under the Kyoto Protocol, i.e., the average of 1985-87, emissions were significantly reduced in the energy (-46%), industrial processes and product use (-59%), and agriculture (-48%) sectors. In contrast, emissions in the waste sector are higher by 4%).

Looking at the most recent trends since 2005, emissions have significantly decreased in the energy, industrial processes and waste sectors by 24%, 33% and 22%, respectively. The agriculture sector seems to have recovered and could show an increase of 4% since 2005.

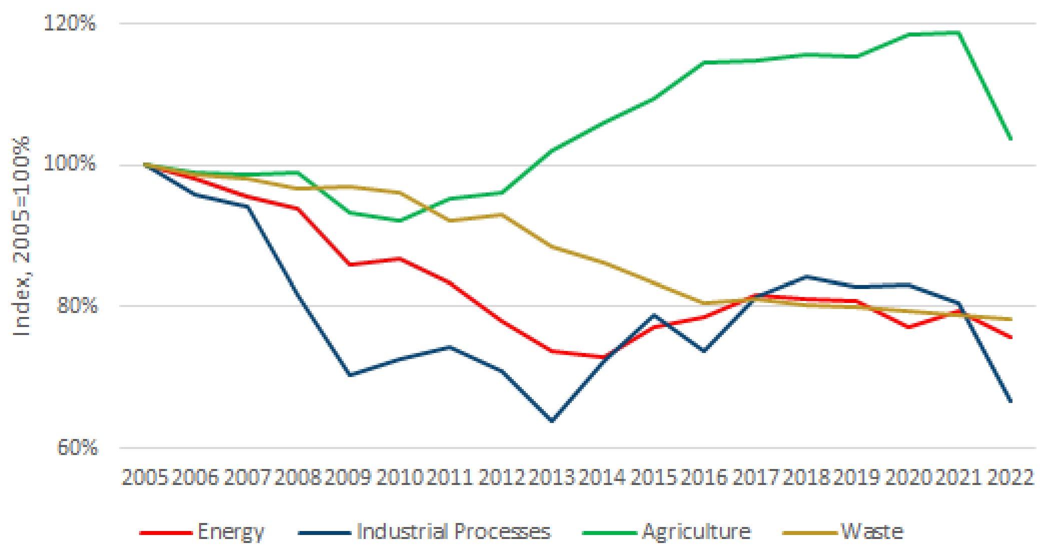


Figure 2.1 *Recent trend of sectoral emissions (2005-2022)*

For a better understanding of the Hungarian emission trends, the time interval of the inventory could be split into three periods with different emission relevant economic processes in the background. The first period (1985-1995) would be the years of the regime change in Hungary, whereas in the second period (1995-2005) the rules of the market economy became decisive. The second period can also be characterized by the decoupling of GDP growth from the GHG emission trend which is undoubtedly an important development. By 1999, the GDP reached the pre-1990 level; however, emission levels remained significantly below the levels of the preceding years. Thus, the emissions per GDP were decreasing.

In the third period, after 2005, Hungary experienced an emission reduction of 24% up to 2013, out of which 7% occurred in the first three years up to 2008: basically, due to mild winters, higher energy prices, and modernization in the chemical industry. Then in 2009, the global financial-economic crisis made its radical influence felt which can also be seen at the dropping GDP values in *Fig. 2.2*. From 2010 on a slight recovery of the economy could be observed, the emissions, in contrast, not just remained at a relatively low level but decreased again quite significantly. However, the decreasing trend stopped in 2013 and an increase of 11% could be observed altogether up to 2017. After four years of increase, emissions have remained more or less at the same level between 2017 and 2019.

In 2020, emissions decreased by almost 3% to around 2016 levels, mainly due to a significant reduction in transport emissions as a consequence of COVID-19. This decrease, however, proved to be temporary, in 2021 emissions increased again by 2 per cent. Then in 2022, emissions fell by almost 7% due to decreasing production and consumption levels driven by rising energy prices, and especially due to a 15% drop in natural gas consumption, but we have not yet reached the previous low point of 2013-2014.

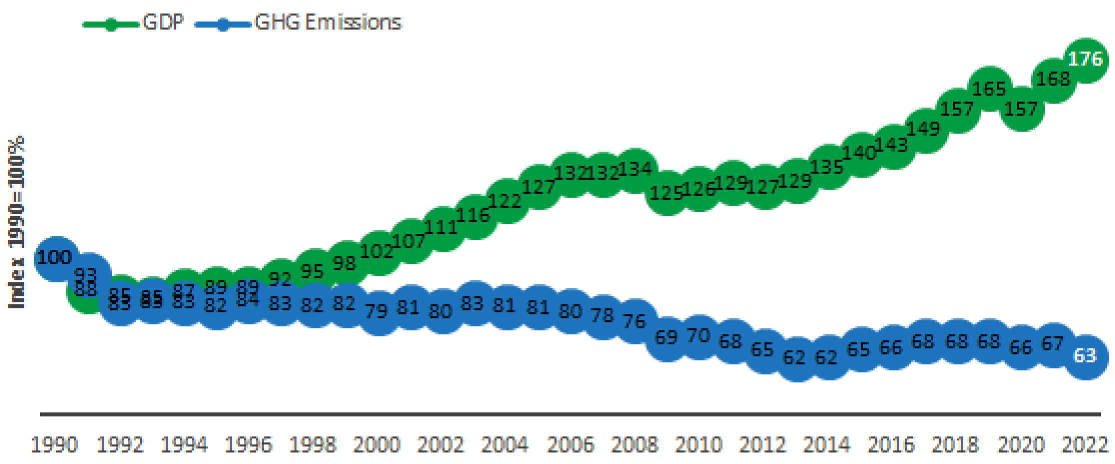


Figure 2.2 *Comparison of trends in GDP and GHG emissions*

Starting with the first period, the process of transition into market economy brought in its train radical and painful decline in the output of the national economy. The production decreased in almost every economic sector including also the GHG relevant sectors (energy, industry and agriculture). Consequently, GHG emissions decreased substantially in these years by around 33 million tonnes CO_2 equivalent. Between the mid 80's and the mid 90's emissions fell back in the *energy* sector by around 27%, and even more, by around 45-50% in the *industrial processes* and *agriculture* sectors.

The most significant drop in energy use occurred in the industry especially in the energy-intensive industrial sectors (manufacture of basic metals and machinery, mining etc.). The industrial output of

1992 was two third of that of 1989. Several factories were closed down, capacity utilization was reduced, consequently the production decreased more or less drastically in each industrial sector.

Some examples:

- Iron and steel production: two out of three plants were provisionally closed down;
- Aluminum: two out of three plants were closed down in 1991 (aluminium production stopped in 2006 eventually);
- Ferroalloys: ceased to exist (1991);
- Ammonia: four out of five plants were closed down (1987, 1991, 1992 and 2002);
- Nitric acid: three out of four plants were closed down (1988, 1991 and 1995).

The agricultural sector suffered a similar decline. As a result of the political and economic processes, the number of agricultural farms was reduced by more than 30%, the number of employees by more than 50%, the volume index of the gross agricultural production by more than 30%, the livestock by about 50%, and the use of fertilizers by more than 60%. As a consequence, the share of the agricultural sector in total GHG emissions decreased from 11% to 8%.

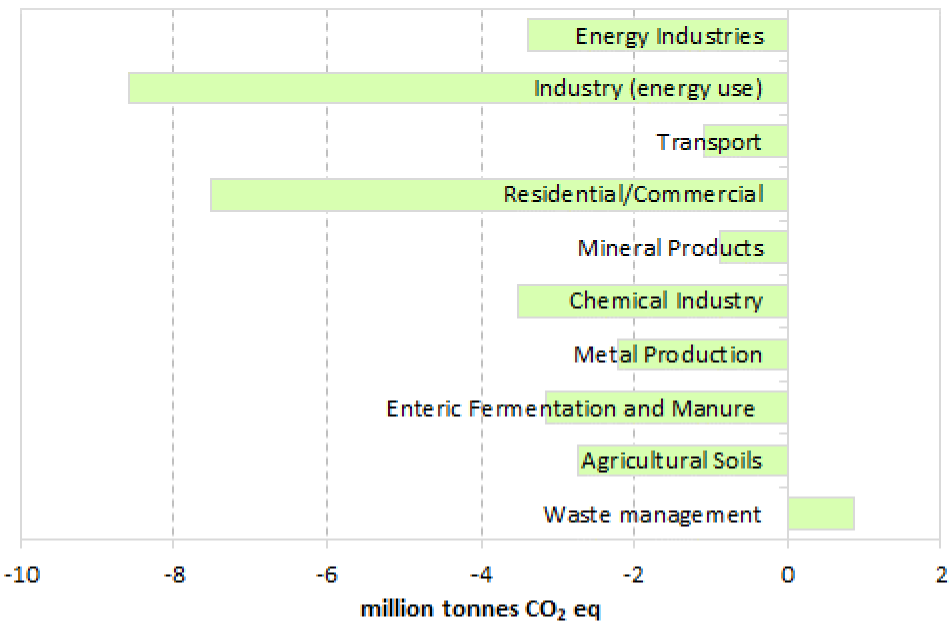


Figure 2.3 *Changes in emissions due to regime change, between base year and 1995, million tonnes CO_2-eq*

The small increase of emissions in the Waste sector is exceptional among all the sectors, and it is attributable to the slightly increasing quantities of waste generated and collected but more importantly to the applied calculation method which assumes that the degradable organic component in waste decays slowly throughout a few decades.

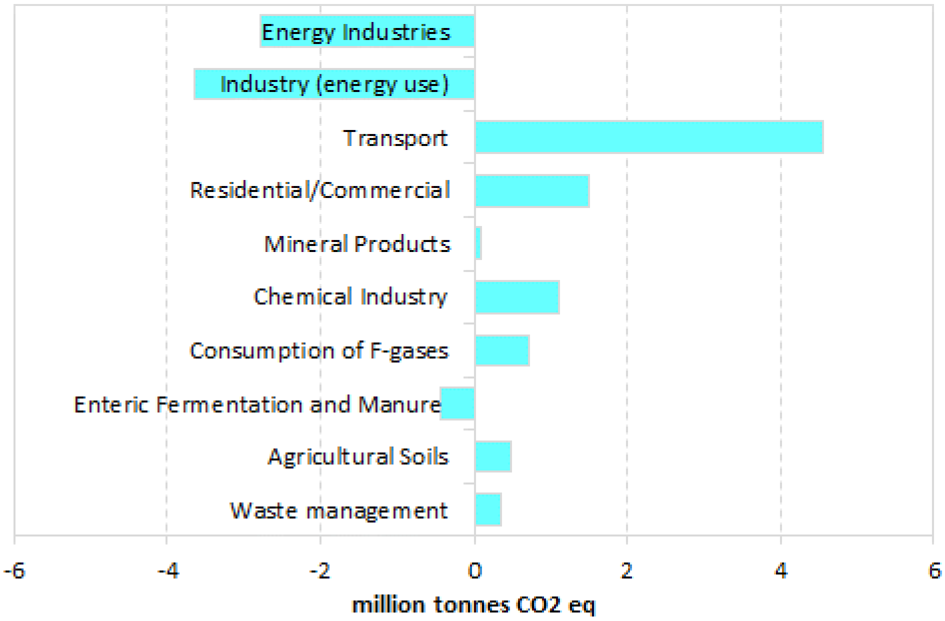


Figure 2.4 *Changes in emissions between 1995 and 2005, million tonnes CO_2-eq*

After the mid 90's, emissions seemed to have stabilized around 77-78 million tonnes CO_2 equivalent. However, behind the quite stable emission level opposite processes could be observed which can be illustrated by the relatively bigger changes in the energy sector. The fuel use of industry decreased further which led to about 6% share only in GHG emissions around 2005. In contrast, emissions from transport increased significantly by almost 5 million tonnes CO_2 equivalent which represented a growth of 60%.

In the third period, between 2005 and 2022, emissions fell by 17.7 million tonnes or 23%. About 30% of this decrease occurred already between 2005 and 2008. The decreasing energy use by other sectors and manufacturing industries, and the diminishing process related emissions in the chemical industry were the main drivers of these changes. Most importantly, total fuel consumption in the residential sector decreased by about 16% (including a 33% drop in solid fuel and a 16% decrease in natural gas use) – mainly due to extreme mild winter in 2007 but probably the growing energy prices and the support for modernization of buildings might have played a role as well. Decreased production volumes and modernization in the chemical industry led to an emission reduction of about 45%. In contrast, emissions from energy industries and transport grew further.

Then in 2009, the Hungarian economy was hit hard by the global economic crisis that exerted a significant effect on the emission level. Emissions (excluding LULUCF) decreased by 8% (-6.0 million tonnes) between 2008 and 2009. In comparison with 2008, emissions in 2009 were lower in all major sectors. The highest relative reduction (-14%) occurred in the industrial processes and product use sector mainly due to lower production volumes especially in mineral product manufacturing (-28%). Parallel to that, also energy use decreased in manufacturing industries and construction, consequently GHG emission also fell by 27% here. Regarding absolute changes in emissions, out of the 6 million tonnes reduction, fuel combustion was responsible for about 4.5 million tonnes. Although the energy demand increased in the heating season due to less favorable weather conditions, the fall in the production of energy intensive sectors led to an overall decline in energy use.

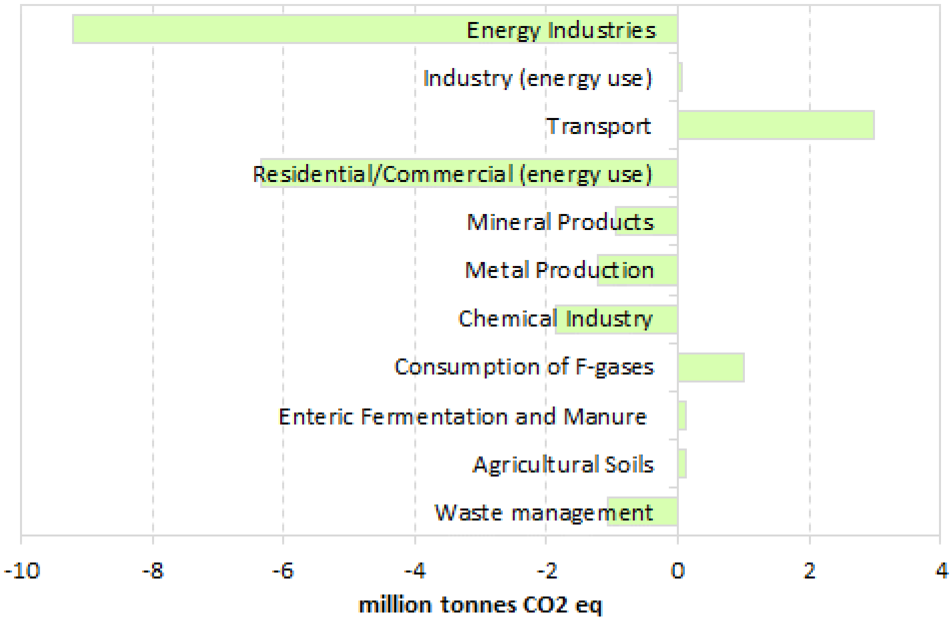


Figure 2.5 *Changes in emissions between 2005 and 2022, million tonnes CO_2-eq*

The decline in economic output stopped in the first quarter of 2010. Mainly driven by the growth in export-oriented industrial production, the GDP grew by 1% in 2010. The change in GHG emissions was about the same. In the next three years, however, emissions decreased again altogether by 12%.

In 2011, we could see decreases in many areas but especially in the energy sector. Electricity production decreased by 4% which resulted in a similar fall in GHG emissions. Natural gas consumption of the residential sector dropped by 9%. Transport emissions fell by 5%, mineral production by a further 15%. In this overall decreasing trend, agricultural soils were the main exceptions. In agriculture, we had higher fertilizer use, and greater crop production (hence higher emissions from crop residues). In this respect, it is worth noting that the economic growth in 2011 was mainly driven by agricultural production.

In 2012, the decreasing trend in emissions continued. The decrease of 3.3 million tonnes (or -5%) can almost be explained by processes in the energy sector alone (e.g., further decrease in electricity production, a 13% drop in natural gas consumption in “other sectors”) as it will be elaborated more in chapter 2.3.

2013 was not an exception in the decreasing trend, either. Total emissions have decreased by a further 5% corresponding to 2.9 megatons in CO_2-eq. The decrease was dominated again by the energy sector. Emissions from power and heat production alone dropped no less than 2.5 Mt CO_2-eq due to significantly lower electricity production from fossil fuels.

Total emissions did not change much in 2014. In the energy sector, we could observe some counterbalancing processes. After several years of decreasing emissions, the transport sector started to show some growth. Nevertheless, the diminishing fossil fuel based electricity production, and the lower and lower energy consumption in the residential sector led to an overall decrease of emissions.

After the lowest point in 2013, emissions started growing again. Up to 2017, the overall increase reached 11%. Between 2016 and 2017, the growth rate was 4%, to which all sectors contributed to a greater or lesser extent.

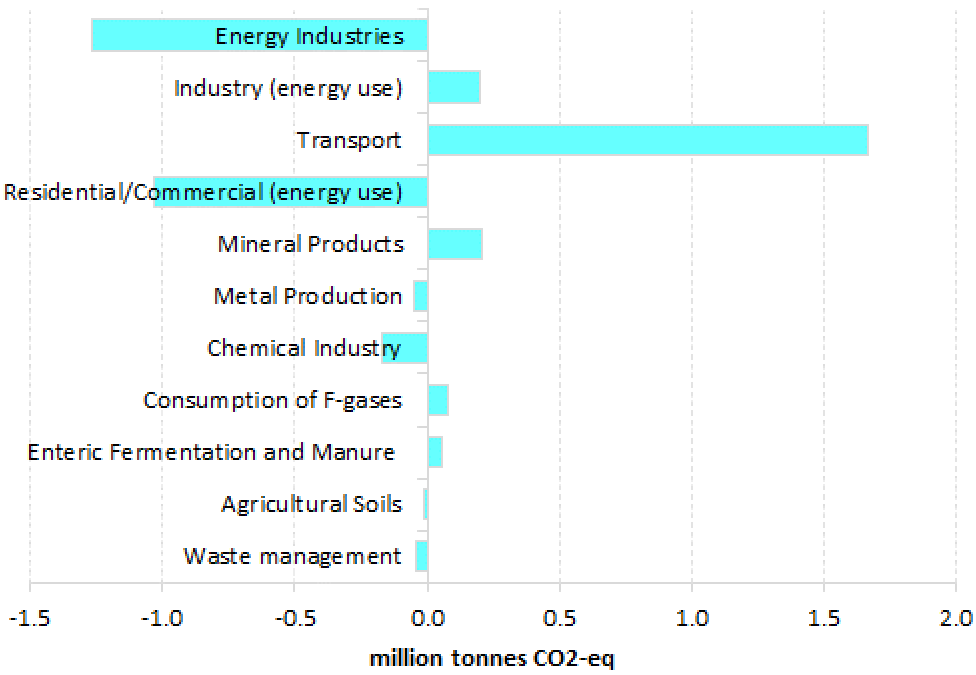


Figure 2.6 *Changes in emissions between 2017 and 2019*

Between 2017 and 2019, total emissions seemed to have stabilized. However, this stabilization of total emissions was a net result of several balancing processes: (1) increased emissions especially in transport, and (2) decreases in domestic energy use, and in the power sector.

Then in 2020, the first COVID year, emissions decreased by close to 3%. The transport sector due to reduced commuting, tourism and business travel contributed particularly to the decline of emissions as demonstrated by *Fig. 2.7* below.

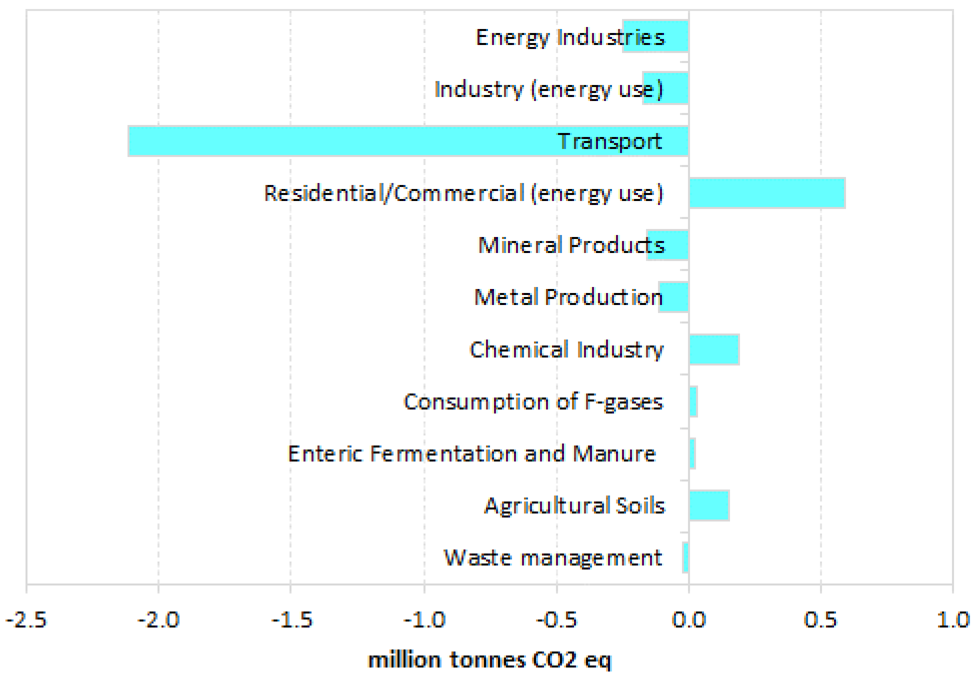


Figure 2.7 *Changes in emissions between 2019 and 2020*

In 2021, emissions grew again (+2%): especially in the transport sector but buildings used also more energy due to higher heating demand. In contrast, emissions from energy industry decreased as coal-based power production fell significantly.

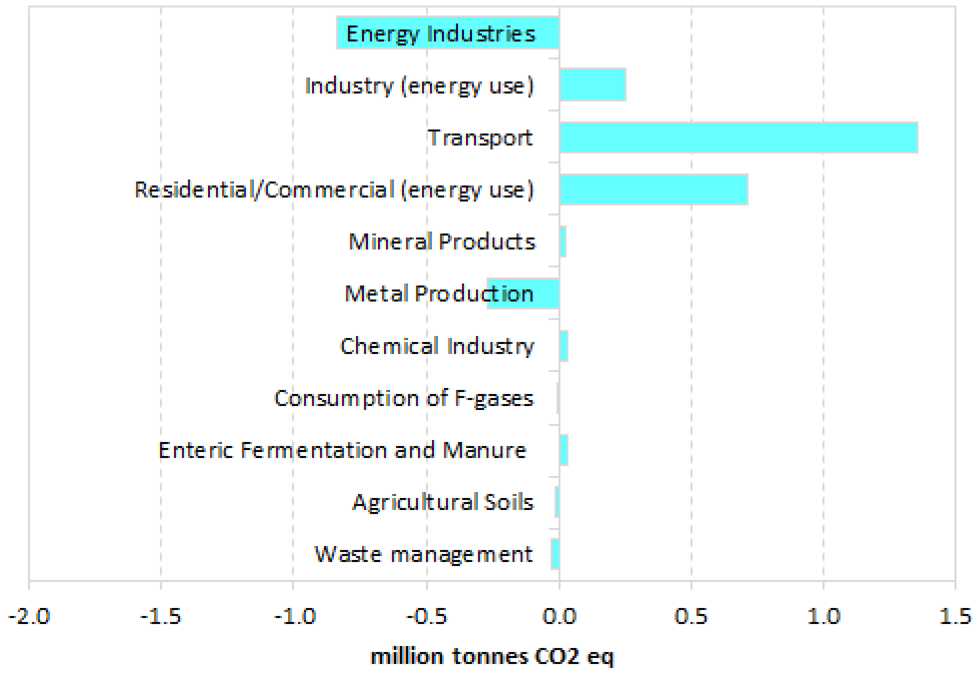


Figure 2.8 *Changes in emissions between 2020 and 2021*

In 2022, emissions decreased almost everywhere, especially in buildings, in industrial production and in agricultural soils. The only notable exception was transport with an 8% growth.

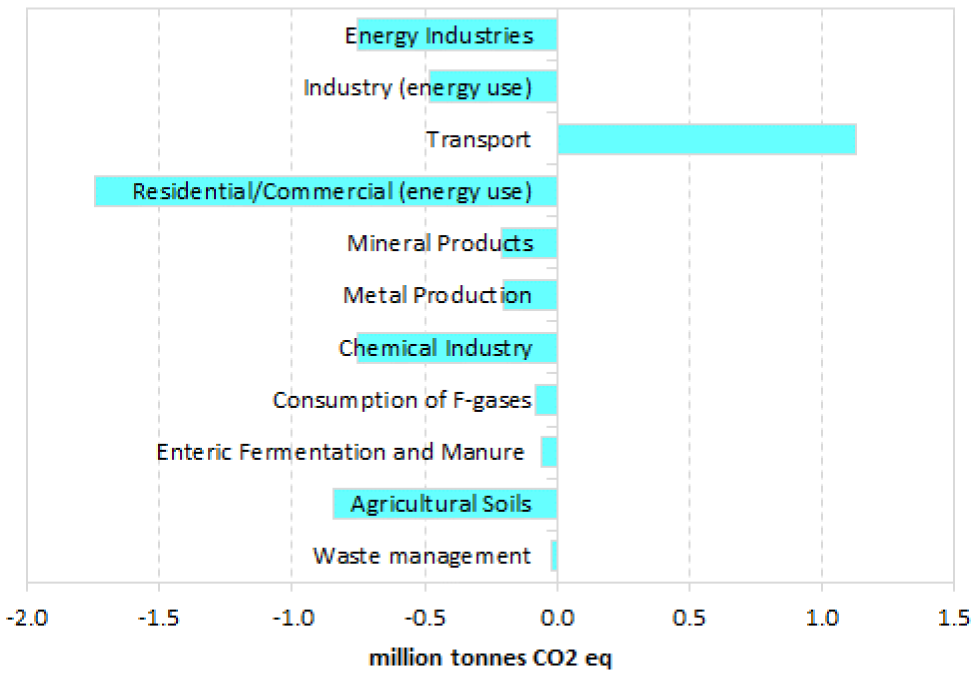


Figure 2.9 *Changes in emissions between 2021 and 2022*

2.2 Description and interpretation of emission trends by gas

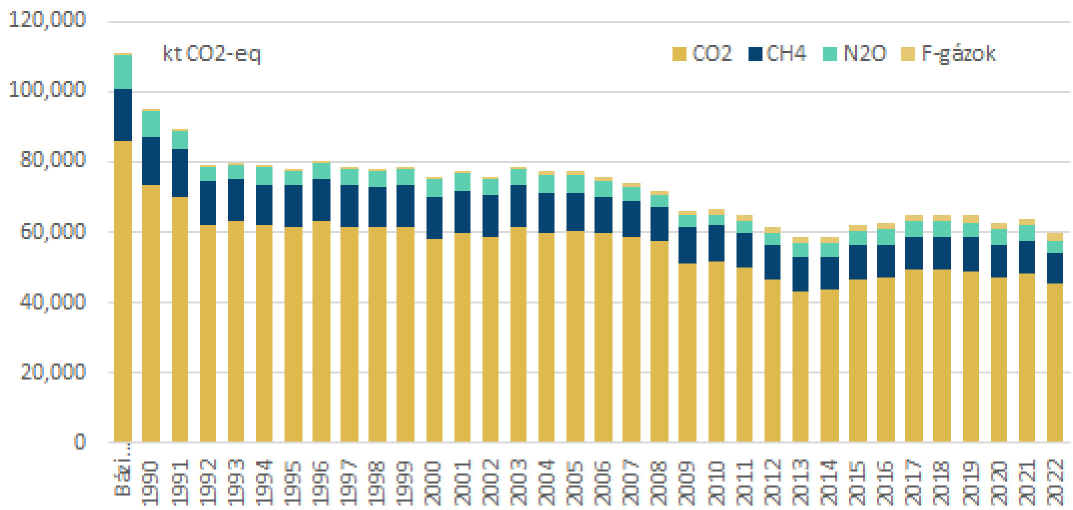


***Figure 2.10** Greenhouse gas emissions by gas between base year and 2022*

The drop of **CO_2** emissions during the early 1990's was attributable to the reduction of fuel uses in conjunction with the decline of the national output. From the second half of the 1990's, emissions showed stagnating or slightly decreasing tendencies reflecting the effects of restructuring following the economic growth. The changes in the fuel-mix resulted in reduction of the specific emission levels. Between 2005 and 2013, CO_2 emissions decreased by 28 per cent, at about the same rate as during the regime change around 1990. The drop of emission accelerated after 2008 mainly driven by the global economic crisis, and the reduced fossil fuel based electricity production. Between 2013 and 2019, however, emissions increased again by 13%. Electricity production increased, transport sector showed a steadily increasing trend, and fuel consumption increased in manufacturing industry. In 2020, an exceptional year because COVID-19 we thought, CO_2 emissions dropped by 4%. In 2022, CO_2 emission fell even more, by 6%. Currently, CO_2 emissions are lower by 25% compared to 2005.

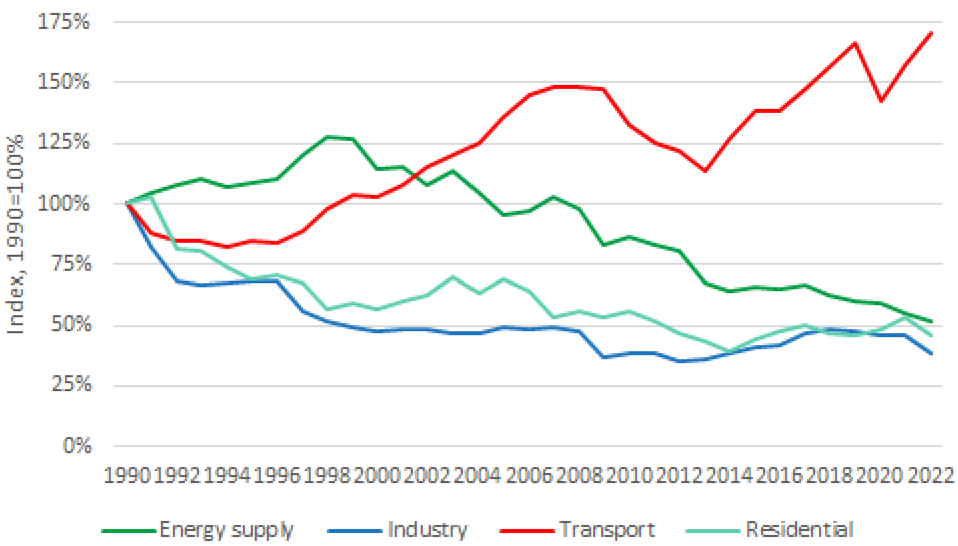


***Figure 2.11** Trend of CO_2 emissions from some selected important sources*

As regards **CH_4** emissions, agriculture, fugitive emissions, and waste management are the trend setting sectors. Most importantly, reductions in the livestock resulted in lower emissions especially in the early part of the time series. Also, fugitive emissions from fuels declined significantly due to gradual closure of underground mines and modernization in the gas transmissions and distribution systems. Besides, emissions from waste disposal grew until 2008, but started to decrease recently. This is the reason why the resultant trend was relatively stagnating until the first half of the last decade, and why it has been slowly decreasing since then.

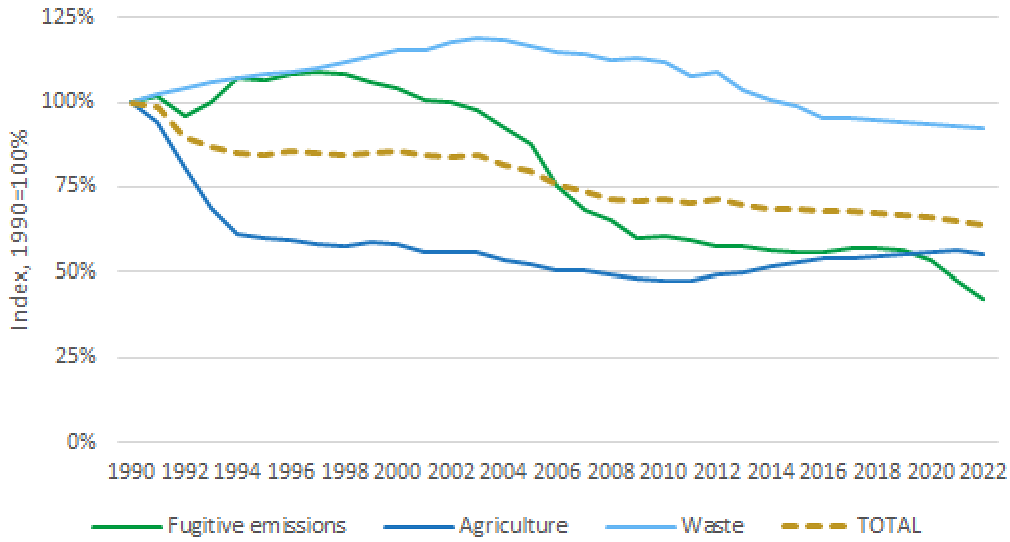


Figure 2.12 *Trend of CH_4 emissions from some selected important sources*

Due to the above factors (i.e., fall in agricultural and industrial production), also **N_2O** emissions decreased significantly in the beginning of the period. Later it showed a slightly rising trend, followed by another drop primarily reflecting the fluctuations in agricultural output and the modernization of nitric-acid production. Then, after 2010, agricultural emissions started growing again, and especially emissions from agricultural soils grew by 40% between 2010 and 2021 then it fell by 24% in 2022.

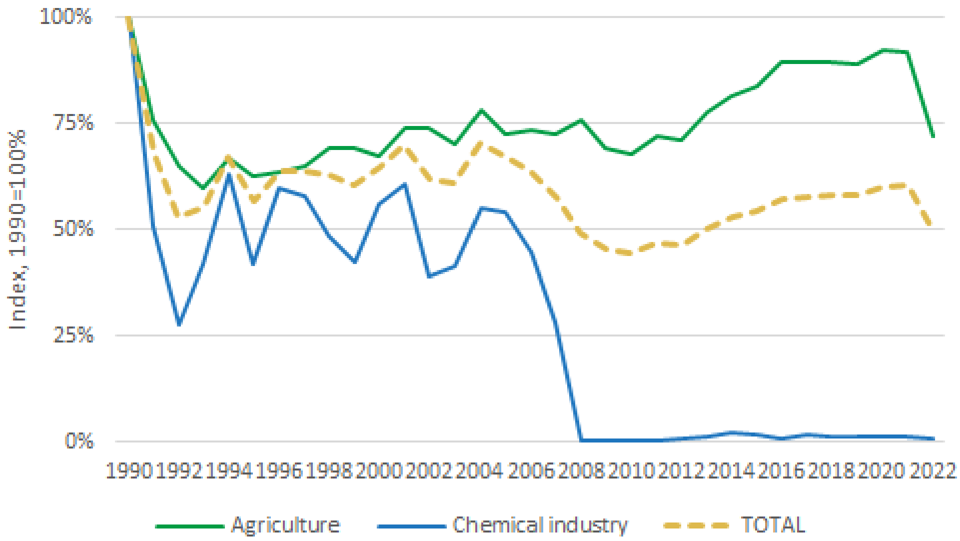


Figure 2.13 *Trend of N_2O emissions from some selected important sources*

The use of **HFC** gases became more intensive in the second half of the 1990's in conjunction with the restriction of the use of chlorofluorocarbons as refrigerants. The rise of emissions is obvious.

PFCs emissions are principally related to aluminium production processes. Therefore, the tendencies of PFC emissions reflect the changes in aluminium production. Following a drastic reduction in the beginning of the period, the levels showed a slow but steady increase. Then the aluminium production ceased suddenly in 2006.

SF_6 emissions primarily depend on the uses in electricity transmission, as it is mainly used in electrical equipment, first of all in switchgears for insulation and arc quenching. So, the growth of the electricity consumption results in an increasing application of SF_6, however the tendencies vary according to the manufacturing/application needs and the steep increase seems to be stopped in the recent years in SF_6 emissions too.

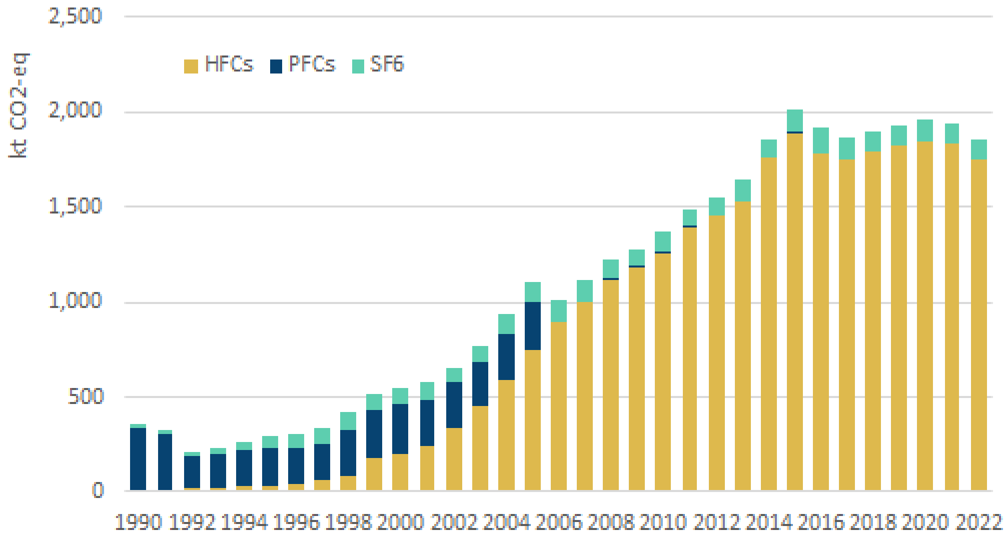


Figure 2.14 *Trend of F-gas emissions (1990-2022)*

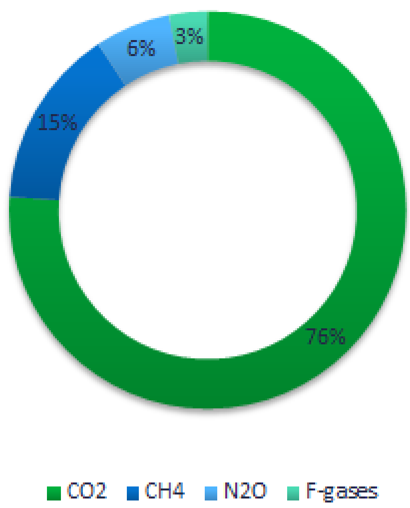


Figure 2.15 *Share of the different GHGs in 2022*

2.3 Description and interpretation of emission trends by category

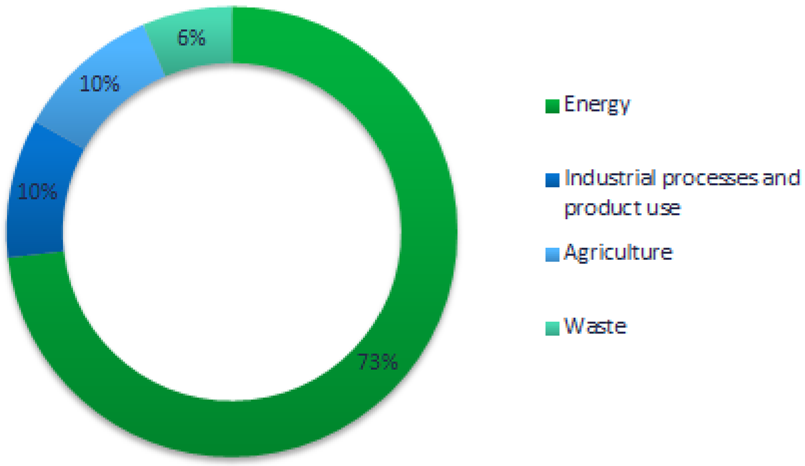


Figure 2.16 *Share of the different sectors in 2022*

The figure above shows the emissions by sources and removals by sinks for each sector. The biggest emitting sector was the energy sector contributing 73% to the total GHG emission in 2022. Industrial processes and product use, and Agriculture had a similar share of 10% each. The waste sector contributed 6%. Compared to the base year, emissions significantly decreased in the energy (-46%), industrial processes and product use (-59%), and agriculture (-48%). In contrast, emissions in the waste sector have increased since 1985-87 (+4%). The land use, land-use change and forestry (LULUCF) sector shows fluctuating behavior. Looking at the most recent trends since 2005, emissions significantly dropped in the energy and industrial processes sectors by 24% and 33%, respectively. The agriculture sector seems to have recovered and could show an increase of 4% since 2005 despite of a significant drop in 2022. The previous growing trend turned back in the waste sector (-22%).

Production and use of energy generate most greenhouse gases, largely CO2. The ***energy sector*** was responsible for 73% of total GHG emissions in 2022. Emissions in the energy sector decreased in the first part of the period as a result of reduced energy consumption and a more favorable fuel mix. The significant reduction in emissions between the base year and 1995 was mainly due to the economic transformation which caused sudden decrease in energy demand. (In this respect, it is perhaps worth mentioning that the decrease in fuel consumption between 2005 and 2014 was even higher!) In addition, ongoing changes in fuel-structure, i.e., gradual replacement of solid fuel by natural gas, led to further decrease of total emissions. Between 2005 and 2008 growing emissions from energy industries and transport could be observed, which were more than offset by the drastic reductions in the residential sector and manufacturing industries. And then the economic crisis came: total combustible fuel consumption decreased by 6% in 2009. Fuel consumption decreased further until 2014 by 14%, but then it increased again by 11% until 2019. In 2020, the first COVID year, total fuel consumption decreased by 2%. In 2021 fuel consumption increased again, by 5%, reaching the level of 2011. Then in 2022 fuel use fell by 5% but it is still higher by 8% than the so far lowest figure in 2014. Combustible fuel use in 2022 was 16% lower than in 2005.

Currently, 16% of domestic primary energy supply is nuclear, 13% is renewable which means that the remaining - overwhelming - part of primary energy demand has to be met by fossil fuels. Natural gas accounts for the largest share (43%) of incinerated, largely fossil fuels, followed by petroleum products (34%). Emissions have been positively influenced by the fact that the proportion of coal with higher specific emissions has fallen from 31% to 6% in the last 35 years, which is well below the current share of biomass in fuel consumption (15%).

The three most important sources of emissions in the energy sector are transport, energy industries, and “other sector” (mostly including residential and other buildings), representing respectively 25%, 18% and 19% of total national emissions in 2022. Energy use and emissions from manufacturing industries and construction contributed 8% to domestic total emissions. Fugitive (mostly methane) emissions from the domestic natural gas system represent 3% of total emissions

In recent years, the transport sector became the largest emitter, not only within the energy sector but also across all sectors. Although emissions from the road transport-dominated sector fell sharply by 14% in 2020 as a result of preventative measures for COVID-19, transport emissions increased significantly both in 2021 and 2022, and now transport accounts for a quarter of total domestic emissions. In 2022, transport emissions were 50% higher than in 2013, the previous low point. (However, preliminary fuel sales data suggest that the growth stopped in 2022, and a decline of emissions is expected for 2023 in this sector.)

As far as energy industries are concerned, domestic electricity production decreased somewhat (-1%), within which natural gas-based production fell more significantly (-8%). A welcome development is the rapid increase in the utilization of solar energy: now 13% of gross electricity production (150% of the production of coal power plants!) comes from solar energy. The share of nuclear power generation was 44%. Electricity imports are still relatively significant (a quarter of consumption). As a result of all this, total emissions from energy industries decreased by 7% in 2022.

In 2022, the winter was milder than average with lower heating demand. In addition, higher energy prices also contributed to a 10% drop in household heating energy consumption. The use of natural gas decreased the most (-14%), the use of firewood less so (-3%). The energy consumption of buildings in the service sector also dropped significantly (-15%), as did that of industrial plants (-10%).

As a result of all this, the emissions of the energy sector decreased by 5% (2.1 million tons of carbon dioxide equivalent) between 2021 and 2022.

The ***industrial processes and product use*** sector contributed 10% to total GHG emissions in 2022. The most important greenhouse gas was CO2, contributing 63% to total sectoral GHG emissions, followed by F-gases with 31%. In 2022, 33% of the emissions came from chemical industry, followed by 29% from product uses as ODS substitutes. Mineral industry has 19%, metal (namely iron and steel) industry has 11% contribution to sectoral GHG emissions, respectively. Other product uses (containing SF6 and N2O) and non-energy products from fuels and solvent use have the smallest influence on the 2022 IPPU inventory with 6% and 2%, respectively. Process related industrial emissions decreased by 59% between the base year and 2022, and by 33% between 2005 and 2022.

In 2022, the downward flight of pig iron production continued due to problems in the operation of Hungary’s only pig iron manufacturer, therefore the output of iron and steel production decreased by 24%. The growth of chemical industry emissions stopped in 2021 and started to decrease in 2022: due to the sharp fall of ammonia and urea based fertilizers production, the emissions of this sector decreased by 28%. Emissions from mineral industry (mainly from cement production) started to decrease again, it was 16% less in 2022 than in the previous year. Emissions from the non-energy use of fuels and solvent use increased by just 1% after the stronger growth in 2020.

Almost a third of industrial emissions come from the operation of equipment containing F-gases and from use of F-gas containing products. Category 2.F.1. (Refrigeration and air-conditioning) accounts for 84% of total F-gas emissions, emissions growth has stopped in recent years. Use of fluorinated and perfluorinated compounds (HFCs, PFCs) has been significant in Hungary since the early 1990s, but these gases became a commonly used refrigerant in the second half of the decade. Most of the equipment with F-gas installed after this period is now coming to the end of its lifetime. Disposal and regeneration of increasing quantities of gases from equipment end-of-life helps to stop emissions growth.

In 2022, the ***agriculture*** sector accounted for 10% of total emissions. The contribution of agriculture to total emissions was similar also in 1990. Emissions from agriculture include CH4 and N2O gases. 81 per cent of total N2O emissions were generated in agriculture in 2022. Emissions from agriculture have decreased by 48% over the period of 1985-2022. The bulk of this reduction occurred in the years between 1985 and 1995, when agricultural production fell by more than 30 per cent, and livestock numbers underwent a drastic decline.

Between 1996 and 2008, agricultural emissions had stagnated around 6.1 Mt with fluctuations up to 3.5%. Behind this trend there were compensatory processes. While the number of livestock decreased further leading to lower emission, the use of fertilizers increased by 68% in the period 1995-2007 which caused growing nitrous oxide emissions from agricultural soils. In 2008 the significantly rising fertilizer prices led to lower fertilizer use, which resulted in some reduction in the emission levels.

Agricultural emissions decreased both in 2009 and 2010. A major reduction in emissions occurred in 2009, when 11 per cent decline in swine population also contributed to the downward trend. Agricultural emissions, after hitting the lowest point in 2010, had increased until 2018, mainly because of the increase in the inorganic fertilizer use, cattle livestock, and milk production per cow.

The GHG-emissions reflect the restructuring in the agricultural production has taken place since 2004, namely the increased ratio of crop to livestock production. Share of CH4 emissions, which derive mainly from the animal husbandry, has decreased, while the N2O emissions, originating primarily from the crop production has grown, since 2004.

Certain types of inorganic fertilizers as urea containing fertilizers and calcium ammonium nitrate (CAN) fertilizers contribute to the agricultural GHG-emissions not only with their nitrogen, but also their carbon content. In Hungary CAN fertilizers have become increasingly popular in the recent years, as a result N2O and CO2 emissions has tripled from this source since 2005.

In 2019, emissions growth temporarily slowed down, mainly due to the decreasing swine livestock and synthetic fertilizer use, but emissions increased again in 2020. The significant decrease in emissions from agricultural soils in 2022 compared to 2021 is mainly due to the decrease in nitrogen fertilizers use, and the yields of major crops were also lower than in 2021.

With an average annual net sink of above 4 million tCO2 equivalent, the ***Land Use Land-Use Change and Forestry*** sector has been a net carbon sink over the entire inventory time series. In 2022, the net sink (including that from the harvested wood product carbon pool) reached 6.8 million tCO2 equivalent/year. Forests removed 6.2 million tCO2 from the air in 2022. Of the factors explaining these processes in the long-term, this was a result of a rather intensive afforestation for decades as well as the sustainable management of the existing forests. The carbon balance of the harvested wood product pool varies but considerably increased in the last five years, with a net sink of over 900 ktCO2/year both in 2021 and in 2022. The non-forestry land-use sectors used to be small net sinks before 2016 but they have turned small sources since then. The net emission of these sectors has been estimated as 317 kt CO2-eq/year in 2022. Due to its complex dynamics, the variation of the annual greenhouse gas balance of the LULUCF sector is relatively high, with no trend in the years since 2005, i.e., for those with reliable data.

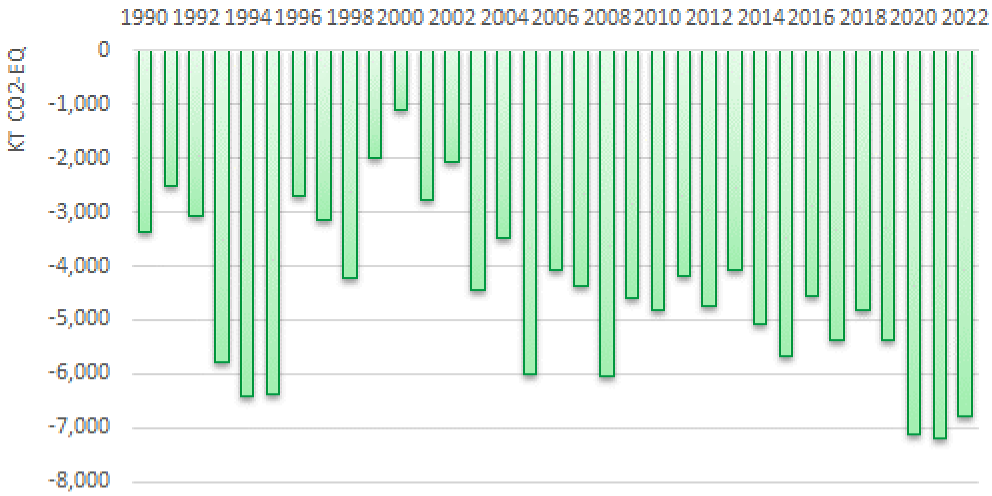


Figure 2.17 *Sinks of LULUCF, Gg CO_2-eq*

The ***waste*** sector was responsible for 6% of total national GHG emissions in 2022 amounting to 3.8 million tons of CO2 equivalent. The largest category was solid waste disposal on land, representing 87% in 2022, followed by wastewater treatment and discharge (9%), biological treatment of solid waste (4%), and incineration of waste without energy recovery (less than 1%). In contrast with other sectors, emissions from the waste sector are by 4% higher now than in the base year. However, the growth in emissions stopped in the last decade, and a reduction of 22% could be observed between 2005 and 2022. The degradation process in solid waste disposal sites is quite slow which means that waste that were disposed many years earlier have still an influence on current emission levels. However, the amount of disposed waste had dropped significantly since 2005 (e.g., landfilled municipal waste decreased by more than 50%) consequently methane emissions started to decrease as well. GHG emissions from wastewater handling have a pronounced decreasing trend due to a growing number of dwellings connected to the public sewerage network.

2.4 Trends of indirect gases and SO_2

NO_X, CO and NMVOC gases are referred to as indirect gases because they (together with SO_2) influence atmospheric warming indirectly, via secondary effects. Nitrogen oxides, carbon monoxide and (non-methane) volatile organic compounds are precursor of ozone which is itself a naturally occurring greenhouse gas. Sulphur dioxide can contribute to formation of aerosols that scatter some of the solar radiation back into space. Calculation of the emissions of these gases is required by the UNFCCC reporting guidelines. It should be noted that Hungary (as well as the other European countries) has calculated the emissions of such gases for several decades and the Geneva Convention of 1979 (CLRTAP) also laid down such obligations. Emissions are reported consistently in the above two reporting regimes.

The following table shows the main trends in emissions:

Table 2.3 *Trends in emissions of indirect greenhouse gases and SO_2 excluding LULUCF (Gg)*

GASES	1990	1995	2000	2005	2010	2015	2020	2021	2022
NOX	244	191	189	180	148	128	108	110	101
CO	1416	981	857	698	546	460	334	337	327
NMVOC	314	227	202	183	142	135	122	121	118
SO2	832	615	427	42	30	24	17	14	14

(Source: CLRTAP/NECD reporting)

The substantial reduction in sulphur dioxide emissions (-95%) is attributable to the decreased use of fossil fuels in general and the decreasing share of coal with higher sulphur content. After 2000, further reductions were observed due to the introduction of SO_2 precipitators in coal-fired power stations. Reduced carbon monoxide emissions are obviously a consequence of decreased fuel uses. The decrease in NO_X emissions is relatively moderate due to the increasing significance of transport.

3 ENERGY (CRF sector 1)

Recent key developments:

- Between 2005 and 2014, Hungary experienced an almost constant emission reduction in the energy sector. However, after a 27% reduction, the decreasing trend stopped, and total emissions increased by 12% between 2014 and 2017. Emissions remained at a similar level in 2018 and 2019, and then – mostly due to COVID-19 – decreased by 5% in 2020. This decrease, however, proved to be temporary, emissions increased by 4% in 2021.
- Then in 2022, emissions fell by almost 5% due to decreasing consumption levels driven by rising energy prices, and especially due to a 15% drop in natural gas consumption. Current GHG emissions are by 24 per cent lower than in 2005.
- The three most important sources of emissions in the energy sector are transport, energy industries, and “other sector” (mostly including residential and other buildings) representing respectively 25%, 18% and 19% of total national emissions in 2022.
- In recent years, the transport sector became the largest emitter, not only within the energy sector but also across all sectors. Although emissions from the road transport-dominated sector fell sharply by 14% in 2020 as a result of preventative measures for COVID-19, transport emissions increased significantly both in 2021 and 2022, and now transport accounts for a quarter of total domestic emissions.
- Natural gas-based electricity production fell by 8%. A welcome development is the rapid increase in the utilization of solar energy: now 13% of gross electricity production (150% of the production of coal power plants!) comes from solar energy. Electricity imports are still relatively significant (a quarter of consumption). Total emissions from energy industries decreased by 7% in 2022, and altogether by 22% since 2017.
- In 2022, the winter was milder than average with lower heating demand. In addition, higher energy prices also contributed to a 10% drop in household heating energy consumption. The use of natural gas decreased the most (-14%), the use of firewood less so (-3%). The energy consumption of buildings in the service sector also dropped significantly (-15%), as did that of industrial plants (-10%).

Major changes compared to previous submission:

- The latest version of the Annual IEA/Eurostat Questionnaires submitted end of October 2023 and slightly updated in March 2024 were used as activity data.
- Activity data have been generally rounded to TJ values with zero decimals.
- 1A3b: CO_2 emission factor for gasoline has been changed to 71.61 t/TJ (from 72.47 t/TJ in the 2023 submission and from 71.28 t/TJ in earlier submissions). The reasons for this change were the followings: (1) It was noted that our previous approach (i.e. using the measured carbon content of the E5 blend and applying the ratio of default CO2 EFs for fossil petrol and E5 (3.169/3.063=1.035) from Table 3-12 in the 2019 EMEP/EEA Guidebook) led to one of the highest EF among reporting Parties. (2) This approach was introduced earlier on the basis of a former version (2013) of the EMEP/EEA Guidebook with a lower ratio of CO2 EF of fossil and E5 fuel (3.18/3.125=1.0176). (3) It was also noted that the bio component was lower than 5% in one of the samples for which the default CO2 fossil/CO2 E5 ratio might not be suitable. Therefore, for this submission, we applied the “French method” from the EU methodology

paper “Country-specific CO2 emission factors from road transport” although based on much less samples.

- 1A3b: We have switched to the COPERT model (version 5.7.2, November 2023) for the whole time series.
- 1A3a: Activity data (aviation gasoline and kerosene used for national aviation) have been revised based on latest Eurocontrol data.
- “Autoproducers”: Following the ERTs repeated recommendation, we did some further re-allocations of fuel consumption in the early period of the time series to include the emissions of autoproducers in their relevant industrial end-use categories. It must be noted that there are still some autoproducers that are included in the source category 1A2gviii. In the early 1990s, some energy consumption is reported as "industrial boilers" in the energy statistical yearbooks without further specification, therefore it seems impossible to allocate the corresponding emissions to a specific industrial branch.
- 1.A.2: NCV of (mostly imported) lignite used in industry have been revised for the period 1985-1998 based on traditional printed energy statistical publications that seemed more appropriate than the quite low (and constant) NCV values included in the IEA/Eurostat Coal Questionnaire.
- 1.A.4.a/1.A.4.b: Natural gas consumption is reported as included in the IEA/Eurostat Gas Questionnaire (except for some addition of autoproducers in 1.A.4.a). This means that no natural gas is re-allocated from 1.A.4.a to 1.A.1.c and no “theft” is taken into account in 1.A.1.b as in previous submissions. With this, we are more in line with the official energy statistics. Also, the amount of stolen natural gas is a highly uncertain figure, and currently not as significant as around 2010. (Based on newspaper articles from that time, theft increased drastically from 2008 and reached an estimated amount of 80-90 million cubic meters in 2010-2011 but it was reduced to a third by 2015, and most probably it decreased further since then.) Also, we would like to note that in the energy statistics we see negative statistical differences of 5-17 PJ in recent years, which means higher observed than calculated inland consumption, so further additions to the sectoral fuel consumption seem unnecessary.
- 1.A.2.f: CO2 emissions from coal and petroleum coke was revised for 2020-2021 based on ETS data
- 1.B.2: Natural gas, transmission: CH4 emissions have been revised for 2020-2021 based on information received from the owner and operator of the whole domestic natural gas transportation system (FGSZ Ltd.)
- Natural gas, distribution: amended activity data in 2005-2008 affected also interpolated data between 1994 and 2004.

3.1 Overview of sector

Emitted gases: CO2, CH4, N2O
Methods: T1, T2, T3
Emission factors: D, CS, PS

This sector covers emissions from combustion processes and fuel-related fugitive emissions from exploration, transmission, distribution and conversion of primary energy sources.

For a better understanding of the principal drivers behind fossil fuel related emission trends and variations, the main characteristics of the Hungarian Energy System will be described shortly in the following. First of all, not enough, cheap and clean domestic energy resources of good quality are available in Hungary, therefore the energy demand has to be met by import to a great extent. In 2022, primary energy production amounted to 449.4 PJ which was by 27 per cent less than in 1990 and more or less at the same level as in 2005. Most importantly, uneconomical deep coal mines were closed down, but also crude oil and natural gas production decreased. Net import of energy with 700.2 PJ in 2022 was larger by 18% than in 1990 but by 5% smaller than in 2005. Hungary's import dependency is quite significant, over 50%, currently 64.2% (calculated as the ratio of net imports and primary energy consumption). Domestic supply of primary energy was 1074.8 PJ in 2022, a decrease of 6% compared to 2021. Final consumption decreased also: from 889.4 PJ in 2021 to 827.9 PJ in 2022. Looking at the main sectors, energy consumption of both industry and the residential sector decreased by 9%. The latter can be explained by lower heating demand (HDD) to a large extent but the increasing gas prices might also have played a role.

(Data source: Hungarian Energy and Public Utility Regulatory Authority (HEA), and HCSO: https://mekh.hu/download/1/10/61000/7_2_annual_national_energy_balance_2014_2022.xlsx https://www.ksh.hu/stadat_files/ene/en/ene0002.html

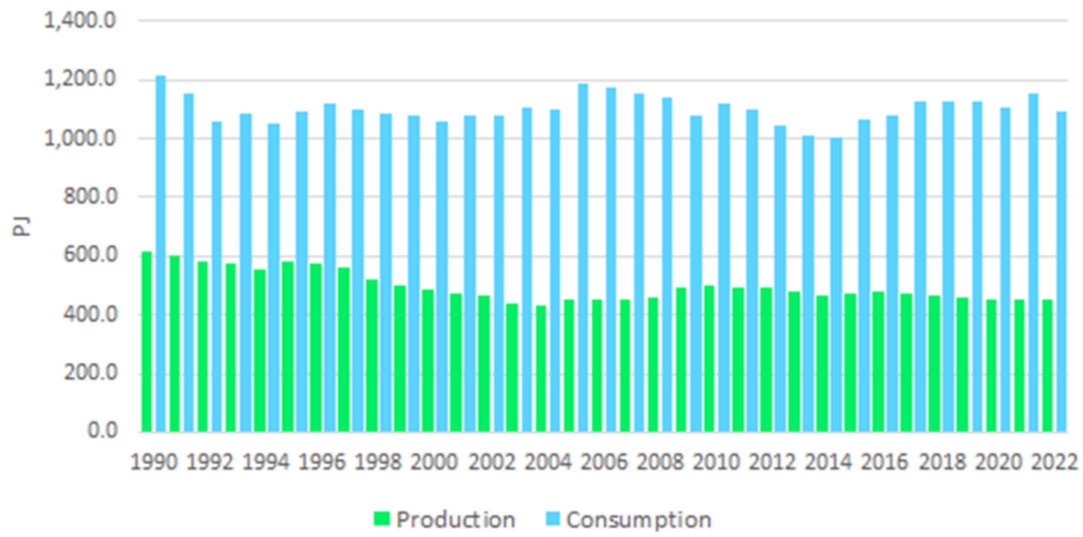


Figure 3.1.1 *Primary energy balance of Hungary (1990-2022)*

In 2022, final domestic electricity use amounted to 42,413 GWh, 1% less than in the previous year. Electricity consumption increased by 28% since 1990. The market penetration of the nuclear electricity started in 1983 in Hungary when the first 440 MW block of the Nuclear Power Plant in Paks was put into service. In the last 10 years, 44% (2022) to 53% (2014) of the domestic generated electricity was produced by nuclear energy whereas the share of fossil fuels decreased to 40% in 2013 and remained below that level afterwards. According to the official statistics of the Hungarian Energy and Public Utility Regulatory Authority, the share of electricity from renewable sources in gross final consumption of electricity increased from 4.4% is 2005 to 15.3% in 2022. The last few years saw significant increases in solar electricity production (from 1 GWh in 2011 to 4732 GWh in 2022) and also wind power production increased to 610 GWh in 2022 from 10 GWh in 2005. At the same time, electricity produced from combustible fuels decreased from 21,710 GWh in 2005 to 14,365 GWh in 2022.

By far, the biggest emitting sector is the energy sector contributing 73% to the total GHG emission in 2022. *Figure 3.1.2* shows the emission trends in the sector compared to the total.

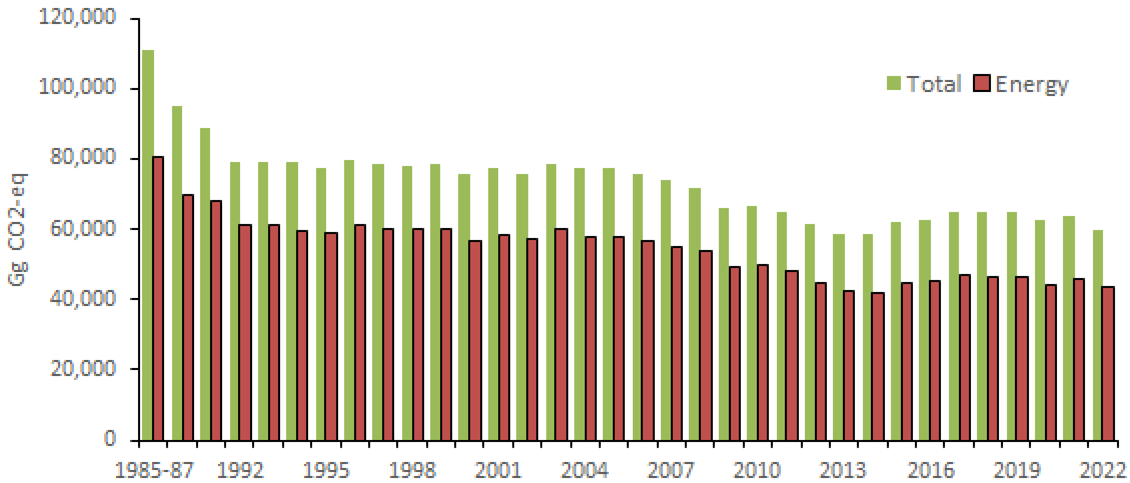


Figure 3.1.2 *GHG emissions of the Energy sector compared to total (BY-2022)*

The significant reduction in emissions between the base year and 1995 was mainly due to the economic transformation which caused sudden decrease in energy demand. (In this respect, it is perhaps worth mentioning that the decrease in fuel consumption after 2005 was even higher!) In addition, ongoing changes in fuel-structure, i.e., gradual replacement of solid fuel by natural gas, led to further decrease of total emissions. Some classical types of fossil fuels have disappeared or their use decreased significantly, e.g., city-gas, heavy fuel oil (by destructive technologies it has been transformed to motor fuels and partly petrol-coke is produced from it). At the same time, the market penetration of new fuel types became significant e.g., petrol-coke, bio-ethanol, LPG and compressed natural-gas (CNG) for cars and buses, biomass for firing in power plants, biogas produced by fermentation of sludge and animal carcasses etc. All these changes were taken into consideration in our emission calculations.

Between 2005 and 2014, Hungary experienced an almost constant emission reduction in the energy sector basically due to mild winters and higher energy prices. In 2009 also the global economic crisis affected the emissions especially in the energy and manufacturing industries sectors. Then in 2010, the growth in industrial production led to somewhat increased emissions again. In the next four years, however, emissions from the energy sector decreased further and reached their lowest level in the whole time series in 2014. Altogether, emissions decreased by 27% between 2005 and 2014.

However, the decreasing trend stopped in 2015. Total emissions from the energy sector have increased by 12% or 5 million tonnes between 2014 and 2017 and then remained more or less at the same level in 2018 and 2019. Above all, transport related emissions started to increase again already in 2014, and they grew by 46% in the period 2013-2019.

The residential sector produced also higher and higher emissions between 2014 and 2017, after many years of dominantly decreasing trend. Then, mostly due to the fact that 2018 and 2019 were the warmest years ever, total fuel consumption of households decreased by 13% between 2017 and 2019. While biomass use decreased by 22%, fossil natural gas consumption by only 6%.

And then in 2020, the COVID-19 pandemic caused a significant drop in transport emissions and somewhat higher energy demand in the residential sector as described above. In 2021, transport emissions started growing again, and so did commercial and industrial emissions. As the heating demand was the highest since 2011, residential emissions grew as well.

2022, however, proved to be definitely warmer than 2021, HDD decreased by 9%. Total fuel combustion decreased by 5%, total consumption natural gas use fell by 15%.

Carbon dioxide from fossil fuels was the largest item among greenhouse gas emissions contributing 95% to the sectoral emission. Among all sectors, the energy sector contributes the most to the total CO_2 emissions as well (91% in 2022).

As regards methane emission, its contribution is 5% and 3% to the energy sector's emissions and to the total greenhouse gas emission (without LULUCF), respectively. Primarily, this results from fugitive emissions associated with conventional oil and gas production and processing (which also includes fugitive emissions from natural gas transmission). Among methane emitters, this sector's proportion is 23% (waste and agriculture sectors dominate here, see Fig. 3.1.3).

Considering nitrous oxide emission, this sector represents 1% (without LULUCF) of the total greenhouse gas emission. Among nitrous oxide emitters, its proportion is 8% which represents the second highest contribution compared to other sectors but it is still far behind agriculture.

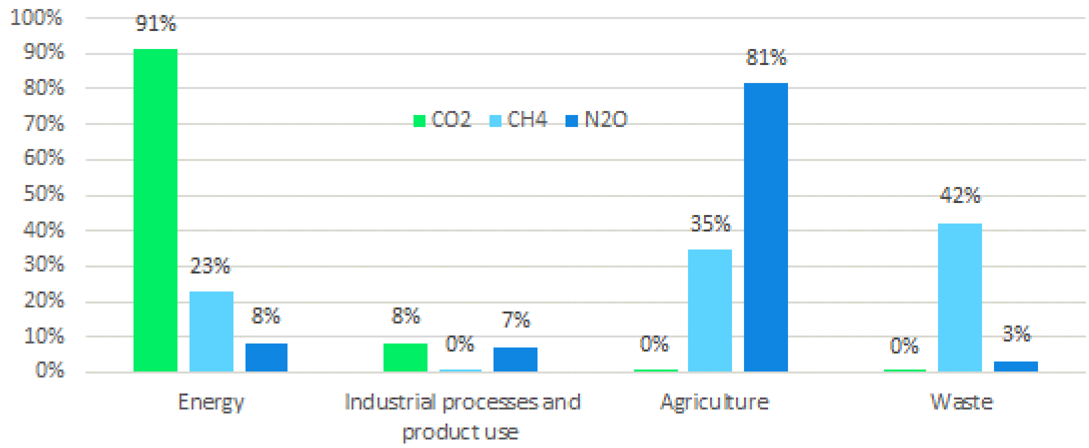


Figure 3.1.3 *Sectoral contributions to the total emissions of the main GHG gases (2022)*

The three most important sources of emissions in the energy sector are transport, energy industries, and “other sector” (mostly including residential and other buildings), currently representing 25%, 18% and 19% of total national emissions, respectively, see *Fig. 3.1.4.* In the time series there were changes in the relative contributions of the different subsectors within the energy sector, most notably the growing share of transport emissions (from 11% in the base year to 32% in 2019, dropping temporarily to 28% in 2020 but increasing again to 31% in 2022) and the diminishing share of manufacturing industries (from 21% in the base year to 6% in 2009 and 11% in 2022).

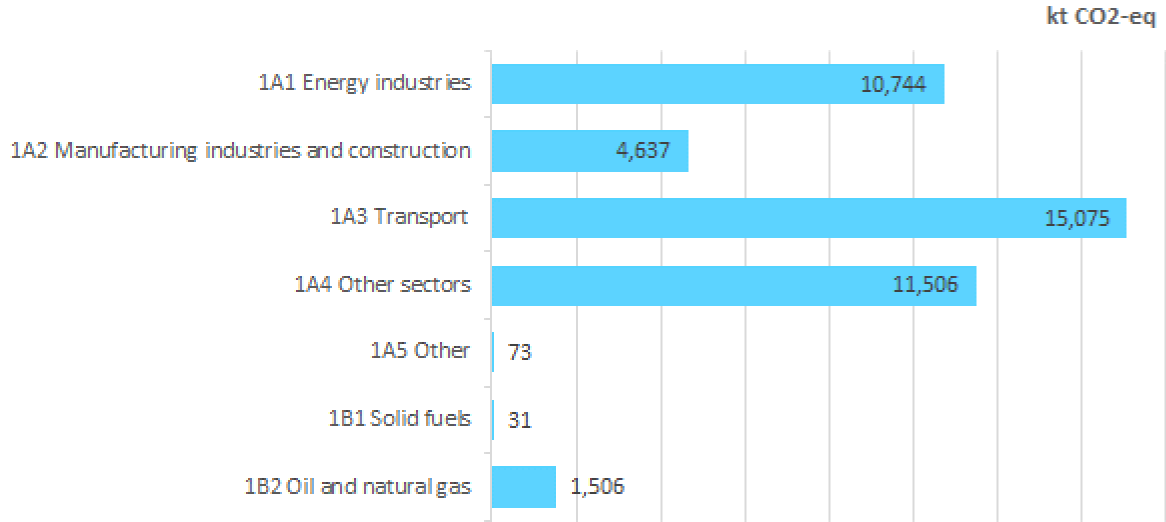


Figure 3.1.4 *Share of the different source categories in 2022*

Fugitive emissions from fuels played only a small role with 4% out of which 98% originate from oil and natural gas production, processing, transmission and distribution. Emission in subsector 1.B.1 – Fugitive emissions from solid fuels are 98% smaller than the base year caused by the huge recession of underground coal mining in Hungary. The aggregate change of sector 1B – Fugitive emissions is 64% decrease compared to the base year.

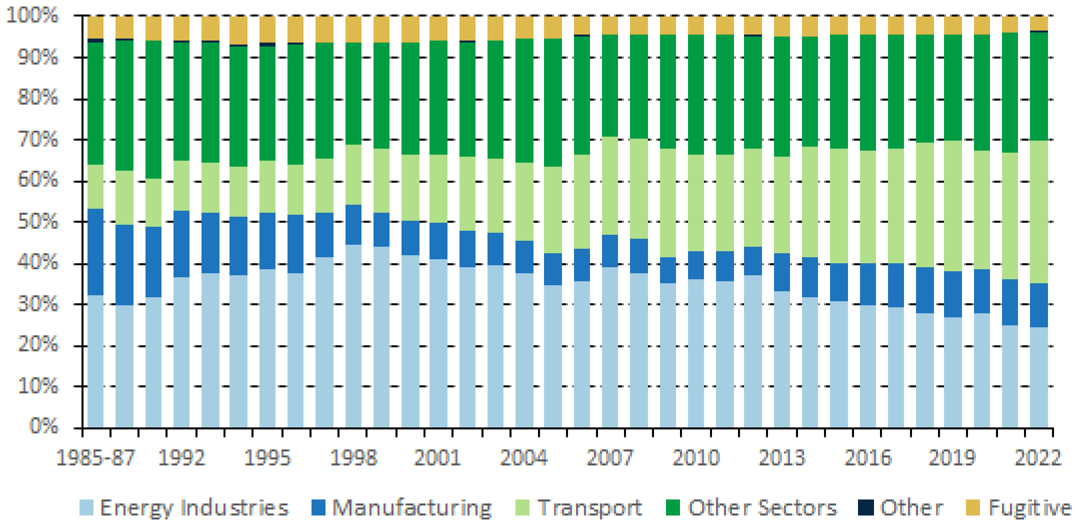


Figure 3.1.5 *Changing shares of the different subsectors (BY-2022)*

3.2 Fuel combustion (CRF 1.A)

The principal driver of emissions in the energy sector is fuel consumption, therefore emissions of the sector strongly depend on the amount of combusted fuel. The use of combustible fuels decreased quite considerably, by 20% between 1990 and 2022. Two periods need to be emphasized in this respect. The regime change around 1990 had the first significant effect: the fuel use in 1995 was by a fifth less than in the base year. The decrease in energy use after 2005 was even more significant (-22% until 2014) where the global economic crisis must have played a role. Then, fuel use increased again by 12% between 2014 and 2017, and decreased slightly by 1% in the next two years, and by 2% in 2020. In 2021 fuel consumption increased again, by 5%, reaching the level of 2011. Then, in 2022 fuel use fell by 5% but it is still higher by 8% than the so far lowest figure in 2014.

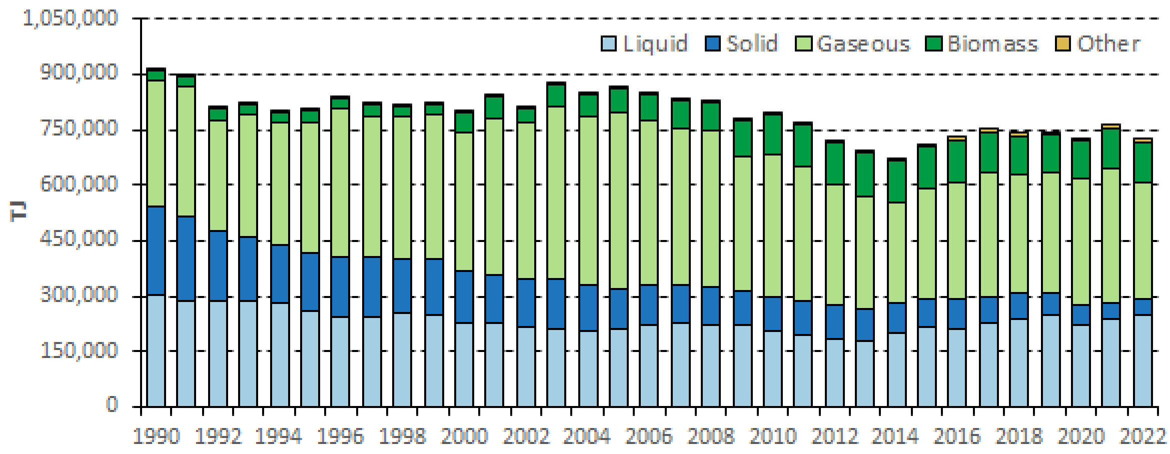


Figure 3.2.1 *Fuel consumption by main fuel types (1990-2022)*

Beside the amount, also the type of the used fuels has a great influence on the emission levels. Considering fuel use in combustion processes, gases had the highest proportion (43%) in 2022, liquids and solids represented 34% and 6%, respectively. It is worth mentioning that the share of biomass in fuel combustion grew to 15%. Especially solid fuels lost their importance: their share in the fuel mix was around 26% in 1990 (and even higher in the base year), see *Fig. 3.2.2*.

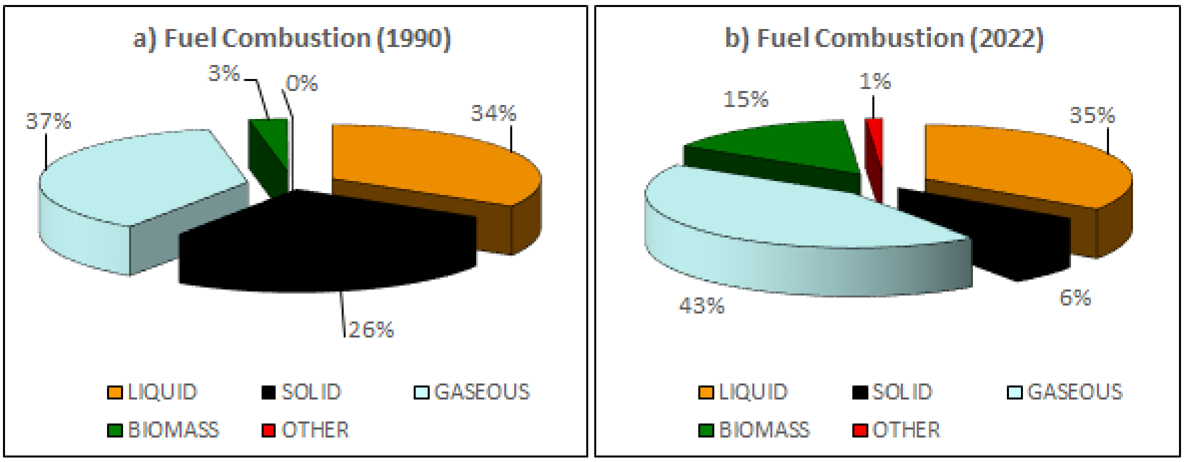


Figure 3.2.2 *Fuel mix in 1990 and in 2022*

Calculation of greenhouse gas emissions from combustion is based on the amount of fuel used. For this purpose, the energy balance of Hungary, the fuel balance for each fuel type and the fuel consumption for each subsector compiled by the Hungarian Energy and Public Utility Regulatory Authority are used dominantly. After discussion with the energy statistics provider and following their recommendation, it was decided that, starting with the 2014 submission, the basis of the inventories would be on the IEA/Eurostat Questionnaires. (Previously, these energy statistics were available to the inventory compilers basically as hard copies of the publication series Energy Statistical Yearbook. For some years, also electronic versions (tables in Excel files) were provided. However, this publication ceased, the last yearbook contained data for 2010.)

To increase consistency of the time series, we had to make some minor amendments of the allocation of fuel consumption compared to the IEA annual questionnaires, as follows:

- Based on 2011-2017 data allocations and value-added volumes of industrial production for previous years, some gasoil consumption has been reallocated from road transport to non-road mobile machinery (1A2gvii);
- The time series of gasoil use in navigation has been improved by interpolation where the missing amounts were taken again from road transport;
- The original IEA Gas Annual Questionnaires do not contain data for oil and gas extraction before the year 2013 nor for pipeline transport before the year 2010 therefore the existing time series had to be extrapolated back to 1990.

It has to be noted that the traditional Hungarian coal terminology as published in the Energy Statistical Yearbooks differs from that of the IPCC. The partitioning was created according to the age of coal; Table 3.2.1 shows the classification according to the Hungarian and IPCC categories. Practically this means that imported "brown coal" in the Hungarian terminology would classify as sub-bituminous coal whereas domestically produced brown coal falls under the IPCC category of lignite. Basically, most of the coal produced in Hungary can be classified as lignite. Furthermore, the Energy Statistical Yearbook dealt with anthracite, hard coal, brown coal and lignite in the fuel balance separately, while the sectoral energy consumption for coal was the aggregate of hard coal, brown coal, lignite, gas coal and coking coal. Now, as our reporting is based on the IEA statistics, the reported fuel data follow the IPCC categories consistently.

As regards carbon emissions, solid fuels caused the most problems mainly because the fuel classification had been changed. The formerly used country specific carbon emission factors were previously determined for the Hungarian categories, namely for hard coal, brown coal, and lignite. (Until the 2014 submission, the following constant values had been used based on the 2005 ETS data: 27 tC/TJ for hard coal and brown coal and 30.9 tC/TJ for lignite.) Now, new factors had to be applied for other bituminous coal, sub-bituminous coal and lignite. Most of the coal produced in Hungary can be classified as lignite in this new system irrespectively whether it stemmed from surface or underground mines, although they have different characteristics. To take into account the changing share of the higher quality lignite from underground production, a time dependent carbon emission factor (changing between 103.0 and 108.6 t CO_2/TJ) was introduced and applied for the pre-ETS years. For the lowest quality lignite from surface mines the following parameters are used: EF=112.2 t CO2/TJ, OX=0.974. As for Hungarian brown coal EF=100.8 t CO2/TJ and OX=0.952 is applied. It is worth noting that the share of the lower quality lignite in production increased from 20% in 1990 to 84% in 2010. For other bituminous coal and sub-bituminous coal, the IPCC default values are used.

***Table 3.2.1** Comparison of Hungarian and IPCC coal terminology*

Hungarian Terminology	Net Calorific Values	IPCC Category (Gross calorific value)
Hard Coal	17-33 MJ/kg	Other Bituminous Coal (>23.865 MJ/kg)
Hard Coal	17-33 MJ/kg	Sub-Bituminous Coal (17.435 MJ/kg - 23.865 MJ/kg)
Brown Coal	10-17 MJ/kg	Lignite (<17.435 MJ/kg)
Lignite (young brown coal)	3.5-10 MJ/kg	Lignite (<17.435 MJ/kg)
Gas Coal and Coking Coal		Coking Coal

(Source: Bihari, 1998; IPCC, 2006)

Fuel use and emissions of autoproducer plants (that generate electricity or heat, wholly or partly for their own use as an activity which supports their primary activity) are accounted for *fully* in under the relevant economic sector in the period 1998-2021 as required by the guidebook, and to the extent possible also for previous years. (In earlier submissions, almost all autoproduction was allocated to the source category “other stationary combustion 1A2gviii” for all years before 2013 with a few exceptions (e.g., coke oven gas and blast furnace gas were also previously reallocated from autoproducers to iron and steel, and to manufacture of solid fuels).

The problem of the network losses in the natural-gas transmission and distribution system should be also mentioned here. These losses are partly not technical ones in the reality, but the result of accounting, e.g., due to issues as measurement accuracy, temperature or pressure conversion, or theft. (For more details see description in Ch. 3.3.2.5) The point is that only 30-50% of the losses reported in statistical publications as distribution losses was taken into consideration as real loss (i.e., that is emitted into the atmosphere as methane), while some of the remaining part was assumed to be fired.

Input data for the fugitive emission calculation came from the Statistical yearbook of Hungary, Energy Statistics, the Hungarian Oil and Gas Company Plc. (MOL), the Hungarian Office for Mining and from the Hungarian Energy Office.

LPG and petroleum coke were taken into account as liquid fuels which had significant influence on the IEF value of this fuel type.

3.2.1 Comparison of the sectoral approach with the reference approach

The quantity of CO_2 from energy consumption was determined both on national level (reference approach) and on sectoral level (sectoral approach). The reference approach (RA) is based on national energy balance: production, import, export, stock changes, and international bunkers. The sectoral approach (SA) allocates the emissions by source category and includes only the combusted amount of fuels. The reference approach was compared with the sectoral approach as a check of combustion-related emissions. The check was performed for all years from 1985 to 2022 and is an integral part of reporting to the UNFCCC. The analysis includes also the comparison from the base year (1985-87). The reference approach, in theory, includes all CO_2 emissions from all fossil fuel uses in a country and should be compared with a set of emissions from the sectoral approach that includes all CO_2 emissions from energy use of fossil fuels.

Emissions from feedstocks and non-energy use of fuels are taken into account in the IPPU sector (2B and 2G) in case of sectoral approach (SA), therefore the energy and carbon content of these fuels are removed from the RA (the fraction of carbon stored is 1 for all these fuels in the 1D sector), too. Similarly, emissions from coke used for transformation in the iron and steel industry were allocated to the relevant source category of the industrial processes sector, thus removed from the reference approach.

Since the 2015 submission, more fuel has been removed from the reference approach than in previous submissions (see also Table 3.2.3):

- All coke related emissions (including blast furnace gas) in the iron and steel industry are allocated to the IPPU sector;
- More natural gas consumption in the chemical sector is allocated to the IPPU sector.

In the CRF reporting software, the RA is directly compared with the sectoral fuel combustion total. This direct comparison shows that the total fuel consumptions of the RA are mostly larger than the SA totals (*Fig. 3.2.3*) on average by 0.8%. The remaining differences – after extracting the feedstock and non-energy use of fuels – are basically statistical differences, fugitive emissions and transformation losses which are occurring during coking, briquetting or oil refining.

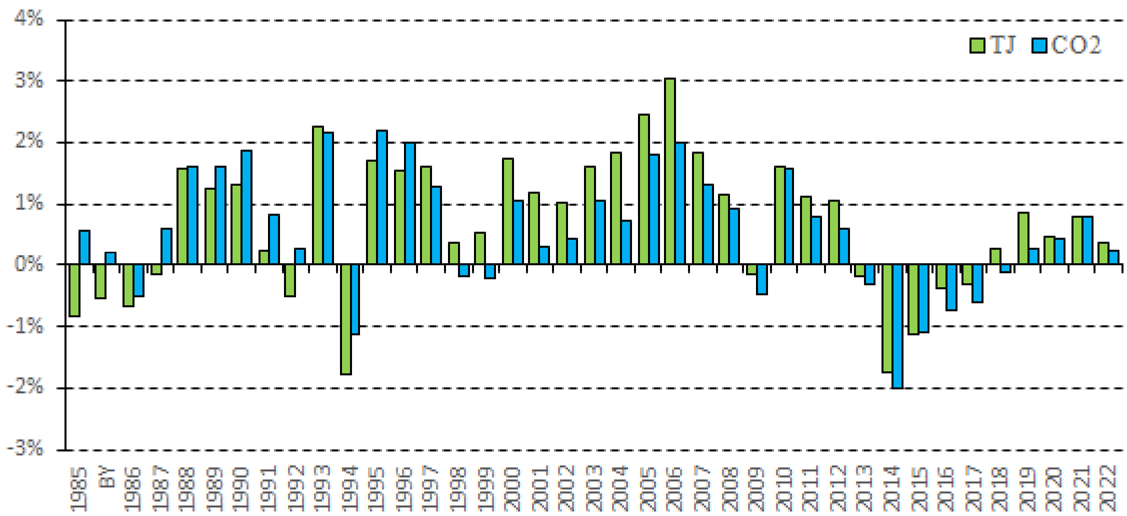


Figure 3.2.3 *Differences between the reference and the sectoral approach as regards fuel consumption and CO_2 emissions*

In 2022, the difference between the two approaches was 0.4% in energy consumption and 0.2% in CO_2 emission (*Fig. 3.2.3*). The ranges of differences are between -1.8% (1994) and 3.0% (2006) with a mean value of 0.7% as regards fuel consumptions, and similarly -2.0% (2014) and 2.2% (1993) with a mean value of 0.6% as regards CO_2 emissions.

3.2.2 International bunker fuels

In accordance with the reporting guidelines, emissions from international aviation were included under the category International Bunkers on the basis of the quantities of kerosene used. In the time-series of the resulting CO_2 emission, significant jumps are present at certain places, which are obviously due to the changes in kerosene consumption. Naturally, changes in kerosene consumption reflect the travelling/transport needs. This is clearly illustrated in Figure 3.2.4 which shows the air travelling/transport performance of the past years

Consumption in international navigation was not considered, because separate data on the uses for international navigation are not included in the national statistics.

International navigation depends not only on geographical and economic but on political conditions, too. International conflicts, wars have significant impact on international navigation, which could be seen in Hungary during and after the war in Yugoslavia. The war set back the navigation on the Danube South to Hungary, and decreased also the trade in Hungary. In the last years, the sea navigation (there was only tramp navigation) has relapsed due to falling into disuse of ship-fleet. This process could be traced back to the absence of Hungarian harbor on seas and Danube-sea ships. Between 1990 and 2000 the role of transportation of goods on waterways decreased from 28.2% to 2.9% among goods transportation in other ways. (Source: webpage of Központi Közlekedési Felügyelet)

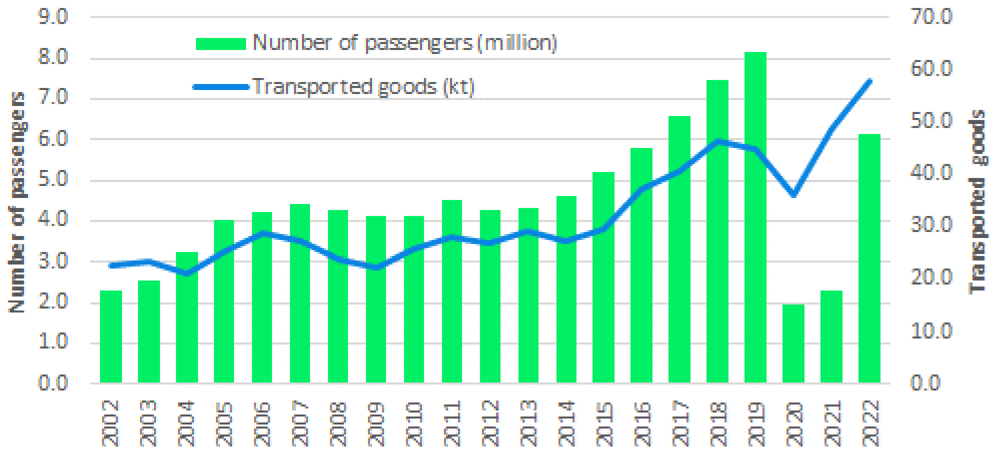


Figure 3.2.4 *Outgoing traffic from Budapest Ferenc Liszt International Airport*

3.2.3 Feedstocks and non-energy use of fuels

The 2006 IPCC Guidelines introduced significant changes regarding feedstocks and non-energy use of fuels. It is good practice now to report all the feedstock and non-energy use of fuels in the *IPPU Sector* within the source category in which the process occurs.

In addition, also chapter1.2 of Volume 2 states: "*Combustion emissions from fuels obtained directly or indirectly from the feedstock for an IPPU process will normally be allocated to the part of the source category in which the process occurs. These source categories are normally 2B and 2C."*

So, in present submission all the fuels regarded as NEU in IEA Energy Statistics are allocated into IPPU sectors and also some amount from the quantities regarded as energy use in order to follow the suggestion of IPCC2006. This is the case for natural gas use in sector 2B1 Ammonia, naphtha use in 2.B.8 Petrochemical, and coke used in 2C1 Iron and steel.

Therefore, the fuel quantities for NEU reported in CRF Table 1.A.(d) and QA/QC check Table for NEU included in Annex of the NIR are higher than the actual quantity reported in IEA Energy Statistics. Nevertheless, the differences are well-known and documented.

Table 3.2.3 *Allocation of feedstocks and non-energy use of fuels*

Fuel type	Allocated under IPCC sector
Other kerosene	2.B.8 -Petrochemical and Carbon Black Production
Gas/diesel oil	2.B.8 -Petrochemical and Carbon Black Production
Liquefied petroleum gases (LPG)	2.B.8 -Petrochemical and Carbon Black Production
Naphtha	2.B.8 -Petrochemical and Carbon Black Production
Bitumen	2.D Non-energy Products - Other *(no CO_2)*
Lubricants	2.D.1 - Lubricant Use
Other oil	2.D.2 - Paraffin Wax Use 2.B.8 - Petrochemical and Carbon Black Production
Coking coal	2.C.1 -Iron and Steel Production
Coke oven/gas coke	2.C.1 -Iron and Steel Production
Natural gas	2.B.1 -Ammonia Production 2.C.1 - Iron and Steel Production 2.B.8 - Petrochemical and Carbon Black Production

Carbon content of all fuels which are allocated under the Industrial Processes sector is taken as stored carbon in the 1.AD sector (and in the *reference approach*), however the calculation of emission in the IPPU sector is not based on a default carbon-stored approach, but usually plant-specific (EU ETS) data, except for Lubricant and Paraffin wax use source categories.

3.2.4 Country-specific issues: on the use of plant level EU-ETS data

It is important to note first that generally emission data are not taken directly from the ETS database and put into the CRF as they are without analysis. Instead, facility level activity data (fuel use) and carbon emission factors are used from the ETS database to calculate weighted averages of the emission factors for different fuel types. These derived country specific EFs are then applied with the fuel use from the national energy statistics. The time series of these country specific emission factors and their comparison with the default values are summarized in Table 3.2.4. Fuel uses in energy statistics and ETS are compared also to see whether the fuel use in a given category is fully covered by ETS plants or not. Fuel consumption data are compared both in natural units and in energy units to reveal any possible differences in net calorific values. Should such difference occur, emission factors need to be amended to achieve consistency in energy balance and verified emissions since national energy data serve always as activity data. It is also checked whether the oxidation factor used by the facilities is included in their EFs. Measured oxidation factors, especially in case of coal firing plants, are always taken into account.

Generally, country specific emission factors derived from the ETS data are used for lignite, blast furnace gas, mix of coal and petroleum coke used in cement industry, other oil.

Starting with the 2021 submission, new country-specific CO2 emission factors were introduced also for natural gas for the entire time series. In practice, the weighted averages of EFs of all ETS installations reporting EF with Tier 3 and Tier 2b were calculated for all years separately in the period

2008-2021. The yearly averages changed between 55.2 t/TJ (2008) and 56.3 t/TJ (2015). For all years before 2008, the average of 2008-12 is used (55.6 t/TJ)

Other country-specific issues are included under the source category descriptions and methodological chapter of each category.

3.2.5 Energy Industries (CRF sector 1A1)

Emitted gases: CO2, CH4, N2O
Methods: T1, T2, T3
Emission factors: D, CS, PS
Key sources:
1A1 Fuel combustion - Energy Industries - Liquid Fuels – CO2 – L, T
1A1 Fuel combustion - Energy Industries - Solid Fuels – CO2 – L, T
1A1 Fuel combustion - Energy Industries - Gaseous Fuels – CO2 – T
1A1 Fuel combustion - Energy Industries - Other Fossil Fuels – CO2 – L, T

3.2.5.1 Category description

This subsector includes facilities generating electricity, district heating stations, oil refineries and coking and briquetting plants. On an overall level, here are the largest energy consumers.

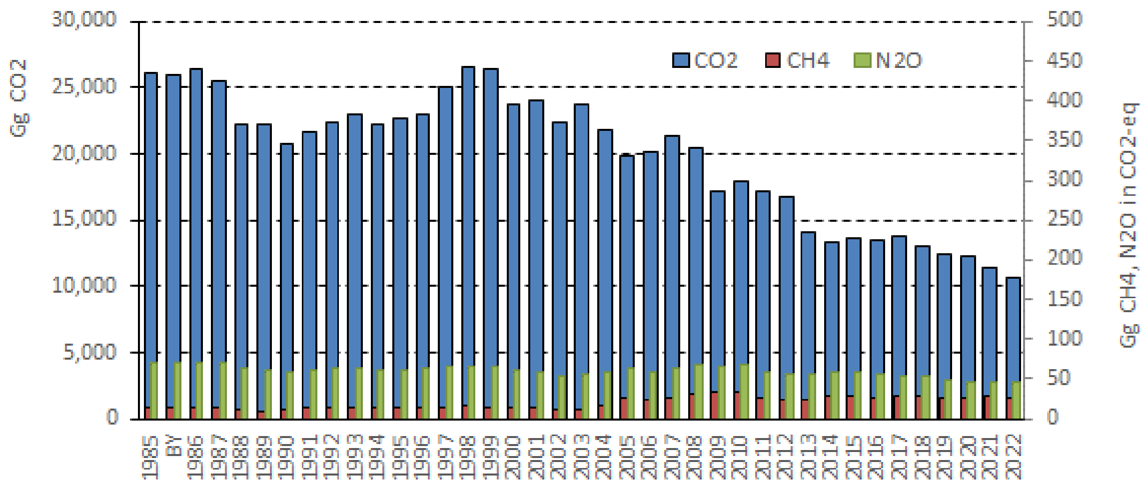


***Figure 3.2.5.1** Trends of CO2, CH4 and N2O emissions in the Energy Industries (1985-2022)*

Public Electricity and Heat Production was responsible for about 83-85% of fuel use in energy industries. Fuel consumption of oil refining showed a pronounced drop around 2000 but remained more or less at the same level afterwards. In the last six years, however, larger fuel consumption could be observed. Currently, the share of the refinery’s fuel consumption is about 14% within energy industries. Less significant is manufacture of solid fuels and other energy industries with a portion of 2-4%.

Domestic electricity production showed an overall increasing trend up till 2008; even during the years of the regime change around 1990, whereas import suffered a more severe drop from 28% to 6-7%. In addition to the effects of the financial crisis, an interesting incident occurred in 2009 when domestic production fell back by more than 10% whereas consumption decreased only by 6%. There was a multi-week break in the natural gas supply through Ukraine, thus the electricity generation of our natural gas firing power plants had to be substituted by import electricity and by increased production of the oil-fired power plants. After 2010, until 2014, domestic electricity production decreased every year, and it has dropped quite substantially in 2013 by 13%. Between 2014 and 2021 domestic production grew again altogether by 23%. Then in 2022 production decreased slightly by 1%. The share of import is a highly variable figure: in the previous decade, it changed between 8% (2001) and 18% (2004). After 2010, however, it grew constantly and has reached a share of 31% in 2014 and remained close to 30% afterwards and decreased to 25-27% in the period 2019-2022.

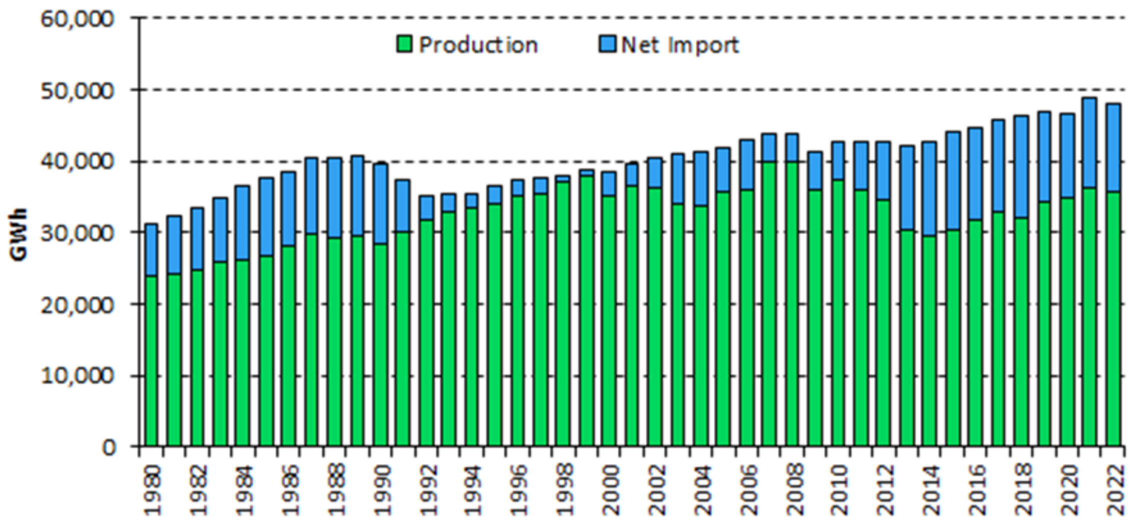


Figure 3.2.5.2a *Domestic Electricity Production and Net Import (1980-2021)*

Naturally, as domestic emissions are related to domestic production, the yearly fluctuation of production is one of the decisive factors. Not less important is the way how electricity is produced, e.g., what energy source is used. In Hungary, this sector consumes the deterministic part of our solid fossil fuel production, and around one third of the domestic primary energy consumption.

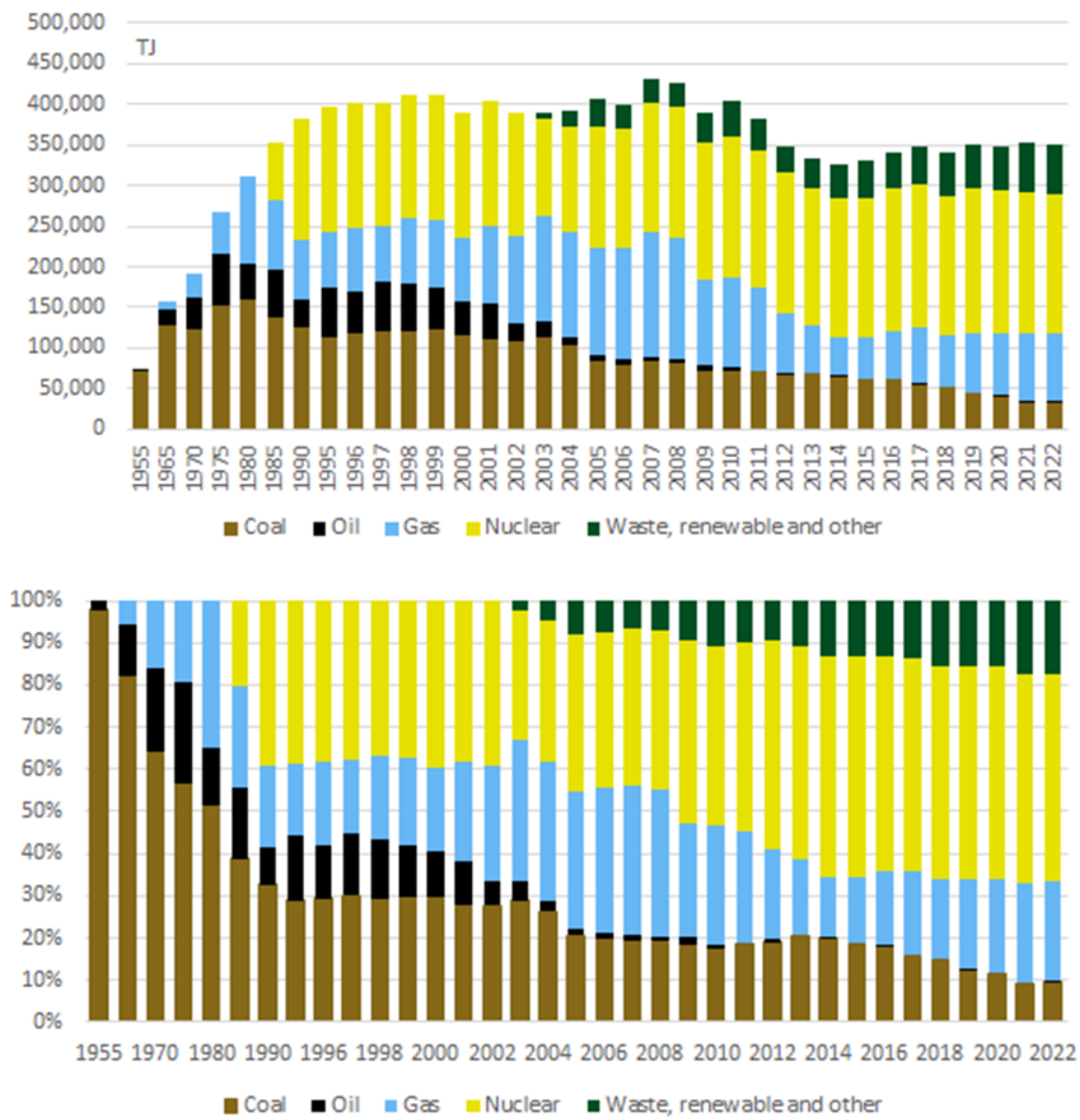


Figure 3.2.5.2b *Energy consumption of power plants (above) and the share of different energy sources in power production (1955-2022)*

Looking at the above figure, the most striking development is the diminishing share of coal combustion in power generation: in 1990 coal still had a share of 33% which then decreased to 21% in 2005, and eventually to 9% in 2021. During this process, new combined cycle gas-turbine units were installed (Újpest, Kelenföld, Százhalombatta, Gönyű, Ajka, Nyíregyháza Power Plants), and aged coal fired units (Inota, Bánhida, AES Borsodi) of low efficiencies were taken out of service or blocks have been converted to the combustion of biomass (Pécs, Kazincbarcika, Ajka Power Plants). An equally important recent development is that the use of all traditional fossil fuels has roughly halved compared to the mid-2000s. In contrast, increasing use of renewable sources could be observed by some public power plants.

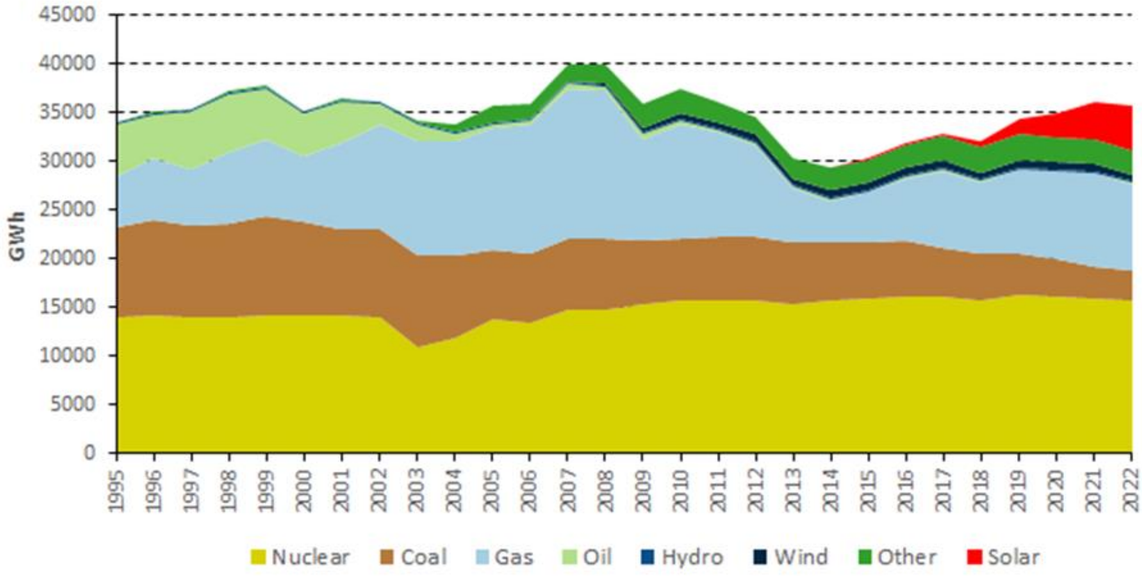


***Figure 3.2.5.3** Share of produced electricity by fuel (1995-2022)*

The installed capacity of the domestic electricity system, including small-scale household power plants, increased from 11,440.8 MW of the year 2021 to 12,475.3 MW by the end of 2022. The 9% capacity growth was mainly the result of the 666.8 MW generated by the connecting of new solar power plants above 50 kW, while the remaining 367.7 MW is added by the increasing capacity of small-scale household power plants. In total, solar power plants account for nearly one-third of the total installed capacity, which means a 6.4 percentage point growth compared to the previous year (MEKH-MAVIR).

It has to be noted also that the utilisation of domestic power plants is strongly influenced by the fuel costs and the regional wholesale electricity prices changing country by country. For example, the market share of gas-fired power plants depends on the level of basically oil price-indexed gas prices, the CO2 allowance price system, the increase of electricity generation from renewables, etc. Lower level of domestic generation needs to be compensated by import.

3.2.5.2 Methodological issues

Activity data

Energy consumption data were taken from the IEA annual questionnaires compiled by the Hungarian Energy and Public Utility Regulatory Authority. Besides, waste statistics and ETS data were taken into account.

As it can be seen in Figure 3.2.5.4, total fuel consumption (without nuclear energy) in the energy industries sector shows strong fluctuations. After a significant decrease around the political and economic regime change in 1990, fuel consumption increased quite significantly by 26% until 1998, then decreased by 15% between 1998 and 2005. We experienced a more pronounced drop after 2008 due to the global financial crisis. After 2010, until 2014, fuel consumption has reached record low values every year; combustible fuel use fell altogether by 37% between 2008 and 2015. In 2015, however, the decreasing trend stopped, and we observed a small increase in energy use. Fuel consumption seemed to have stabilized around 195 PJ in recent years. Then in 2022, fuel consumption decreased by 7%. Within the inventory period, the consumption of liquid and solid fuels has decreased significantly. In contrast, the consumption of natural gas has increased until 2007 to a great extent then it shrunk substantially afterwards. Biomass use due to burning co-burning in power plants has become more and more important and exceeded in amount the liquid fuel use in 2005.

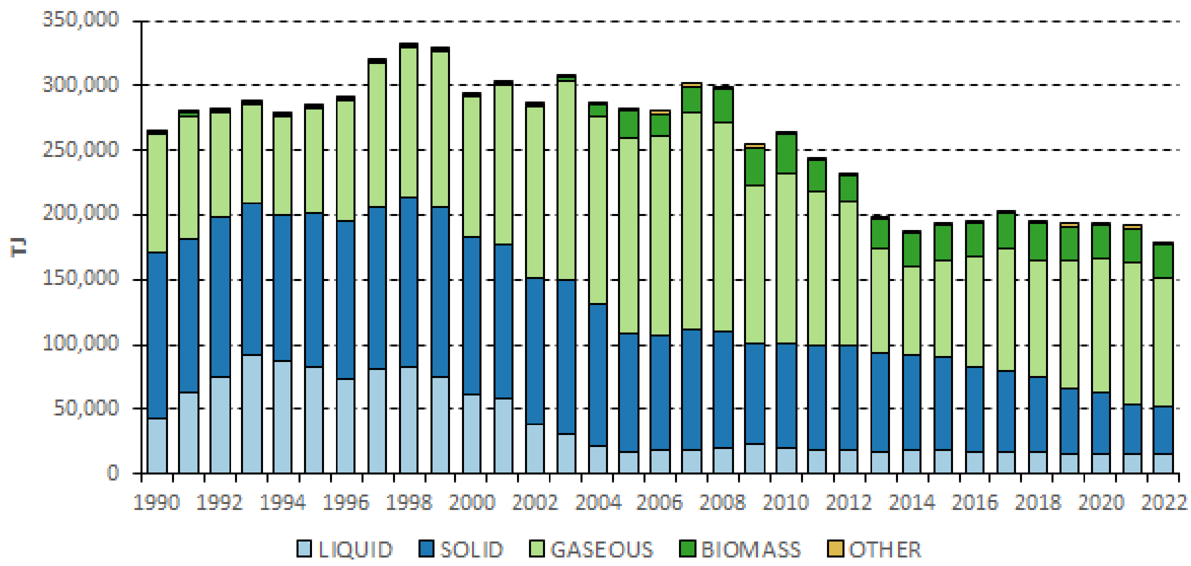


Figure 3.2.5.4 *Fuel combustion in the Energy Industries Sector (1990-2022)*

Going into more detail regarding fuel use, it can be seen that domestically produced lignite is the dominant fuel among solid fuels (Fig. 3.2.5.5). In energy industries, solid and gaseous fuels are dominant representing together around 76% of all fuel use. In contrast, liquid fuel use became almost negligible in electricity and heat generation. At the same time, refinery gas used in oil refinery became the most important liquid fuel type whereas the formerly dominant fuel oil almost disappeared (Fig. 3.2.5.6).

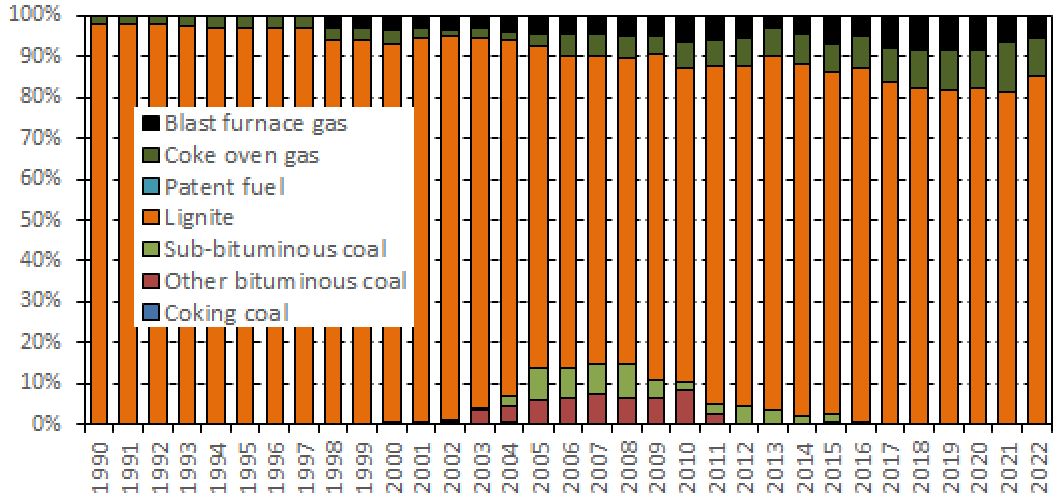


Figure 3.2.5.5 *Share of different solid fuels used by energy industries (1990-2022)*

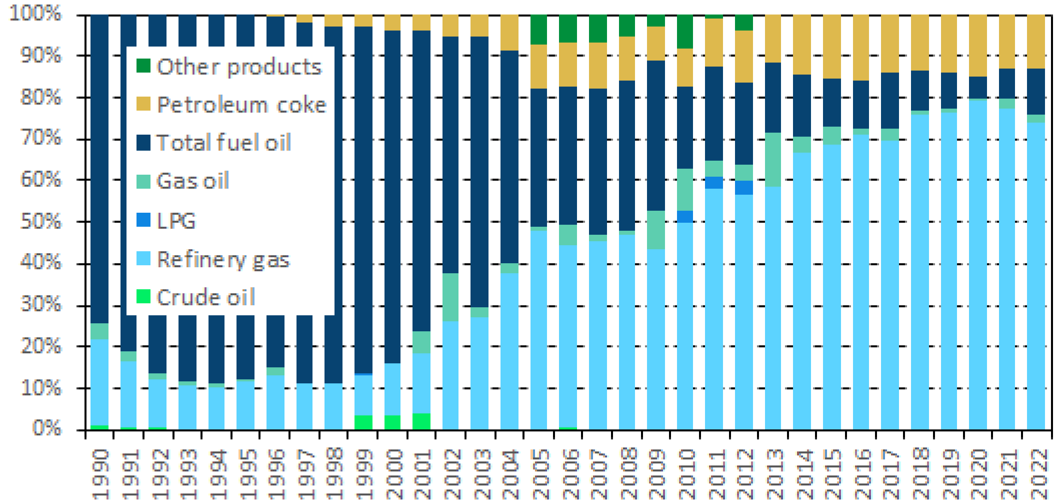


Figure 3.2.5.6 *Share of different liquid fuels used by energy industries (1990-2022)*

Traditionally, refinery gas and heavy fuel oil were reported together in the Hungarian Energy Statistical Yearbooks. Expressed in mass units, three-four times more refinery gas is used in the refinery as fuel oil.

However, as the ETS data show, refinery gases have significantly different characteristics. Based on plant specific information from the period 2008-2022, "real" heavy fuel oil burned by the refinery has a net calorific value between 39.7 TJ/kt to 40.9 TJ/kt and a CO2 emission factor between 79.3 t/TJ and 83.7 t/TJ. Refinery gases show in contrast more diverging values. (Even more so, if we include tail gases and purge gas, too.) We can see here calorific values between 34.1 TJ/kt and 66.1 TJ/kt with corresponding CO2 emission factors between 32.2 t/TJ and 60.6 t/TJ. On yearly average, it can be calculated with a NCV of 48.7-52.4 kt/TJ and an EF of 49.8-55.0 t/TJ for refinery gases.

There are some differences between the classification of fuels in the plant and in the energy statistics. However, considering these fuels together, we could see a better agreement. Moreover, the calculated average CO_2 IEF based on the IEA energy statistics for the pre-ETS period (2000-2007) and the ETS period (2008-2013) is the same (i.e., 62.2 t CO_2/TJ). For the 90's, where the share of refinery gas was definitely lower with 40% on average. On the other hand, the use of end-gases and purge gas (as reported under the EU ETS) became more important after 2013. All the factors applied in the calculations are summarized in the following table. Please note that the factors in the table below can be regarded as implied factors for the ETS period as ETS data are directly used in the inventory.

Table 3.2.5 *Country specific parameters used in the category petroleum refining*

Period	Fuel	(Avg.) NCV [TJ/kt]	EF [t CO2/TJ]	Comment
2008-2022	refinery gas	32.2-66.1	32.2-60.6	ETS data
2008-2022	other liquid fuel	39.7-40.9	79.3-83.7	ETS data
1985-2007	gasoil	43.0	74.1	IPCC default
1985-2007	refinery gas	49.5	57.6	IPCC default
1985-2007	fuel oil	40.2	77.4	CS / IPCC default
1985-2021	petroleum coke	32.5	106.0	EF based on ETS

Emission factors

Carbon dioxide emissions were calculated in accordance with the 2006 IPCC Guidelines. Country specific OF and EF values – taken mostly from the ETS database – were used for most solid fuels and some liquids. The used factors are summarized in Table 3.2.6.

Table 3.2.6 *CO2 emission factors used in energy industries in the 2022 inventory year*

Fuel type	Emission factor (CO2 t/TJ)	Oxidation factor
Coking coal	94.6	1.0
Other Bituminous Coal	94.6	1.0
Lignite (imported brown coal)	**98.4**	**0.982**
Lignite (domestic brown coal)	**100.3**	**0.951**
Lignite (domestic lignite)	**111.5-112.7**	**0.943-0.951**
Coke Oven Gas	44.4	1.0
Blast Furnace Gas	**252.7**	1.0
Gas/Diesel Oil	74.1	1.0
Residual Fuel Oil	77.4	1.0
RFO in refinery	**82.05**	1.0
Refinery gases (IEF)	**55.4**	1.0
Petroleum Coke	97.5	1.0
Natural Gas (in PPs)	**56.3**	1.0
NG in coking plant	-	1.0
NG in the refinery	**55.9**	1.0
Biomass (Solid)	112.0	1.0
Biogases	56.6	1.0
Waste (IEF)	101.4	1.0

(Source: 2006 IPCC Guidelines; in bold – EU ETS database of Hungary

**For waste, only IEF is reported in summary the table, because the emission was calculated from country-specific waste amount and component data taken from Waste Information System database and the emission factors were calculated using the default or measured (from EU ETS) carbon content and fossil carbon fraction data from Table 2.4 – 2.6 in the 2006 Guidelines.*

It should be noted that only those measured factors were applied where the EU ETS covers all or most of the installation of the sector. For methane and nitrous oxide, default emission factors were used generally.

As recommended by the ERT and required by the guidelines, the emissions from waste incineration for energy purposes have been allocated to the energy sector. However, emissions estimation in the energy sector is somewhat different from the methodology used in the waste incineration category. Activity data in this source category are expressed in energy consumption units (TJ) whereas in the waste sector mass and composition of waste serves as basis of calculations. For our calculations four main activity data sources were used: data from the Waste Incineration Works (FKF) of Budapest (1985-2022), the Hungarian Waste Management Information System (2004-2022), the IEA Annual Renewable Questionnaire, and the ETS data (2006-2022). The Hungarian Waste Management Information System comprises facility level data on mass and composition of waste in line with the European Waste Catalogue (EWC codes) but also on waste management methods in accordance with the Waste Framework Directive. The latter made it possible to distinguish between waste incineration on land (D10) and use of waste principally as a fuel or other means to generate energy (R1).

Incinerated waste data expressed in energy unit were either directly taken out from the IEA statistics or from the ETS database. (The latter made it possible to distinguish between fossil and biogenic waste in case of mixed waste incineration.) It should be stressed, however, that the reported TJ values are (mostly) not used for CO_2 emission estimations, especially in the case of the biggest municipal waste incineration plant in Budapest, therefore the resulting IEF values may have little significance.

As only CO_2 emissions resulting from incineration of carbon in waste of fossil origin should be included in the national CO_2 emission estimate, the fossil fraction of waste had to be determined. To do so, country-specific waste amount and composition data were needed, and the emission factors could be calculated using the default carbon content and fossil carbon fraction data from Table 2.4-2.6 in the 2006 Guidelines. In case of the two biggest incinerators, plant specific data were used. BKM Nonprofit, where also Waste Incineration Works of Budapest belongs, determines regularly the composition of municipal solid waste (MSW), therefore the fossil carbon fraction could easily be calculated with the help of Table 2.4 of the 2006 Guidelines. The fossil carbon fraction of MSW grew from 5% in 1990 to 17-18% around 2010 and decreased to 10-13% in 2014 and afterwards. (In 2022, it was 11.9%.) CO_2 emissions were estimated then with an oxidation factor of 1.0.

The biggest co-incinerator plant is Mátra Power Plant. Since this plant reports its verified emissions in the framework of the European emission trading, direct ETS data relating its fuel use and CO_2 emissions were taken over. (Also verified emissions of all other smaller plants reporting waste combustion under the ETS were taken into account).

All in all, waste incineration contributed around 218 Gg CO_2 to GHG emissions in this category in 2021.

CH_4 emissions from waste incineration have also been added to the inventory. Using the default emission factors (30 kg/TJ) from Table 2.2 of the 2006 Guidelines (Chapter 2: Stationary Combustion), the resulting emissions are not significant at all. The same can be stated about N_2O emissions that were estimated the same way with the default emission factor of 4 kg/TJ.

3.2.5.3 Uncertainties and time-series consistency

Practically, the accuracy and uncertainty range of the energy statistics data are determined by the accuracy of the measuring equipment (except for stock changes, which are based on expert estimates and are not comparable with the quantity of fuels from other sources). Taking all this into account, the estimated uncertainty of the energy consumption data is ±1% (for biomass 5%). This is particularly likely because the quantities of fuels used by power stations were verified using the report of MVM Rt. (Hungarian Power Companies Plc.)

The estimated specific uncertainty for CO_2 is 2-5%. The uncertainty of the methane factor is significantly higher (50-150%), while that of N2O may be of an order of magnitude.

The time series can be regarded as consistent.

3.2.5.4 Category-specific QA/QC and verification

Energy consumption data were subject of several rounds of verification before use.

National energy statistics as published in the yearbooks were compared with the statistics provided to international organizations (both prepared by the same institute). This verification pointed out some problems also previously (e.g., on coke oven/blast furnace gas use, missing refinery gas and petroleum coke consumption) which were corrected. This work has been extended, and a comprehensive consistency check between data in the IEA time series and the Hungarian Energy Statistical Yearbooks has been conducted. Based on the results of this consistency check, and after several consultations with the energy statistics provider, it was decided to build the calculations on the IEA/Eurostat questionnaires.

Verified energy use from EU ETS was compared to statistical data. It was noticed that data in metric tonnes are similar in the ETS to those in the statistics, but there are some differences in energy values due to different NCVs. Since the energy consumption in sectoral approach should be compared with those of reference approach, we kept the NCVs of the energy statistics, however the emission factors of coals were corrected for some years to achieve consistency in energy balance and verified emissions. Measured oxidation factor was also applied in the calculation for the above-mentioned reason. (As the fuel amounts in the ETS database and in the energy statistics shows good agreement, this means in practice that CO2 emissions from solid fuel use reported under the ETS can be used directly.)

Emissions from natural gas were generally estimated using default calorific values and emission factors. For a justification of this approach, about 40 emission reports from the ETS had been analyzed. Using the same activity data as reported by these facilities, we have calculated CO2 emissions with default parameters and compared our results with the reported CO2 emissions from the ETS database. It turned out that the difference was minor: with default parameters, the emissions were overestimated only by 0.4%. This small difference allowed us to change our previous approach. To be more consistent with the emissions reported under the ETS regime, we have switched to country specific emission factors for 2010-2013. (For all other years, for the time being, default EFs are applied.)

A comparison between the ETS data (based on mass balance methodology) and calculations based on fuel use was also made for the coking plant. This comparison led to changes in methodology for this submission as described in recalculation part below.

As the main fuel consumption is related to public electricity and heat production, a comparison was also performed with independent dataset collected by the Hungarian Energy Office. For the main power plants the total fuel consumption's difference between the ETS and this dataset was around 1% in 2009.

As a new practice, the compiler institute receives the draft version of the energy balance (the IEA annual questionnaires) before its official submission to Eurostat. The data are checked and the comments are discussed with the energy statistics provider and many of them are taken into account in the final energy statistics.

3.2.5.5 Category-specific recalculations

Activity data (other oil) has been revised 1A1ai for the period 2005-2012 in line with IEA statistics.

3.2.5.6 Category-specific planned improvements

None.

3.2.6 Manufacturing Industries and Construction (CRF sector 1A2)

3.2.6.1 Source category description

Emitted gases: CO_2, CH_4, N_2O
Methods: T1, T2, T3
Emission factors: D, CS, PS
Key sources:
1A2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels - CO_2 – L, T
1A2 Fuel combustion - Manufacturing Industries and Construction - Solid Fuels - CO_2 – T
1A2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels - CO_2 – L, T
1A2 Fuel combustion - Manufacturing Industries and Construction – Other Fossil Fuels - CO_2 – L, T

This subsector covers emissions from the combustion of fuels in the industrial sector. One of the advantages of using the IEA/Eurostat questionnaires instead of the (previously used) energy statistical yearbooks is that the industrial sectors in the questionnaires and in the CRF tables can be more easily harmonized. Emissions from autoproducers have been re-allocated to the relevant end-use category to the extent possible, the remaining part that could not have been allocated elsewhere, was included in the category *1A2gviii Other* for years before 1998. Emissions from off-road vehicles and other machinery are reported as a separate category (1.A.2.g.vii).

Emissions in the Manufacturing Industries and Construction Sector:

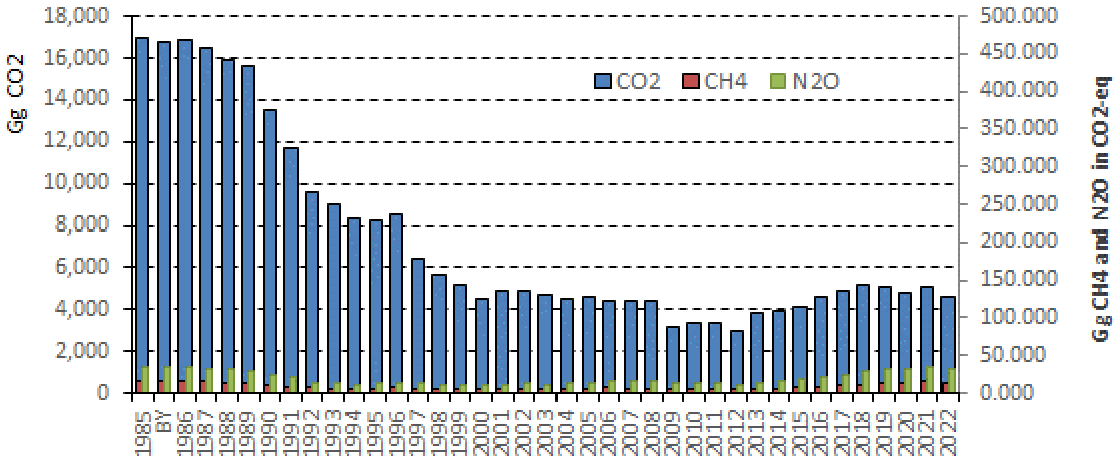


Figure 3.2.6.1 *Trends of CO_2, CH_4 and N_2O emissions in the Manufacturing Industries and Construction Sector (1985-2022)*

3.2.6.2 Methodological issues

The energy consumption data have been taken from the IEA/Eurostat questionnaires. All feedstock and non-energy use were removed from the chemicals subsector for the entire time-series, and all relating CO_2 emission originating from non-combustion processes can be found in the Industrial Processes Sector.

Part of the emissions from waste incineration for energy purposes was allocated to this source category. Activity data in energy units were taken directly from the IEA Renewable questionnaire/ETS database with preference to ETS data in case of differences. Special attention was given to the four (currently three) big cement factories, as they incinerate large amount of waste of fossil origin (plastics, rubber etc.). Their verified ETS data (emissions and fuel use) were analyzed, from which a specific emission factor was derived: 85.5 tonne CO_2/TJ waste. This EF was used for the years 2004-2007 in case of fossil wastes. From 2008 on, ETS data (emission) of the cement factories were used directly. The ETS data made it also possible report the fossil part of mixed industrial (or municipal) waste separately. It could be seen that other industrial facilities incinerate predominantly waste of biogenic origin, mostly wood waste, therefore their CO_2 emissions did not contribute to the national total. The insignificant CH_4 and N_2O emissions were estimated for all waste (not only fossil but also biogenic) using the default emission factors of 30 kg/TJ and 4 kg/TJ, respectively.

The methodology for off-road vehicles and other machinery used in industry and construction was changed recently. Tier 2 method from the 2023 EMEP/EEA Guidebook was implemented. This method classifies the used equipment into the fuel types and layers of engine technology. The engine technology layers are stratified according to the EU emission legislation stages, and three additional layers are added to cover the emissions from engines prior to the first EU legislation stages. The used layers are as follows: <1981; 1981-1990; 1991-Stage I; Stage I; Stage II; Stage IIIA; Stage IIIB; Stage IV; Stage V. The penetration of the new technology is taken into account in the form of split (%) of total fuel consumption per engine age (irrespective of inventory year) as it can be seen for diesel-fueled non-road machinery in Table 3-3 in the Guidebook.

Activity data

Figure 3.2.6.2 illustrates the energy consumption of the sector. After 1990, following the economic changes, fuel use decreased significantly. The underlying reasons are clearly illustrated by the decreasing production data presented in the IPPU sector (Chapter 4).

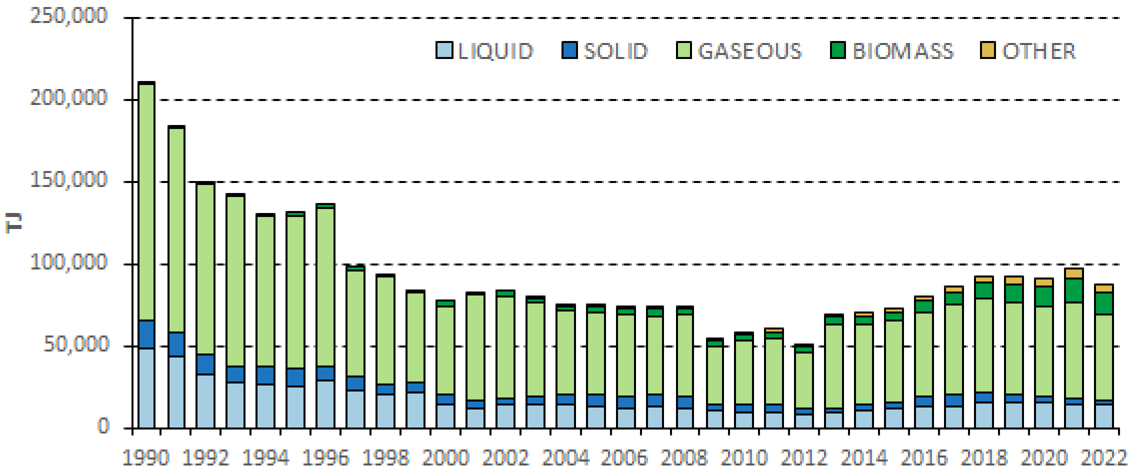


Figure 3.2.6.2 *Fuel combustion in the Manufacturing Industries and Construction Sector (1990-2022)*

In 2009 the global economic crisis caused a drop of fuel consumption by more than 25% which led to lower emissions. After a few years of relatively low energy demand, fuel consumption started increasing after 2013: fuel consumption has increased altogether by 61% since 2009.

Fig. 3.2.6.2 clearly demonstrates the dominance of natural gas (59% in 2022). Biomass use became popular especially in the last decade. (As a consequence, the relative share of methane and nitrous oxide emissions increased.) Combustion of oil products continues to lose its importance among fossil fuels in stationary combustion. Liquid fuels represented 16% in 2022 out of which gas oil seems to be the most important used mostly in mobile machinery.

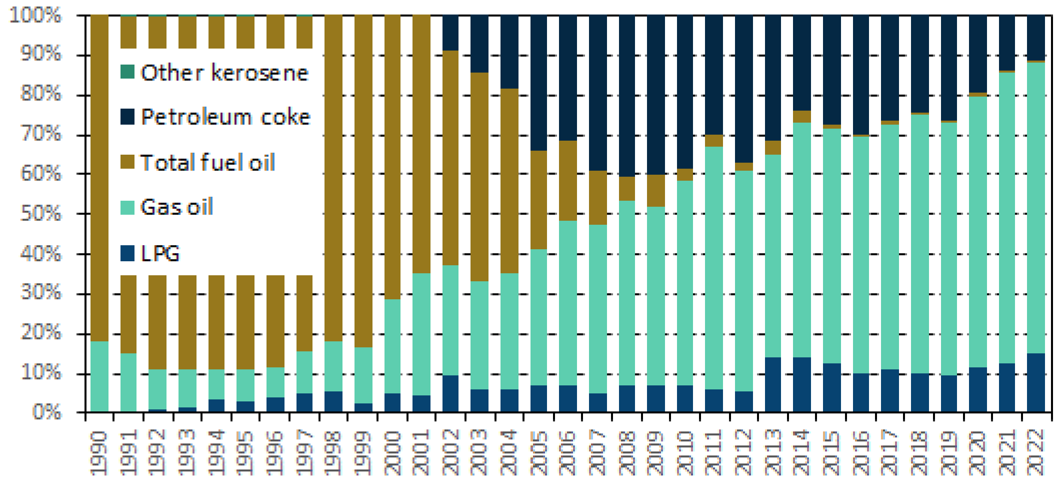


Figure 3.2.6.3 *Share of different liquid fuels used by manufacturing industries (1990-2022)*

The share of solid fuels became quite low (4% in 2022). Also, the fuel mix has been changing as demonstrated by Fig. 3.2.6.4. The growing relative share of coke oven gas define the CO_2 IEF in the iron and steel category since coke oven gas has a very low (44.4 t/TJ) CO_2 emission factor. It is worth noting the relatively high IEF in food processing, beverages and tobacco which is due to the fact that dominantly (recently almost exclusively) coke was used as solid fuel by this industry. In 2016, a new co-generation power plant that uses solid fuels, including the paper mill's own residual waste from paper production, but also biomass and coal, started its operation, this is why the consumption of other bituminous coal increased as seen in the figure below.

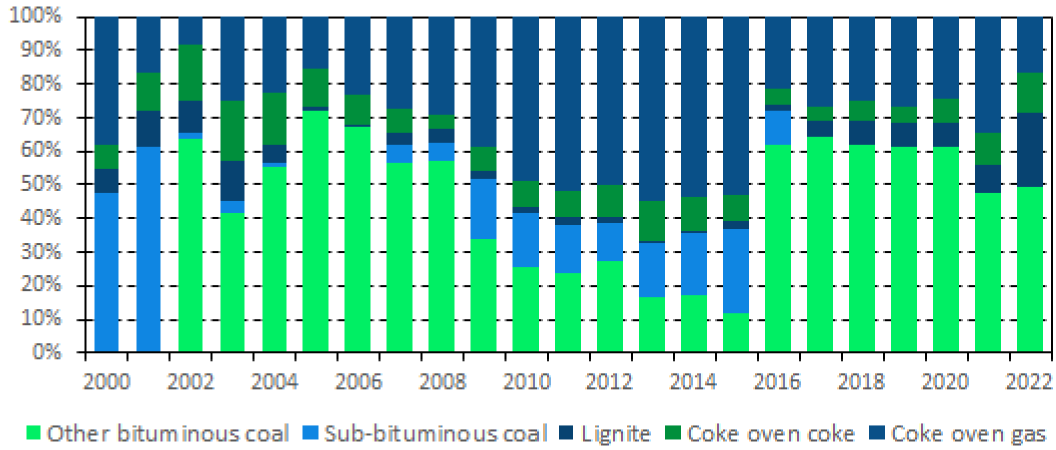


Figure 3.2.6.4 *Share of different solid fuels used by manufacturing industries (2000-2022)*

Biomass cannot be considered as the most important fuel but its contribution grew slowly to 15 per cent. Within this, the use of biogases (especially in autoproducer plants) might deserve our attention as the default emission factors are quite different for solid biomass and biogas.

<u>**Emission factors**</u>

With the introduction of county-specific CO_2 EF for natural gas, the share of emissions calculated with default CO_2 factors were significantly reduced. Special country specific emission factors are applied in the *non-metallic minerals* category (based on ETS information). The situation is somewhat complicated here as the cement factories often use mixed fuels. The country specific CO_2 emission factors for petroleum coke/coal mix are varying between 92.3 t/TJ and 95.0 t/TJ for the period 2008-2022.

3.2.6.3 Uncertainties and time-series consistency

Practically, the accuracy and uncertainty range of the energy statistics data are determined by the accuracy of the measuring equipment (except for stock changes, which are based on expert estimates and are not comparable with the quantity of fuels from other sources). Taking all this into account, the estimated uncertainty of the energy consumption data is 5% in consideration of the fact that uses are less easy traceable due to the high number of users.

The estimated specific uncertainty for CO_2 is 2-5%. The uncertainty of the methane factor is significantly higher (50-150%), while that of N_2O may be of an order of magnitude.

3.2.6.4 Source-specific QA/QC and verification

Energy consumption data were subject of several rounds of verification before use.

Verified energy use from EU ETS was compared to the statistical data. It was noticed that data in metric tonnes are similar in the ETS to those in the statistics, but there are some differences in energy values due to different NCVs.

Non-energy use of fuels was cross-checked with the Industrial Processes sector.

3.2.6.5 Source-specific recalculations

Revised energy statistics was used (as submitted to the IEA/Eurostat end of October 2023 and updated in March 2024. A different approach on autoproducer re-allocations led also to changes, especially in the early period of the time series. In addition, NCV of (mostly) imported lignite was amended on the basis of earlier energy statistical publications (1985-1998). In mineral industries, emissions from coal and petroleum coke was amended on the basis of ETS data (2020-2021).

3.2.6.6 Source-specific planned improvements

It was noted that some ETS facilities report fuel amount in dry mass. It will need to be investigated whether energy statistical data combined with emission factors derived from the ETS database does not lead to any overestimation of emissions.

3.2.7 Transport (CRF sector 1A3)

3.2.7.1 Source category description

Emitted gases: CO_2, CH_4, N_2O
Methods: T1, T2, T3
Emission factors: D, CS, M
Key sources:
1A3b Road Transportation – CO_2 - L, T;
1A3c Railways – CO_2 – T
1A3d Navigation – CO_2 - T

This sector covers all the emissions from fuels used for transportation purposes. International aviation and navigation are excluded from the national total.

Looking at the whole period of our time series, a sharp decrease of 60% in transport of goods could be observed during the regime change in the early 90's. The Hungarian transport performance expressed in freight ton-kilometers had not reached the level of 1985 until 2005. Beside these significant changes of volume, also the structure of goods transport altered. Currently, the most important means of freight transport is road transportation with a share of 68%, followed by rail (21%), pipeline (9%) and waterway (3%). In 1990 we saw a completely different picture with railway and waterway being the dominant mode of transport representing 40% and 34%, respectively.

In 2020, there was a drop in transport (-10% in freight tonne-kilometres) especially due to a 13% decrease in road transportation, then it increased again in 2021. Goods transport did not change significantly in 2022.

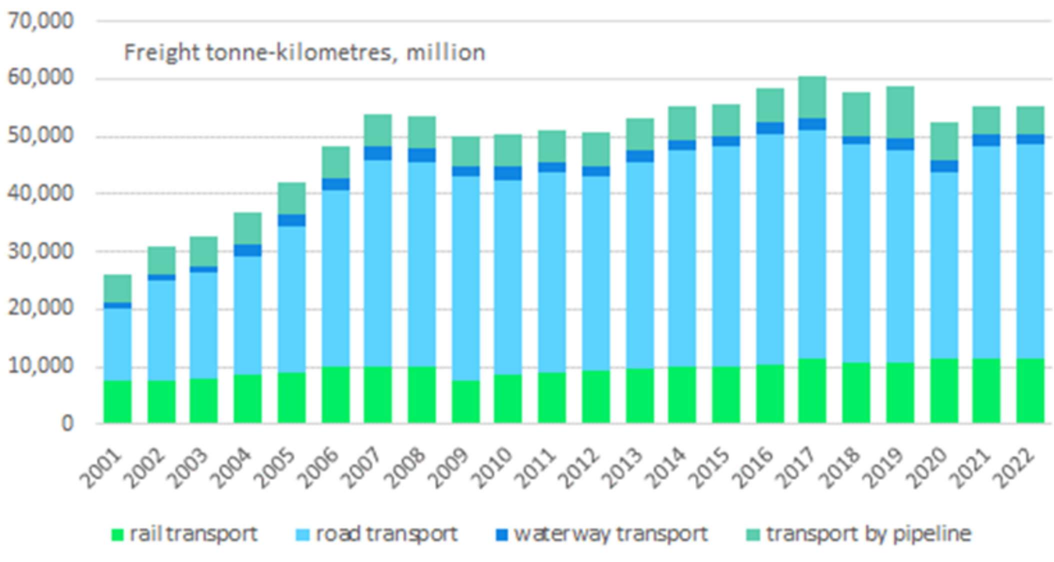


Figure 3.2.7.1 *Trends in goods transport (2001-2021). Source: HCSO*

Passenger transport also underwent considerable changes. The stock of passenger cars had more than doubled since 1990. Within this increase, the proportion of Eastern European cars characterized by high fuel consumption and obsolete technology decreased; for example, currently 63% of passenger cars complies with at least the Euro 4 emission standards. At the same time, the average age of the car fleet has increased again in recent years to over 15 years in 2022. (The lowest average age of vehicles

(10.3 years) was observed in 2006, before the economic crisis.) Figure 3.2.7.2 summarizes the above-mentioned developments.

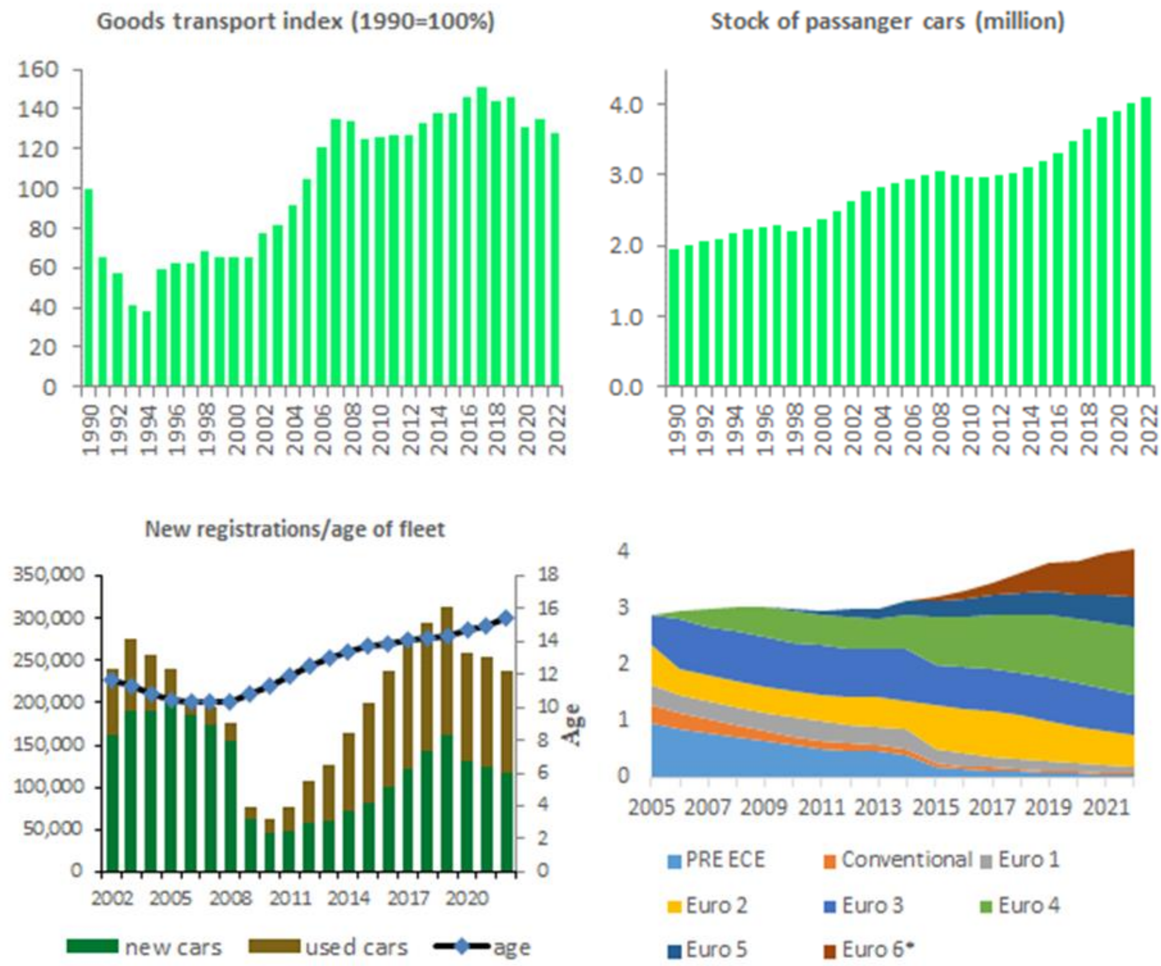


Figure 3.2.7.2 *General changes in the transport sector*

Electrification of the railways in Hungary eliminated mostly the solid fuel consumption. (Today there are only few lines where steam engines are used during non-scheduled vintage train trips.) Diesel oil consumption of railways decreased as well, by 80% between 1990 and 2022.

Emissions were calculated generally from the national fuel consumption data from the IEA/Eurostat annual questionnaires. The national energy statistics usually does not include the quantities of aviation gasoline used for in-country (or international) aviation, and of the diesel oil used for international (river) navigation. However, aviation gasoline consumption appeared in the latest energy statistics for the years 2016-2022. Fuel consumption data (i.e. both aviation gasoline and jet kerosene) of domestic aviation are also taken from the Eurocontrol database containing data on IFR flights. We can also assume (based on personal communication with the energy statistics provider) that 0.9-1.0 kt aviation gasoline is consumed for domestic flights. It is still possible that some minor amount of aviation fuel (for VFR flights) is included elsewhere in the inventories (e.g., under road transport).

According to the information received from the energy statistics provider, natural gas use related to natural gas transport was previously included under distribution losses in the energy statistics. In the inventory, however, a complete time series of emissions from pipeline transport is included separately. Figures below illustrate the fuel consumption of the sector:

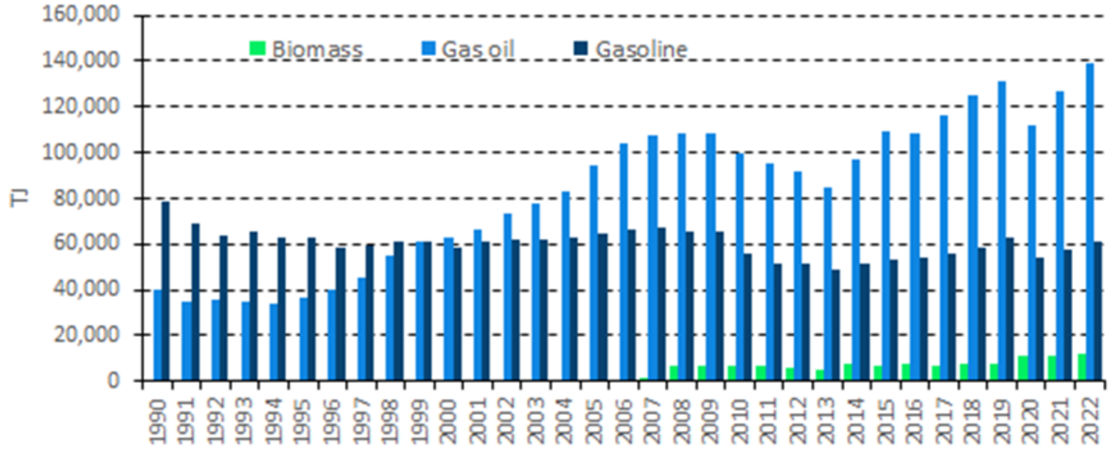


Figure 3.2.7.3 *Gasoline, diesel and biomass consumption in the Transport Sector (1990-2022)*

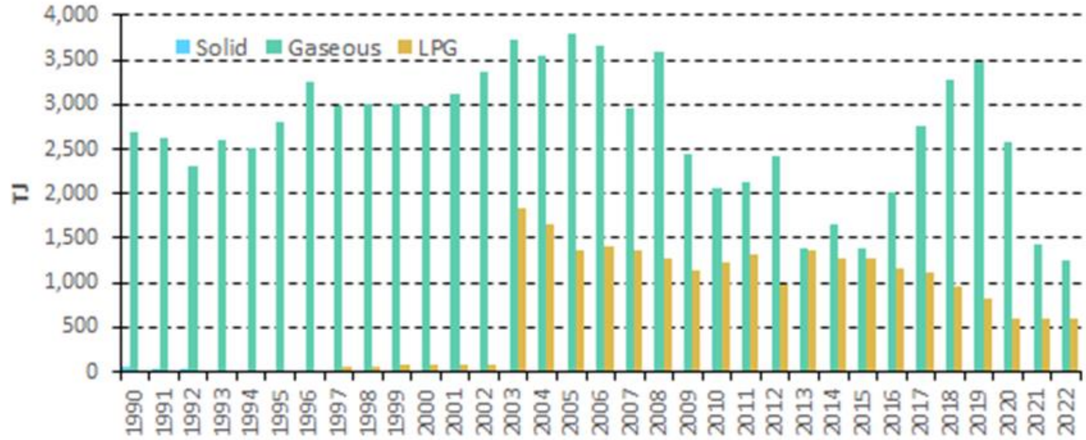


Figure 3.2.7.4 *LPG, natural gas and solid fuel combustion in the Transport Sector (1990-2022)*

Figure 3.2.7.5 clearly shows that in contrast to the other described sectors, transport consumption had a rising overall tendency from the mid 90's until 2008. Starting in 2009, the trend of fuel consumption has changed due to the economic crisis. Both fuel consumption and mileage of vehicles (km/year) increased until 2009 and started decreasing afterwards. The increasing fuel prices (up to 2012) could also be one of the reasons of a record low gasoline consumption in the transport sector. It is worth mentioning that the mass of domestically transported goods via road transport decreased by 44% between 2008 and 2012. However, the decreasing trend stopped, fuel consumption started to grow again and goods transport increased by 28% since 2012. Then, in 2020, there was a drop of 8% in national transport of goods, and at the same time fuel consumption decreased quite significantly by 12%. However, the drop in 2020 proved to be temporary, fuel consumption increased again in reached its (so-far) highest value in 2022.

In the second half of 2005 the Hungarian oil and gas company's refinery, MOL Danube Refinery, started to process bioethanol from vegetable raw material with high sugar content, also biodiesel have been used for blending. These bio components appear also in Fig. 3.2.7.3.

LPG has been used since 1992. It should be noted that due to the current commercial practices, in-container (household, institutional) uses are difficult to separate from traffic uses (i.e., distribution at petrol stations). This may be the reason for the sharp increase in 2003, which does not fully reflect the actual changes but is the result of a change in the approaches used for the preparation of the statistics. Accordingly, liquid fuel uses by the general public (currently including LPG only) show a significant drop – in line with the national energy statistics.

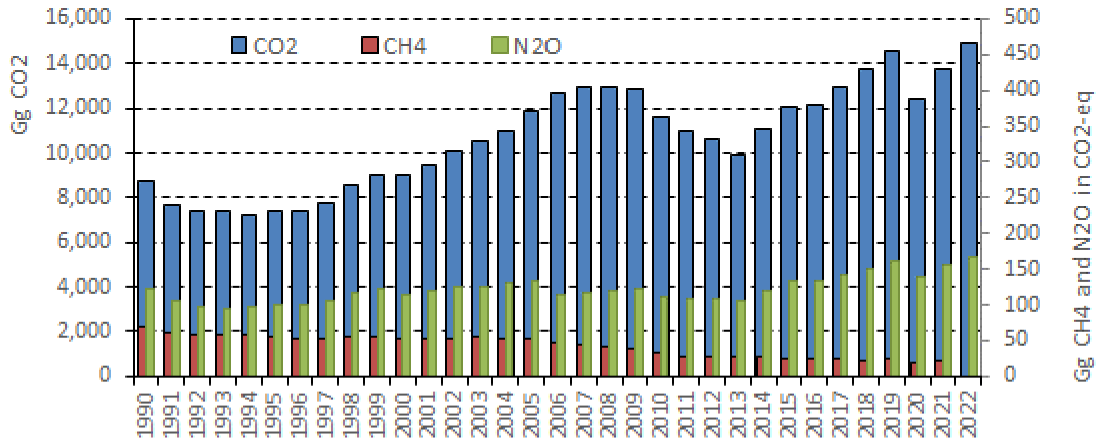


***Figure 3.2.7.5** Trends of CO_2, CH_4 and N_2O emissions in the Transport Sector (1990-2022)*

3.2.7.2 Methodological issues

CO_2 emission from transport was previously calculated by multiplying fuel consumption taken from Energy Statistics Yearbooks (1985-2010) by the default IPCC emission factors. In 2013, as the compiler institute received data on carbon content of gasoline and diesel oil from the refinery, the default emission factors were replaced to country specific values in road transportation (see Table 3.2.9). From the 2014 submission, activity data are basically taken from the IEA/Eurostat joint questionnaires with a few modifications.

For non-CO_2 emissions, the COPERT-5 (**Co**mputer **P**rogramme to Calculate **E**mission from **R**oad **T**ransport) model, specifically version 5.7.2 was used for the whole time series. The transition to the COPERT program family was a necessary step in the area of national road transport emission calculations, since most countries use this program which ensures international comparability. By using the latest version of the model, also consistency of the time series is ensured.

The COPERT model requires quite detailed background information. To produce input data for the model for the whole time series, basically three data sources were used:

1./ The compiler institute received the COPERT input/output data from the Institute for Transport Sciences for the years 2006, 2007, 2009, 2011, and the period 2012-2022. The structure of the input data was produced in a way which fully complies with that described in the software requirement.

Generally, the input data required by the COPERT model are as follows:

- vehicle fleet [n]

- mean activity [km/year], lifetime cumulative activity [km]
- traffic situations: vehicle share [%], average speed [km/h], trip characteristic
- national annual energy consumption [tons/year]
- country-specific environmental information:
    - national monthly averages of daily minimum and maximum temperatures [°C]
    - monthly average relative humidity [%]
    - Reid vapor pressure [kPa]
    - determination of country-specific sulfur content of petrol and diesel fuels [ppm wt]
    - determination of bioethanol ETBE (Ethyl tert-butyl ether) content (biodiesel FAME (Fatty acid methyl ester) content is provided in the model because it is known from EU data)

As the input data were not obtained from the same source and were not always suitable for direct use, therefore the data were needed to be processed prior. The largest bulk of the work was processing the vehicle stock data, since this data ensures the basis for emission calculations performed by COPERT5. Therefore, it was crucial to perform an utmost precise work regarding the vehicle stock data, which was obtained from the Ministry of the Interior (BM). At the request of the KTI, vehicle data tables required to perform the task were extracted from the BM database. The vehicle stock classifications and emission categorizations were prepared using the following table:

Table 3.2.7.1 *Vehicle categories used in the COPERT model*

Category	**Fuel**	**Engine capacity [cm^3] / Gross weight [t]**
Passenger Cars	Gasoline	2-stroke (≤1000 cm^3)
		≤800 cm^3
		801 – 1400 cm^3
		1401 – 2000 cm^3
		≥2001 cm^3
	Petrol Hybrid	≤800 cm^3
		801 – 1400 cm^3
		1401 – 2000 cm^3
		≥2001 cm^3
	Petrol PHEV	801 – 1400 cm^3
		1401 – 2000 cm^3
		≥2001 cm^3
	Diesel	≤800 cm^3
		801 – 1400 cm^3
		1401 – 2000 cm^3
		≥2001 cm^3
	Diesel PHEV	≥2001 cm^3
	LPG Bifuel	≤800 cm^3
		801 – 1400 cm^3
		1401 – 2000 cm^3
		≥2001 cm^3
	CNG Bifuel	≤800 cm^3
		801 – 1400 cm^3
		1401 – 2000 cm^3
		≥2001 cm^3
Light Commercial Vehicles	Gasoline	N1-I ≤1305 t
		N1-II 1306 – 1760 t
		N1-III 1761 – 3500 t

Category	Fuel	Engine capacity [cm³] / Gross weight [t]
	Diesel	N1-I ≤1305 t
		N1-II 1306 – 1760 t
		N1-III 1761 – 3500 t
Heavy Duty Trucks	Gasoline	> 3,5 t
	Diesel	Rigid <=7,5 t
		Rigid 7,5 - 12 t
		Rigid 12 - 14 t
		Rigid 14 - 20 t
		Rigid 20 - 26 t
		Rigid 26 - 28 t
		Rigid 28 - 32 t
		Rigid >32 t
		Articulated 14 - 20 t
		Articulated 20 - 28 t
		Articulated 28 - 34 t
		Articulated 34 - 40 t
		Articulated 40 - 50 t
		Articulated 50 - 60 t
Buses	Diesel	Urban Midi <= 15 t
		Urban Standard 15 - 18 t
		Urban Articulated> 18 t
		Coaches Standard <= 18 t
		Coaches Articulated > 18 t
	Diesel Hybrid	Urban
	CNG	Urban
L-Category	Petrol	Mopeds 2-stroke <50 cm³
		Mopeds 4-stroke <50 cm³
		Motorcycles 2-stroke >50 cm³
		Motorcycles 4-stroke <250 cm³
		Motorcycles 4-stroke >750 cm³
		Motorcycles 4-stroke 250 - 750 cm³

In the case of traffic situations, the percentage of runtime distribution and average speed values within driving conditions (urban, rural, motorway) for each vehicle category were used based on the results of previous research carried out by the Institute for Transport Sciences.

Specifying the average speed is less important in the case of rural and highway traffic as the function takes similar values between 45-105 km/h. However, determining the average speed for urban transport is more important, because of a difference of 1 km/h in the first third of the function results in a larger difference in emissions. Naturally, the functions vary from one pollutant to another, but the influence of speed is similar in each case.

Among the trip characteristics, it is important to mention the average travel time and duration. According to available statistics, European average of 12.5 km were determined by experts. The distribution of the distances traveled varies from country to country, but typically a large proportion (80%) travel only short distances (less than 15 km). It plays a significant role in the emissions of the cold start phase. The average travel distance of 12 km average travel time of 25 minutes was used.

Detailed and accurate calculations of mean activity could not have been made in previous years. Previously, data were obtained from queries extracted from the RKF (Regular Environmental Review) database provided by the Ministry of the Environment, and subsequently corrected based on the annual fuel consumption. However, in COPERT5 it is possible to provide fuel balanced mean activity, which the program automatically counts and takes into account when calculating the emissions. From 2018, there was a development research in the Institute for Transport Sciences and the project outcomes will be used for the 2019 emission calculations. From now on, the mean activity data will be more precise and the query system calculates the mileage records of the Vehicle Inspection Database for each vehicle category.

The source of the annual fuel consumption data was the national energy statistics provided by the Hungarian Energy and Public Utility Regulatory Authority (MEKH). The data published by the MEKH will also be transmitted to EUROSTAT. Energy conversions were executed following the values given in the EMEP/EEA air pollutant emission inventory guidebook 2023.

Table 3.2.7.2 *Default density and calorific values of primary fuels determined using the 2023 EMEP/EEA air pollutant emission inventory guidebook 2023 (Table 3-28)*

Fuel	Density [kg/m3]	Calorific values [MJ/kg]
Gasoline	750	43.774
Diesel	840	42.695
LPG	520	46.564
CNG	175	48
Biodiesel	890	37.3
Bioethanol	794	28.8

2./ For all the years in the period 2000-2018 for which no domestic data were provided by the Institute for Transport Sciences, data purchased from Emisia SA, developer of the COPERT model, were used as inputs. As claimed by the data provider, *"the vehicle fleet and activity data provided by EMISIA SA for the compilation of national emission inventories with use of the COPERT model reflect our best knowledge of national situation in each country until 2013. These data have been updated using the road transport dataset and methodology of the TRACCS research project. More specifically, TRACCS dataset of the period 2005-2010 has been combined with the previous FLEETS research project dataset (2000-2005) and with latest official statistics available (2011-2013) to produce aligned and up to date time series for the period 2000-2013 (no projection included). The quality, completeness, and consistency of these two projects datasets, which have been extensively reviewed and cross-checked, ensure that the compiled countries data are also of good quality."*

In case of larger discrepancies between the Emisia database and domestic data, preference was always given to data from domestic sources, and the time series was smoothed out. Again, whenever necessary, the mileage data were slightly modified to reflect better the domestic statistics on fuel sold.

3./ The compiler institute produced input data for the remaining years (i.e., 1985-1999). Quantification of the stock of each road vehicle type was based on Statistical yearbooks of Hungary and annual reports of Ministry of Economy and Transport about the Hungarian vehicle fleet. Also, personal communications with experts took place. Compared to recent years where about 200 vehicle categories were taken into account, the input database for the earlier part of the time series is less detailed containing 35 vehicle categories, and it probably has a higher uncertainty.

It should be noted that unleaded gasoline was sold only after 1989. Since lead is poison for catalytic converters, it was assumed that real catalyst vehicle has been used after this time.

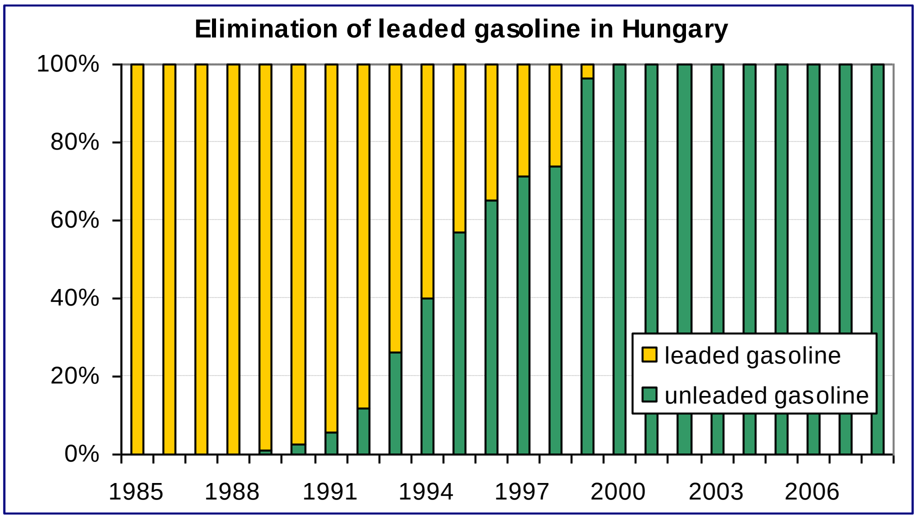


Figure 3.2.7.6 *Elimination of leaded gasoline in Hungary*
(Source: Hungarian Petroleum Association (MÁSZ), Annual Reports 1996-2008)

Emissions from ***in-country aviation***, which represent a very low proportion, were taken previously equal to the emission from consumption of aviation gasoline, and calculated in those years when the related data were available in the energy balance. Where aviation gasoline was not indicated in a separate line, consumption and emissions were calculated together with road traffic gasoline.

Upon receiving data from Eurocontrol, the above approach was slightly modified. Although there are no scheduled commercial domestic flights in Hungary, (updated) Eurocontrol data for the period 2005-2015 suggested that about 0.53 per cent of total jet kerosene is used for domestic flights. Using the same share back to 1985, some kerosene (i.e., 29-52 TJ) is now allocated to domestic aviation. As regards aviation gasoline, the used energy statistics contain values between 1 to 3 kt but not for all years. For the missing years, a fuel use of 1 kt was assumed. (Based on earlier personal communication with the energy statistics provider, generally 0.9 kt aviation gasoline is sold in the country). The resulting CO_2 emission (from both aviation gasoline and jet kerosene) is 8 Gg on average (i.e., far below the significance threshold).

*(Background of the **Eurocontrol data**: At the end of 2010 the European Commission signed a framework contract with EUROCONTROL, the European organization for the safety of air navigation, regarding 'the support to the European Commission in relation to climate change policy and the implementation of the EU ETS'.*
This support project is organized in different Work Packages. One of these Work Packages pertains to the improvement of GHG and air pollutant emissions inventories sub-mitted by the 28 Member States and the European Union to the UNFCCC and to the UNECE. The main objective of the WP is to assist EU Member States improve the reporting of annual greenhouse gas (and other air pollutant) emission inventories by e.g., estimating the fuel split domestic/international using real flight data from EU-ROCONTROL.
To support the inventory process for the submission in 2017, in November 2016 MS received fuel and emissions data for the years 2005 to 2015 as calculated by EUROCONTROL using a TIER 3b methodology applying the Advanced Emissions Model (AEM).
The individual fuel burn and emission data associated with each flight are processed with AEM, Excel reports covering UNFCCC and CLRTAP are generated then made available to EEA Member states via the EUROCONTROL ftp site.
All flights having a flight plan are captured by EUROCONTROL. Military flights are excluded. Civil flights flying on Visual Flight Rules (VFR) are not known to EUROCONTROL and are therefore not part of this system.
Looking at flight types in the database, it is possible to distinguish between domestic and international flights. Three aircraft groups are currently included in the EUROCONTROL dataset: jet, turboprop and piston.)

The annual total emissions of the national ***railway*** were determined as an exhaust gas component based on the data received from the national energy statistics provider, the Hungarian Energy and Public Utility Regulatory Authority which calculated the quantity of the fuel used in the national railway transport. Railway transport emissions are affected by many factors. However, since the currently used method of calculation is based on the fuel consumption of the rail traction, the factors described below do not have a direct influence on the calculation.

Neither the total length of railway lines nor the number of locomotives have changed significantly in recent years. The total volume of interurban passenger transport in terms of the number of persons transported decreased between 2001 and 2022 by about 28 percent whereas passenger km decreased only slightly by 2%. As far as the railways are concerned, the decrease in passenger numbers was smaller (-13%). However, expressed in passenger kilometers, the decrease was more pronounced (-22%). In 2020 alone, due to COVID-19, number passengers decreased by 28% generally, railways passengers by 31%. Considering transport of goods, rail transport has been showing some sign of growth since 2011, especially domestically, but there was also a significant drop in 2020.

Emissions from ***pipeline transport*** are reported separately since the 2015 submission. The calculations are based on (amended) energy statistical data and country specific emission factors. The IEA Annual Gas Questionnaire contains fuel consumption data only for the period 2010-2022. Comparing the IEA data to the ETS data reported by FGSZ Natural Gas Transmission Ltd (Hungary's transmission system operator), we detected an underestimation in the IEA data for 2010 which was corrected on the basis of IEA data. For the earlier years in the time series backward interpolation was carried out as follows:

- for 2005-2009 fuel consumption data were taken from the ETS database;
- for the years before 2005, the sum of natural gas production + import was used as proxy information.

Emission factors

Carbon dioxide emissions were calculated using country-specific emission factors for gasoline in road transportation, for diesel and natural gas in all relevant categories, and for kerosene in aviation. Otherwise, default factors were applied as summarized in Table 3.2.7.3 below.

Table 3.2.7.3 *Some CO_2 emission factors in the Transport Sector*

Fuel type	Emission factor (t CO2/TJ)	Source of EFs
Gasoline	69.3	2006 IPCC Guidelines
in road transport		Refinery
fossil	**71.61**	based on carbon content
bio	77.1	
Gas/Diesel Oil		Refinery
fossil	**73.57-74.52**	based on carbon content
bio	84.4	
LPG	63.1	2006 IPCC Guidelines
Residual fuel oil	77.4	2006 IPCC Guidelines
Natural Gas	**55.2-56.3**	ETS database

Fuel type	Emission factor (t CO2/TJ)	Source of EFs
Lubricants	73.3	2006 IPCC Guidelines
Jet kerosene	**72.46-73.03**	Refinery

It has to be noted that the cited CO_2 emission factors in road transport are derived values based on mass of the fuels and not necessarily on their energy content. We have also slightly deviated from the NCVs reported in the IEA/Eurostat Annual Questionnaire. Originally, the net calorific value applied in the Hungarian energy statistics was usually 42 TJ/kt for both fuels. However, there were indications that the real calorific value might be different. For example, the default NCVs are 43.8 TJ/kt for gasoline and 42.7 TJ/kt for diesel in the COPERT model. In the 2006 IPCC Guidelines, we can find even higher values: 44.3 TJ/kt and 43 TJ/kt for gasoline and diesel, respectively. And we have also one measurement from the refinery for diesel oil: that is 43.04 MJ/kg. So, in the 2017 submission the calorific values were changed to 44 TJ/kt and 43 TJ/kt for (fossil) gasoline and diesel oil, respectively. (Meanwhile, NCVs have been revised upwards also in the energy statistics.)

The basis of the emission factor was carbon content of the fuels received from the refinery in 2012, i.e., 0.8406 t C / t gasoline and 0.86275 t C / t diesel. However, the carbon content of the fuels related to the fuel mix E5 (i.e., 5% biofuel) back then, so it could not be used for the fossil part of the fuel unchanged, especially in case of gasoline. In an earlier approach, we have changed the used emission factor for gasoline (fossil part) by taking into account the difference between the default CO_2 emission factor for gasoline (3.180 kg CO_2/kg fuel) and for the blend E5 (3.063 kg CO_2/kg fuel) (See Table 3-12 in the 2022 EMEP/EEA Guidebook). This means, we have multiplied the original EF with 3.169/3.063 for the fossil part. All the resulting EFs are included in Table 3.2.9 above. (In earlier submissions the ratio 3.180/3.125 was used from the 2016 EMEP/EEA Guidebook.) For this submission, the fossil emission factor was derived from measured ethanol content of gasoline (which was not exactly 5% in the samples) using the following equation:

$$EF_{foss} = (EF_{foss+bio} - \%m_{bio} \times EF_{bio}) / (1 - \%m_{bio})$$

The value for EF_{bio}, i.e. 1.911 kg CO2 per kg of ethanol, was taken from Table 3-29 of the 2023 EMEP/EEA Guidebook.

For the years starting in 2016, the refinery provided us with carbon content and calorific value of the *fossil part* of diesel from which the following country-specific values could be derived:

Gasoil	-2015	2016	2017	2018	2019	2020	2021	2022
NCV (GJ/t)	43.0	42.8	42.7	42.7	42.7	42.8	42.7	42.6
CO_2 EF (t/TJ)	73.57	73.99	74.27	74.26	74.21	74.09	74.10	74.52

Also, the CO_2 emissions from the ***fossil part of the carbon of biodiesel*** have been calculated and added to the national total. The refinery confirmed that diesel had only FAME content (HVO is expected only from 2020). Therefore, CO_2 emission was calculated with the default parameters specific for FAME, i.e., 76.5% kg C/kg FAME, and 5.4% fossil part of C of FAME. The resulting emissions were not significant: they increased from 0.3 kt in 2007 to 33.0 kt in 2020. These CO_2 emissions are reported separately as “other fossil fuels/fossil part of biodiesel”. As regards the biofuel part: in case of biodiesel (FAME), the default carbon content of 76.5% kg C/kg FAME was used with the default bio part of carbon content (1-5.4%=94.6%). In case of biogasoline, a biogenic carbon content of 55.1% was applied in the calculations.

CO_2 emissions from lubricants in 2-stroke engines are also included in the transport sector. Activity data have been taken from the COPERT database (i.e., fuel consumption of 2-stroke cars, mopeds, and motorcycles. With an assumption of a 1:40 mixing ratio, the total amount of lubricants combusted could be calculated. Using default NCV and EF, the resulting emissions remained at a moderate level as summarized in the table below.

***Table 3.2.10** CO_2 emissions from lubricants in 2-stroke vehicles (with activity data)*

		BY	1990	1995	2000	2005	2010	2015	2020	2021	2022
Fuel consumption	kt	425.6	460.0	295.9	173.0	65.1	36.8	17.9	16.1	15.7	16.1
2-stroke cars	kt	416.1	452.0	285.2	159.9	41.8	13.7	5.1	1.9	1.8	1.7
L-Category	kt	9.5	8.1	10.7	13.1	23.3	23.1	12.8	14.3	13.9	14.4
Lubricants	kt	10.6	11.5	7.4	4.3	1.6	0.9	0.4	0.4	0.4	0.4
CO_2 emissions	kt	**31.1**	**33.6**	**21.6**	**12.6**	**4.7**	**2.7**	**1.3**	**1.2**	**1.1**	**1.2**

CH_4 and N_2O emissions from road transport were calculated using the COPERT model (COPERT 5.7.2) for the whole inventory period for gasoline and diesel. For all other fuels (and categories) default IPCC emission factors were applied. For example, non-CO_2 EFs from Table 3.4.1 of the 2006 IPCC Guidelines are applied for railways.

Besides gasoil as described above, country-specific calorific value and CO_2 emission factors are applied also for kerosene as summarized in the table below.

Kerosene	-2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
NCV (GJ/t)	43.4	43.5	43.4	43.4	43.3	43.3	43.3	43.3	43.5	43.3	43.3	43.3	43.3	43.4	43.2	43.3
CO2 EF (t/TJ)	72.6	72.6	72.6	72.56	73.00	72.77	72.71	72.70	72.46	72.75	72.69	72.79	72.79	72.62	72.81	73.03

3.2.7.3 Uncertainties and time-series consistency

We assume that the uncertainty of the transport-related fuel consumption data is higher than in case of stationary equipment because such data are more difficult to collect and verify. Considering the above, the estimated uncertainty of the energy consumption data is ±5%. The estimated uncertainty of the emission factors for CO_2 is ±1-5%. It should be noted, that in the 2006 IPCC Guidelines the uncertainty for default methane and nitrous oxide factors is much higher (200-300%).

3.2.7.4 Source-specific QA/QC and verification

IEA data were compared with the national statistics. For clarification of the differences, additional data were required from the energy statistics provider. This led to revision of the time series of fuel consumption.

We consider the technical review of the EU as a very important QA activity. In summer 2012, the EU conducted a more thorough than usual review of the inventories of all member states. After the review, Hungary was recommended to obtain the C content and net calorific values of gasoline from fuel suppliers, to develop a country-specific EF for CO_2 from gasoline that is representative for gasoline used in Hungary and to revise data accordingly.

During the 2016 review, it was recommended that CO_2 emissions from lubricants for non-energy use should be reported under 2D1 Lubricant use and emissions from energy uses (such as in 2-stroke engines) should be reported under 1A3b Road transportation. Following this recommendation, this submission contain estimates of CO_2 emissions of lubricants from 2-stroke engines taking fuel consumption data (FC_t) from the COPERT database (2-stroke passenger cars, mopeds, and motorcycles).

3.2.7.5 Source-specific recalculations

The used methodology remained basically the same. However, the following changes were implemented:

- The latest IEA Annual Questionnaires (as submitted end of October 2023) was used that contained some revisions for 2020;
- A newer version of the COPERT model (5.7.2, November 2023) was applied for the whole time series consistently;
- The CO_2 EF for gasoline has been changed to 71.61 from 72.47 t/TJ in the 2023 submission and 71.28 t/TJ in the 2022 submission.
- Activity data (aviation gasoline and kerosene used for national aviation) have been revised based on latest Eurocontrol data (2005-2022). This revision also affected the activity data for earlier years due to backward extrapolation.

Altogether, emissions decreased by 49.6 kt CO_2-eq (0.04% of the national total) in the base year, by 62.4 kt in 1990 (0.07% of the national total, and by 45.6 kt (0.07% of the national total) in 2021.

3.2.7.6 Source-specific planned improvements

None.

3.2.8 Other Sectors (CRF sector 1A4)

3.2.8.1 Source category description

Emitted gases: CO_2, CH_4, N_2O
Methods: T1, T2
Emission factors: D, CS
Key sources:
1A4 Other Sectors - Liquid Fuels – CO_2 – L, T;
1A4 Other Sectors - Solid Fuels – CO_2 – L, T;
1A4 Other Sectors - Solid Fuels – CH_4 - T
1A4 Other Sectors - Gaseous Fuels – CO_2 – L, T;
1A4 Other Sectors - Biomass – CH_4 – L,T.
1A4 Other Sectors – Other Fossil Fuels – CO_2 - T

This sector covers combustion in public institutions, by the population and in the Agriculture /Forestry/Fisheries Sector. Emissions in the Other Sectors are summarized in the figure below:

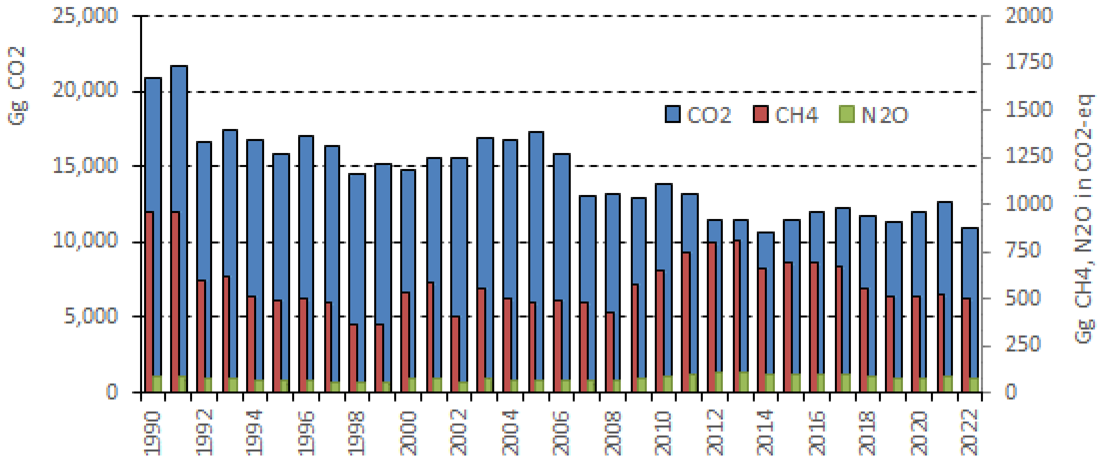


Figure 3.2.8.1 *Trends of CO2, CH4 and N2O emissions in the Other Sector (1990-2022)*

3.2.8.2 Methodological issues

Activity data

Activity data was obtained from the IEA/Eurostat questionnaires as described in the introduction section of the chapter. Figure 3.2.8.2 illustrates the fuel consumption of the sector by fuel types.

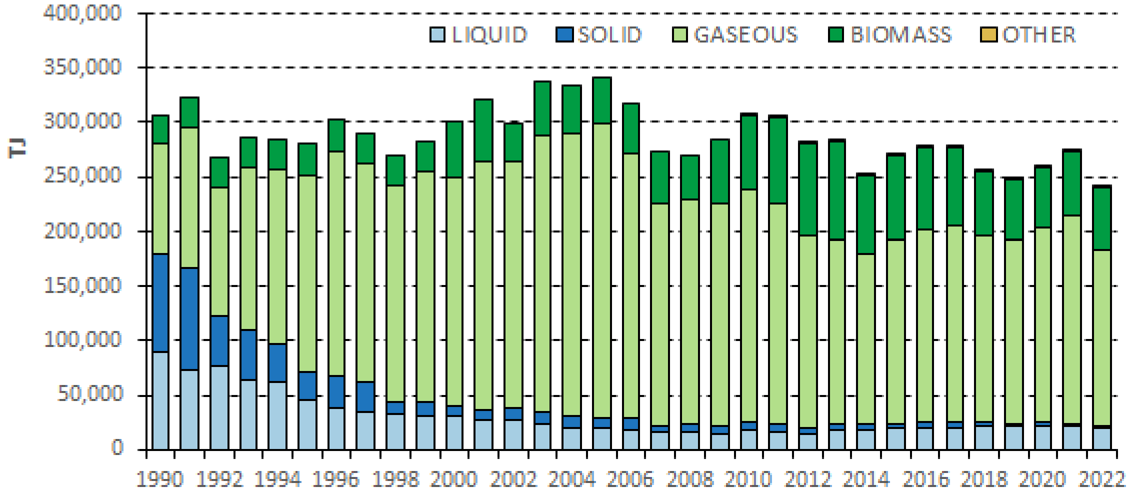


***Figure 3.2.8.2** Share of different combusted fuel types in the Other Sectors (1990-2022)*

Since about two third of the fuel consumption is related to the residential category, the fuel structure is influenced principally by changes in this sector (see Fig. 3.2.8.3).

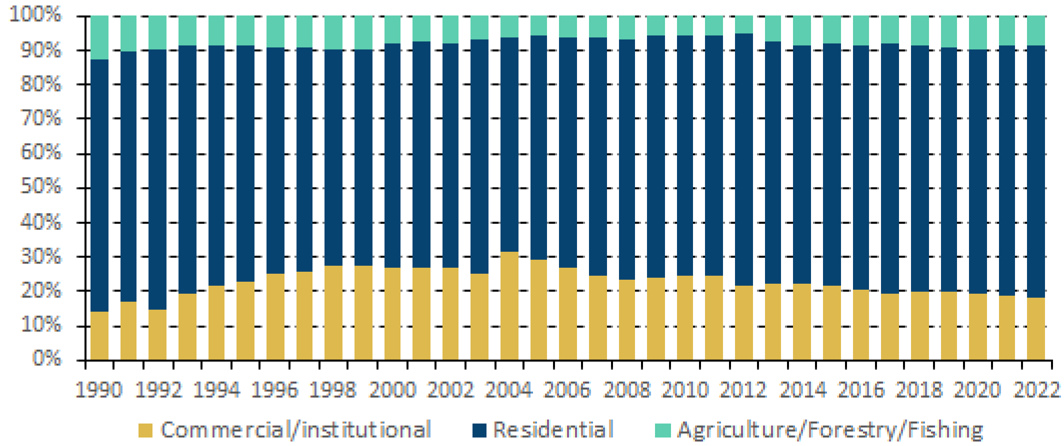


***Figure 3.2.8.3** Fuel combustion in the subsectors of the Other Sector (1990-2022)*

Generally, in contrast with the significant reduction of coal and oil consumption, natural gas consumption has increased significantly. The population switched from coal to natural gas combustion. Household heating oil was completely replaced by LPG (see Table 3.2.8.1).

***Table 3.2.8.1** Oil and LPG consumption in the Commercial/Institutional and Residential Sectors in selected years after 1990 (TJ)*

		1990	2000	2005	2010	2015	2018	2019	2020	2021	2022
Commercial Institutional	Oil	10,510	769	379	0	1,024	938	771	772	775	603
	LPG	1,457	2,162	1,081	893	658	554	508	738	508	508
Residential	Oil	35,991	1,118	86	0	40	0	0	0	0	0
	LPG	13,536	12,079	7,802	5,640	3,055	3,184	3,091	3,322	3,091	2,768

During the period 1990-2022, the length of natural gas pipe-network increased from 22,549 km to 85,532 km. The number of households supplied with natural gas increased from 1.6 million in 1990 (42%) to 3.4 million in 2010 (77%) but decreased a little to 3.3 million (73%) since 2010. Residential consumption represented 36% of total inland demand of natural gas in 2022. Piped gas is available in 91% of all settlements in Hungary, and this figure has not changed much since 2005 (but it was only 15% in 1990). 72% of households use natural gas for heating purpose as well. Although individual residential heating became more and more widespread, still over 650 thousand dwellings (15% of all dwellings) are supplied with district heating and over 600 thousand with hot water. Most of this heat (around 70%) is generated from natural gas use; however, the resulting emission was not accounted for here but under the Energy industries subsector.

Natural gas consumption can be influenced by several factors. One of these factors might be the weather and the resulting heating demand. Heating degree day (HDD) is a quantitative index that reflects demand for energy to heat houses and businesses. This index is derived from daily temperature observations. The inside temperature is 18°C and base temperature (the outside temperature above which a building needs no heating) is 15°C in our calculation (following the standard European methodology). Figure 3.2.8.4 illustrates the relationship between residential fuel consumption and HDD. The figure demonstrates that increased fuel use can often be explained by increased HDD values and vice versa. Heating demand (HDD) increased by 7% in 2020 and by further 11% in 2021 (after the two warmest years in 2018-2019) which is reflected in the higher energy consumption of the residential sector. However, heating demand decreased again by 9% in 2022.

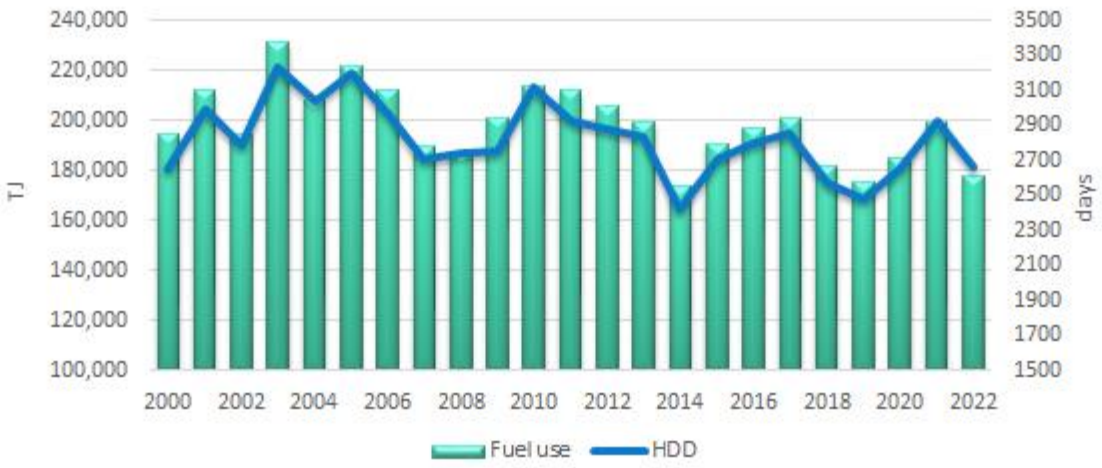


Figure 3.2.8.4 *Comparison of residential fuel consumption and HDD between 2000 and 2022*

Another factor is definitely the price. The (nominal) price of pipelined gas increased from 325 to 1360 Ft/10 m3 between 2000 and 2012. This price increase might have led to increased biomass use as a substitute fuel in the residential sector. However, the above-mentioned trends have changed in recent years. Gas prices have dropped by 26% between 2012 and 2015, consequently consumption started growing again. Gas prices remained stable until 2021. In 2022 all energy prices increased significantly.

So, it seems that the price elasticity of demand of natural gas and other fuels. We know that the price of natural gas was significantly higher in the period 2008-2013 than that of biomass, and in this very period natural gas consumption decreased and biomass consumption increased. After 2014, however, the trend changed due to decreased natural gas prices (the price advantage of biomass disappeared), so gas consumption started increasing again while biomass consumption decreased. This is demonstrated in Figure 3.2.8.5 below.

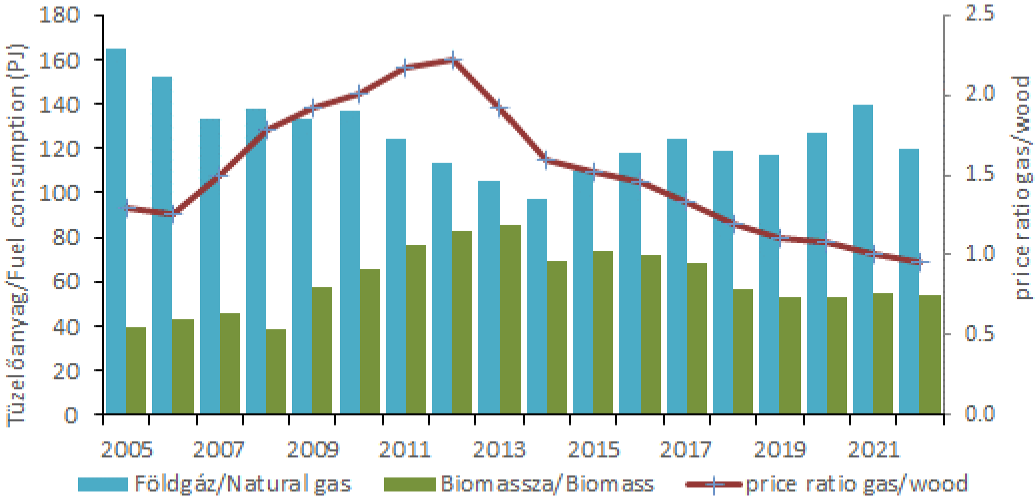


Figure 3.2.8.5 *Price elasticity of natural gas and fuelwood (2005-2022)*

The monthly natural gas consumption of an average household decreased from 125 m^3 in 2003 to 70 m^3 in 2014, and then increased to 99 m^3 in 2021 but decreased to 94 m^3 in 2022. In this significant decreasing trend - beside the higher energy prices – most probably also the more energy-conscious approach of the population plays a role and is definitely greatly affected by the weather. In addition, larger decrease in biomass use indicates some fuel switch from fuelwood to natural gas in the residential sector.

Emissions from household machinery are reported separately in the category 1A4bii. Based on the latest survey of the Statistical Office, 56% of the households have garden or backyard on their own. There are 3.9 million households in Hungary; 56% of which is 2.2 million. It was assumed that for every garden 5 liters gasoline is used in a year. This would translate to 10.95 million liters or 8.2 kt gasoline. As part of the households use electronic devices, 6 kt of gasoline use was assumed for the whole time series. (The required activity data have been reallocated from the category 1A3b road transportation.) The resulting emissions are not at all significant (i.e., 19 kt CO2). We would like to stress here that we consider the above approach as a rough estimate and as currently no other reliable information is available that would justify the introduction of any trend into the time series, constant amount is reported. In this regard it is worth mentioning that (1) all gasoline consumption in the energy statistics from the annual IEA/Eurostat questionnaires is accounted for in the inventory therefore it is merely an issue of allocation, and (2) emissions are below the threshold of significance.

In the ***Agriculture*** category, the trend in biogas use might deserve our attention as its share within biomass can be higher as 60% as in 2013-14, or around 40% as in 2018-2022.

In order to report separate emissions for the source category “Agriculture/Forestry/Fishing: Off-road vehicles and other machinery”, diesel oil consumption had to be split between stationary and mobile combustion. The Energy Statistical Yearbooks published around 1990 contained separate data for gasoil used in tractors and harvesters. Based on this information, a bit more than 60% could be allocated to mobile consumption in the early period of the time series. Considering the generally diminishing role of liquid fuels in stationary combustion, it is assumed that after 2001 all gasoil allocated to agriculture in the energy statistics has been used for mobile off-road machinery.

To be consistent with the air pollutant inventory submitted under the CLRTAP, the methodology for off-road vehicles and other machinery used in agriculture and forestry was changed for the 2017 submission, and the Tier 2 method from the 2019 EMEP/EEA Guidebook was implemented. This method classifies the used equipment into the fuel types and layers of engine technology. The engine technology layers are stratified according to the EU emission legislation stages, and three additional layers are added to cover the emissions from engines prior to the first EU legislation stages. The used layers are as follows: <1981; 1981-1990; 1991-Stage I; Stage I; Stage II; Stage IIIA; Stage IIIB; Stage IV; Stage V. The penetration of the new technology is taken into account in the form of split (%) of total fuel consumption per engine age (irrespective of inventory year) as it can be seen for diesel-fueled non-road machinery in Table 3-3 in the Guidebook. As domestic information on stock of agricultural machinery indicated a somewhat slower penetration of new technology (as in Denmark), original data in Table 3-3 have been modified as follows:

Table 3.2.8.2 *Used values for the split (%) of total fuel consumption per engine age (irrespective of inventory year) for diesel-fueled non-road machinery in Agriculture*

Engine age	USED	ORIGINAL in Table 3-3
0	4	8
1	4	7.6
2	4	7.2
3	4	6.79
4	6	6.39
5	6	5.99
6	6	5.59
7	6	5.18
8	6	4.78
9	6	4.38
10	6	3.98
11	4	3.57
12	3	3.17
13	3	2.77
14	3	2.37
15	3	1.97
16	3	1.9
17	3	1.83
18	3	1.76
19	3	1.69
20	3	1.62
21	2	1.55
22	1	1.48
23	1	1.41
24	1	1.34

25	1	1.28
26	1	1.21
27	1	1.14
28	1	1.07
29	2	1

As recommended by the ERT, non-CO_2 emissions were calculated separately for forestry. Separate activity data (gasoil consumption) was provided by the energy statistics provider for the first time only for 2016 therefore we allocated the same share (6%) of all gasoil consumption in this source category to forestry in previous years. As on average, this fuel consumption does not represent a significant amount (around 20 kt), the T1 method with default emission factor from the EMEP/EEA Guidebook seems appropriate here.

Emission factors

Default emission factors for CO_2 are used for liquid and for most of the solid fuels. The only exception is the residential lignite emission factor, which is the same as described under Energy Industries, because power plants that report measured carbon content of lignite, sell directly to residential consumers, too.

Since (almost) the entire quantity of liquid fuels used in residential combustion is LPG and the majority of institutional uses are also based on LPG, the IEF factor for CO_2 is very low.

For non-CO_2 emissions, default emission factors were applied (except for the category 1A4cii as described above).

3.2.8.3 Uncertainties and time-series consistency

We assume that the uncertainty of the fuel consumption data, especially biomass, in the Other Sector is higher than in case of industrial processes because such data are more difficult to collect and verify. Considering the above, the estimated uncertainty of the energy consumption data is ±5-20%.

The estimated specific uncertainty for CO_2 is 2-7%. The uncertainty of the methane factor is significantly higher (50-150%), while that of N2O may be of an order of magnitude.

3.2.8.4 Source-specific QA/QC and verification

Comparing residential coal consumption data in the Hungarian Energy Statistical Yearbook and the IEA/Eurostat statistics, large discrepancies in NCV were found for the years before 1999. After discussing this issue with the energy statistics provider, the higher values from the domestic publication were kept.

3.2.8.5 Source-specific recalculations

As a general practice, the latest available energy statistics has been used for the calculations considering all modifications. This time, the IEA/Eurostat Annual Questionnaires as submitted in October 2023 were used. In this submission we also assumed that large part of the official (=as reported in the IEA/Eurostat Annual Questionnaire) distribution losses are actually combusted especially before 2010: either in pipeline transport (accounted for in source category 1.A.3.e) or in gas and oil extraction (included in 1.A.1.c). Illegal activities are not taken into account specifically in this submission. (Based on newspaper articles from that time, gas theft increased drastically from 2008 and reached an estimated amount of 80-90 million cubic meters in 2010-2011 but it was reduced to a third by 2015, and most probably it decreased further since then.). This amended approach means that no natural gas is re-allocated from 1.A.4.a to 1.A.1.c and no theft *as additional amount* is taken into account in 1.A.1.b as in previous submissions. In order to be more in line with the official energy statistics, fuels reported in the "Not elsewhere specified (Other)" category in the energy balance are moved from source category 1.A.4.a to 1.A.5.a.

As a result, GHG emissions decreased by 114.5 kt CO2-eq (0.2% of the national total) in 2021, and by 390.3 kt (0.4% of the national total) in 1990.

3.2.8.6 Source-specific planned improvements

None.

3.2.9 Other (CRF sector 1A5)

Following a recommendation of the EU ESD Review, we have included the first broad estimate for emissions from military aviation into this source category (1.A.5.b. Mobile). The table below contains our first estimates which is based on flight hours. Although exact flight hours of military aircraft are confidential but we learned from different press sources (referencing the Hungarian Defense Force) that the Hungarian combat fleet had altogether 14000 flight hours (including domestic and international training operations) in the last 10 years. This would mean 1400 hours per year. Based on another source, the average of flight hours was 1756 between 2011 and 2015, higher than in previous years. For our calculations, we took the highest fuel consumption factor (per hour) from Table 3.6.7 (i.e., 3283 kg fuel per hour) which resulted in a (probably somewhat conservative) kerosene use of 5.8 kt per year. First preliminary information from the energy statistics provider indicates a kerosene consumption of 4-5 kt used by the Hungarian Defense Force which more or less verifies our estimate. Emissions are then calculated with default EFs, (i.e., 71.5 t CO2/TJ kerosene, 0.5 kg CH_4/TJ and 2 kg N_2O/TJ) resulting in 18 kt CO2-eq. This figure is by about 40% below the threshold of significance (i.e., 30.5 kt in 2015).

For 2016, for the first time, kerosene consumption was allocated to the „Other" category also in the energy statistics so it could directly be used as activity data.

Table 3.2.9.1 *The first broad estimate of emissions from military aviation. Values for 2005 were kept constant back to the base year. From 2016, energy statistics could be used directly therefore years after 2017 are not included in this Table.*

		2005	2008	2009	2010	2012	2013	2014	2015	2016	2017
Flight hours	hour/year	1400	1044	1044	1044	1756	1756	1756	1756	NE	NE
Kerosene consumption	kt	4.60	3.43	3.43	3.43	5.76	5.76	5.76	5.76	7	8
	TJ	199.48	148.75	148.75	148.75	250.20	250.20	250.20	250.20	302.96	346.6
CO_2	kt	14.26	10.64	10.64	10.64	17.89	17.89	17.89	17.89	21.66	24.78
CH_4	kt	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002
N_2O	kt	0.0004	0.0003	0.0003	0.0003	0.0005	0.0005	0.0005	0.0005	0.0006	0.0007

In accordance with the latest energy statistics, stationary natural gas, fuel oil and some coal consumption is also reported in the source category 1.A.5.a in the years 1985-2002 and 2015-2022. (These amounts were partly allocated to 1.A.4.a in earlier submissions.) Emissions are calculated with the same methodology as in 1.A.4.a.

3.3 Fugitive emissions from solid fuels and oil and natural gas and other emissions from energy production (CRF 1.B)

3.3.1 Fugitive emissions from solid fuels - (CRF sector 1.B.1)

3.3.1.1 Source category description

Emitted gas: CH_4, CO_2

Methods: T1, T2
Emission factors: CS, D
Key sources: 1B1 Solid fuels - CH_4 – T

Category *1B1a* includes fugitive CH_4 emission released during coal mining and handling. Emissions from fuels used during these activities are calculated under the combustion part of the inventory, mostly in the source category *1A1c.*

Emissions from category *1B1b* – fugitive emissions originating from solid fuel transformation are also mostly included in sector *1A1c*. The reason is that it is not possible to separate the GHG emissions from fugitive and non-fugitive sources during coking, and there is no reference in any of the Guidelines for emission estimation methodology in category *1B*. However, in this submission, CO_2 and methane emissions from *flaring of coke oven gas* have been allocated to this source category (i.e., 1B1b).

In Hungary, only surface coal mines are present. Although underground mining was the predominant form in the 1960's and 1970's, it eventually ceased in 2018. Drastic reduction in coal production was observed between 1987 and 1988, as well as between 1989 and 1990. Underground mining decreased in both relative and absolute terms; therefore, distribution of mined coal types underwent significant changes. After 2015 only one minor underground mine was working after the closure of the mine of the last bituminous/sub-bituminous coal fired power plant.

The significant decrease of emissions is well explainable as emissions are strongly related to activity data (production of coal mined underground). So, the fall of underground coal mining described in the paragraph before and presented in Figure 3.2.1 resulted in decreasing trend of emissions.

Please note that all the coal mined in Hungary is classified now as lignite (except for very small amounts of sub-bituminous and coking coal).

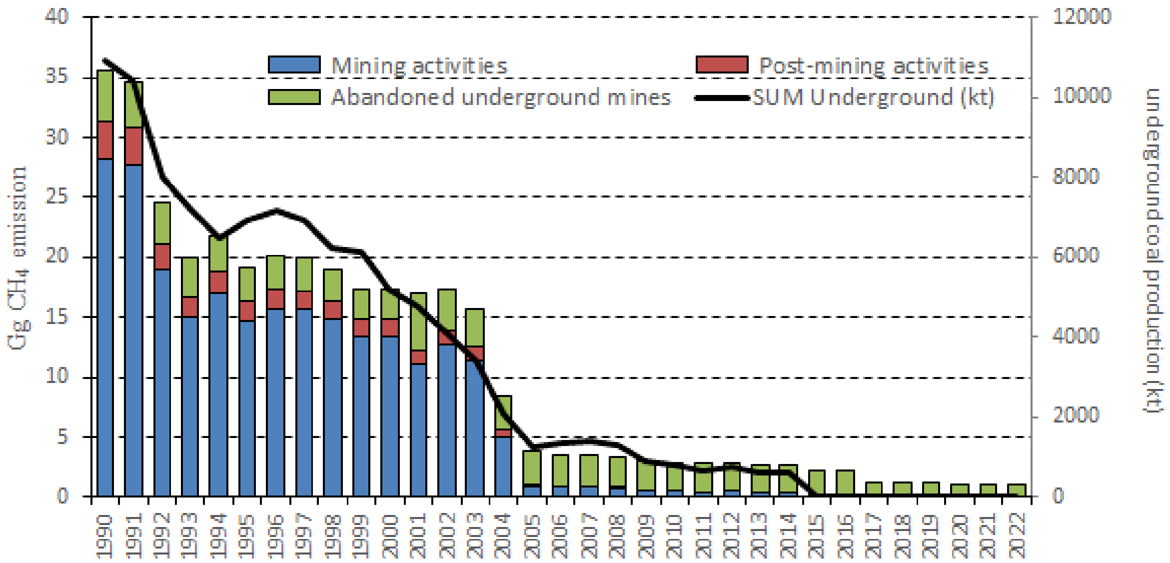


Figure 3.3.1 *Trend of emissions from solid fuels and underground production of coal*

3.3.1.2 Methodological issues

During the 2016 in-country review it was suggested to provide more detailed description of methodologies in categories of fugitive emissions to increase transparency. A detailed table summarizes the sources of activity data and emission factors of all subsectors which can be found in A3.1 of Annexes.

Activity data

Production data were taken from the IEA Coal statistics, where both coal types and underground and surface productions are distinguished. Following the IEA Coal classification, all the coal mined in Hungary is classified as lignite, (except for very small amounts of sub-bituminous and coking coal in the years 1990-91). Mine and coal basin level data are received from the Mining and Geological Survey of Hungary (former Mining Bureau of Hungary). In the last four years, reported underground coal production differs at the two data provider. The difference was 3 kt at the most, which can be regarded as negligible, but also the production was very low, so the uncertainty is high. Since the inventory team always receives data from the Mining and Geological Survey of Hungary (former Mining Bureau of Hungary) earlier and data are more detailed, value from this dataset was used for the calculations (e.g., for the year 2017).

Table 3.3.1 *Underground and surface coal production in Hungary*

Year	SUM Production (kt)	SUM Surface production (kt)	SUM Underground production (kt)	out of which: Mecsek basin production (kt)
1985	24042	7387	16655	2639
1985-87	23338	7198	16141	2441
1986	23129	6983	16146	2325
1987	22844	7223	15621	2360
1988	20875	5634	15241	2255
1989	20030	5883	14147	2127
1990	17830	6919	10911	1819
1991	17135	6680	10455	1760
1992	15844	7815	8029	1210
1993	14832	7588	7244	950
1994	14084	7622	6462	1030
1995	14772	7834	6938	856
1996	15259	8067	7192	882
1997	15764	8828	6936	854
1998	14668	8445	6223	813
1999	14547	8425	6122	716
2000	14033	8848	5185	753
2001	13914	9174	4740	573
2002	13027	8929	4098	726
2003	13301	9871	3430	667
2004	11242	9135	2107	259
2005	9570	8321	1249	0
2006	9952	8601	1351	0
2007	9818	8421	1397	0
2008	9404	8118	1286	0
2009	8986	8078	908	0
2010	9113	8301	812	0
2011	9555	8890	665	0
2012	9290	8527	763	0
2013	9558	8941	617	0
2014	9551	8950	601	0.011*
2015	9261	9239	22	5.687*
2016	9216	9210	6	0.748*
2017	7974	7972	2	0.789*
2018	7898	7898	0	2.083*
2019	6847	6847	0	6.095*
2020	6125	6125	0	1.513*
2021	4988	4988	0	0,252*
2022	4927	4927	0	0,418

* Surface production in Mecsek basin

Emission factors

Table 3.2.2 shows the measured methane content of coal for the mines operating since 1985 in Hungary together with the emission factors applied and defaults of the 2006 IPCC Guidelines. Data on in-situ methane content of mines in Hungary originates from research project conducted by Regional Centre for Energy Policy Research (available at: http://www.rekk.eu/images/stories/letoltheto/uhg-ag-vol2.pdf) included in list of References. The results are published in USGS, 2002 (please see the Reference list). The measured data is in accordance with the classification of mines regarding risk of firedamp received every year from the Mining and Geological Survey of Hungary (former Hungarian Mining Authority), which is also based on the m^3 methane/ t coal value. Based on the above-mentioned references, two different emission factors are applied for underground mines - the same as in case of previous inventory submissions. One is applied for coals from Mecsek coal basin and the other for all other underground production. The former is within the range of default average emission factor from 2006 IPCC Guidelines, the latter is well below but the difference might be explained by country specific properties.

Table 3.3.2 *In-situ CH_4 content in Hungarian mines, the emission factors used and default emission factors from 2006 IPCC Guidelines*

Coal basin	**Mine**	**In-situ CH_4 content (m^3/t)**	
		mine-specific value	average in basin
Mecsek coal basin	Pécsbánya – Karolina	18.26	19.5
	Vasas – Észak	20.75	
Other underground coal mines	Balinka	1.29	1.00
	Lencsehegy	0.00	
	Mány I/a	0.98	
	Márkushegy	0.93	
Surface coal mines	Bükkábrány	0.00	0.00
	Visonta	0.00	
defaults from 2006 IPCC Guidelines	*Low*	*10*	
	Average	***18***	

Generally, no emissions occur in Hungary in case of surface mining based on the above-mentioned references. The reason is that the mined Hungarian lignite is relatively young in the coalification (NCV is under 10 MJ/kg). At the end of 2014 an old surface mine in the Mecsek basin was re-opened with relatively high (20.75 m^3 CH_4/t coal) in-situ methane content, but the amount of mined coal was almost negligible in the first year. Coal production remained also in later years generally below 6 kt. (It should be noted that all emissions of Mecsek basin were reported in the category of underground mines in the first part of the time series but under surface mines after 2014.)

Please note that the implied emission factor is changing because the activity data in CRF is the SUM coal produced underground while the emissions are mainly related to the production in Mecsek basin where also some recovery activity occurred. Between 2005 and 2013 there was only one operating underground mine, so implied emission factor (0.623+0.0623=0.68541 please see above) became steady for those years.

Recovery

In 1.B.1.a Underground coal mining category, CO_2 emissions are reported from CH_4 recovery for the years 1985-1996. In this case CO_2 emissions are not direct emissions, but it is calculated from the amount of recovered CH_4 (CH_4 combusted for energy use) as follows:

CO_2 emissions = (Recovered CH_4) * 44/16

(M_{CO2}= 44 g/mol; M_{CH4}= 16 g/mol)

The yearly amount of recovered CH_4 and the stop of the recovery (due to the closure of the mines) were communicated by the Mining and Geological Survey of Hungary (former Hungarian Office for Mining, also former Mining Bureau of Hungary).

Post-mining

For post-mining activities, the same activity data and 10% of the mining emission factor is used the same as in the case of previous inventory submissions, which is in line with the suggestion for mines using pre-drainage of 2006 IPCC Guidelines chapter 4.1.3.2.

Abandoned underground mines

Activity data

It is very hard to collect detailed data on activities performed more than 50 years before that is required by the method of 2006 IPCC Guidelines, so several assumptions are applied. Chapter 4.1.5.2 of the 2006 IPCC Guidelines states that "Abandoned mines that were considered non-gassy when they were actively mined are presumed to have negligible emissions" and no emissions are to be reported from flooded mines.

So, emissions from this subsector are not significant in Hungary as coal mines are anyway "non-gassy" (please see Table 3.2.2 above) except for Mecsek basin. In addition, abandoned mines are usually flooded with water in Hungary.

In 2019, the Mecsek Mining Resources and Extraction Nonprofit Ltd. (Bányavagyon-hasznosító Nonprofit Közhasznú Kft.) was contacted to receive information on closed but not yet flooded mines in Mecsek basin to replace our previous estimates on numbers of unflooded mines.

Table 3.3.3 *Revised activity data used in 1B1a – Abandoned coal mines*

	1901-1925	1926-1950	1951-1975	1976-2000
1985	1	1	3	9
1986	1	1	3	9
1987	1	1	3	9
1988	1	1	3	9
1989	1	1	3	9
1990	1	1	3	9
1991	1	1	3	9

	1901-1925	1926-1950	1951-1975	1976-2000
1992	1	1	3	9
1993	1	1	3	9
1994	1		3	9
1995	1		3	8
1996	1		3	8
1997	1			8
1998	1			8
1999	1			8
2000	1			8
2001	1			7
2002	1			6
2003	1			6
2004	1			6
2005	1			5
2006	1			5
2007	1			5
2008	1			5
2009				5
2010				5
2011				4
2012				4
2013				4
2014				4
2015				4
2016				4
2017				4
2018				4
2019				4
2020				4
2021				4
2022				4

Emission factors

Set of Tier 1 emission factors from 2006 IPCC Guidelines Table 4.1.6 and Equation 4.1.11 is used for the calculation of emissions. Since time-series of emission factors begins with 1990 in the mentioned table of the 2006 IPCC Guidelines, Hungary had to complete with factors back to 1985. In the 2015 and 2016 submissions, constant values of 1990 were applied for previous years, but according to the hyperbolic decline curve of real emissions of abandoned coal mines it was planned to change these factors for more appropriate ones. For the 1901–1925, 1926–1950 and 1951-1975 periods emission factors were applied using the values of the original table for the next time-interval (2009-2014). For the 1976-2000 time interval this rule couldn't be applied. After discussions with experts from the European Union, Hungary asked the authors of this chapter of the guidelines to provide the missing values. The following table (Table 3.3.4) represents the completed table highlighting the new factors.

Table 3.3.4 *Emission factors for abandoned coal mines (Mm3 methane/mine)*

	Time interval of mine closure				
	1901–1925	**1926–1950**	**1951-1975**	**1976–2000**	**2001-Present**
1985	***0.2900***	***0.3610***	***0.5420***	***4.0289***	NA
1986	***0.2880***	***0.3570***	***0.5290***	***2.8881***	NA
1987	***0.2860***	***0.3530***	***0.5180***	***2.2894***	NA
1988	***0.2840***	***0.3500***	***0.5070***	***1.9148***	NA
1989	***0.2830***	***0.3460***	***0.4960***	***1.6561***	NA
1990	0.2810	0.3430	0.4780	1.5610	NA
1991	0.2790	0.3400	0.4690	1.3340	NA
1992	0.2770	0.3360	0.4610	1.1830	NA
1993	0.2750	0.3330	0.4530	1.0720	NA
1994	0.2730	0.3300	0.4460	0.9880	NA
1995	0.2720	0.3270	0.4390	0.9210	NA
1996	0.2700	0.3240	0.4320	0.8650	NA
1997	0.2680	0.3220	0.4250	0.8180	NA
1998	0.2670	0.3190	0.4190	0.7780	NA
1999	0.2650	0.3160	0.4130	0.7430	NA
2000	0.2640	0.3140	0.4080	0.7130	NA
2001	0.2620	0.3110	0.4020	0.6860	5.7350
2002	0.2610	0.3080	0.3970	0.6610	2.3970
2003	0.2590	0.3060	0.3920	0.6390	1.7620
2004	0.2580	0.3040	0.3870	0.6200	1.4540
2005	0.2560	0.3010	0.3820	0.6010	1.2650
2006	0.2550	0.2990	0.3780	0.5850	1.1330
2007	0.2530	0.2970	0.3730	0.5690	1.0350
2008	0.2520	0.2950	0.3690	0.5550	0.9590
2009	0.2510	0.2930	0.3650	0.5420	0.8960
2010	0.2490	0.2900	0.3610	0.5290	0.8450
2011	0.2480	0.2880	0.3570	0.5180	0.8010
2012	0.2470	0.2860	0.3530	0.5070	0.7630
2013	0.2460	0.2840	0.3500	0.4960	0.7300
2014	0.2440	0.2830	0.3460	0.4870	0.7010
2015	0.2430	0.2810	0.3430	0.4780	0.6750
2016	0.2420	0.2790	0.3400	0.4690	0.6520
2017*	0.2410	0.2770	0.3360	0.4390	0,6250
2018*	0.2390	0.2750	0.3330	0.4320	0,6040
2019*	0.2380	0.2730	0.3300	0.4250	0,5860
2020*	0.2370	0.2720	0.3270	0.4190	0,5690
2021*	0.2360	0.2700	0.3240	0.4130	0.5550
2022*	0.2350	0.2680	0.3210	0.4070	0.5410

**EF values for 2017-2021 were taken from the 2019 Refinement*

3.3.1.3 Uncertainties and time-series consistency

Uncertainty of activity data is estimated based on chapter 4.1.3.6 of the 2006 IPCC Guidelines. Consistency with the value used as uncertainty of activity data in other subsectors in *Energy* is also taken into account where usually also IEA Energy Statistics are applied as activity data.

Unfortunately, no uncertainty is provided for measurement data used for emission factors applied in mining subsector and Tier 1 approach is used in post-mining and abandoned coal mined subsectors. So, the uncertainty of emission factor in *1B1* is estimated to be „factor of 2" based on Table 4.1.2 of 2006 IPCC Guidelines.

	AD	EF	Combined
1B1 Solid fuels (uncertainty +/-%)	**5.00**	**200**	**200.06**

3.3.1.4 Source-specific QA/QC and verification

General QA/QC procedures apply.

Activity data is compared with old time-series used in previous inventory submissions (data from the Mining Bureau of Hungary) and the differences are cc.1%.

Country specific emission factors are compared to defaults of 2006 IPCC Guidelines as it is presented in Table 3.2.2 above.

3.3.1.5 Source-specific recalculations

None.

3.3.1.6 Source-specific planned improvements

None.

3.3.2 Fugitive emissions from oil and natural gas activities (CRF sector 1.B.2)

3.3.2.1 Source category description

Emitted gas: CO_2, CH_4, N_2O
Methods: T1, T2, T3
Emission factors: CS, PS
Key sources:
1B2b Natural Gas - CH_4 – L, T;
1B2c Venting and flaring - CO_2 – T

In category *1B2* fugitive emissions arising during exploration, production, processing, transmission and distribution, and storage of oil (*1B2a*) and natural gas (*1B2b*) are reported. In addition, GHG emissions from venting and flaring activities connected to the operations mentioned before are included in a separate subcategory (1B2c). In subcategory *1B2d - Other* Hungary reports fugitive CH_4 emitted during extraction of thermal water and gas and fugitive CO_2 from mining of natural CO_2 occurrence.

In the past, oil production and processing was an important sector in Hungary, but production's importance is decreasing as the reserves are running out. Gas mining shows similar tendencies, although the reduction is less intensive. At the same time, natural gas consumption significantly increased compared to the 1980s but the demand is mainly covered by import. However, the increase of natural gas consumption stopped in 2005, and a slow decreasing trend could be observed until 2014. After 2015, natural gas consumption increased again until 2021 but in 2022 it decreased quite significantly by 15%.

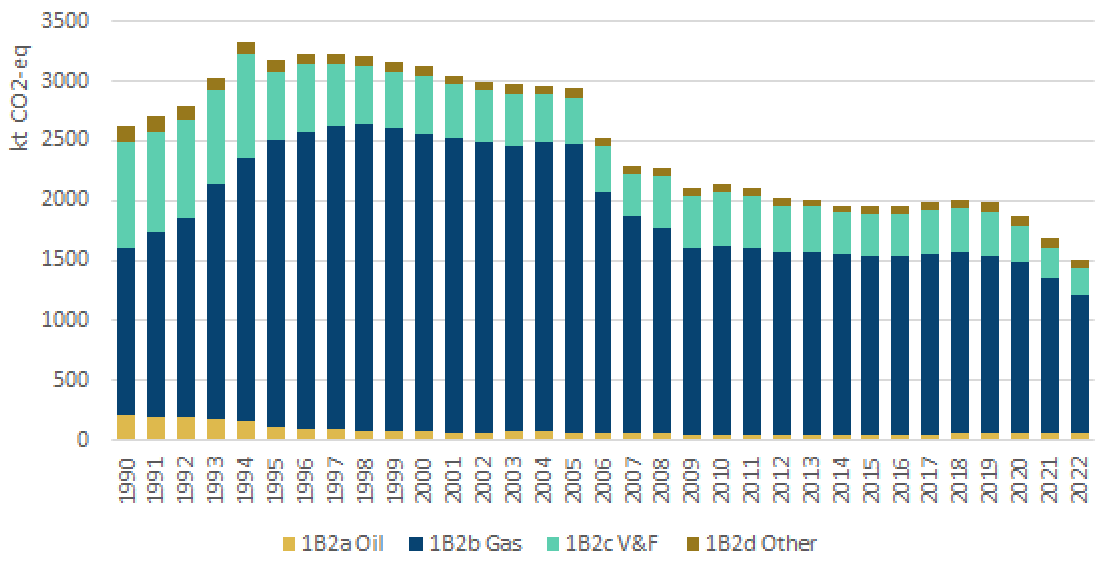


Figure 3.3.2 *Trends of emissions in CO_2-eq from 1.B.2 by subsector (Gg CO_2-eq emissions)*

3.3.2.2 Methodological issues

During the 2016 in-country review it was suggested to provide more detailed description of methodologies in this category to increase transparency. A detailed table summarizes the sources of activity data and emission factors in 1.B.2 subsectors which can be found in A3.1 of Annexes.

Activity data

Activity data is taken from IEA Energy Statistics. Data that is not included in IEA Energy Statistics has been provided by individual companies. In Hungary, the number of companies present in oil and gas sector is very limited, so full coverage might be assured. In subsector *1.B.2.c.i - Oil Flaring*, plant specific (EU ETS) data is also used, as very detailed verified data is available on flaring in oil refineries.

Emission factors

Default emission factors from 2006 IPCC Guidelines are applied. Chapter 4.2.2.3 of Vol2 contains one set of emission factors (Table 4.2.4) for “Developed Countries” and another Table (Table 4.2.5) for “Developing Countries and Countries with Economies in Transition”.

However, Hungary was regarded as a country with economy in transition in the beginning of the 1990’s, the economy underwent significant changes since then. Hungary is now part of the European Union, and there is a great change regarding the application of state-of-the-art technologies and environmental investments as well.

So, in order to reflect more the real trend, emission factors from Table 4.2.5 have been applied for the years 1985-1994 and emission factors from Table 4.2.4 have been applied from the year 1995.

EU ETS data in 1.B.2.c.i – Oil Refinery Flaring

CO_2 emissions from oil refineries of Hungary are taken from EU ETS annual emission reports and oil refinery flaring data is extrapolated for the years before 2005 using the amount of “Refinery intake” as surrogate data. In this way, full coverage and consistency within the time-series has been reached.

1B2b4 Natural Gas Transmission and storage and 1B2b5 Natural Gas Distribution.

Instead of applying the T1 methodology from the 2006 IPCC Guidelines, methane emissions from natural gas transmission, storage and distribution were re-evaluated based on information on technological losses determined by experts of the Hungarian Energy and Public Utility Regulatory Authority for the purpose of cost review of the domestic natural gas systems for the current price control cycle. Specific data on fugitive natural gas losses were received separately for transmission, storage, and distribution for the years 2016-2020. For the beginning of the time series (1985-1993), default emission factors from the 2019 IPCC Refinement were taken. For the intermediate years, interpolation techniques were applied. For 2021, the reported data were based partly on extrapolations.

1B2b4 Natural Gas Transmission and storage:

Data on technological losses in the transmission system received from the Authority was directly used in the inventory (27.8-29.0 Mm3/year in the period 2016-2019). Experts of the authority used basically two sets of data available from FGSZ Natural Gas Transmission Ltd, the single Hungarian transmission system operator (TSO) of the entire domestic natural gas transmission system: on the one hand, the annual gas purchases between 2016 and 2019 to cover the deficit/losses, and secondly the own technological use (operation of compressors, etc.). Fugitive emissions are assumed to be the difference of these two. Since gas purchases showed differences and the technological loss is essentially a stable value, fugitive losses were calculated by taking the average of the purchases in this period and deducting the own use for the given year.

For the period 2020-2022, estimations by FGSZ, the Hungarian TSO, have been taken into account. FGSZ as a member Oil & Gas Methane Partnership 2.0 (OGMP 2.0), started estimating its emissions applying the OMGP 2 methodology. FGSZ set out serious goals regarding methane emission reduction: based on 2015 base year data, it will reduce its emission by 50% until 2025 and by 60% till 2030.

Please note that the new default methane emission factors in the 2019 Refinement are between 2.08 t/km pipeline ("extensive LDAR, and around 50% or more of centrifugal compressors have dry seals") and 4.10 t/kilometre pipeline ("limited LDAR or less than 50% of centrifugal compressors have dry seals"). At the same time, our current numbers indicate an IEF of 3.2 t/km for the period 2016-2020 which seems to be in the middle of the above interval. For the remaining part of the time series, the EF has been extrapolated assuming that in 1993 (and all earlier years) the higher default emission factor was valid (i.e., 4.1 t/km pipeline).

Similar interpolation methodology was applied for gas storage. Actual data on technological losses (2.0 to 3.0 million cubic meter natural gas per year) indicated an average IEF of 0.17 t CH4/Mm3 natural gas consumption. The new default T1 emission factors in the 2019 Refinement are between 0.29 and 0.67 t/Mm3, and again, it was assumed that the higher value was representative for 1993, and the emission factors were interpolated between 1993 (0.67) and 2015 (0.17).

1B2b5 Natural Gas Distribution:

In previous submissions before 2021, we applied a T1 methodology based on utility sales with a default IPCC emission factor of 1.1 t CH4/million m3 of gas consumption. For recent submissions, our calculation is based on country-specific information on acknowledged distribution losses used for price regulation of gas distribution system operators.

Losses in distribution networks can be analyzed in the context of the 'Delta In-Out'. The Delta In-Out represents a difference observed when comparing the measurements at the intake points with the sum of downstream measurements of final customers off-take points, within a certain period. The delta in-out originates from many different factors. Based on a paper by the Council of European Energy Regulators (CEER, 2020), the full list of delta in-out components is the following:

1. Measurements frequency
2. Measurements accuracy
3. Linepack change
4. OBA changes
5. Blow-out during maintenance
6. Leakages
7. Theft

Similar to the above, experts of the Hungarian Energy and Public Utility Regulatory Authority determined the following four elements of distribution losses (see in brackets the values for 2020):

1.) measurement accuracy 1 (20.5 Mm3)
2.) measurement accuracy 2 - due to temperature or pressure conversion issues (12.2 Mm3)
3.) technological losses = leakages and blow-out during maintenance (56.4 Mm3)
4.) theft (15.8 Mm3)

From the above, only technological losses were taken into account in the inventory as fugitive methane emissions, and all other elements can be interpreted as "real" natural gas consumption, i.e. combustion. (It has to be noted that the real amount of theft might be somewhat higher; the above figure represents the acknowledged amount which is low enough to provide an incentive for companies to further reduce this loss element.) The estimated level of the main elements of the Hungarian delta in-out are summarized in the figure below:

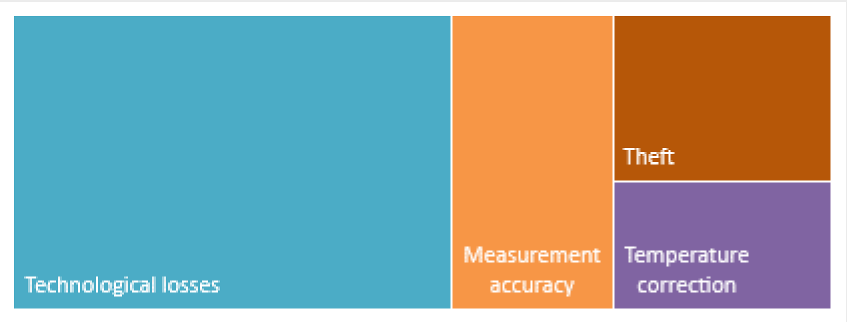


Figure 3.3.3 *Acknowledged distribution losses in the Hungarian natural gas distribution system in 2019-2020*

Coming back to technological losses which are relevant for this source category. Here, the expert determined a fixed annual value during the 2016 cost review. The two main parameters in the estimation were the proportion of low-pressure pipeline sections within the distribution network (lower pressure generates less loss) and the ratio of the total length of steel pipeline sections (higher leakage on steel pipelines). The expert, of course, compared the estimates with the values recorded by the companies. The price regulation of natural gas takes place in four-year price regulation cycles pursuant to the provisions of Act XL of 2008 on Natural Gas Supply. The last cycle commenced on January 1, 2017 and expired on December 31, 2020 therefore the same value was kept for 2020. The slightly different figure reported for 2021 was calculated using the equation presented below.

As the estimation of technological losses (=methane emission) serve basically the purpose of tariff determination in the natural gas system, it is changed only by the Authority if the underlying drivers change significantly. Experience shows however, that within one cycle none of the most important parameters change significantly: neither the total pipeline length, nor the segments of the pipelines operated on low pressure, nor the distribution of pipeline material. For example, total pipeline length changed only by 1% in the last four years which is most probably well below the uncertainty of the estimation of distribution losses anyway.

The general equation used for the estimation is as follows:

$$LOSS(total) = LOSS(techjust) * K(pressure) * K(material) * Q(<20) + LOSS(techjust) * K(material) * Q(20\text{-}100) + LOSS(techjust) * K(material) * Q(>100) + LOSS(techjust) * Q(notmeasured).$$

The calculation is made separately for four user categories: for example, Q(<20) stands for gas consumption (m3/year) of users with less consumption than 20 m3/h. LOSS(techjust) means the justified technological loss which has currently a value of 0.6% for measured and 0.3% for unmeasured consumption. The parameter K(pressure) corresponds to the experience that if a distributor operates only medium or high pressure systems, the technological loss might increase by 50% (so from 0.6% to 0.9%. In contrast, losses might decrease to 0.3% with only low pressure pipelines. So,

K(pressure) = 1.5 - (Length[lowpress]/Length[total]).

Currently, the share of low pressure pipelines is 11.3%.

With the parameter K(material) it is taken into account that with steel pipelines the leakage might by higher by 10% whereas with plastic pipelines by 10% lower. Hence:

*K(material) = 0.9 + 0.2 * (Length[steel]/Length[total]).*

The share of steel pipelines is 7.5%, a rather constant value recently.

Calculating an implied emission factor would result in a much higher value as in the 2006 IPCC Guidelines (e.g., 3.63 t CH4/Mm3 natural gas consumption in 2019 vs 1.1 t/Mm3 in the 2006 IPCC Guidelines). So, our IEF is higher than the default IPCC - even when looking at the 2019 Refinement where the new T1 default emission factors are between 0.62 and 2.92 t/Mm3. However, the 2019 Refinement suggests that the length of distribution pipeline is thought to best reflect emissions from distribution, and if pipeline data are available, they should be applied. Calculating an IEF on the basis of pipeline length, we would get 0.44 t/km which fits the interval of the new T1 EFs of the Refinement very well (0.23-1.17 t/km). (Which also means that the new T1 emission factors from the Refinement lead to quite different emission estimates depending on whether gas consumption or pipeline length is chosen as activity data.)

From the authority, we received estimated amounts of technological losses for the years 2016-2020 therefore backward extrapolation had to be carried out. In case of distribution losses, pipeline length was used as proxy data assuming that in 1993 the higher T1 emission factor from the 2019 Refinement representing a situation with "less than 50% plastic pipelines, or limited or no leak detection and repair programs" was valid.

1.B.2.d Other Fugitive emissions

Within this subsector fugitive CH_4 from groundwater extraction and fugitive CO_2 emissions from CO_2 mining is reported. No method is available in 2006 IPCC Guidelines for these activities, so country specific data has to be applied.

In the case of groundwater extraction, Geological and Geophysical Institute of Hungary provided expert estimate for the first time in 2015 based on 278/2015 Govt. Decree on data provision of Inventory preparation. This Institute is responsible for the monitoring, authorization and research of underground waters. They provided two set of data for the years 2004-2006 and noted that one method probably underestimates CH_4 emissions, while the other overestimates them.

So, the average of the two datasets has been applied and data have been extrapolated using Annual Groundwater extraction data from HCSO (replacing the previously used Eurostat data) as surrogate data.

In the case of CO_2 mining, activity data (million m^3 CO_2 mined/year) is available from the Mining and Geological Survey of Hungary (former Hungarian Office for Mining and Geology) from 1987. For the years 1985 and 1986 the data from 1987 is applied as extrapolation. Due to lack of emission factor, the EFs for fugitive emissions from natural gas production (extraction) from Table 4.2.4 (from 1995) and 4.2.5 (between 1985 and 1994 as described above) have been applied.

3.3.2.3 Uncertainties and time-series consistency

Uncertainty values from Table 4.2.4 have been aggregated using error propagation rule for the determination of emission factor uncertainty. For the uncertainty of AD, the same value is included as in other parts of the inventory for IEA Energy Statistics.

	AD	EF	Combined
1B2aOil – CH_4	5.00	84	90.17
1B2aOil – CO_2	5.00	44	45.47
1B2b Natural Gas – CH_4	5.00	276	337.58
1B2b Natural Gas – CO_2	5.00	278	267.54
1B2c Venting and flaring – CH_4	5.00	50	50.38
1B2c Venting and flaring – CO_2	5.00	472	429.89
1B2c Venting and flaring – N_2O	5.00	546	611.91
1B2d Other - CH_4	5.00	200	200.06
1B2d Other - CO_2	5.00	200	200.06

3.3.2.4 Source-specific QA/QC and verification

General QA/QC procedures apply. Plant specific data is verified with data in IEA Energy Statistics or with data received from the Mining and Geological Survey of Hungary (former Hungarian Mining Authority) where appropriate.

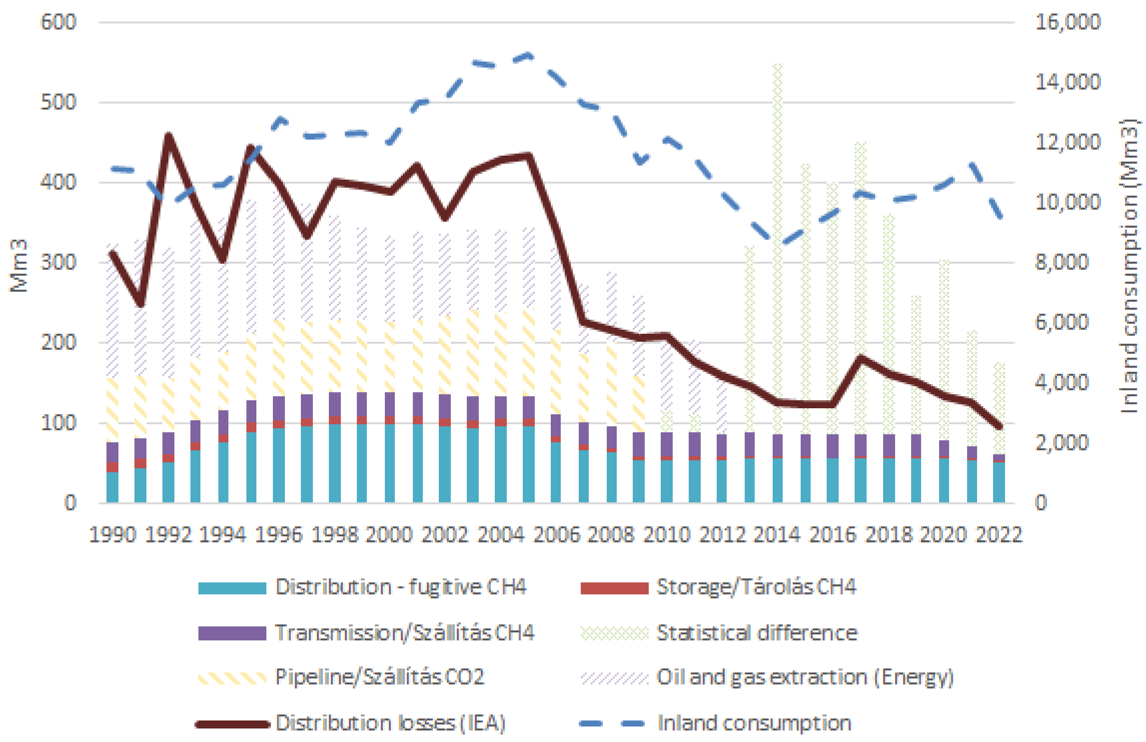
In the following graph, comparison is made between the total distribution losses reported to the IEA and the different elements reported here as fugitive emissions. In addition, some other sources are shown in the graph that might be part of the IEA figure but are assumed to be energy uses for example in gas extraction or pipeline transport.

3.3.2.5 Source-specific recalculations

Natural gas, transmission: CH4 emissions have been revised for 2020-2021 based on information received from the owner and operator of the whole domestic natural gas transportation system (FGSZ Ltd.)

Natural gas, distribution: amended activity data in 2005-2008 affected also interpolated data between 1994 and 2004

Our emission estimates remained the same in 1990 (and in the base year) but are lower by 240.2 kt CO2-eq (or 0.4% of the national total) in 2021.



3.3.2.6 Source-specific planned improvements

Generally, it is planned to apply the 2019 Refinement fully for fugitive emissions.

3.4 CO_2 transport and storage (CRF 1.C)

Not applicable.

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4 INDUSTRIAL PROCESSES (CRF sector 2)

Major changes compared to previous submission:

2.A.4.a – Ceramics and bricks. Activity data and CO2 emissions were recalculated for the year 2021 caused by a minor calculation error.

2.A.4.d – Waste gas scrubbing. Activity data and CO2 emissions were recalculated causing minor changes in the period 2019-2021 because of a calculation error.

2.B.8.d – VCM production. Instead of reporting as confidential, vinyl-chloride monomer activity data are reported from the year 2016, based on the producer's permission for reporting.

2.C.1 – Iron and steel. Coke consumption for sinter production for the year 2022 has been changed compared to the 2024 January submission causing -5.41 kt change in the CO2 emissions of the whole sector.

2.D.3 – Indirect CO2 emissions. Because of various recalculations in the different sources, the amount of indirect emissions (NMVOC emissions) have been changed for the whole time series.

2.F.1. Refrigeration and air conditioning – Revision of activity data for category of MAC. In the case of the output of trains, the entire time series has been recalculated for this submission, as more detailed data have been received from the largest Hungarian railway company. For buses, trams and cars emission values only for recent years have been corrected.

2.F.2. Foam blowing agents – Production data of activity data (PRODCOM - Cellular plates, sheet, film, foil and strip of polymers of styrene and of polyurethanes) have been updated for the year 2021.

2.G.2. SF6 and PFCs from other product use – Emission from subapplication particle accelerators are reported. In response to a recommendation from review conducted in 2023 Hungary should report emission from particle accelerators. A first estimate is included in this submission.

The overall effect of the above recalculations is not significant: -5.4 kt CO2-eq (0.01% of total emissions) in 2021 caused mainly by recalculations of F-gases and indirect emissions from the non-energy products from solvent use, and +27.9 kt CO2-eq (0.03% of total emissions) in 1990 caused by recalculations of indirect emissions in the 2.D.3 sector.

4.1 Overview of sector

Industrial Processes sector includes emissions generated by non-combustion processes related to industrial production. Emissions from the industrial processes and the agriculture are the second largest following the energy having a similar share of 10% each in 2022 (see Chapter 2).

Emissions from this category comprise the following subcategories:

- Mineral Products (CRF 2.A),
- Chemical Industry (CRF 2.B),
- Metal Production (CRF 2.C),
- Non-energy Products from Fuels and Solvent use (CRF 2.D),
- Electronics Industry (2.E),
- Consumption of Halocarbons and SF_6 (CRF 2.F) and

- Other Product Manufacture and Use (CRF 2.G).

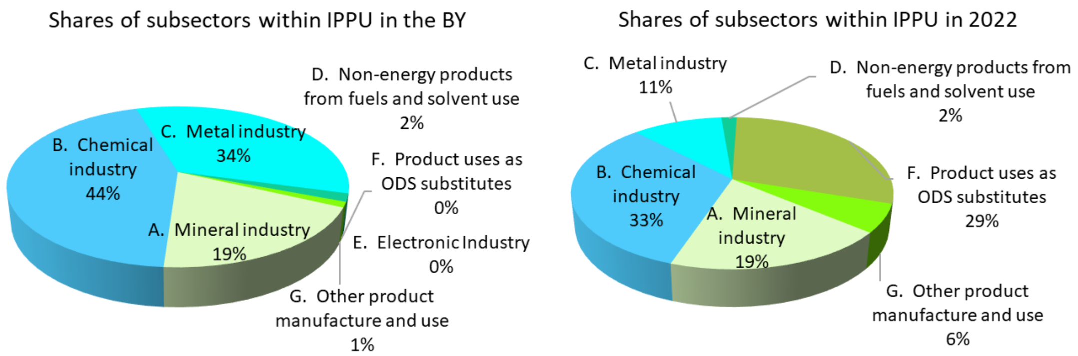
Under Mineral Products, Hungary reports the emissions from cement production (CO_2), lime production (CO_2), limestone glass (CO_2,), and other mineral products including bricks and ceramics production, mineral wool production, waste gas scrubbing and soda ash use (CO_2).

Under Chemical Industry, emissions from ammonia (CO_2), nitric acid (N_2O), and petrochemical and carbon black production (CO_2, CH_4) are reported.

Under Metal Industry, emissions from pig iron (CO_2, CH_4), steel (CO_2, CH_4), ferroalloys (CO_2), aluminium (CO_2, CF_4, C_2F_6) are taken into account. Consumption of halocarbons and SF_6 means emissions from different sources, for example: refrigeration, air conditioning equipment, foam blowing, aerosols, electrical equipment. The 2.G sector contains emissions from manufacturing and use of electrical equipment and SF_6 and N_2O use in other products (SF_6 and N_2O).

Indirect GHGs are reported in an aggregated way, but the time-series are fully consistent with CLRTAP Air Pollutants Emission Inventory reporting of Hungary.

The base year is the average of 1985–1987 for CO_2, CH_4 and N_2O, and 1995 for HFCs, PFCs and SF_6.



***4.1.1. Figure**: Shares of subsectors within Industrial sector (Gg, CO_2-eq)*

Several subsectors within Industrial Processes sector consist of emission originating from industrial facilities that are also falling under the scope of European Union Emission Trading System (EU ETS) - Directive 2003/87/EC. EU ETS data reported by the individual operators (summed together by industrial sector) is more accurate than the use of default factors, its use in inventory preparation needs special attention due to time-series consistency problems. In the Industrial Processes sector, EU ETS data is directly used in sector *2.A.1 Cement production*, *2.A.2 Lime production* (since 2014 submission), *2.A.3 Glass production, 2.A.4.d Other mineral (Other - Waste gas scrubbing)* and partly in *2.A.4.a Ceramics, 2.B Ammonia, Nitric Acid and Petrochemical production* and *2.C.1 Iron and Steel* sectors. Consistency is ensured by the fact that before including extrapolation, the implied emission factor is always analyzed and depending on the trend either the IEF of the last year, or the average implied emission factor of the years is applied.

In the case of indirect greenhouse gases, consistency with CLRTAP/NEC reporting has been reached since 2014 submission. The calculation method of the indirect GHG and SO_2 emissions is described in detail in the Informative Inventory Report of Hungary submitted for CLRTAP reporting, available for each year at:

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

Summary of tier methods in the mineral, chemical and metal industries as well as in the non-energy products uses of the IPPU sector are given in the table below.

4.1.1. Table: *Tier methods, emission factors and key sources in the IPPU sector for categories A-B-C-D*

Category	Tier method				Emission factor				Key sources
	CO_2	CH_4	N_2O	PFCs	CO_2	CH_4	N_2O	PFCs	
2.A.1 Cement Production	T2, T3				CS, PS				L
2.A.2 Lime Production	T2, T3				CS, PS				T
2.A.3 Glass Production	T2, T3				CS, PS				
2.A.4 Other Process Uses of Carbonates	T2, T3				CS, PS				
2.B.1 Ammonia Production	T3				CS, PS				L
2.B.2 Nitric Acid Prod.			T3				PS		T
2.B.8 Petrochemical and Carbon Black Prod.	T2, T3	T1			CS, PS	D			CO_2 – L, T
2.C.1 Iron and Steel Prod.	T3	T2			PS	D			CO_2 – L, T
2.C.2 Ferroalloy Production	T1				D				
2.C.3 Aluminium Production	T1			T2	D			D	PFCs – T
2.D Other Products Use	T1, T2				D				

QC of completeness and allocation of CO_2 from Non-Energy Uses and other fuels used in IPPU sector

Please find in A3.2 of Annexes based on Table 1.3 in Volume 3 of the 2006 IPCC Guidelines recommended for check of completeness of non-energy use (NEU) of fuels filled in for year 2017.

4.2 Emission Trends

Total emissions estimated from industrial processes were 5915 kt CO_2-eq in 2022, or 10% of the total national emissions compared to 13% in the base year. Total sectoral emissions decreased by 59% between the base year and 2022, by 33% between 2005 and 2022, and by 17% between 2021 and 2022.

Greenhouse gas emissions from the industrial processes sector fluctuated slightly in the beginning of the inventory period, then a considerable decline happened: emissions reached their minimum in 1992, which was mainly due to economic crisis. Later on, emissions had been fluctuating again until 2005. Since then, emissions have been showing a decreasing tendency again until 2009 and aggregated emissions decreased by 31% between 2005 and 2016. There was a slight growth in year 2010 and 2011, but GHG emissions from industrial processes sector were again lower both in 2012 than in 2013, the latter was the absolute minimal value of the whole time-series. In 2015 emissions increased again by 12% due to higher production volumes in several subsectors. In 2017 the revival of the economy can be seen also in emission data of all industrial sectors except of 2.G. However, after this increase, emissions started to slightly decrease again, turning into a steeper decline in 2022.

Figure 4.2.1 shows the trend of GHG emissions from industrial processes by subcategories from the base year to 2022. *Chemical industry* was the most important emitter in the beginning of inventory period, especially N_2O emission from nitric acid production (for details see chapter 4.4). Between 1990 and 2005 *Chemical industry*, *Mineral industry* and *Metal production* were fluctuating around the same level. After the significant fall of emission in *Chemical Industry* thanks to the N_2O abatement technology introduced in *Nitric acid production* in 2007, and the hard recession of the *Mineral industry*, *Metal production* took up the leading role. The growing tendency of *Consumption of Halocarbons and SF_6* has also stopped in 2008.

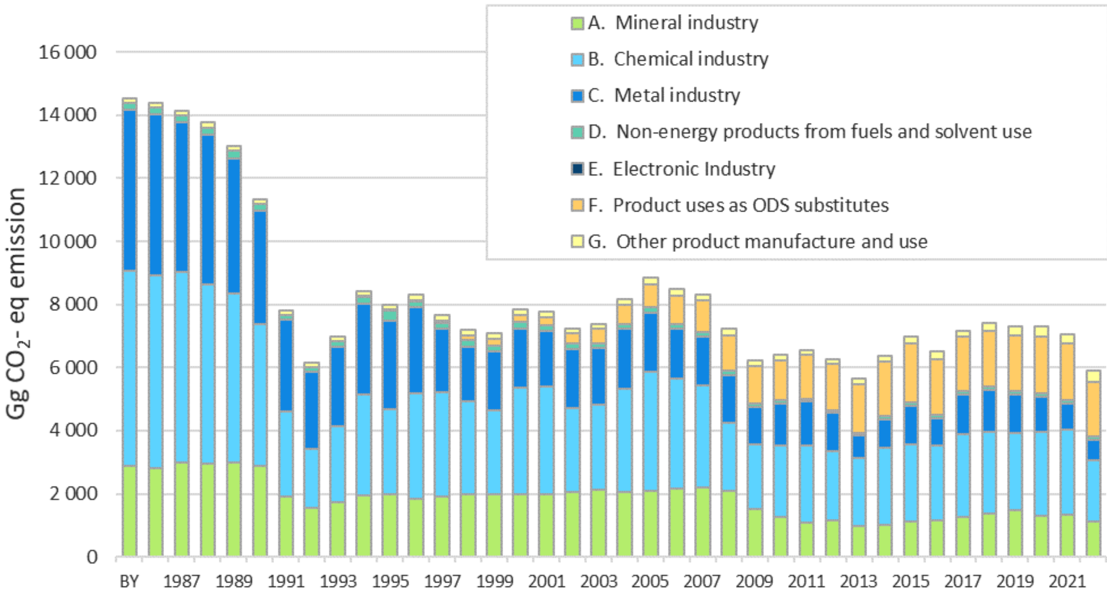


Figure 4.2.1: *GHG emissions from Industry sector by subsectors (Gg CO_2-eq)*

The significant decrease of emissions in the period between 1989 and 1993 is strongly represented in the above figure. The reason for that is the economic transition mentioned already in previous chapters. In the course of transition, factories were closed down, capacity utilization was reduced, consequently the production decreased more or less drastically in each industrial sector.

Some examples:

- Iron and steel production: two out of three plants were closed down;
- Aluminium: two out of three plants were closed down in 1991 and the aluminium production stopped in 2006;
- Ferroalloys: ceased to exist (1991);
- Ammonia: four out of five plants were closed down (1987, 1991, 1992 and 2002);
- Nitric acid: three out of four plants were closed down (1988, 1991 and 1995).

The privatization was slower in the industry than in other areas of the economy. Foreign investments were made rather in medium or smaller sized enterprises than in the big companies of the Hungarian industry.

One of the reasons of temporary production decrease was the modernization process of the remaining factories which was carried out that time and which by the way lead to favourable changes of specific emission factors as well. This was the situation e.g. in the cement and limestone industry. In some cases, however, also plants having more advantageous emission factors were closed, causing unfavourable changes in the national emission factor. This was the situation e.g. in the production of nitric acid before 1995.

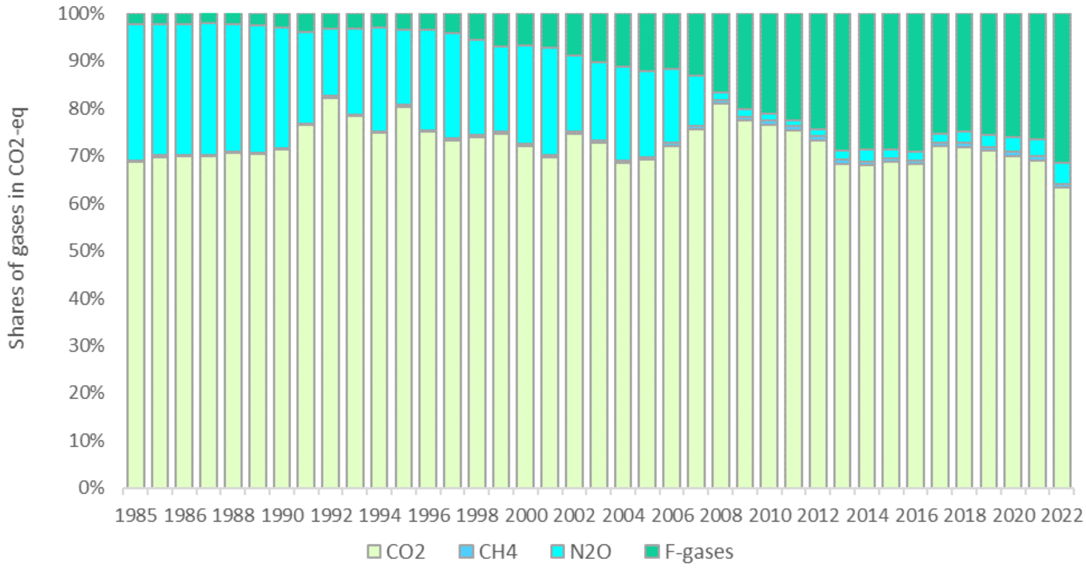
Since the mid-1990s, emissions by industry have been showing a fluctuating behaviour reflecting the actual demands of production in the national economy.

In 2022, the downward flight of pig iron production continued due to problems in the operation of Hungary's only pig iron manufacturer, therefore the output of iron and steel production decreased by 24%. The growth of chemical industry emissions stopped in 2021 and started to decrease in 2022: due to the sharp fall of ammonia and urea based fertilizers production, the emissions of this sector decreased by 28%. Emissions from mineral industry (mainly from cement production) started to decrease again, it was 16% less in 2022 than in the previous year. Emissions from the non-energy use of fuels and solvent use increased by just 1% after the stronger growth in 2020.

Almost a third of industrial emissions come from the operation of equipment containing F-gases and from use of F-gas containing products. Category 2.F.1. (Refrigeration and air-conditioning) accounts for 84% of total F-gas emissions, emissions growth has stopped in recent years. Use of fluorinated and perfluorinated compounds (HFCs, PFCs) has been significant in Hungary since the early 1990s, but these gases became a commonly used refrigerant in the second half of the decade. Most of the equipment with F-gas installed after this period is now coming to the end of its lifetime. Disposal and regeneration of increasing quantities of gases from equipment end-of-life helps to stop emissions growth.

4.2.1 Emission trends by gases

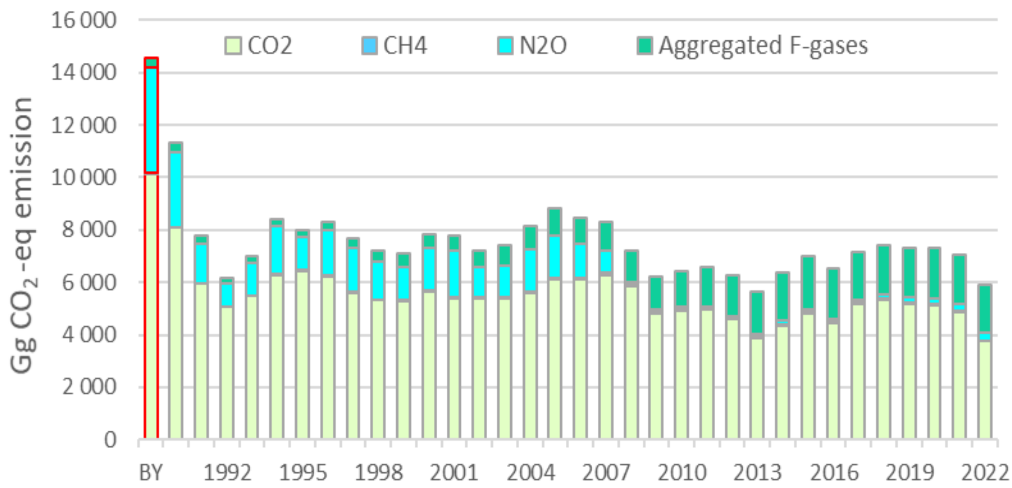
The most important GHG in Industrial Processes sector is carbon dioxide, contributing 63% to total GHG emissions in this sector in 2022, followed by F-gases with 31% . CH_4 and N_2O contributed 1 and 5%, respectively *(Figure 4.2.2).*



(BY: average of 1985-87 but 1995 for F-gases)

Figure 4.2.2 *Shares of gases in Industry sector (Gg CO_2-eq)*

The figure below *(Figure 4.2.3)* shows the emissions of this sector by gases. It can be seen that in 2008, N_2O emission from Industrial Processes are 99.89% below the level of the base year and dropped by 99.44% from 2007 to 2008 which is due to the introduction of a new nitric acid plant.



(BY=average of 1985-87 but 1995 for F-gases- data in red frame)

Figure 4.2.3 *Trend by greenhouse gases in Industry sector*

4.2.2 Emission trends by sources

In the base year, the chemical subsector accounted for 42% of total industrial GHG emissions, followed by metal subsector 35%, mineral subsector 20%. In 2022, 33% of the emissions came from chemical industry, followed by 30% from product uses as ODS substitutes. Mineral industry has 19%, metal industry has 11% contribution to sectoral GHG emissions, respectively. Other product uses (containing SF6 and N2O) and non-energy products from fuels and solvent use have the smallest influence on the 2021 IPPU inventory with 6% and 1%, respectively. (See ***Figure 4.2.1*** above.) Emissions by sources and by gases appear in *Table 4.2.1* for 2022.

Table 4.2.1 *Emissions of Industrial processes sector in 2022 (CO_2-eq)*

	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	Total
2. Industrial processes	**3744**	**42**	**268**	**1746**	**2**	**110**	**5912**
A. Mineral industry	1128	NO	NO	NO	NO	NO	**1128**
B. Chemical industry	1872	39	23	NO	NO	NO	**1934**
C. Metal industry	636	3	NO	NO	NO	NO	**639**
D. Non-energy products from fuels and solvent use	108	NO	NO	NO	NO	NO	**108**
E. Electronic industry	NO	NO	NO	NO	NO	NO	**NO**
F. Product uses as ODS substitutes	NO	NO	NO	1746	2	NO	**1748**
G. Other product manufacture and use	NO	NO	245	NO	NO	110	**355**
H. Other	NO	NO	NO	NO	NO	NO	**NO**

4.3 Mineral Products (CRF sector 2.A)

4.3.1 Cement Production (CRF sector 2.A.1)

4.3.1.1 Source category description

Emitted gas: CO_2

Methods: T2 (1985-2004), T3 (2005-)
Emission factors: CS, PS
Key sources: 2A1 Cement Production – CO_2 – L

CO_2 is generated during cement production in the clinker production phase:

- on the one hand, during the combustion of the fuels used,
- on the other hand, during the degradation of the limestone ($CaCO_3$) fed into the furnace, which occurs at around 1,300˚C and results in CaO (calcium oxide) and CO_2 (calcinations).

Both dry and wet technologies may be used for the preparation of the raw clinker. Wet technology is used by one of the three cement production plants in Hungary.

In this sector the emission estimation methodologies are very similar in the case of IPCC and EU ETS (Methodology of EU ETS reporting is prescribed in 601/2012/EC EU ETS Monitoring and Reporting Regulation). From 2005, in their EU ETS Annual Report, cement producing companies report the amount and CO_2 content of the used raw material and CKD supported by monthly measurement results.

Significant decrease of emissions has occurred in this sector between 2008 and 2013, but in 2014 the trend has changed (see *Figure 4.3.1*). The decrease of emissions correlates with the decrease of activity data. Activity data is reported directly by the cement producer companies via EU ETS Annual Emission Reports since the last years and verified with the data of HCSO if the latter is available. The decrease of activity data can be explained by decrease of the production, due to the continuous recession of this industrial sector. In building industry, the recession also turned up and 2014 is the first year that brought some recovery since 2010. The producing facilities were struggling to survive, which is published also on their website and reflected in volume indices (NACE Rev.2 classes CG- 2351 Manufacture of cement - Volume index of industrial gross output). Although solely 3 cement plants have been operating since 2014 (compared to 5 in 2010), cement production has been rising steadily in every year. After a temporary decline in 2020, the growing trend of the sector continued in 2021, however in 2022 it started to decrease again, it was 16% less in 2022 than in the previous year.

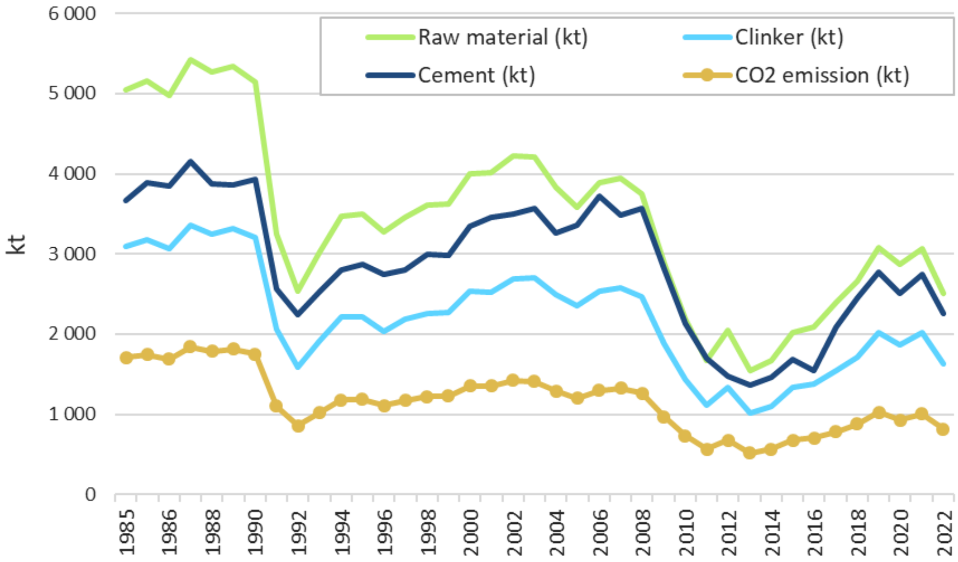


Figure 4.3.1 *Trend of activity data and CO_2 emission in cement production*

4.3.1.2 Methodological issues

In this category, only emissions from the production processes are determined. Gases originating from fuels are included in *Energy subsector 1.A.2*.

From 2005, emissions are estimated using Tier 3 method: according to the EU ETS directive (2003/87/EC) introduced by the European Union, the factories report their CO_2 emissions. The factories calculate their CO_2 emissions based on the amount and the CO_2 content of all of the used raw materials and not recycled CKD filtered by dust collectors in a following way: CO_2 content of raw flour multiplied by the amount of raw flour minus CO_2 content of filtered dust multiplied by the amount of filtered dust. According to the 601/2012/EU directive and the valid greenhouse gas emissions permits issued by the Hungarian Energy and Public Utility Regulatory Authority, CO_2 content is analyzed by a certified laboratory. Detailed data of carbonate composition is not needed for this method.

For the period 1985-2004, emissions are estimated using Tier 2 method, which follows Eq.2.2 (Tier2 emissions based on clinker production data) of the 2006 IPCC Guidelines, fulfilling the assumptions given on page 2.10. The emission factor is a plant specific factor calculated by averaging the measured CO_2 content of raw meals for the period 2005-2010 (in case of one plant for 2005-2013) with the assumption that every CDK was recycled to the kiln.

Production data for the whole time-series were obtained directly from the factories and from the EU Emission Trading System (*Table 4.3.1*).

The UN review (ARR) of 2016 suggested to use a good practice data splicing technique given in the 2006 IPCC Guidelines (e.g. overlap technique or surrogate data), as appropriate for Hungary's national circumstances, to fill data gaps in the time series of the CO_2 IEF for the period before 2005. The suggested calculation was implemented in 2017 submission. The methodology was described in the 2017 NIR and emission changes appeared in the 2017 CRF tables. There were no recalculations in the submissions after 2017.

Table 4.3.1 *Amount of raw flour used in process, clinker and cement production (kt) in Hungary and the CO_2 emission and implied emission factor in 2.A.1 sector*

	Total raw flour (kt)	Total clinker (kt)	Total cement (kt)	2A1 SUM CO_2 (kt)	*2A1 CO_2 (kt)per clinker (kt)*
1985	5044	3098	3671	**1707**	*0.5511*
1985-87	5152	3173	3889	**1745**	*0.5498*
1986	4982	3070	3845	**1687**	*0.5497*
1987	5430	3352	4151	**1839**	*0.5487*
1988	5264	3250	3871	**1785**	*0.5492*
1989	5338	3321	3857	**1813**	*0.5459*
1990	5148	3210	3933	**1751**	*0.5453*
1991	3247	2067	2563	**1102**	*0.5329*
1992	2533	1591	2246	**859**	*0.5397*
1993	3010	1907	2521	**1022**	*0.5359*
1994	3477	2211	2795	**1181**	*0.5341*
1995	3493	2214	2875	**1186**	*0.5356*
1996	3275	2034	2745	**1111**	*0.5460*
1997	3463	2185	2806	**1174**	*0.5373*
1998	3603	2262	2995	**1222**	*0.5401*
1999	3617	2271	2979	**1224**	*0.5393*
2000	3998	2532	3348	**1353**	*0.5344*
2001	4009	2522	3452	**1357**	*0.5379*
2002	4218	2687	3504	**1426**	*0.5306*
2003	4209	2696	3565	**1412**	*0.5237*
2004	3828	2495	3267	**1289**	*0.5168*
2005	3579	2353	3364	**1199**	*0.5096*
2006	3884	2533	3723	**1296**	*0.5116*
2007	3939	2577	3485	**1328**	*0.5153*
2008	3747	2468	3570	**1261**	*0.5107*
2009	2889	1883	2808	**973**	*0.5166*
2010	2181	1433	2134	**735**	*0.5131*
2011	1672	1109	1692	**564**	*0.5081*
2012	2047	1333	1478	**678**	*0.5091*
2013	1552	1018	1364	**516**	*0.5067*
2014	1537	1095	1467	**566**	*0.5167*
2015	2015	1331	C	**676**	*0.5076*
2016			C	**705**	
2017			C	**783**	
2018			C	**882**	

4.3.1.3 Uncertainties and time-series consistency

Time-series of emissions is consistent using country specific emission factors before 2005 – derived from measurements reported to EU ETS (detailed description can be found in the methodological part of this section).

Uncertainties are estimated based on the minimum requirements of EU ETS Monitoring and Reporting Regulation (601/2012/EU) for determination of AD and EF in the case of cement production:

Uncertainty		**AD**	**EF**	**Combined**
2A1 Cement Production	CO_2	2.5	2.5	3.54

As the use of ETS data means the use of verified data, where carbon contents should be measured in accredited laboratory (or at least a laboratory yearly validated and inter-compared with accredited laboratory as it is prescribed in 601/2012/EC Regulation on Monitoring and Reporting in EU ETS).

4.3.1.4 Source-specific QA/QC information and verification

According to the EU ETS directive (2003/87/EC) introduced by the European Union, the factories report their CO2 emission from 2005 on. The factories calculate their CO2 emissions on the basis of their production data, and the analysis of raw flour, and cement kiln dust (CKD), which contains CO2 generated from all carbonates, including MgCO3 and other. The analysis must fulfill the strict requirements of 601/2012/EU regulation which prescribes the use of ISO17025 accredited laboratories and the minimum annual frequency of analysis (modified by the Commission Regulation (EU) 743/2014 replacing Annex VII to Regulation (EU) No 601/2012 as regards minimum frequency of analyses). In addition, the annual emission reports of the factories are verified by independent EU ETS verifiers and checked by the authority responsible for EU ETS in Hungary every year.

The factories calculate their CO_2 emissions based on the amount and the CO_2 content of all of the used raw materials and not recycled CKD filtered by dust collectors in a following way: CO_2 content of raw flour multiplied by the amount of raw flour minus CO_2 content of filtered dust multiplied by the amount of filtered dust. According to the valid greenhouse gas emissions permits issued by the Hungarian Energy and Public Utility Regulatory Authority, detailed data of carbonate composition is not needed for this method.

Cement production data from report of factories and EU ETS are always verified with the official statistical data. Usually the difference is low but there are some years where significant difference (more than 2%) appears. Hungarian Central Statistical Office (HCSO) started to investigate this problem on our proposal. According to its finding after 2011 the difference connected to one factory and this factory was asked to check the reported data. It would be important to further analyze this problem for those years which were not covered in this project however archived individual data before 2000 is not so easily accessible at HCSO.

Clinker production data was compared to Eurostat data. Unfortunately, Eurostat has incomplete time-series. 2012 is the only year when Eurostat database corresponds to our data source.

4.3.1.5 Source-specific recalculations

None.

4.3.2 Lime Production (CRF Sector 2.A.2)

4.3.2.1 Source category description

Emitted gas: CO_2

Methods: T2 (1985-2004), T3 (2005-)
Emission factors: CS, PS
Key sources: 2A3 Lime Production – CO_2 – T

This subsector includes quicklime production by limestone heating. During heat transfer, the following reaction occurs:

$CaCO_3$=CaO+CO_2

Here, only CO_2 is generated according to this formula. In Hungary, high-purity limestone is processed. Raw material contains high percent of $CaCO_3$ (96.8% in 2018) and minor amount of $MgCO_3$ (2.3% in 2018). CO_2 generated by combustion processes is accounted under the *Energy sector in 1.A.2*.

During the 2012 EU Technical review, a question was raised whether the autoproduction of lime of sugar producers is included. The investigation resulted that sugar producing companies have never reported technological (originating from dissociation of limestone) emissions in the EU ETS annual emission report (as they do not have this emission source in their GHG emission permit). However, the practice is right because no technological CO_2 emissions arise from Hungarian sugar producers since all of them use $Ca(OH)_2$ + CO_2 precipitation technology to remove impurities. This technology is described in the sector specific IPPC BAT BREF document as well (European Commission, 2006).

> *"**2.1.4.11.3 Description of techniques, methods and equipment***
>
> *Carbonation is the introduction of the milk of lime, calcium hydroxide, and carbon dioxide gas (CO_2) into a liquid to form calcium carbonate and to precipitate and remove impurities. The effect of lime and CO_2 is the precipitation of insoluble calcium salts, the flocculation of colloidal components, the chemical degradation of other molecules such as invert sugar and amides, and the absorption of non-sugars on precipitated calcium carbonate. Lime and CO_2 are normally produced in lime kilns by the thermal dissociation of limestone.)"*

In addition, Hungarian BAT reference document prepared in 2005 by Hungarian Sugar Industry Research Institute for the Ministry of Environment and Water (KVVM, 2005 - available only in Hungarian) states that CO_2 emission from lime kilns in sugar production facilities are attributable solely to fuel combustion of the lime kilns since "*CO_2 originating from dissociation of limestone is rebound again into $CaCO_3$.*" (Section 4.1.2.2.2) Fuel consumption of lime kilns are reported in *Energy* sector. Precipitated $CaCO_3$ is used for liming of soils (in general) reported in *Agriculture* sector.

During informal review organized by EEA in November 2015, a question was raised if it was verified that all emissions from lime production was reported and all lime was produced only in lime plants which are included in the EU ETS (except sugar production as described above). Regarding this issue industrial associations in the field of mineral industry have been looked over and no other plants have been found. In addition, lime production data in EU ETS annual emission reports and data from the

Hungarian Statistical Office was also compared and strange result has been found that usually statistics are the lower. The average difference between years 2004 and 2012 is that HCSO data on lime production is 8% lower than EU ETS data. However, EU ETS data seems to be more accurate as EU ETS annual emission reports are verified every year. So, it seems that emissions are not underestimated due to incompleteness of the sector.

Please also note that emissions from lime and dolomite used in iron and steel industry are reported in sector *2.C.1 Iron and steel*.

4.3.2.2 Methodological issues

The amount of CO_2 generated by this subsector is reported by using plant-specific (EU ETS) emission data of companies after 2005 and using a country specific IEF for extrapolation for the years before 2005.

The country specific IEF has been created taking into account that IEFs of years between 2005 and 2012 do not show a clear trend as it is presented in the following *Figure 4.3.2*, therefore the average seems to be applicable for extrapolation for the years before 2005 in order to reach consistent time series. The average of years 2005-2012 results in 0.7388 t CO_2/t lime produced which is 5.9% lower than the stoichiometric IEF of 0.785 and it is well fitting in the IEF range 0.56-0.8 applied by other countries as presented in the 2013 Synthesis and Assessment Report of UNFCCC.

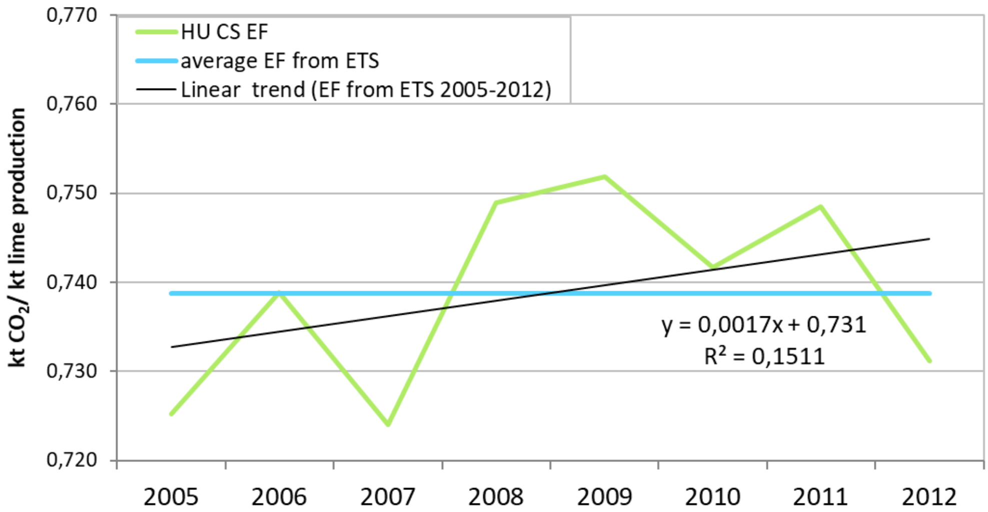


Figure 4.3.2 *Trend of kt CO_2/kt lime produced IEF between years 2005 and 2012*

Exact carbonate contents of the raw material and the remaining carbonate content of the products determined by accredited laboratories are used for the calculations in EU ETS Annual Emission Reports (AERs). Using EU ETS data, the emissions from the minor proportion of dolomitic lime (containing $MgCO_3$), impurities and the eventual presence of hydraulic lime (which has the same stoichiometric ratio as lime but has a lower CaO content and the eventual recycling of lime kiln dust are also taken into account as it is required by the 2006 IPCC Guidelines. As EU ETS data for the years 2005-2012 contains the above-mentioned corrections, also the IEF used for extrapolation contains them.

In 2018, two companies produced lime in Hungary. According to their EU ETS annual reports, raw material contained high percent of CaCO3 and minor amount of MgCO3. Calculation of their reported emission is based on Equation 2.7 of 2006 IPCC Guideline (page 2.21), where fraction calcination achieved for carbonate$_i$ (F_i) equals to 1 for both carbonates, and fraction calcination achieved for lime kiln dust equals to 1. Emission factors for the carbonates are determined by monthly laboratory measurements.

The difference between the country–specific EF and the default EF is below 1 % (see *Table 4.3.2*).

Table 4.3.2 *Comparison of country-specific and default emission factors in case of lime production*

Source of EF	**Value (kt CO_2/kt limestone)**	***difference to default***
Default Tier 1 EF of 2006 IPCC Guidelines *(Vol3 2.3.1.2 - Table 2.4) = (CO_2/CaO) * CaO content = 0.785* 0.95 =)*	0.7458	
HU CS EF	0.7388	*-0.93%*

Time-series of lime production and related emissions can be seen in *Figure 4.3.3.*

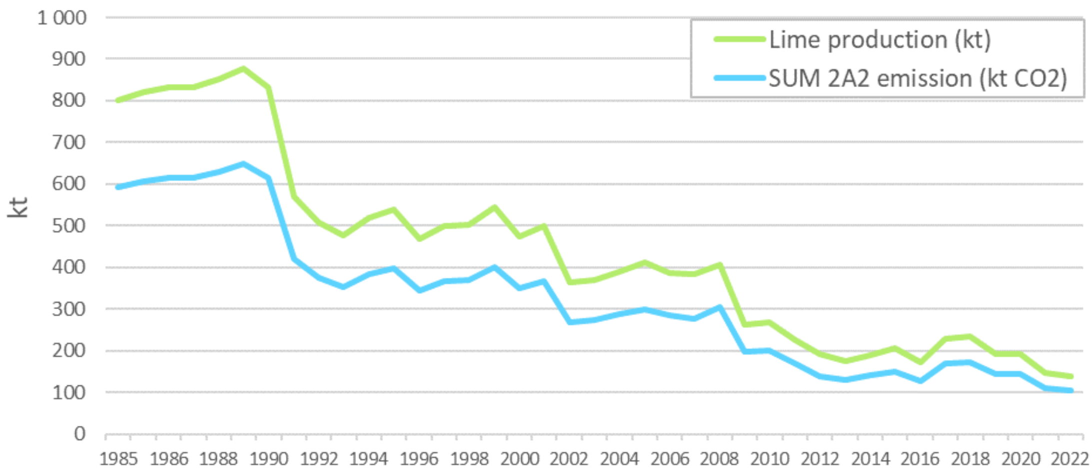


Figure 4.3.3: Trend of production and emissions in sector 2.A.2 Lime

4.3.2.3 Uncertainties and time-series consistency

Time-series of emissions is consistent using country specific emission factors before 2005 – derived from measurements reported to EU ETS.

Uncertainties are estimated based on the minimum requirements of EU ETS Monitoring and Reporting Regulation (601/2012/EU) for the determination of AD and EF in the case of Lime production:

Uncertainty		**AD**	**EF**	**Combined**
2A2 Lime Production	CO_2	2.5	2.5	3.54

4.3.2.4 Source-specific QA/QC information and verification

According to the EU ETS directive (2003/87/EC) introduced by the European Union, the factories report their CO2 emission from 2005 on. The factories calculate their CO2 emissions on the basis of their consumed raw material and final product, and the analysis of chemical composition of both them.

The analysis must fulfill the strict requirements of 601/2012/EU regulation which prescribes the use of ISO17025 accredited laboratories and the minimum annual frequency of analysis (modified by the Commission Regulation (EU) 743/2014 replacing Annex VII to Regulation (EU) No 601/2012 as regards minimum frequency of analyses). In addition, the annual emission reports of the factories are verified by independent EU ETS verifiers and checked by the authority responsible for EU ETS in Hungary every year.

4.3.2.5 Source-specific recalculations

None.

4.3.2.6 Source-specific planned improvements

Reported analysis of uncertainty in measurements will be included in the NIR when it will be available for all plants.

4.3.3 Glass Production (CRF sector 2.A.3)

4.3.3.1 Source category description

Emitted gas: CO_2

Methods: T2 (1985-2004), T3(2005-)
Emission factors: CS,PS
Key sources: None

In the case of glass production, CO_2 emission is generated by adding the carbonates (mainly soda ashes) of alkali metals (Ba, Li, Na, etc.) to the melt in the course of glass melting. Glass production is also within the scope of EU Emissions Trading System. Please note that solely process emissions are reported in this sector, as combustion emissions are included in *1.A.2*.

4.3.3.2 Methodological issues

Most of the glassworks are covered by EU Emission Trading System, the quantity of CO_2 emitted from carbonates reported by them is used as emissions between 2005 and 2016 submissions, and country-specific IEFs have been created for extrapolation for the years before 2005.

In inventory submissions before 2015, one single IEF was used for all glass types. As it was suggested by the ARR of 2014, new IEFs by glass types are now applied (details in Table 4.3.3). The difference between the default and country-specific IEFs might be further investigated, however they are within the range of Tier 2 default emission factors of the 2006 IPCC Guidelines.

Table 4.3.3 *Comparison of country-specific and default IEFs in the case of glass production*

source/ type of emission factor	Value (t CO_2 / t glass)
Default T1 IEF (Eq.2.13)	0.200
Default T2 IEFs (Table 2.6)	0.03 -0.25
CS IEF - Float glass	0.156
CS IEF - Container glass	0.181
CS IEF - Speciality glass	0.154
Default IEF - Fiberglass (glass wool)	0.250
OLD HU submission IEF	0.164

Quite detailed activity data is available from HCSO, so time-series by different glass-types could have been separated for the extrapolation.

During informal review organized by EEA in November 2015, a question was raised if it was verified that all emissions from glass production was reported and all glass was produced only in plants which are included in the EU ETS. Unfortunately, in glass sector it is not possible to perform comparison of activity data from Hungarian Central Statistical Office with EU ETS data, as in this case in EU ETS Annual emission reports there is no information on production, but solely on the amount of input materials (and emissions of course). So, also in this case industrial associations in the field of mineral industry has been looked over and only very small plants with technological emissions (emissions from carbonates) have been found in addition to those covered by EU ETS. However, in the National Air Emissions Database (LAIR) at least one bigger glass producer had been found that is not covered by EU ETS. Therefore, in the case of glass sector +10% had been added in order to cover the emission of plants not covered by EU ETS since the 2016 submission.

Further investigation was carried out to cover all non-ETS plants. Unfortunately, this mentioned plant with high reported production rate has not sent any data on multiple requests until now, but it confirms, that the production data in the LAIR database is not correct (the reported amount exceeds the EU ETS capacity threshold and much higher than the reported capacity of the plant). Surprisingly our data request had positive effect on LAIR database, namely the reported 2017 production data of this plant is lower with two orders of magnitude than before and this amount fits to all capacity thresholds. So, time-series of production data of this firm was corrected. It was known that Hungary has another small glasswork – producing handmade glassware. This firm has made available the amount of input material containing carbon and also emissions from them. Knowing production data of this firm for the 2005-2013 period, implied emission factor and also an average value of them were calculated for the time-series. As both of the two mentioned glassworks produce table wares, this average IEF was applied in the emission estimation in case of missing data.

In 2016 one of the plants covered by EU ETS announced capacity reduction with which it no longer falls under the EU ETS and therefore it has no more ETS reports, but this firm still reports data on production to the LAIR database. Implied emission factor from the EU ETS emission report of the last known year of this firm was applied in the calculation of emission for the 2016 and 2017 years.

This research pointed out that the statistics did not cover some special glass products – production was accounted elsewhere -, which are part of the ETS glass sector. During the preparation of Allocation Plan of Hungary under the EU ETS, these plants made available emission data for the 1998-2004 period which are consistent with the 2005-2017 calculations. For the missing years production data of bulbs from HCSO was used as surrogate data. As the amount of glass used to produce bulb needs further investigation, activity data was not changed in the time-series.

As the non-ETS part is much lower than it was assumed before, therefore the additional 10% of the implied emission factor for the non-ETS period was replaced by a new calculation. The calculation is based on the quantity of product manufactured (glass and other special product) and the implied emission factor derived from the ETS reports for each type of glass products.

Figure 4.3.4 below shows the complete CO_2 emission from this category.

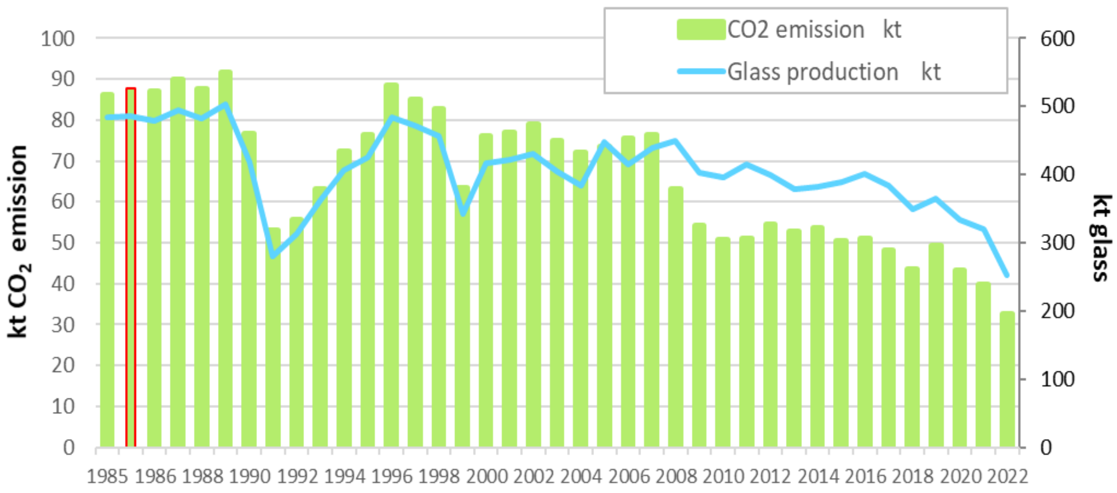


Figure 4.3.4 *Trend of CO_2 emission and Glass Production (kt)*

4.3.3.3 Source-specific QA/QC information and time-series consistency and uncertainty

Uncertainties are estimated based on the minimum requirements of EU ETS Monitoring and Reporting Regulation (601/2012/EU) for the determination of AD and EF in the case of glass production:

Uncertainty		AD	EF	Combined
2A3 Glass production	CO_2	2.5	2.5	3.54

4.3.3.4 Source-specific recalculations and verification

More detailed data request was sent to HCSO in 2017 to verify the information from LAIR database. Also glass manufacturers were asked to declare their used technology and amount of used raw material. Unfortunately, HCSO has no full production time-series in mass unit for those factories which are not covered by EU ETS. Only one glass manufacturer fulfilled data request and provided detailed dataset about the amount of used raw material containing carbonate before this submission. Emission of this plant is 0.1kt CO2/year at the most in the 2005-2016 period, which is 0.2% at the most of the total emission of glass production in Hungary. Another small manufacturer declared last year that this small plant does not use carbonate containing raw material, they use glass pellet for manufacturing glass. In chapter 4.3.3.2 mentioned plant which was found in LAIR database was also contacted several times. Until this submission no data was provided about its technology and activity for the 2005-2016 period.

Investigation of addition of 10% to the data reported under the EU ETS for 2005 and onwards was finished this year. (This was a recommendation of the last UNFCCC review.) The non-ETS part in glass production was recalculated for the 2005-2016 period. This research pointed out that the statistics did not cover some special glass products – production was accounted elsewhere -, which are part of the ETS glass sector. As the non-ETS part is much lower than it was assumed before, therefore the additional 10% of the implied emission factor for the non-ETS period was replaced by a new calculation. The calculation is based on the quantity of product manufactured (glass and other special product) and the implied emission factor derived from the ETS reports for each type of glass products.

This recalculation resulted positive changes in the total CO2 eq emission of Hungary only in 1999 (0.0008%), in 2003 (0.0017%) and in 2004 (0.0025%), every other year small decrease (less than 0.01%) can be observed.

4.3.3.5 Source-specific planned improvements

None.

4.3.4 Bricks and ceramics (CRF sector 2.A.4.a Other)

4.3.4.1 Source category description

Emitted gas: CO_2

Methods: T3
Emission factors: CS, PS
Key sources: None

During manufacturing of bricks, tiles and ceramic products, CO_2 emission is generated from the degradation of carbonates in raw materials (mainly from clay) on the one hand, and from burning of materials added to bricks on the other. Please note that in present submission all the fuels (also as additives) are reallocated into *1.A.2* together with all other combustion emissions from *Bricks and Ceramics production*.

4.3.4.2 Methodological issues

Tier 3 method is used to determine emission as in case of other EU ETS sectors. Plant-specific data is reported for the years 2005-2016 and a country-specific IEF is generated for the extrapolation of emissions before 2005 based on IEFs from 2005-2013 and national statistics of produced bricks and ceramics. Also in this case, the trend of IEFs is taken into consideration, in order to decide if average or the IEF of year 2005 represents better. In the case of bricks and ceramics, the latter is applied as the trend is decreasing.

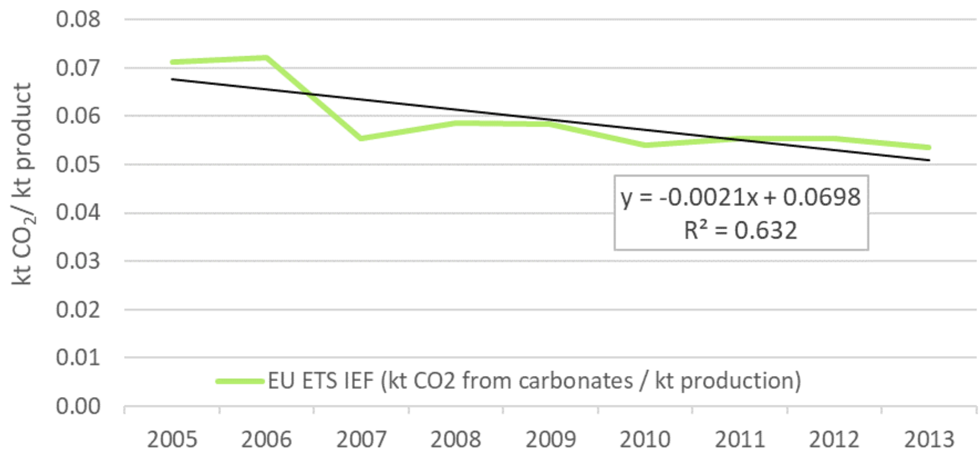


Figure 4.3.5 *Trend of plant specific IEF between 2005 and 2013 in Bricks and ceramics*

In previous inventory submissions – until 2015 -, +10% of the EU ETS emissions have been added supposing that not all the factories fall within the scope of EU ETS. This supposition could not be demonstrated until now, so, it was not applied in the 2015-2017 submissions.

During the 2020 review, a question arised that carbonates contained in raw materials are not described in the NIR. Brick and ceramics producing companies (in 2018, there were 22 companies) use different types of clay and refractory mass as raw material. In EU ETS, companies report the carbon and CO_2 content of their raw material supported by measurement results of certified analytical testing laboratories. CO_2 emissions from the organic carbon and carbonate content of raw materials, reported in ETS, is calculated based on the analytical results.

During the informal review organized by EEA in November 2015, a question was raised if it was verified that all emissions was reported and all bricks, tiles and ceramics are produced only in plants which are included in the EU ETS. The Hungarian Brick Association still has no information about plants not included under EU ETS, but small factories have reported activities in this field to the LAIR database. Unfortunately, product data from individual plants reported to the HCSO is confidential. Therefore, data request was sent to HCSO in 2017 and 2018 to calculate the non-ETS part of products (for years 2005-2017) comparing the list of firms reporting bricks and ceramics production to national statistics and firms reporting to the EU ETS. It is worth to mention that emission from different type of ceramics was calculated with the appropriate implied emission factors for the non-ETS part. The investigation pointed out that also that time-series is not fully consistent because statistics do not include some categories which have only confidential time-series. Also, the preparation of activity data in tonne unit from the official available statistics (e.g. bricks given in small bricks unit) is a challenge, besides the reporting requirement has changed several times and in several categories, the categorization is not permanent, as well. The results of the recalculation summarized in the following table.

4.3.4. Table: Proportion of non-ETS products and CO2 emission in Bricks and ceramics

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013
Proportion of non-ETS products (%)	5,7	6,2	5,1	11,6	6,8	3,8	5,4	5,7	5,3
Prop. of non-ETS CO_2 emission (%)	6,7	6,4	5,3	13,2	7,3	3,8	5,6	5,8	5,4
Emission (kt CO2)	285,9	293,3	281,9	266,7	92,8	81,5	75,8	66,9	61,6
Year	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Proportion of non-ETS products (%)	4,0	4,2	2,9	2,9	2,9	2,6	3,3	2,9	2,7
Prop. of non-ETS CO_2 emission (%)	3,8	4,0	2,9	2,9	3,0	2,6	3,5	2,9	2,7
Emission (kt CO2)	59,7	66,5	85,6	95,6	99,8	105,6	76,1	84,4	76,4

4.3.4.3 Uncertainties and time-series consistency

Time-series is not fully consistent, reasons are summarized in chapter *4.3.4.2 Methodological issues*

Uncertainties are estimated based on the minimum requirements of EU ETS Monitoring and Reporting Regulation (601/2012/EU) for the determination of AD and EF of process uses of carbonates:

Uncertainty		AD	EF	Combined
2A4 Other Process Uses of Carbonates	CO_2	2.5	2.5	3.54

4.3.4.4 Source-specific QA/QC information and verification

General QA/QC procedures apply.

4.3.4.5 Source-specific recalculations

None.

4.3.4.6 Source-specific planned improvements

Time-series inconsistency appears before 2003 when the preparation of activity data in tonne units causes difficulties (i.e., brick production is given by the number of produced bricks). Alternative sources of information are hardly available, time-series inconsistency is planned to be resolved by a mathematical method in a medium term.

4.3.5 Soda Ash Use (CRF sector 2.A.4.b)

Emitted gas: CO_2

Methods: T3
Emission factors: D
Key sources: None

4.3.5.1 Methodological issues

Carbon dioxide is released when soda ash (Na_2CO_3) is heated.

During the 2013 centralized review, the ERT recommended to compare total import-export data of soda ash in Hungary and soda ash use in glass production in order to ensure that all soda ash uses are reported. (Please note that soda ash is not produced in Hungary.) Although the difference changes year by year, the sum of 2005-2016 of total import-export is higher than the sum of soda ash used in glass industry in 2005-2016. Therefore, additional reporting of CO_2 emission arising from soda ash not used in glass industry is needed in *2.A.4.b*.

Activity Data

Total import/export of soda ash

Time-series of activity data is presented in *Figure 4.3.7* and *Figure 4.3.6*. As it was recommended by the ERT, total domestic soda ash consumption has been estimated "from domestic production plus net imports data available from statistics. Last year statistics were obtained from of UNComtrade (http://comtrade.un.org) (imports minus exports, for disodium carbonate)".

Both HS classification code 283620 and SITC classification code 52323 for disodium carbonate results the same time-series. Hungarian Central Statistical Office publishes import-export data from year 2003 on its website. Differences between UNComtrade data and HCSO data are below 0.007% (6(t) Na_2CO_3). To have consistent and complete time-series data request was sent to HCSO for the whole period and it was recalculated in this submission. Unfortunately, still no data is available for years before 1991 on import/export of soda ash neither in UNComtrade and EUROStat databases, nor in the database of the Hungarian Central Statistical Office. Therefore, extrapolation was needed applying volume indices of total trade presented in *Table 4.3.5* as sector-specific volume indices are available only from 1999 within the databases mentioned above.

Table 4.3.5 *Volume indices of total trade of soda ash*

		1985	1986	1987	1988	1989	1990	1991	1992
Volume indices of trade (compared to previous year)	import	0.98	0.98	1.00	0.97	1.08	0.83	1.21	0.83
	export	1.02	0.97	0.94	1.00	1.04	1.05	0.99	1.15

Source: http://www.ksh.hu/docs/hun/xstadat/xstadat_hosszu/h_qkt001.html

Determination of the amount of soda ash not used in glass industry

Comparison of total domestic soda ash consumption and soda ash used in glass industry is presented in ***Table 4.3.6***. The data on Na_2CO_3 used in EU ETS glass production have been extracted from the EU ETS Annual Emission Reports of the glass producing companies.

In several years, the soda ash used in glass production is higher than the total (import-export), while in other years it is lower. We assume that this changing trend might be due the volatility of the market and the stockpile of the glass producing companies.

In order to level off negative values, average values of the years 2005-2015 are taken into consideration. The average of soda ash NOT used for glass production /year is 2180 t/year, which results 0.905 Gg CO_2/year. The average of soda ash NOT used in glass production (=2180 t) compared to the average of total import – export (=63803 t) results 3.42%.

In other words, the difference between the SUM of total import-export of soda ash and the SUM of soda ash used in glass production is 3.42% as it is presented in *Table 4.3.6*. As the amount of soda ash used for other purposes than glass production accounts for only 3-3.5% of the total amount and can be used in a variety of applications, we do not have a plan to identification of soda ash use in other industry sectors.

Table 4.3.6 *SUM of total domestic soda ash consumption and soda ash used in glass industry*

	SUM of 2005-2015
Total import-export (t) Na_2CO_3	701,837
(t) Na_2CO_3 in EU ETS glass	677,856
(t) Na_2CO_3 difference	23,980
(t) Na_2CO_3 difference /(t) Total	3.42%

So, for our calculations, 3.42 % of the total import-export data of the given year is considered to be the amount of soda ash not used in glass production.

This ratio seems to be applicable for extrapolation for years before 2005 as the slope of the trend is quite small: R2 < 0.1 as it is presented on the figure below (*Figure 4.3.6*).

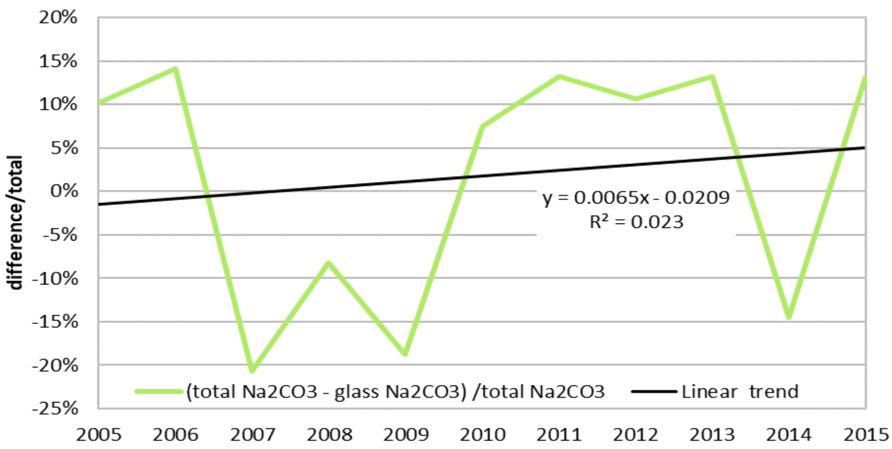


Figure 4.3.6 *Trend of soda ash not used in glass production between 2005 and 2015*

The following equation is applied for the entire time series and the results are presented in the below:

Soda ash NOT used in GLASS industry in year (n) = AD of 2.A.4.b=

(Total import-export of soda ash in year (n)) *3.42%

Emission factor and CO_2 emission of sector 2.A.4.b

In 2013, ERT recommended us to calculate CO2 emissions from other soda ash use than for glass production in category 2A4b. In 2006 IPCC Guideline, Tier 1 and Tier 2 methods for calculating CO2 emissions from other process use of carbonates are based on limestone and dolomite, thus we chose Tier 3 method for calculating emissions from Na2CO3 (soda ash). The emission factor is the factor for soda ash from Table 2.1 (0.41492 tonnes CO2/tonne carbonate). As in Hungary there is no soda ash production, activity data equals to the exported minus imported amount of soda ash minus soda ash used in glass production with the assumption that 100 percent of calcination is achieved (Tier 3 method for the choice of activity data, page 2.37, 2006 IPCC Guideline).

Figure 4.3.7 summarizes the time-series of activity data and CO_2 emissions in *2.A.4 Soda Ash use*.

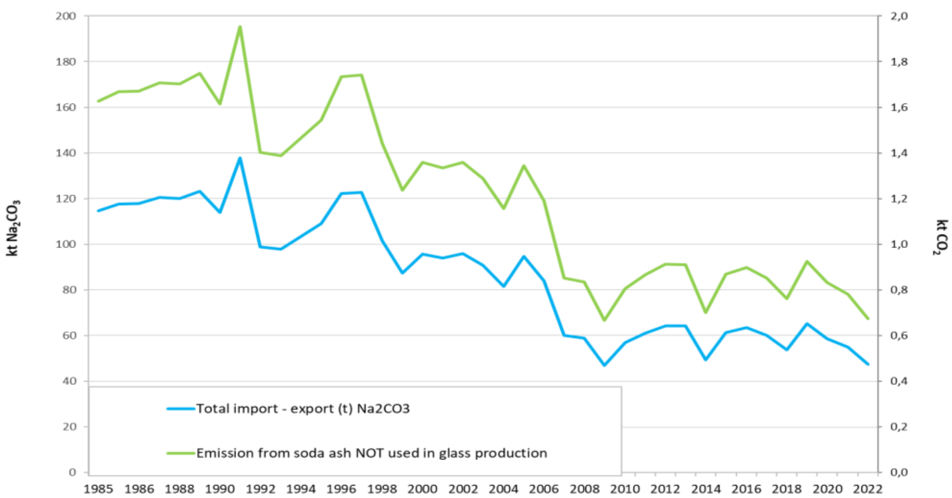


Figure 4.3.7 *Trend of total domestic consumption of soda ash and CO_2 emissions in sector 2.A.4.b.*

4.3.5.2 Source-specific QA/QC information and verification, uncertainties and planned improvements

General QA/QC procedures apply.

The same uncertainty values have been applied as in the case of all subcategories of *2.A.4.d Other Mineral Industry*.

4.3.5.3 Source-specific recalculations

None.

4.3.6 Other Process Uses of Carbonates (CRF sector 2.A.4.d)

4.3.6.1 Source category description

Emitted gas: CO_2

Methods: T2, T3
Emission factors: CS, PS, D
Key sources: None

This subsector includes processes in which calcinations (CO_2 loss) occur as a result of heating carbonates. CO_2 emissions generated by the degradation reaction are calculated while gases from fuel combustion are included in subsector *1.A.2*. In this sector limestone and dolomite use for flue gas scrubbing and process emissions from mineral wool production are included.

Situation of other possible uses of limestone and dolomite in Hungary:

- carbide production is not occurring in Hungary as far as our knowledge;

- various uses during iron and steel production are included in *2.C.1*;

- emissions from carbonates during production of clay-based products are included in *2.A.4.a Bricks and ceramics;*

- emissions from carbonates during production of glass are included in *2.A.3. Glass*, which includes also glass wool production.

We have no information of other uses of limestone and dolomite in Hungary.

4.3.6.2 Methodological issues

Flue gas desulphurization has been carried out in one power plant since 2002 and in another one since 2004. Activity data on the use of carbonates for SO_2 scrubbing is either reported by the operators directly to the HMS or to EU ETS competent authority. In EU ETS the operators are required to report also CO_2 emission from the use of carbonate for scrubbing separately in their annual emission report since 2008. So, direct, plant-specific emission data is used in *2.A.d.i.* subcategory from year 2008 and emissions are calculated using stoichiometric ratios (included in Table 2.1 of Vol3. of the 2006 IPCC Guidelines: 440 kg CO_2 / ton limestone) for the years before 2008. In 2016 six plants reported emission from flue gas desulphurization to the EU ETS.

In the case of EU ETS plant specific data, emissions are also calculated by the operators using usually the stoichiometric ratio and fraction of purity of 1 (440 kg CO_2 / ton limestone). In 2013 one operator started to analyze the exact carbonate content of the limestone used in laboratory (fulfilling the requirements of 601/2013/EU Regulation). In 2014 a new entrant of EU ETS declared that its fraction of purity is lower than the theoretical one, because part of the carbonate remains in ash. So, these plants do not use a purity fraction of 1 anymore.

Process emissions from mineral wool production are small, but it is included in order to improve completeness of the inventory. Mineral wool producers report their CO_2 emissions since 2008 under the EU ETS. So, plant-specific emissions and activity data is available for these years. However, mineral wool production has been present in Hungary since 2001 due to EuroStat Prodcom database. Therefore, extrapolation was applied for the years 2001-2008 for the estimation of emissions. Activity data was taken from EuroStat Prodcom database and from HCSO database, and IEF of process emissions of year 2013 is applied for the extrapolation due to lack of other detailed data.

Please note that in CRF waste gas scrubbing and mineral wool are reported together under *2.A.4.d*, as it is not possible to add child node in this category.

Unfortunately, activity data are also different in the two subsectors. Carbonates used for waste gas scrubbing was chosen as AD in the CRF as it is much more significant than mineral wool.

Please find the detailed time-series of activity data and emission in *Table 4.3.7* below. Please note, that activity data and CO2 emissions were recalculated causing minor changes in the period 2019-2021 because of a calculation error.

Table 4.3.7 *Emissions from different sources and activity data within 2.A.4.d Other Carbonate Uses*

	Carbonates used for waste gas scrubbing (AD in CRF) (kt)	***Emission from waste gas scrubbing ($Gg\ CO_2$)***	**Mineral wool production (kt)**	***Emission from mineral wool production ($Gg\ CO_2$)***	***Sum emission 2.A.4.d (EM in CRF) ($Gg\ CO_2$)***
1985-2000	NO	*NO*	NO	*NO*	***NO***
2001	NO	*NO*	45.0	*2.1*	***2.1***
2002	262.6	*115.5*	51.0	*2.3*	***117.9***
2003	315.2	*138.7*	57.1	*2.6*	***141.3***
2004	388.2	*170.8*	58.0	*2.7*	***173.5***
2005	504.8	*222.1*	61.0	*2.8*	***224.9***
2006	487.2	*214.3*	84.2	*3.8*	***218.2***
2007	493.2	*217.0*	99.9	*4.6*	***221.6***
2008	467.5	*205.7*	61.1	*2.8*	***208.5***
2009	437.8	*192.6*	36.7	*1.7*	***194.3***
2010	429.9	*189.2*	40.6	*1.9*	***191.0***
2011	478.2	*210.4*	51.4	*2.4*	***212.8***
2012	466.7	*205.3*	46.7	*2.1*	***207.5***
2013	473.7	*203.9*	45.4	*2.1*	***206.0***
2014	438.6	*186.9*	43.3	*2.7*	***189.5***
2015	440.0	*191.0*	48.8	*2.9*	***194.0***
2016	432.4	*187.0*	48.5	*3.1*	***189.3***
2017	357.9	*155.4*	48.8	*2.8*	***158.2***
2018	372.3	*161.2*	49.5	*2.5*	***163.7***
2019	331.3	*140.5*	49.4	*2.4*	***142.9***
2020	272.1	*118.2*	50.5	*1.8*	***120.0***

2021	231.3	*96.3*	55.6	*2.1*	***98.4***
2022	237.7	*97.2*	49.8	*2.2*	***99.4***

4.3.6.3 Uncertainties and time-series consistency

Uncertainties are estimated based on the minimum requirements of EU ETS Monitoring and Reporting Regulation (601/2012/EU) for the determination of AD and EF of process uses of carbonates:

Uncertainty		**AD**	**EF**	**Combined**
2A4 Other Process Uses of Carbonates	CO_2	2.5	2.5	3.54

4.3.6.4 Source-specific QA/QC information and verification

General QA/QC procedures apply.

4.3.6.5 Source-specific recalculations

None.

4.3.6.6 Source-specific planned improvements

Further verification of activity data for mineral wool and improvement of country-specific implied emission factor is planned.

4.4 Chemical Industry (CRF sector 2.B)

The relevant processes operated in Hungary include:

- Ammonia production
- Nitric acid production
- Production of other organic chemicals: carbon black, ethylene, dichloroethylene and formaldehyde.

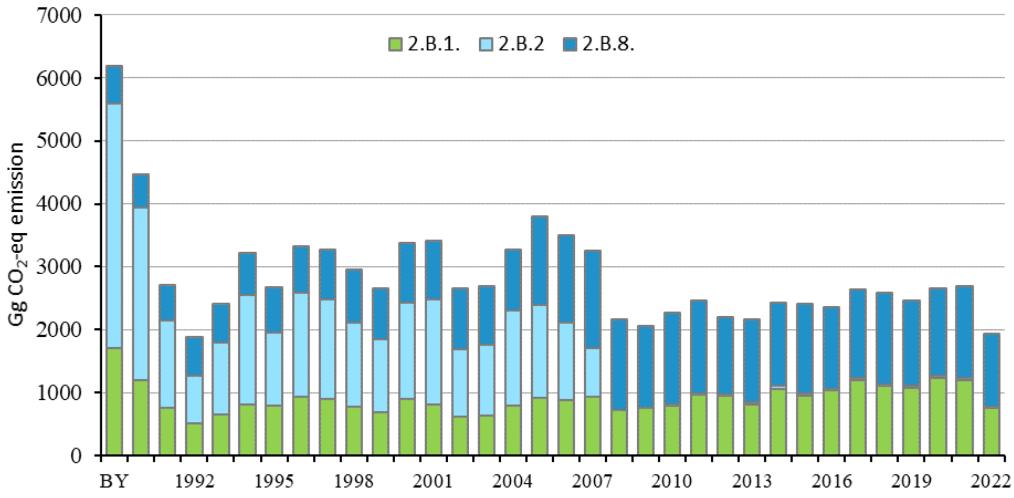


Figure 4.4.1 *Shares of subsectors within chemical industry*

Also in the case of chemical industry, the decrease of emissions after 1990 was due to the regime change (see *Figure 4.4.1*). Several factories were closed down and the production decreased drastically. Another significant drop of emissions occurred in 2007 when a state-of-the–art N_2O abatement technology has been introduced in a nitric acid plant (Nitrogénművek Zrt., 2008).

Production of the chemical industry is fluctuating since 2010, which is reflected in the volume index of this sector's gross output (corresponding period of the previous year= 100 (per cent): 2009: 83.9; 2010: 113.7; 2011: 107.7; 2012: 99.7; 2013: 105.6; 2014: 108.6; 2015: 102.4, 2016: 98.2). It is worth to mention that production of ammonia was 10% higher in 2016 meanwhile volume index of chemical industry decreased. The difference between the trend of production of chemical industry and the trend of emissions in *2.B* sector might be explained by the increasing environmental performance of the chemical plants.

However, the growth of chemical industry emissions stopped in 2021 and started to decrease in 2022: due to the sharp fall of ammonia and urea based fertilizers production, the emissions of this sector decreased by 28%.

It is also worth to take into consideration that the 2006 IPCC Guidelines Vol. 3 Chapter 1 suggests that:

"Combustion emissions from fuels obtained directly or indirectly from the feedstock for an IPPU process will normally be allocated to the part of the source category in which the process occurs. These source categories are normally 2B and 2C."

Therefore, all natural gas used in chemical industry for process purposes are accounted now here. Please find below the table (*Table 4.4.1*) showing the allocation of natural gas use in IEA Energy Statistics and in the HU GHG inventory.

Table 4.4.1 *The allocation of natural gas use in IEA Energy Statistics and in the HU GHG inventory*

	Natural gas use in *Chemical Industry* in IEA Energy Statistics (TJ NCV)			**Natural gas allocation in *Chemical Industry* in HU GHG Inventory (TJ NCV)**						
	Energy used in 2.B sector	Non-energy use	SUM	2.B.1 Ammonia	2.B.1. Hydro-gen	2.B.1 Tail gas treat-ment Nitric Acid	2.B.8 Petroche-mical	*SUM 2B*	*Reported in 1.A sector*	SUM
1985	19919	34294	**54212**	35317	0	1373	1722	38411	*15801*	**54212**
BY	21461	33968	**55430**	34371	0	1483	1720	37574	*17855*	**55430**
1986	22205	33897	**56102**	33820	0	1432	1718	36970	*19132*	**56102**
1987	22260	33715	**55975**	33976	0	1646	1719	37341	*18633*	**55975**
1988	21373	30393	**51766**	30583	0	1529	1706	33817	*17949*	**51766**
1989	22578	31115	**53693**	31182	0	1127	1701	34010	*19683*	**53693**
1990	22831	23113	**45944**	24342	0	993	1640	26974	*18970*	**45944**
1991	18754	14869	**33623**	14687	0	702	1586	16974	*16649*	**33623**
1992	17847	10099	**27946**	10111	0	445	1580	12136	*15810*	**27946**
1993	16622	12871	**29493**	12358	0	574	1675	14607	*14886*	**29493**
1994	13573	15560	**29133**	14683	0	1116	1866	17665	*11468*	**29133**
1995	17537	15950	**33486**	14536	0	981	2061	17577	*15909*	**33486**
1996	18580	17169	**35749**	16223	0	1669	2092	19984	*15765*	**35749**
1997	21939	12574	**34513**	15555	0	1678	2274	19506	*15007*	**34513**
1998	14162	12575	**26736**	13779	0	1476	2401	17656	*9080*	**26736**
1999	10892	11215	**22107**	12299	0	1357	2324	15980	*6127*	**22107**
2000	10266	13668	**23935**	15865	63	1567	2616	20112	*3823*	**23935**
2001	10256	13867	**24123**	14288	188	1599	2651	18726	*5397*	**24123**
2002	9383	8712	**18095**	10167	1765	1024	2536	15493	*2602*	**18095**
2003	8097	9169	**17267**	10114	1948	1141	2507	15709	*1557*	**17267**
2004	6368	13454	**19822**	13035	2028	1235	2403	18701	*1121*	**19822**
2005	8257	15055	**23312**	14729	2393	1392	2781	21295	*2017*	**23312**
2006	7938	14192	**22130**	13856	2760	1328	2944	20888	*1242*	**22130**
2007	9031	16409	**25439**	15115	2973	911	3304	22303	*3136*	**25439**
2008	7937	14719	**22656**	11486	2919	6	3634	18045	*4612*	**22657**
2009	5391	13534	**18925**	12730	2568	8	2555	17861	*1063*	**18924**
2010	6538	15149	**21686**	13699	2644	9	3128	19480	*2207*	**21687**

2011	6579	17134	**23713**	15788	3603	17	2868	22276	*1437*	**23713**
2012	4467	19000	**23467**	14022	4409	16	3147	21594	*1872*	**23466**
2013	10059	16472*	**26531***	11377	4991	9	5176	21553	*4978**	**26531**
2014	9594	20713*	**30307***	15392	5552	12	4220	25176	*5130**	**30307**
2015	9792	18596*	**28388***	12682	5622	16	4046	22366	*6021**	**28388**
2016	10308*	20406*	**30713***	14342	5773	21	3712	23848	*6866**	**30713**
2017	10879	23322	**34201**	16513	6474	28	3720	26735	*7469**	**34204**
2018	10792	20395	**31187**	13514	6697	28	4036	24275	*6909*	**31184**
2019	10994**	20763	**31757****	13690	6967	32	4123	24812	*6844***	**31656****
2020	10084**	22996	**33080****	16706	6367	46	3498	26668	*6462***	**33130****
2021	9746	22414	**32160**	15125	7035	40	3287*	25487*	*6676**	**32163***
2022	8210	13546	**21756**	7588	6053	22	2627	16290	*5484*	**21774**

* Recalculated IEA values
** Recalculated in 2023 IEA values

4.4.1 Ammonia Production (CRF sector 2.B.1)

4.4.1.1 Source category description

Emitted gas: CO_2

Methods: T3
Emission factors: CS, PS
Key sources: 2B1 Ammonia Production – CO_2 – L

Ammonia (NH_3) production in Hungary uses natural gas. In the case of ammonia manufacture, natural gas provides both feedstock and fuel, whose carbon content is released in the form of carbon dioxide.

The same process occurs in the case of hydrogen production and the treatment of tail gas with natural gas in nitric acid plants.

In Hungary, the significant part of hydrogen synthesized is used also for ammonia production, but the hydrogen plant is operated by another company. The share of hydrogen/nitrogen-based ammonia production within all ammonia production has been about only 5%. 95% of ammonia production has been "traditional" natural gas based. In the last few years "traditional" ammonia production varies between 12% (in 2017) and 16% (in 2015). As in the new CRF Reporter Software there is no possibility to report CO_2 in sector *2.B.2,* the emission from tail gas treatment with natural gas is reported here. The process (emission factor) is anyway the same as in the case of ammonia and hydrogen production.

In 2017 UNFCCC ERT disapproved of allocation of hydrogen production and tail gas treatment with natural gas of nitric acid production at 2B1. Hungary explained that only a small part (in 2016 less than 5%) of hydrogen production is NOT used for ammonia production, but the hydrogen production facilities are individual companies. It could be allocated to 2B10, but then both categories (2B1 and 2B10) will be confidential, and IEF of ammonia production will be very low. Tail gas treatment could also be moved to 2B10. However, the CO_2 emission from this source is very small (0.88 kt was in 2015) and with present methodology it can be easily compared the plant's whole emission reported to EU

ETS, also the total fuel consumption can be easily allocated from energy sector. So, for practical reasons (increasing the transparency in the national system) these categories are reported here.

The 2006 IPCC Guidelines requires also subtraction of amount of CO_2 emitted from ammonia production but used for urea production (and the reporting of urea used in agriculture and as catalyst in vehicles). In the 2020 review, a revised estimation of CO_2 recovery for years 2005 and 2016-2018 was proposed and accepted by ESD. CO_2 recovery was recalculated based on the exported amounts of urea and the stoichiometric ratio of CO_2 to urea. The recalculation was performed for the whole time period resulted in recalculations of CO_2 emissions from 2.B.1 ammonia production. Moreover, urea balance was calculated taking into account urea imports and exports and considering urea-based CO_2 emissions reported in CRF 3H and 2D3. Export, import, production and stock change of urea are in balance in the long run. A detailed table of trade, production and consumption of urea is presented in Chapter 4.4.1.4.

4.4.1.2 Methodological issues

CO_2 emission from ammonia production is reported using Tier 3 methodology from the 2006 IPCC Guidelines. The Tier 3 method requires total fuel requirement (SUM TFR_i), which has been available from the reporting of the plants. In the 2020 review the ERT suggested to use country/plant specific carbon content factor (CCF) in this sector. Default CCF was replaced by a newly calculated country specific CCF for the years 1985-2006, and plant specific CCF values reported by the producers are used from 2007 onward. The country-specific CCF for 1985–2006 was calculated by taking the average of the CCFs for 2007–2019 because there was no significant trend in the CCF for these years. CO_2 emissions were recalculated for the whole time series. *Table 4.4.2.*presents the recalculated time-series of the different emission sources and the recovery. In 2018, the production of the urea plant fell to a quarter of that of the previous year and was almost entirely exported, thus the CO_2 recovery dropped drastically.

Table 4.4.2. *CO_2 emission from the different sources in 2.B.1 sector*

	Ammonia production with urea recovery	CO_2 recovery in urea production	Hydrogen production	Tail gas treatment by nitric acid production
	Gg CO_2	Gg CO_2	Gg CO_2	Gg CO_2
1985	1719.78	244.22	NO	76.35
BY	1632.15	279.25	NO	82.50
1986	1599.51	281.26	NO	79.61
1987	1577.16	312.26	NO	91.54
1988	1361.88	338.86	NO	85.01
1989	1400.38	333.71	NO	62.65
1990	1144.99	208.67	NO	55.20
1991	719.31	97.43	NO	39.02
1992	492.36	69.93	NO	24.73
1993	620.18	67.08	NO	31.94
1994	754.99	61.54	NO	62.07
1995	746.38	61.96	NO	54.54
1996	842.41	59.78	NO	92.84

1997	803.12	61.89	NO	93.30
1998	698.13	68.17	NO	82.06
1999	610.62	73.34	NO	75.49
2000	803.46	78.81	3.52	87.16
2001	710.56	84.00	10.47	88.91
2002	472.85	92.55	98.17	56.97
2003	464.89	97.53	108.30	63.45
2004	614.28	110.60	112.76	68.67
2005	702.78	116.34	133.05	77.41
2006	659.54	111.01	153.50	73.86
2007	726.33	111.36	164.75	50.47
2008	561.75	74.12	161.59	0.31
2009	611.91	94.48	142.50	0.46
2010	657.54	101.35	146.50	0.47
2011	771.46	104.11	199.83	0.93
2012	704.07	75.82	245.24	0.91
2013	538.26	95.62	278.10	0.49
2014	748.60	108.67	309.23	0.69
2015	633.01	77.74	315.10	0.87
2016	714.44	87.34	322.72	1.16
2017	835.67	86.39	361.50	1.56
2018	729.57	26.59	374.72	1.58
2019	692.03	69.30	387.45	1.75
2020	880.69	48.33	356.99	2.56
2021	807.63	41.08	391.31	2.25
2022	418.85	6.83	321.88	1.22

CO_2 recovery for urea production occurs only in one plant, which has provided data on the quantity recovered in since 2013 onwards. In addition, it has provided data on the exported quantity and the share of the different sectors in which urea is used domestically. For the years before 2013 extrapolation was applied using domestic urea use as surrogate data. Time-series of ammonia production and emitted CO_2 are presented in *Figure 4.4.2*.

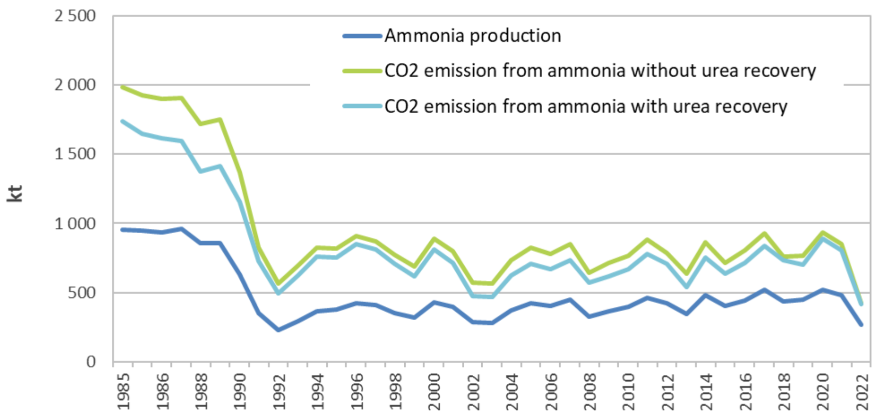


Figure 4.4.2 *Trend of production of ammonia and CO_2 emissions*

Please note that in HU CRF submissions the activity data is the sum of natural gas used for ammonia and hydrogen production and for nitric acid flue gas scrubbing (TJ NCV). HU IEF calculated based on ammonia production is almost the same value which is provided in the 2006 IPCC Guidelines for "modern plants in Europe". The continuous decrease of implied emission factor in *Ammonia production* might be attributed to the fact, that obsolete technologies are abandoned. The existing factories have invested in several modernization and energy rationalization projects in recent years, which improved environmental performance and resulted in decrease of emissions per unit of ammonia produced.

Several environmental investments are listed on the public website of the company responsible for most of the production too, which explains the decrease of implied emission factor. The energy rationalization projects are for example:

2002 Ammonia Plant (expansion turbine) to utilize the pressure energy of the natural gas coming in pipeline to generate electricity

2003 Ammonia Plant (natural gas saturation) to reduce natural gas consumption

2005 Ammonia Plant Modernization of gas compressor

(http://www.nitrogen.hu/nat/index.php?option=com_content&view=article&id=122%3Akoernyezet vedelmi-beruhazasok&catid=9%3Akoernyezetvedelem&Itemid=19&lang=en)

From 2013, the extension of the scope of EU ETS also to ammonia production has been an incentive for further energy rationalization.

CO_2 emissions from *Hydrogen production* and *Tail Gas treatment with Natural Gas* are reported using direct plant specific data. Companies provided data on quantity of natural gas used for the whole time-series. Default CCF was replaced by a newly calculated country specific CCF for the years 1985-2006, and plant specific CCF values reported by the producers are used from 2007 onward.

The main producer of hydrogen in Hungary uses state-of-the-art technology, when CO_2 emitted by hydrogen production is recovered for the industrial production of CO gas. However, the amount of CO_2 recovered is not reported (not subtracted) in HU GHG Inventory at the moment, as the CO produced might be regarded as short term storage. So, all CO_2 is accounted for in the case of GHG inventory which causes a difference in the consistency check with EU ETS emissions (as the operator is also falling within the scope of EU ETS). The other reason of the difference in this subsector is that not all the hydrogen producers are required to report within the framework of EU ETS.

Please find the time-series of emissions from hydrogen production and tail gas treatment with natural gas in nitric acid production in the Table 4.4.2. above.

The quantities of natural gas used for the different processes have been compared with IEA Energy Statistics, as it is presented in Table 4.4.1.

4.4.1.3 Uncertainties and time-series consistency

Uncertainties are estimated based on the minimum requirements of EU ETS Monitoring and Reporting Regulation (601/2012/EU) for the determination of AD and EF in the case of *Ammonia Production*:

Uncertainty		AD	EF	Combined
2B1 Ammonia Production	CO_2	5	5	7.07

4.4.1.4 Source-specific QA/QC information and verification

General QA/QC procedures apply. The quality and reliability of the emission data were greatly improved by using production data obtained directly from the factories. In 2013 data provided by the factory Nitrogénművek (responsible for the 90-95% of Hungarian production) was fully reviewed and the time-series has been affirmed. The decreasing IEF of CO_2 is also verified and the result is described in the methodological issues subchapter above (4.4.1.2).

Consistency with IEA Energy Statistics was checked and it is presented in *Table 4.4.1*.

As planned improvement from previous years' inventory database from ammonia production received from firms was compared with data of HCSO also obtained from firms. It became clear that national statistics include not only liquid ammonia – which was produced from natural gas or hydrogen - but also ammonia solution in water. Aqua ammonia can be produced by solution of liquid or anhydrous ammonia in water or by ammonia containing waste gas treatment with water, both processes do not release CO_2. Comparing the time-series only for anhydrous ammonia (for years 2005-2015) only one value was different. Request was sent for clarification to the company concerned and it was confirmed that value in the inventory database is correct.

In Hungary, only one plant produces urea. Produced amount and the ratio of exported and domestically sold urea are provided by the plant. According to this, the major part of domestic quantity is used as fertilizer in agriculture, other minor parts are used in AdBlue production, waste gas scrubbing and other industrial production. Annual amount of used AdBlue is calculated based on diesel fuel consumption in CRF 2D3, while urea consumption is derived from the sales statistics by products reported annually by the Agricultural Economics Research Institute in CRF 3H. Note, that the sales of a given year can be performed from the stocks, therefore the consumption and production do not belong to the same year in every case. Additional imported amounts of urea are involved in both activities. Emissions from urea-based waste gas scrubbing is well below the significance threshold, while urea-based CO2 emissions are not calculated in other industrial sectors, therefore recovery is not needed. Export, import, production and stock change of urea are in balance in the long run. *Table 4.4.3.* shows the trade, production and consumption amount of urea between 2010 and 2019. Trade values are from HCSO, the national statistical office. Values presented in 3H, 2D3 and 2A4 rows are calculated in CRF. Other industrial values are provided by the urea plant. In the 10-year-long period, the ratio of supply and demand is -4%.

Table 4.4.3. *Imported, exported, produced and consumed amounts of urea*

urea [t]		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
domestic usage											
3H - agriculture	t	63 051	79 007	75 725	107 834	101 612	132 875	134 426	154 403	152 346	158 106
2D3 - urea besed catalysts	t	4 437	7 908	11 867	16 287	20 105	28 234	30 020	33 298	36 643	40 542
2A4 - waste gas scrubbing	t								2 313	2 118	1 446
other industrial	t	5 976	19 320	19 029	11 737	11 223	8 370	13 367	11 380	45	9 228
trade											
import	t	41 745	29 068	49 761	67 833	70 627	91 348	107 992	118 411	134 940	130 410
export	t	117 794	106 997	102 952	96 621	125 953	48 431	87 616	46 295	43 490	45 754
production	t	146 883	166 843	132 339	147 421	164 475	115 697	134 246	130 438	36 310	104 269
supply	t	70 833	88 914	79 148	118 633	109 148	158 615	154 622	202 554	127 760	188 925
demand	t	70 469	100 897	98 610	124 864	119 369	150 421	157 550	178 918	166 418	181 956
ratio of supply and demand		1%	-12%	-20%	-5%	-9%	5%	-2%	13%	-23%	4%

4.4.1.5 Source-specific recalculations

The 2006 IPCC Guidelines requires also subtraction of amount of CO_2 emitted from ammonia production but used for urea production (and the reporting of urea used in agriculture and as catalyst in vehicles). In the 2020 review, a revised estimation of CO_2 recovery for years 2005 and 2016-2018 was proposed and accepted by ESD. CO_2 recovery was recalculated based on the exported amounts of urea and the stoichiometric ratio of CO_2 to urea. The recalculation was performed for the whole time period resulted in recalculations of CO_2 emissions from 2.B.1 ammonia production.

In the 2020 review the ERT suggested to use country/plant specific carbon content factor (CCF) in this sector. Default CCF was replaced by a newly calculated country specific CCF for the years 1985-2006, and plant specific CCF values reported by the producers are used from 2007 onward. CO_2 emissions were recalculated for the whole time series.

4.4.1.6 Source-specific planned improvements

None.

4.4.2 Nitric Acid Production (CRF sector 2.B.2)

4.4.2.1 Source category description

Emitted gas: N_2O, (CO_2)

Methods: T3
Emission factors: PS
Key sources: 2B2 Nitric Acid Production - N_2O - T

Nitric acid (HNO_3) is produced by oxidizing ammonia. The process tail gas contains N_2O and NO_X. In order to control the emissions, the latter is reduced to nitrogen using natural gas and the carbon content of the natural gas is released in the form of carbon dioxide.

In 1985. 3 plants operated with 9 units. Among the old factories using obsolete technologies, one was abandoned in 1988, another in 1991, and a third in 1995. Until 2007 two production lines were operated in the country – the older one was established in 1975 and used GIAP technology which consists of four units with four different factors. These four units represented the major part (about 80%) of the production volume. Emissions from this process were measured from 2004. The other existing technology represented only 20% and had been operational since 1984 (combined acid factory producing diluted and concentrated nitric acid). *Figure 4.4.3* below shows the operating nitric acid plants since 1985.

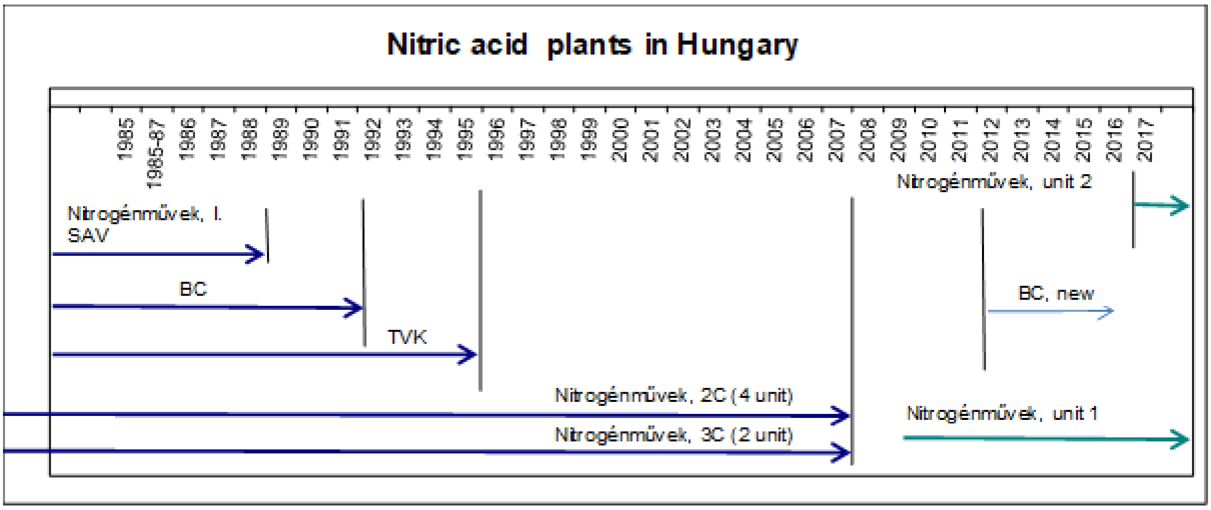


Figure 4.4.3 *Nitric acid plants in Hungary. 1985-2017*

Implementation of a new and more advanced production technology in Nitrogénművek plant was started in 2005, in the framework of a joint implementation project (one of the flexible mechanisms facilitated by the Kyoto Protocol), and it was installed in September 2007. At the same time the old production lines were closed down. Now a state-of-the-art technology is used, therefore drastic emission reduction is reported in this inventory.

At the end of year 2011 one of the former nitric acid plants has been restarted after renovation and its production has been increasing year by year. In 2017 a new nitric acid unit started to work at Nitrogénművek Zrt. increasing the capacity significantly.

4.4.2.2 Methodological issues

Measured emission data were not available for a long time. Therefore, during the first phase of the recalculation project, the default specific emission factor recommended by the IPCC (6 kg N_2O/t nitric acid) was used.

In 2004 an emission measurement system was installed at one of the factories and this has resulted in fundamental changes in the previously estimated values. N_2O meter is placed after the catalyst which measures emissions continuously. The regular monitoring report is based on daily average measurement data but the system is capable to provide data for shorter time period, e.g. hourly averages. The factory makes available its measured data to the inventory compiler.

The requirements of the set up and functioning of the continuous measurement system is prescribed in the IPPC (Integrated Pollution Prevention and Control) permit of the installation, as the plant is falling under the scope of the IPPC Directive (Directive 2008/1/EC). IPPC Directive in general is implemented in the Hungarian law by the 314/2006. Government Decree and further requirements on the set up and functioning of continuous emission measurement systems is regulated by 6/2011. (I.14.) Ministerial Decree. The IPPC permit is issued, updated and enforced by the competent authority (Inspectorate for Environment and Nature).

In addition, the facility is also falling under the scope of E-PRTR Regulation (Regulation (EC) No 166/2006 concerning the establishment of a European Pollutant Release and Transfer Register). This means that on one hand data can be verified with data reported in E-PRTR (as all E-PRTR data is available to the public on http://prtr.ec.europa.eu/FacilityLevels.aspx), on the other hand the E-PRTR Regulation require also using internationally recognized measurement standards.

Therefore, on the basis of almost one year of experience with measurements, the calculated emission factors of the factories using different technologies were between 10 to 19 kg/t. For calculation of emissions of the oldest factory (established in the 1950's), which was abandoned in 1988, the highest value recommended by the 2000 Good Practice Guidance was used (19 kg N_2O/t). 14.5 kg/t was used as specific emission factor for the three other abandoned factories including the one which was abandoned in September 2007. For the combined factory, a value of 10 kg/t was used.

At the end of 2004, selective catalytic reduction was introduced in tail-gas treatment which led to emission reductions in the following years. This modernization means furthermore that the EFs before and after 2004 cannot be the same. The emission data of 2005 and 2006 are based on measurements. In the second half of 2005 a new measuring instrument was installed which might partly explain the difference between IEFs. The new factory of Nitrogénművek applies the EnviNO$_x$ technology (please see further details below) consequently a drastic reduction of emission has been reached. N_2O emission from nitric acid production was decreased by 99% between base year and 2009.

Since 2013 nitric acid plants fall within the scope of EU ETS as well, so measurement of N_2O is also required and regulated by the EU ETS directive and 601/2013/EC Regulation that prescribes strict standards for the measurements and reporting.

Thus, the weighted average IEF ranges between 10.01 and 14.51 kg/t in the time-series of the years before 2007, depending on the production volume. In 2007. EF was 6.15 kg/t. 0.0425 kg/t in 2008. 0.108 kg/t in 2009. 0.0715 kg/t in 2010. Since the reopened plant is working IEF is slightly higher in recent years (0.087 kg/t in 2011. 0.113 in 2012. 0.25 kg/ t in 2013. 0.29 kg/t in 2014. 0.25kg/t in 2015 and 0.13kg/t in 2016. 0.19 kg/t in 2017), that can be explained by the increasing production volume of the other reopened factory with a less efficient tail-gas treatment. The sharp reduction in the last reported emission from the reopened plant was investigated because the IEF was halved for 2016. According to the information received from the plant in August 2015 during the summer repairs the DeN_2O catalyst was removed and during the assembly of the reactor 50% of the catalysts were replaced by new catalysts. With the new catalysts N_2O content of the flue gas reduced significantly.

The amount of carbon dioxide generated during the reduction reaction by the tail gas treatment is so low that it has no detectable effect on the inventory as a whole. Since 2004 process tail gas has been treated with ammonia, so CO_2 emissions are no longer an issue in this case. From 2007, further information about consumption of natural gas data was received from the factory. This was used in a new plant as a tail gas reducing agent. As in new CRF Reporter Software there is no possibility to report CO_2 in *2.B.2* sector (no possibility to add child node), this CO_2 is reported under *2.B.1* together with other non-energy uses of natural gas in *Chemical Industry*.

Production data were obtained from the factories (*Figure 4.4.4*).

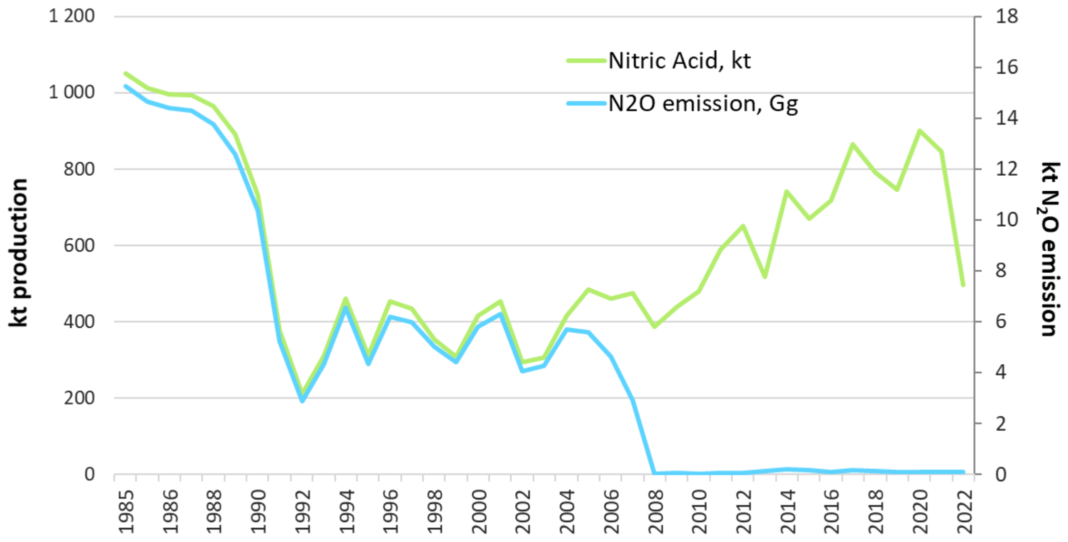


Figure 4.4.4 *Nitric acid production (kt) and N_2O emission in nitric acid subsector*

EnviNO$_x$ technology

The EnviNO$_x$ process is usually located between the final tail gas heater and the tail gas turbine and contains two catalyst beds filled with iron zeolite catalysts operating at the same pressure and temperature and a device for addition NH_3 between the beds. In the first DeN$_2$O stage, the N_2O abatement is effected simply by the catalytic decomposition of N_2O into N_2 and O_2. Since NO_x content of the tail gas promotes the decomposition of N_2O, the required DeNO$_x$ stage is arranged downstream of the DeN$_2$O stage.

In the second stage. NO_x reduction is carried out using NH_3 as a reducing agent similar to natural gas.

Reactions in the DeN$_2$O:

$$2\ N_2O + 2NO \ \text{------->} 2\ N_2 + 2\ NO_2$$

$$2\ N_2O \ \text{<------->} 2\ NO + O_2$$

$$2\ N_2O \ \text{------->} 2\ N_2 + O_2$$

Reactions in the DeNO$_x$:

$$6\ NO_2 + 8\ NH_3 \ \text{------->}\ 7\ N_2 + 12\ H_2O$$

$$4\ NO + O_2 + 4\ NH_3 \ \text{------->}\ 4\ N_2 + 6\ H_2O$$

ATTACHMENT 1 PERFORMANCE TEST RUN SHEET 01-1418-600

Uhde	PERFORMANCE TEST RUN EnviNOx® NZRT					
DESIGNATION	UNIT	GUARANTEED	ACHIEVED			
			DAY 1	DAY 2	DAY 3	AVERAGE
N_2O-REDUCTION IN TAIL GAS	%	min. 94 (initially)	99.63	99.64	99.63	99.63
NO_x CONCENTRATION IN TAIL GAS DOWNSTREAM ENVINOx® SYSTEM	ppm vol.	max. 25	5.7	5.6	5.7	5.7
NH_3 CONCENTRATION IN TAIL GAS DOWNSTREAM ENVINOx® SYSTEM	ppm vol.	max. 5	Laboratory 0.19 AI0808 3.4	Laboratory 0.47 AI0808 3.3	Laboratory 0.57 AI0808 3.3	0.41 3.3
NH_3 CONSUMPTION IN ENVINOx® SYSTEM	mol NH_3 / mol NO_x	max. 2.2	1.36	1.36	1.36	1.36
NATURAL GAS HYDRO-CARBON CONSUMPTION IN ENVINOx® SYSTEM	mol H.C. / mol N_2O	max. 0.2	0.077	0.078	0.077	0.077

Figure 4.4.5 *Presentation of performance of EnviNO$_x$ technology*

For a short description of the used technology can be found in a brochure prepared by ThyssenKrupp Industrial Solutions (see 4.12 References ThyssenKrupp). Performance of EnviNOx technology at Nitrogénművek Zrt. is presented on *Figure 4.4.5* above.

4.4.2.3 Uncertainties and time-series consistency

Uncertainties are estimated based on the minimum requirements of EU ETS Monitoring and Reporting Regulation (601/2012/EU) for the determination of AD and EF in the case of nitric acid production:

Uncertainty		AD	EF	Combined
2B2 Nitric Acid Production	N_2O	7.5	7.5	10.61

4.4.2.4 Source-specific QA/QC information and verification

General QA/QC procedures apply. The data received directly from factories and the requirements of EU ETS since 2013 greatly improved the quality of data.

The significantly decreasing IEF after 2007 was verified and the results are also described in the methodological issues subchapter above. Also the significantly decreased IEF for 2016 was investigated and it is described in chapter *4.4.2.2*.

4.4.2.5 Source-specific recalculations

None.

4.4.2.6 Source-specific planned improvements

None.

4.4.3 Petrochemical and Carbon Black Production (CRF sector 2.B.8)

4.4.4 Source category description

Emitted gas: CO_2, CH_4

Methods: T1, T2, T3
Emission factors: CS, D, PS
Key sources: 2B8 Petrochemical and carbon black production - CO_2 - L, T

During petrochemical production processes, mainly oil products are used as feedstock or other non-energy purposes. Most of the carbons contained in these raw materials are stored in the products too, however during the conversion processes some carbon is emitted in the form of CO_2 or CH_4.

Usually, it is very hard to distinguish the energy and non-energy uses of fuels during the complex processes in petrochemical production. Therefore, the suggestion of the 2006 IPCC Guidelines is to be followed:

„Combustion emissions from fuels obtained directly or indirectly from the feedstock for an IPPU process will normally be allocated to the part of the source category in which the process occurs."

„If surplus methane or hydrogen from the steam cracking of naphtha is combusted within the petrochemical site for another process then the emissions are reported as emissions in IPPU 2B8. On the other hand, if the gases are passed to a nearby refinery for fuel use then the associated emissions would be reported under 1A1b. Petroleum Refining."

In the case of Hungary, no gases are passed for fuel use out of the petrochemical companies, but all are used inside. Therefore, all emissions are reported here in *2.B.8* including the natural gas reported by the petrochemical and carbon black production companies. In addition, all oil products considered as non-energy use (NEU) in IEA Energy Statistics are considered here in sector *2.B.8*, except for lubricants and paraffin waxes (reported in *2.D.1-2*).

In Hungary production of ethylene dichloroethylene (DCE for the purpose of production of further petrochemical products like TDI/MDI) and carbon black are present. Ethylene is made from naphtha. Very few and well-known companies are operating in this sector in Hungary.

From 2018, CO_2 emissions have been reported in the ETS system from formaldehyde production. As the company have been producing formaldehyde from 1998, CO_2 emissions are reported calculated on a new subsector sheet 2.B.8.g.i formaldehyde production from 1998 onward.

Production of bulk organic chemicals fall within the scope of EU ETS since 2013, so the availability of detailed plant-specific data is even more improved. However. EU ETS data has been available already since 2008 for most of the sources of these companies.

4.4.4.1 Methodological issues

CO_2 emissions are reported using plant-specific data from the year 2008 using the very detailed and good quality data from reporting of companies within the EU ETS framework. The good quality of data reported under EU ETS is ensured by the strict monitoring and reporting requirements of Regulation 601/2012/EC including the obligation of the control by independent, accredited verifiers. EU ETS Annual emission reports are available for HMS for GHG Inventory preparation purposes.

2.B.8.b Ethylene production

In Hungary, only one company produces ethylene. According to its EU ETS Annual Report, during the production the company uses three different gaseous fuels. Reported CO2 emission is calculated under the standard methodology (Commission Regulation No 601/2012, Article 24) supported by monthly laboratory measurements.

2.B.8.c ETM/VCM production

In Hungary, only one company produces VCM and TDI. For VCM natural gas, for TDi natural gas, OTD and tar are used in the production process. Reported CO2 emission is calculated under the standard methodology (Commission Regulation No 601/2012, Article 24) supported by monthly laboratory measurements.

2.B.8.f Black carbon production

In Hungary, only one company produces black carbon using quench oil, natural gas and negligible amount of other materials. Reported CO2 emission is calculated under the mass balance methodology (Commission Regulation No 601/2012, Article 25) supported by monthly laboratory measurements.

2.B.8.g.i Formaldehyde production

From 2018, CO2 emissions have been reported in the ETS system from formaldehyde production. As the company have been producing formaldehyde from 1998, CO2 emissions are reported calculated on a new subsector sheet 2.B.8.g.i formaldehyde production from 1998 onward. Reported CO2 emission is calculated under the mass balance methodology (Commission Regulation No 601/2012, Article 25) supported by monthly laboratory measurements.

For the years before 2008 extrapolation is applied using the appropriate petrochemical production data from HCSO as surrogate data.

Please note that extrapolation of emissions is made based on quantities of petrochemical products (ethylene + DCE + carbon black), and the activity data in CRF in *2.B.8* is also kilotons of products.

Time-series of non-energy use of oil products (as raw material in petrochemical production) in IEA EnStat have been taken into account, as all emissions from these sources are excluded from *Energy* sector and reported here. So, in order to be consistent with both EU ETS reports of petrochemical companies and IEA Energy Statistics (EnStat), emissions are reported in *2.B.8* based on EU ETS reporting, and it is supposed that all non-energy use of oil from IEA EnStat and some amount of natural gas (reported by the companies) were used for the production. The related energy sources were subtracted from *Energy* sector.

In this way. IEF compared to petrochemical products is stable (see red line on *Figure 4.4.6* below), while IEF compared to NEU Oil products in IEA EnStat is changing as it is possible to see at the same figure (blue line). But this problem seems to originate from the original time-series of the NEU Oils in the IEA EnStat, as the trend of petrochemical products (t) per NEU Oils (TJ) is changing, too (see green line on the figure).

Unfortunately, it seems that the allocation of NEU Oils within the IEA EnStat is not consistent across the years, so this question is to be clarified with the authority responsible for the preparation of the energy statistics.

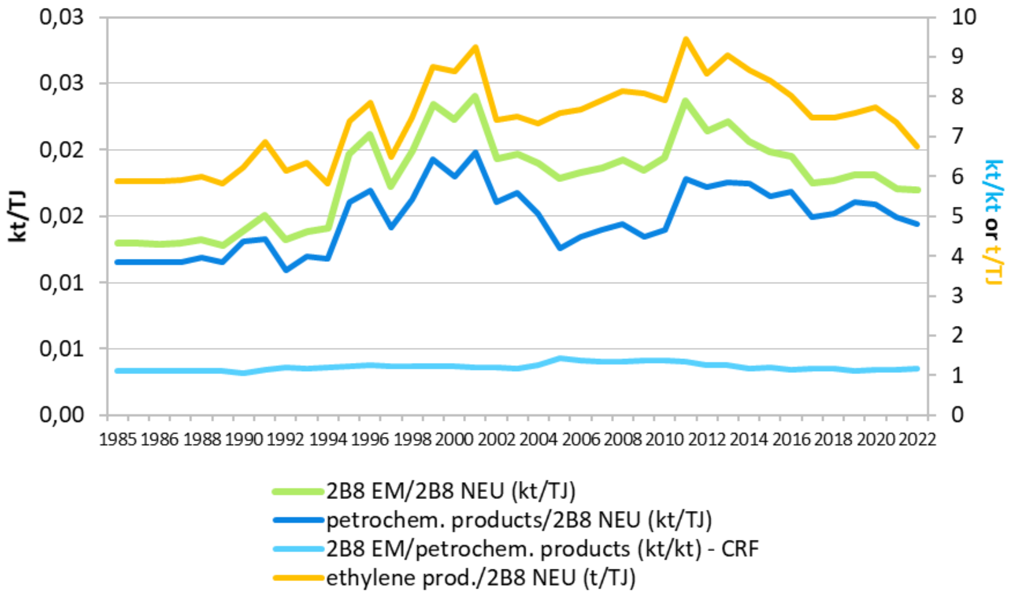


Figure 4.4.6 *Trend of implied emission factors in 2.B.8 compared to petrochemical production and the amount of non-energy use of fuels*

As EU ETS annual emission reports contain only all CO_2 emission sources. CH_4 is reported based on default Tier 1 emission factors from the 2006 IPCC Guidelines for the whole time-series.

4.4.4.2 Uncertainties and time-series consistency

Uncertainties are estimated based on the minimum requirements of EU ETS Monitoring and Reporting Regulation (601/2012/EU) for the determination of AD and EF in the case of nitric acid production:

Uncertainty		AD	EF	Combined
2B8 Petrochemical and carbon black production	CO_2	7.5	7.5	10.61
2B8 Petrochemical and carbon black production	CH_4	3	10	10.44

4.4.4.3 Source-specific QA/QC information and verification

General QA/QC procedures apply. Time-series in IEA EnStat production data from HCSO and the EU ETS emission reporting data have been thoroughly compared as it is described above.

4.4.4.4 Source-specific recalculations

None

4.4.4.5 Source-specific planned improvements

Further investigation of consistency of the trend of non-energy use of oils in IEA EnStat is needed.

4.5 Fluorocarbon Production (CRF sector 2.B.9)

Fluorocarbons are not produced in Hungary.

4.6 Metal Production (CRF sector 2.C)

4.6.1 Iron and Steel Production (CRF sector 2.C.1)

4.6.1.1 Source category description

Emitted gas: CO_2, CH_4

Methods: T2, T3
Emission factors: CS, PS, D
Key sources: 2C1 Iron and Steel Production - CO_2 – L, T

In this subsector, gases emitted by the iron/steel industry (sinter, iron and steel production) are calculated. During sintering (agglomeration), a mixture of iron ore, coke or carbon and limestone are agglomerated by heat transfer to obtain a material suitable for feeding into the furnace. During iron production, coke and carbonate-containing slag-forming additives are added to the agglomerated ore, and the mixture is reduced at a high temperature. This reaction releases CO and CO_2. Therefore. CO_2 is produced from two sources during the process: 1) from fuel, which also serves as a reducing agent, and 2) from carbonate-containing slag-forming agent (limestone or dolomite). The gases arising in the blast furnace during the production of the pig iron are recovered as blast furnace gas (BFG) and used partly for energy purposes.

During steel production, the carbon content of iron is reduced from 4-5% to cca. 1%. (1% in the 2006 IPCC Guidelines). Also, this is released in form of CO_2. Basic oxygen furnace (BOF also known as LD converter) technology for production of steel uses the hot, molten pig iron with scrap iron, additives and quicklime. Electric arc furnace (EAF) technology uses mainly scrap iron with additives and the heat is provided by electric arc formed between graphite electrodes. The consumption of graphite electrodes results CO_2 emission as well.

In Hungary, all the activities connected to iron and steel industry are present: production of coke, sintering, production of pig iron and production of steel using basic oxygen furnace (BOF) and electric arc furnace (EAF) technology, too. Except for the EAF steel production, all the activities mentioned before are located in one single plant, which is however operated by different operators, so it cannot be regarded as an integrated iron and steel plant.

Processes within iron and steel production are very complex, using several fuels either for energy or for non-energy purposes. It is very hard to distinguish energy and non-energy use also in this case, so the recommendation of the 2006 IPCC Guidelines Vol. 3 Bo1.1 is followed that states:

"During these activities, emissions may occur from both the fuel combustion and industrial process stages. However, it is often impractical or impossible to report separately the two types of emissions. Accordingly, the following rule has been formulated to simplify reporting:

Combustion emissions from fuels obtained directly or indirectly from the feedstock for an IPPU process will normally be allocated to the part of the source category in which the process occurs. These source categories are normally 2B and 2C. However. if the derived fuels are transferred for combustion in another source category, the emissions should be reported in the appropriate part of Energy Sector source categories (normally 1A1 or 1A2).

Two examples may help illustrate the definition.

1. If blast furnace gas is combusted entirely within the Iron and Steel industry (whether for heating blast air, site power needs or for metal finishing operations) the associated emissions are reported in the IPPU source subcategory 2C1. If part of the gas is delivered to a nearby brick works for heat production or a main electricity producer, then the emissions are reported in source subcategories (1A2f or 1A1a)."

The example mentioned above is presented in Hungary, one part of the blast furnace gas is used in own processes, while the other part is delivered to an electricity producer. Amount of CO_2 emission from blast furnace gas which is not taken into account in 2.C.1 emission is reported in 2.C.1 as "***Recovery***" – only for transparency purposes - and it is delivered to emissions of *1.A* sector.

Please find the trend of emissions and the trend of production in *Iron and Steel* sector in *Figure 4.6.1* below.

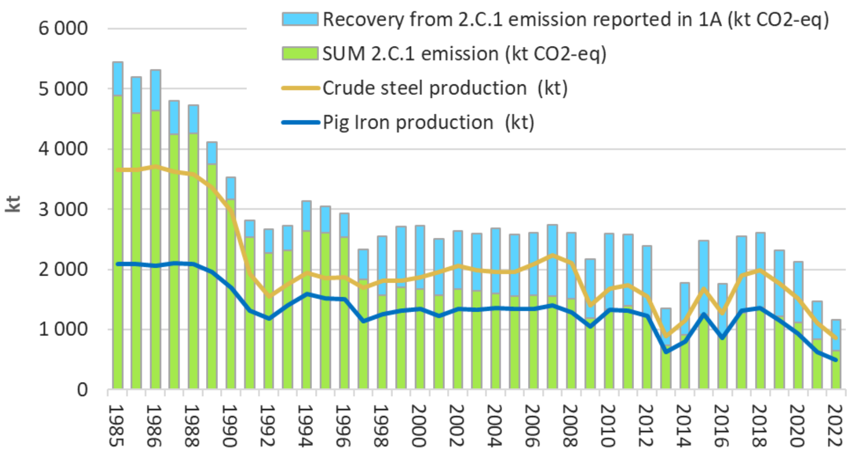


Figure 4.6.1 *Trend of production and emissions in Iron and steel sector*

As it is possible to observe, drastic reduction of the production occurred around 1990 and between 2012 and 2013, too, but in 2014 it seems that recession has stopped. In 2015 iron and steel production reached almost the level before the 2008 economic crisis. Metal industry (particularly in iron and steel production) realized 26% emission reduction in 2016. Amount of both pig iron and steel products decreased, which is the outcome of unfavorable process in export markets. Steel product to building industry could also profit from quickening of housing (more than two-and-one-half times housing permission was granted in 2016 compared to the previous year) with higher production, meanwhile the total amount of steel was lower in 2016 than 2015. Emission increased by 38% in metal industry subsector in 2017, where the favourable EU export market situation and competitiveness of Dunaferr Zrt. in this market resulted from the efficiency improvement measures taken by the company between 2014 and 2016. However, the rising slowed down in 2018.

4.6.1.2 Methodological issues

Earlier only the emissions from carbon content reduction of the input materials during steel production and emission from consumption of graphite electrodes (*2.C.1.1* subsector) were reported within this sector and all the other emissions were included elsewhere. The actual allocation of emissions is summarized in *Table 4.6.1*. All cell comments of IE cells in CRF tables have also been updated accordingly.

***Table 4.6.1** Allocation of emissions connected to Iron and steel production*

IPCC sector code	Activity	Emission source	From the 2015 submission - Emission reported in
1.A.1.a	Combustion of blast furnace gas recovered from Pig Iron production	combustion	1.A.1.a
1.A.1.c	Production of coke	combustion	1.A.1.c (including coke oven gas)
1.A.2.a	Combustion needed for iron and steel production	combustion	1.A.2.a (including coke oven gas)
2.C.1.d-e	Sinter	Coke consumption during sintering	2.C.1.d-e Sinter-Pellet
		Limestone and dolomite use	
2.C.1.b	Pig Iron	Combustion	2.C.1.b Pig Iron
		Consumption of Natural gas for non-energy purposes	
		Limestone and dolomite use	
		Consumption of coke in the blast furnace (after deduction of the amount of recovered blast furnace gas delivered outside for energy production purposes)	
2.C.1.a	Steel	Reduction of carbon content (from 4% to 1 %)	2.C.1.a Steel
		Emission from graphite electrode during EAF steel production	

Emission factors

In the case of CO_2 emissions, default emission factors from the 2006 IPCC Guidelines or plant-specific emission and activity data were used which is available from both direct reporting to the inventory compiler (HMS) and from EU ETS reports. In the case of CH_4, default emission factors from the 2006 IPCC Guidelines are applied.

Activity data

Iron and steel production data were obtained from the reports of the International Iron and Steel Institute. World Steel Association (WORLDSTEEL) and the similar European agency (EUROFER).

Data on consumption of coke, natural gas, coke oven gas in the blast furnace is extracted from IEA Energy Statistics of Hungary as well as the amount of blast furnace gas (BFG) recovered and used. Amounts of limestone and dolomite, other additives including graphite electrode in EAF steel production are available either from direct reporting of the companies to HMS or from EU ETS reports since 2005. Detailed plant-specific data is available from the EU ETS annual emission reports of the companies.

However, the precise allocation among the subsectors (e.g. the amount of coke used in blast furnace or by sintering) is sometimes not available in IEA Energy statistics. In these cases, extrapolation based on the shares of subsectors in plant specific data is applied, but the sum of the subsectors is always the same as the IEA time-series. Please see the example of coke in *Table 4.6.2*.

4.6.1.3 Steel (CRF sector 2.C.1.a)

Carbon dioxide is released from carbon content of pig iron and graphite electrode of the electric arc furnace (EAF) during steel production are reported in *2.C.1.1 Steel* subsector.

During basic oxygen steel production, the carbon content of the pig iron is converted from 4% to 1%. This means that 3% of carbon content present in pig iron is emitted as CO_2 and 1% of carbon content is stored in the steel.

Carbon content of the pig iron might originate from the coke consumed in the blast furnace, iron ore and additives. In order to avoid double counting these emissions should be subtracted from subsector *2.C.1.b Pig Iron*.

The default carbon content of pig iron is: 4% (2006 IPCC Guidelines). In the case of carbon content of steel these guidelines specify it as 1%.

In the case of EAF steel production, data is available in the EU ETS emission reports on carbon content reduction during the process from 2008, therefore plant-specific data is used for the reporting of emissions from EAF steel production and extrapolation of the average of years 2008-2012 is applied using EAF steel production as surrogate data. The factor calculated as average of years 2008-2012 is 0.055 compared to the default 0.05 t CO_2/ t EAF steel.

In the case of EAF steel production the input material is usually scrap iron and other unknown material. This feedstock does contain carbon but it is not originating directly from the use of coke of the blast furnace of the given year. So, EAF steel production is included in „Steel produced (kt)" data of the formula above, but the carbon content reduction of EAF steel production is not subtracted from *2.C.1.b*.

Quicklime used in BOF furnaces is not produced on-site, as it is declared by the operator.

During the investigation of EU ETS data it was discovered, that for 2008, CO2 emissions for EAF steel production was reported years later by one of the EAF companies under the EU ETS. As estimated 2008 emission data were used in the calculated extrapolation for 1985-2006, emission was recalculated for years 1985-2006 and 2008.

4.6.1.4 Pig Iron (CRF sector 2.C.1.b.)

Emission from use of coke, natural gas, coke oven gas (COG) and own use of blast furnace gas is reported in *2.C.1.b*.

In addition, use of limestone, dolomite and other ores and additives is also included here, so the whole process of pig iron production is aimed to be reported here.

The blast furnace gas (BFG) recovered and delivered for energy production purposes is reported in *1.A* sector, while the CO_2 emissions during the carbon content reduction in steel production process (originating from the coke) is reported in *2.C.1.a*. One part of the blast furnace gas is used in own processes, while the other part is delivered to an electricity producer. Amount of CO_2 emission from blast furnace gas which is not taken into account in 2.C.1 emission is reported in 2.C.1 as "***Recovery***" – only for transparency purposes - and it is delivered to emissions of *1.A* sector.

Time-series of coke, BFG, COG and natural gas are available in IEA EnStat, but the precise allocation is not included (or not consistent). But plant specific data on the exact allocation is available from the year 2004, therefore extrapolations are applied where needed (please see the example in above on allocation of coke consumption from IEA EnStat and within subsectors of 2.C.1). In addition, plant-specific net calorific values had been prioritized, where available.

CO_2 emissions from coke are reported using plant-specific data from 2008. For the years before 2008 extrapolations are applied using default emission factors. In the case of CH_4 emissions, emissions from natural gas, COG, limestone and dolomite use are calculated using default factors from the 2006 IPCC Guidelines. Emission from other ores and additives is reported using plan-specific data from 2007 (first year where available) and extrapolation is applied using the average of the implied emission factor of the last two years and pig iron production as surrogate data.

During the investigation of EU ETS data it was discovered that part of the blast furnace gas produced during the BOF pig iron production was not transferred offsite but was flared, therefore this quantity cannot be included in the recovery. CO2 emissions and recovery was recalculated from 2007 onwards.

Table 4.6.2 *Time-series of coke consumption (kt) in IEA EnStat and in 2.C.1*

	IEA EnStat (kt)			2.C.1 (kt)				
	Coke consumption in blast furnaces (Transformation)	Coke consumption in *Iron and steel*	SUM IEA	*2.C.1.b Pig Iron* coke used in BF		*2.C.1.d Sinter* coke used in sinter		SUM 2.C.1
1985	1 471	209	**1 680**	1 565	All IEA Coke - Plant specific data on sintering	115	SUM IEA Coke * 6.8%	**1 680**
B.Y.	1 447	144	**1 591**	1 483		109		**1 591**
1986	1 525	112	**1 637**	1 525		112		**1 637**
1987	1 346	111	**1 457**	1 358		99		**1 457**
1988	1 292	141	**1 433**	1 335		98		**1 433**
1989	1 129	102	**1 231**	1 147		84		**1 231**
1990	1 040	16	**1 056**	984		72		**1 056**
1991	737	115	**852**	794		58		**852**
1992	656	158	**814**	758		56		**814**
1993	778	43	**821**	765		56		**821**
1994	891	50	**941**	877		64		**941**

1995	870	43	**913**	851	62		**913**
1996	815	63	**878**	818	60		**878**
1997	562	83	**645**	601	44		**645**
1998	597	100	**697**	649	48		**697**
1999	590	157	**747**	696	51		**747**
2000	639	108	**747**	696	51		**747**
2001	566	126	**692**	645	47		**692**
2002	606	112	**718**	669	49		**718**
2003	549	161	**710**	662	48		**710**
2004	570	170	**740**	689	51	Plant specific data (average share of SUM IEA Coke = 6.8%)	**740**
2005	596	123	**719**	671	48		**719**
2006	601	111	**712**	665	47		**712**
2007	620	135	**755**	709	46		**755**
2008	599	123	**722**	668	54		**722**
2009	593	38	**631**	599	41		**640**
2010	686	52	**738**	689	49		**738**
2011	687	53	**740**	685	55		**740**
2012	661	49	**710**	661	49		**710**
2013	356	27	**383**	347	36		**383**
2014	462	30	**492**	443	49		**492**
2015	635	50	**685**	639	46		**685**
2016	452	36	**488**	447	41		**488**
2017	655	51	**706**	662	44		**706**
2018	662	52	**714**	666	48		**714**
2019	592	46	**638**	589	49		**638**
2020	535	42	**577**	533	44		**577**
2021	382	30	**412**	377	35		**412**
2022	307	24	**331**	295	36		**331**

Please find the activity data used and the resulting emissions in *2.C.1.b Pig Iron* subsector in *Table 4.6.3* below.

Table 4.6.3 *Trend of activity data and emissions in 2.C.1 b Pig Iron subsector*

	Pig Iron produced	Coke consumption in BF	BFG recovered and used outside for energy	COG used in BF	NatGas Consumption in BF	Limestone used in BF	Dolomite used in BF	SUM CO_2 Emission in 2.C.1.b	SUM CH_4 emission in 2.C.1.b
	kt	TJ	TJ	TJ	TJ	kt	kt	kt	kt
1985	2 095	42 475	2 189	283	3 948	57	2	**3898.98**	**0.43**
B.Y.	2 085	40 234	2 364	436	3 930	57	2	**3616.83**	**0.41**
1986	2 054	41 388	2 690	411	3 871	56	2	**3648.10**	**0.42**

1987	2 107	36 837	2 214	616	3 971	58	2	**3303.39**	**0.37**
1988	2 093	36 231	1 868	679	3 945	57	2	**3327.66**	**0.37**
1989	1 954	31 123	1 443	694	3 683	53	2	**2897.18**	**0.32**
1990	1 697	26 699	1 446	629	3 198	46	2	**2426.70**	**0.27**
1991	1 314	21 541	1 090	656	2 476	36	2	**2005.57**	**0.22**
1992	1 176	20 580	1 503	618	2 216	32	1	**1815.57**	**0.21**
1993	1 407	20 783	1 615	576	2 652	38	2	**1812.03**	**0.21**
1994	1 595	23 820	1 936	794	3 006	44	2	**2062.99**	**0.24**
1995	1 515	23 111	1 674	876	2 855	41	2	**2061.35**	**0.23**
1996	1 496	22 226	1 553	746	2 820	41	2	**1985.46**	**0.23**
1997	1 140	17 470	1 972	746	2 149	31	1	**1375.76**	**0.18**
1998	1 259	19 204	3 859	716	2 373	34	1	**1077.06**	**0.20**
1999	1 310	20 649	3 939	614	2 469	36	2	**1203.20**	**0.21**
2000	1 340	20 719	4 141	673	2 526	37	2	**1160.52**	**0.21**
2001	1 226	19 194	3 685	273	2 311	33	1	**1071.70**	**0.19**
2002	1 335	19 946	3 800	118	2 516	36	2	**1137.44**	**0.20**
2003	1 333	19 535	3 711	311	2 512	36	2	**1125.97**	**0.20**
2004	1 351	20 237	4 236	358	2 952	14	0	**1080.08**	**0.21**
2005	1 338	19 589	4 063	369	2 453	25	0	**1034.86**	**0.20**
2006	1 336	19 619	4 065	906	2 186	20	0	**1041.58**	**0.20**
2007	1 394	20 881	4460*	1 031	1 869	24	0	**1008.28***	**0.21**
2008	1 289	19 685	4310*	774	1 477	28	0	**954.49***	**0.20**
2009	1 050	17 743	3947*	300	605	36	0	**812.49***	**0.18**
2010	1 325	20 618	5238	927	1 757	66	0	**859.94***	**0.21**
2011	1 315	20 354	4692*	831	1 692	61	0	**886.96***	**0.21**
2012	1 228	19 501	4561*	744	490	48	4	**762.63***	**0.20**
2013	628	10 121	2489*	380	530	14	5	**444.95***	**0.10**
2014	801	13067	3494*	599	816	38	0.8	**532.22***	**0.13**
2015	1247	18941	4844*	1130	1584	30	0	**788.34***	**0.19**
2016	863	13424	3250*	688	699	22	0.02	**558.36***	**0.14**
2017	1313	19556	4928*	1018	1590	27	0	**819.67***	**0.20**
2018	1355	19654	4885	1207	1916	29	0	**895.71**	**0.20**
2019	1151	17266	4227	892	1373	21	0	**785.30**	**0.17**
2020	930	15628	3995	809	1117	52	0	**701.71**	**0.16**
2021	621	11038	2482	385	264	23	0	**552.56**	**0.11**
2022	492	8903	2022	209	183	20	0	**395.63**	**0.09**

* Recalculated in the 2020 submission

4.6.1.5 Sinter and pellet (CRF sector 2.C.1.d-e.)

Amount of sinter or pellet produced is not available. However, the amount of coke and natural gas, limestone and dolomite and other ores and additives used during sintering is available from direct reporting of the company from the year 2004. For the years before 2004 activity data was extrapolated knowing material consumption and pig iron production rate after 2004, emission extrapolation is applied using the implied emission factor of the last year or the average of the years available depending on the trend of the IEF.

CO_2 emissions from coke, natural gas, limestone, dolomite and "Other ores and additives" use are reported.

In addition, CH_4 is estimated using default EF for coke (10 kg/ TJ coke), due to lack of data on the amount of sinter or pellet produced. CH_4 is reported from coke combustion in sinter plant and from 2016 submission also the CH_4 emission from natural gas use in sinter plant calculated with default EF has been included due to the recommendation received during the informal review organised by the EU in November 2015. However, this recalculation causes less than 0.01 Gg increase in emissions.

In recent years coke and natural gas consumption are quite stable, meanwhile limestone and dolomite use has strong fluctuation which can be seen also in the emission data.

Please find the activity data used and the resulting emissions in *2.C.1.d-e Sinter* subsector in the table below).

	Coke consumption in sinter plant	NatGas consumption in sinter plant	Limestone used in sinter plant	Dolomite used in sinter plant	SUM emission 2.C.1d-e
	TJ	**TJ**	**kt**	**kt**	**kt CO_2-eq**
1985	3012	207	175	164	552.92
B.Y.	2853	206	174	163	532.59
1986	2935	203	172	161	539.88
1987	2612	208	176	165	504.99
1988	2569	207	175	164	498.49
1989	2207	193	163	153	441.91
1990	1893	168	142	133	380.91
1991	1528	130	110	103	302.49
1992	1460	116	98	92	282.03
1993	1472	139	118	110	303.84
1994	1687	158	133	125	346.70
1995	1637	150	127	119	333.53
1996	1574	148	125	117	324.17
1997	1157	113	95	89	241.74
1998	1250	124	105	99	263.61
1999	1339	129	110	103	279.07

2000	1339	132	112	105	281.70
2001	1241	121	103	96	259.62
2002	1287	132	112	104	274.89
2003	1273	132	111	104	272.96
2004	1333	113	78	137	280.52
2005	1264	157	91	124	273.85
2006	1228	125	104	108	265.50
2007	1147	127	118	103	263.00
2008	1408	137	137	78	293.31
2009	1086	108	91	49	214.35
2010	1338	120	137	65	281.98
2011	1462	128	139	100	310.75
2012	1296	131	110	100	279.04
2013	943	138	35	75	191.04
2014	1340	140	110	76	262.70
2015	1317	131	93	115	272.52
2016	1191	130	36	88	202.43*
2017	1273	124	63	131	257.50*
2018	1350	132	68	132	265.56*
2019	1350	138	76	123	261.88
2020	1239	131	119	108	258.71
2021	980	90	61	79	189.78
2022	957	88	62	54	165.11

Table 4.6.4 *Trend of activity data and emissions in 2.C.1 d. Sinter subsector*

* Recalculated in the 2021 submission

4.6.1.6 Uncertainties and time-series consistency

Uncertainty values are estimated based on maximum uncertainties determined in EU ETS 601/2012/EC Regulation for Iron and Steel production. Uncertainties for CH_4 are estimated based on 2006 IPCC Guidelines.

Uncertainty		**AD**	**EF**	**Combined**
2C1 Iron and Steel Production	CH_4	10	10	14.14
2C1 Iron and Steel Production	CO_2	7.5	5	9.01

4.6.1.7 Source-specific QA/QC information and verification

Please note that in Hungary a quite wide range of emission sources are allocated in present *2.C.1* sector, which might cause differences compared to other countries, although we believe that it is in line with reporting of the 2006 IPCC Guidelines as it is described in the introduction of this chapter above.

For example, during the trial review performed by EU in November 2015 it was noted that the IEF is high compared to other countries both in *2.C.1.b* and *2.C.1.d-e* subsectors. The high IEF can be explained by the fact that several types of emissions, including emissions from BOF and limestone and dolomite use are also included in this category.

In addition, it was also noted that in 1993. 1998 and 2013, the change in CO2 emissions (total of 1.A.2.a and 2.C.1. compared to the previous year) deviated distinctly from the change in pig iron production (compared to the previous year). The explanation is that in HU Inventory BFG delivered outside from iron and steel factory and used for energy purposes is reported in 1.A.1.a sector. If BFG used for energy purposes (and reported in 1.A.1.a) is also taken into consideration, trends are much more parallel (see *Figure 4.6.2* below). In this case the deviations from the trend of pig iron production in the years mentioned also disappear, except for the year 1993. In this year, there might be some problem with pig iron production data, as the trend of emissions and the trend of fuel used in IEA EnStat are in agreement (see blue columns and green line in Figure 4.6.2 below). The amount of BFG used within iron and steel production and delivered outside for energy purposes is based on IEA EnStat allocation.

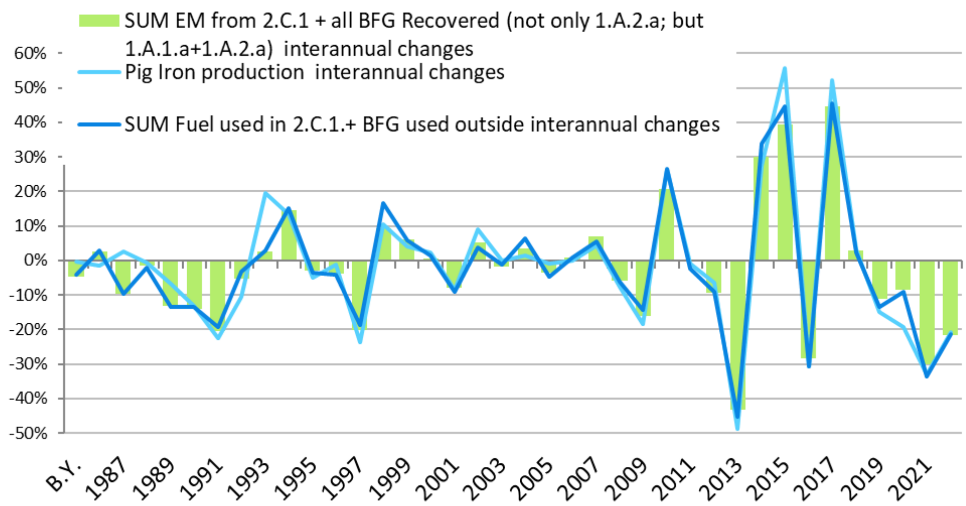


Figure 4.6.2 *Comparison of trends of pig iron production, fuel use and the emissions allocated in different sectors in HU GHG inventory*

4.6.1.8 Source-specific recalculations

In 2.C.1.a – Steel production, from 2009 a double count was performed regarding the CO_2 emissions from EOF production. Corrected CO_2 emissions are reported from 2009 onward.

in 2.C.1.d – Sinter and pellet, from 2016 a double count was performed regarding the CO_2 emissions from produced sinter. Corrected CO_2 emissions are reported from 2016 onward.

4.6.1.9 Source-specific planned improvements

None.

4.6.2 Ferroalloy Production (CRF sector 2.C.2)

4.6.2.1 Source category description

Emitted gas: CO_2

Methods: T1
Emission factors: D
Key sources: None

Upon smelting alloying additive and iron, together with slag-forming additives, a reduction reaction occurs which results in release of CO_2.

Ferroalloy production was present in Hungary only between 1985 and 1990.

4.6.2.2 Methodological issues

Fuels were included in sector *1.A.2.A* and only technological CO_2 emissions were calculated here. The production data were obtained from the HCSO.

Default Tier 1 emission factors from the 2006 IPCC Guidelines have been applied together with the new EF for CH_4 emission.

4.6.2.3 Uncertainties and time-series consistency

Uncertainties are estimated based on 2006 IPCC Guidelines.

Uncertainty		AD	EF	Combined
2C2 Ferroalloys Production	CH_4	5	37.5	37.83
2C2 Ferroalloys Production	CO_2	5	37.5	37.83

4.6.2.4 Source-specific QA/QC information and verification

General QA/QC procedure apply.

4.6.2.5 Source-specific recalculations

None.

4.6.2.6 Source-specific planned improvements

None.

4.6.3 Aluminium Production (CRF sector 2.C.3)

4.6.3.1 Source category description

Emitted gases: CO_2, PFCs (CF_4, C_2F_6)

Methods: T1, T2
Emission factors: D
Key sources: 2C3 Aluminium Production – PFCs – T

During alumina electrolysis, CO_2 is released from carbon anode. At the same time, fluorinated hydrocarbons are produced from cryolite as a result of anode effect when aluminium oxide concentration is low in the electrolyte of the reduction cell. From the beginning of 2006 this technology is no longer in use in Hungary.

4.6.3.2 Methodological issues

PFC emissions were calculated using Tier 1 methodology for CO_2 and Tier 2 methodology for PFCs recommended by the 2006 IPCC Guidelines.

Production data, including data on the sites already abandoned, were obtained directly from the factories. After the major political changes, two electrolysis plants were abandoned. The resulting changes in the volume of aluminium production (Søderberg process) are shown in the table below (*Table 4.6.5*).

Very detailed, equipment-level data is also available from the factories on production: anode effect minutes per cell-day that makes possible the use of Tier 2 method for PFCs. Default slope coefficients from Table 4.16 of the 2006 IPCC Guidelines are applied.

The trend of emissions is also included in *Table 4.6.5* below. CO_2-eq emissions of PFC are calculated using new GWP values from IPCC 4th AR as it is required.

***Table 4.6.5** Amount of aluminium produced (kt) and trend of CO_2 and PFC emissions*

	Production of aluminium (kt)	CO_2 Emission (kt CO_2)	CF_4 emission (kt CO_2-eq)	C_2F_6 emission (kt CO_2-eq)
1985	73.86	125.57	333.35	34.09
B.Y.	73.75	125.37	336.50	34.58
1986	73.87	125.59	337.46	34.67
1987	73.51	124.96	338.67	34.99
1988	74.64	126.89	329.96	33.67
1989	75.19	127.82	357.52	36.90
1990	75.13	127.72	340.18	35.54

1991	62.88	106.89	293.23	30.37
1992	26.82	45.59	165.55	14.49
1993	27.88	47.39	178.93	15.66
1994	29.65	50.40	195.12	17.07
1995	31.91	54.25	204.80	17.92
1996	33.47	56.89	195.68	17.12
1997	33.67	57.25	195.06	17.07
1998	33.71	57.31	209.94	18.37
1999	33.64	57.19	214.99	18.81
2000	33.85	57.55	258.68	22.63
2001	34.59	58.80	243.64	21.32
2002	35.29	60.00	247.63	21.67
2003	35.04	59.56	231.16	20.23
2004	34.35	58.39	245.58	21.49
2005	31.78	54.03	255.15	22.32
2006-	NO	NO	NO	NO

4.6.3.3 Uncertainties and time-series consistency

Uncertainties are estimated based on 2006 IPCC Guidelines.

Uncertainty		**AD**	**EF**	**Combined**
2C3 Aluminium Production	CO_2	2	10	10.20
2C3 Aluminium Production	PFC	2	99	99.02

4.6.3.4 Source-specific QA/QC information and verification

The factory operated an accredited quality assurance system. We have seen very well kept production records. The necessary data were given to us from these records. The company could provide data from almost 20 years of production without any difficulty.

4.6.3.5 Source-specific recalculations

None.

4.6.3.6 Source-specific planned improvements

None.

4.6.4 Zinc Production (CRF sector 2.C.6)

Notation keys for activity data and CO_2 emission were changed from “IE” to “NO” in the whole time-series due to recommendation of ERT (2016 in-country review). The last zinc mine was closed in 1985 and was flooded in 1986, since then only zinc processing is occurring in Hungary with fuel related emissions (it is included in 1A sector).

4.7 Other Products Use (CRF sector 2.D)

4.7.1 Source category description

Emitted gas: CO_2

Methods: T1, T2
Emission factors: D
Key sources: None

In this sector, CO_2 emitted during the use of lubricants (*2.D.1*) and paraffin waxes (*2.D.2*) are included. In these products carbon is mostly stored, however some carbon is oxidized and emitted in the form of CO_2 during their use. In addition, CO_2 emitted during urea-based catalyst in vehicles is reported in *2.D.3* subsector as it was suggested by EU experts; however, these emissions are very low.

Since 2016 submission indirect CO_2 emissions from the oxidation of NMVOC has also been included, but solely from those sectors that had been reported before the 2015 submission, too. This is in line with the recommendation of EU WG1 of February 2016 that states:

"*According to paragraph 29 of the UNFCCC reporting guidelines for GHG inventories (Annex I to decision 24/CP.19) "Annex I Parties may report indirect CO_2 from the atmospheric oxidation of CH_4, CO and NMVOCs. For Parties that decide to report indirect CO_2 the national totals shall be presented with and without indirect CO_2".*

Para 37(b) the UNFCCC reporting guidelines states: "Once emissions from a specific category have been reported in a previous submission, emissions from this specific category shall be reported in subsequent GHG inventory submissions."

Reporting of indirect CO_2 emissions is not mandatory ("may" in paragraph 29), however in combination with paragraph 37(b) those countries that included indirect CO_2 emissions in the past in their GHG inventories shall continue to report indirect CO_2 emissions in their inventory.

In the case of Hungary, indirect CO_2 from the oxidation of NMVOC from old NFR sector *3* (NFR09 codes) had been reported before 2015 submission. This corresponds to NFR sector *2.D.3.a Domestic solvent use*, *2.D.3.d Coating applications*, *2.D.3.e Degreasing*, *2.D.3.f Dry cleaning*, *2.D.3.g Chemical Products Use*, *2.D.3.h Printing* and *2.D.3.i Other* subsectors at the moment. Indirect GHGs reported in an aggregated way under *2.D* sector are taken from the last submission of CLRTAP Air Pollutants Emission Inventory of Hungary. In this way consistency is ensured with the other reporting obligation. In 2019 submission a new source was added - edible and non-edible oil extraction. Extraction of oil from oil seeds is performed either mechanically or through the use of solvents, or both. NMVOC emissions (diffuse and point sources) from solvent used were obtained from the National Air Emissions Database (LAIR) for the 2006-2017 period and implied emission factor was used for the 1985-2005 period knowing the amount of oil seeds processed. This indirect CO_2 emission was added to this category.

4.7.2 Methodological issues

CO_2 emission from lubricants and paraffin wax use are reported using Tier 1 method and default emission factors from the 2006 IPCC Guidelines (see *Table 4.7.1*).

Activity data is taken from IEA Energy Statistics.

In the case of urea based catalyst in vehicles *(2.D.3),* emissions are reported using Tier 1 method and Eq.3.2.2 from Vol. 2 of 2006 IPCC Guidelines. Activity data is taken from COPERT model.

Table 4.7.1 *Default emission factors applied in 2.D.1 and 2.D.2 sectors*

	Lubricant use Paraffin wax use
CC Lubricant = carbon content (default) kg C / GJ NCV (=t/TJ)	20
ODU - oxidised during use factor (default)	0.2

Indirect CO_2 emissions from the oxidation of NMVOC from subsectors mentioned above have been included using default 0.6 t C/ t NMVOC value from 2006 IPCC Guidelines (Volume 1. Chapter 7. p. 7.6). Please note that the same values have been used in case of submissions before 2015 of Hungary. The trend of direct and indirect CO_2 emissions of the whole 2D sector is presented in *Figure 4.7.1* below.

Please note that the trend of emissions from lubricant and paraffin wax use is consistent with the trend of lubricant and paraffin wax use in IEA EnStat.

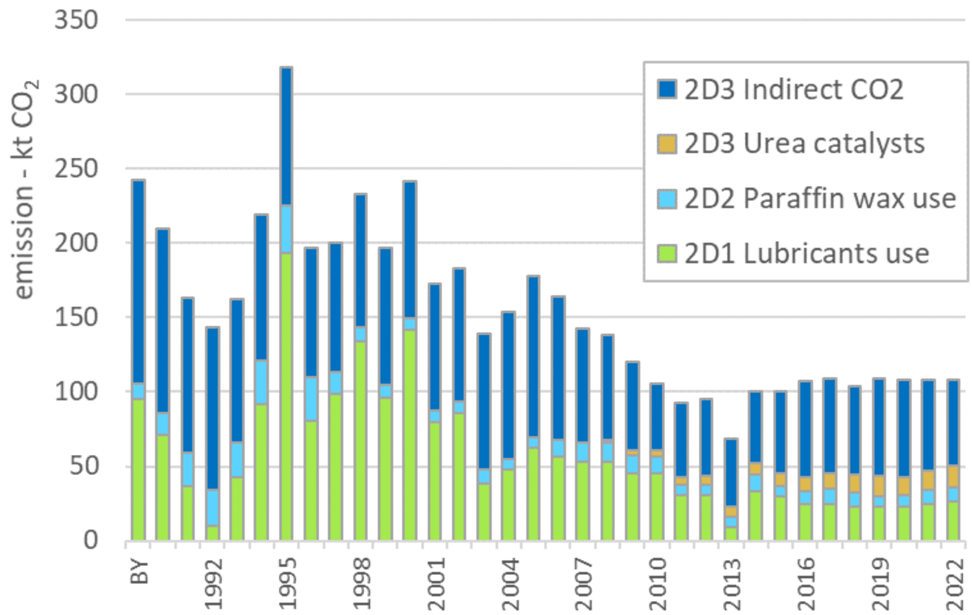


Figure 4.7.1 *Trend of CO_2 emissions in sector 2.D*

4.7.3 Source-specific QA/QC information and verification

General QA/QC procedures apply.

4.7.4 Source-specific recalculations

2.D.3 – NMVOC emission from solvent and other product uses subcategory was recalculated due to revised estimates in NFR: including new source - edible and non-edible oil extraction. Extraction of oil from oil seeds is performed either mechanically or through the use of solvents, or both. NMVOC emissions (diffuse and point sources) from solvent used were obtained from the National Air Emissions Database (LAIR) for the 2006-2017 period and implied emission factor was used for the 1985-2005 period knowing the amount of oil seeds processed. This indirect CO_2 emission was added to this category.

The recalculation has a very small effect on total CO_2 emission of Hungary, also changes within the subcategory „2D3 Other – Indirect CO2 emissions from solvent and other product uses" are lower than 1.5% for the whole time-series.

In the 2020 submission the 2.D.3 – NMVOC emission from solvent and other product uses subcategory was recalculated again. NMVOC emissions have been changed in every year because of corrected activity data in sub-sectors 2.D.3.d, 2.D.3.g and 2.D.3.h and changing from Tier1 to Tier2 methodology in sector 2.D.3.f (Dry cleaning). These recalculations are described in the 2020 IIR report of Hungary.

From the 2020 submission, NMVOC emissions from dry cleaning are reported using Tier 2 approach based on technology-dependent emission factors and the quantity of material cleaned. Activity data are available from the year 2004, for earlier years an extrapolation was made based on an estimated factor of emission per capita using population data.

In the 2021 submission, in sub-sectors 2.D.3.a, d-i – Indirect emissions from solvent use, calculation of CO_2 from default carbon content applied for NMVOC emissions was corrected for the whole time series.

In the 2022 submission, the following recalculations were made:

2.D.1 – Lubricant use. The number of L-category vehicles was recalculated for the period 2009-2019, thus there are minor changes in the activity data and CO2 emissions.

2.D.3 Other – Urea based catalysts. The number of Euro 6 vehicles was recalculated for 2018 and 2019, thus minor changes occur in the activity data and CO2 emissions.

2.D.3 Other – Indirect emissions from solvent and other product uses. In March 2020, recalculation was performed for this sector. CO2 emissions were recalculated and corrected in the 2020 and 2021 reports, while activity data (NMVOC emission from solvent and other product uses) remained unchanged. Activity data are now corrected for the whole time period.

2.D.3 Other – Indirect emissions from solvent and other product uses. Activity data for 2D3a Domestic solvent use and for 2D3d Coating and paints for 2019 was recalculated, thus minor changes occur in the activity data and CO2 emissions of the sector.

In the 2023 submission, the 2.D.1 Lubricant use sub-sector was recalculated. The amount of lubricant consumption was corrected for the year 2020 thus the CO_2 emission was almost halved in this category for 2020.

With the update to a new version of the COPERT 5 model (5.3.0), including also some revisions on stock and mileage:

- lubricant use in 2-stroke engines (reported in the energy sector) has been revised which affected the remaining part of all lubricants accounted here in the IPPU sector;
- amount of urea-based additive consumed for use in catalytic converters calculated from energy consumption in heavy duty vehicles has also been slightly revised.

The resulting change in emissions was less than 1 kt, far below the threshold of significance.

Based on the recommendations of TERT on our NFR reporting and taking into account the solvent emission calculations of ESIG, the 2D3 Other – Indirect emissions from solvent and other product uses category was recalculated in the 2024 submission. Minor changes were carried out in the 2D3f – Deagreasing category from 2017 onward, in 2D3g – Chemical products use from 2014, and in 2D3h – Printing from 1990. A more significant recalculation was carried out in the 2D3a – Domestic solvent use category for the whole time series. The amount of changes is far below the threshold of significance for the whole time series.

4.7.5 Source-specific planned improvements

NMVOC emissions from the Solvent and other product uses sector are further investigated.

4.8 Electronics industry (CRF sector 2.E)

Emitted gas: SF_6
Methods: T3
Emission factors: PS
Key sources: None

Several electronics manufacturing processes utilize fluorinated compounds for plasma etching, cleaning chambers and temperature control. The specific electronic industry sectors are semiconductor, thin-film-transistor flat-panel display and photovoltaic (PV) manufacturing. In Hungary emission from this sector is appears only between 2001 and 2005.

During the search for potential emission sources of fluorinated gases from electronics industry, no NF_3 use has been identified in Hungary before 2019, but a small quantity of SF_6 has been used between 2001 and 2005 by a semiconductor manufacturer company. So, SF_6 is reported in *2.E* sector solely between years 2001 and 2005 based on the data provision of a semiconductor manufacturer company. They also declared that the SF_6 has been acquired domestically, so the amount was allocated from the time-series of annual sales of SF_6 for other use in order to avoid double-counting. This fact is in line with Table 6.7 of Volume 3 of the 2006 IPCC Guidelines, where some amount of “Si design capacities” from Hungary is listed for the years 2003-2005.

Table 4.8.1 *Emission from category 2.E*

	Emission (kt CO_2-eq)
2001	1.19
2002	1.19
2003	1.19
2004	1.19
2005	1.19

In response to a recommendation from review conducted in 2019 Hungary should give an explanation how emissions were determined only between 2001 and 2005 and for only one company.

In Hungary, manufacturing of raw materials for the electronics industry is not significant, mostly only assembly activities take place in this sector. In order to calculate the emission of this sector for earlier years, potential sources have been identified by searching of potential emission sources. ERT recommended that Hungary provide an explanation how these potential sources were determined.

For the earlier years, Hungary got in touch with companies in 2014 which are potential emission sources of greenhouse gases in this category. Only one company said that SF_6 was used between 2001 and 2005, after 2005 the company had not used and had not bought this type of gas (this emission from 2.E category between 2001 and 2005 is below the threshold of significance. In response to the review 2020, this company confirmed that this gas was last used 15 years ago as production of that kind of product was removed from the product range and introduced new substances for cleaning panels.

Other companies said that greenhouse gases are not used during manufacturing. According to the Hungarian Photovoltaic and Solar Collector Association there are no manufacturing of photovoltaic panels in Hungary, but there was a company where technology of slicing of solar cells was used by way of an experiment but the company did not use any type of F-gases.

During the review 2020 ERT would like to know how new researches into new potential emission sources for the electronic industry are progressing. During the Web Conference of review 2020 Hungary informed the ERT that one plant has used from 2001 to 2005 SF_6 and Hungary said that Member State Experts had a list of companies which manufacture/assemble semiconductors, PV cells or other electrical equipment. These 30 plants cover the period between 1996 and 2018 according to the Hungarian Central Statistical Office (HCSO). According to this list of HCSO in 2018 and 2017 there were only 8 company in Hungary which is manufactured several kinds of electrical equipment. During the review member state experts could get in touch these plants. All of these companies confirmed, that they do not use PFCs and SF_6 during manufacturing because they only assemble accessories.

However, after the review the search for potential sources continued. As a result of this, it turned out that since 2019, solar cell production has been going on in a company by test operation and this manufacturer uses NF_3. This quantity was not reported in national statistics until now. Member state got in touch this company and clarified that this company uses NF_3 in production to periodically clean the surface of our deposition equipment. NF_3 is used through a completely closed and continuously monitored system for leaks. After use the remaining and reacted gas is neutralized by a gas burner, and the combustion product of this is treated with alkaline and electrostatic air purifiers. During these processes remaining and reacted NF_3 gas is completely removed.

The company provided information about the amount of NF_3 used and the amount of solar cells produced. According to the manufacturer, during the manufacturing the technology is completely safety. Due to this fact and because there is no emission factor per square meter produced in the case of PV production, Hungarian inventory does not include the emission of this activity.

As far as the Hungarian expert team knows, there is still no semiconductor manufacturing in Hungary according to the latest survey. However, Hungary will look at this subcategory again for the next submission.

4.9 Fluorinated substitutes for ozone depleting substances (CRF sector 2.F)

4.9.1 Overview of sector (2.F)

Emitted gases: HFC-23, HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-152a, HFC-227ea, HFC-236fa, HFC-365mfc, PFC116 (C_2F_6), PFC218 (C_3F_8), PFC-5-1-14 (C_6F_{14})
Methods: T1, T2
Emission factors: CS, D
Key sources: Refrigeration and Air-Conditioning (2.F.1)

HFCs or their blends are mainly used in household, commercial, industrial, transport refrigeration and air conditioning equipment; fire suppression and explosion protection equipment; in aerosol products; by solvent cleaning; as foam blowing agents and other applications.
Category 2.F includes Refrigeration and Air Conditioning (2.F.1.), Foam blowing agents (2.F.2.), Fire protection (2.F.3.), Aerosols/Metered Dose Inhalers (2.F.4.) and Solvents (2.F.5.). These categories use HFCs (fluorinated hydrocarbons) and PFCs (perfluorcarbons) which are alternatives to ozone depleting substances (CFCs, HCFCs, etc.) being phased out under the Montreal Protocol. HFCs are chemicals contain hydrogen, carbon and fluorine, while PFCs contain only carbon and fluorine. HFCs and PFCs might be used alone or mixed in blends. PFCs were started to be used as an ingredient of cooling blends in 1997. In 1998 and 1999, some quantities were also used for adhesive tape production. Please note that PFCs are also emitted during aluminium production to be reported in sector *2.C.3* that used to be the main source of PFCs in the beginning of the time-series, but stopped in 2005.

In Hungary HFCs, PFs, SF_6 and NF_3 are not produced, these gases are all imported for the whole timeseries. HFCs and PFCs, SF_6 and NF_3 are included under the UNFCCC as they have high global warming potentials (GWPs). New GWPs from the IPCC 54th Assessment Report are applied (***Table 4.9.1***). The applicable GWPs are determined based on the effects of greenhouse gases over a 100-year time horizon as provided by the IPCC in its Fifth Assessment Report.

Table 4.9.1 *The list of relevant F-gases in Hungary with GWP values to be used are defined in Annex of Commission Delegated Regulation (EU) 2022/1044.*

Greenhouse gas	Global warming potentials (GWP)	Greenhouse gas	Global warming potentials (GWP)
HFC-23	12400	**HFC-245ca**	716
HFC-32	677	**HFC-245fa**	858
HFC-125	3170	**HFC-365mfc**	804
HFC-134a	1300	**PFC-14**	6630
HFC-143a	4800	**PFC-116**	11100
HFC-152a	16	**PFC-218**	8900
HFC-227ea	3350	**SF_6**	23500
HFC-236fa	8060	**NF_3**	16100

Trend

Use of HFCs started in 1990, first in mobile air-conditioners and household refrigerators. Furthermore, F-gases in medical aerosols has been used since 1992 (and using of it is still significant today). Then the use of HFCs and PFCs as a refrigerant in household refrigerators has strongly declined (for example the only Hungarian producer of household refrigerators uses exclusively R600 (isobuthane) for years), and commercial, industrial refrigeration and air-conditioning became more and more important.

Coverage of all gases and all *2.F.1* subsectors are ensured by the fact that both a Hungarian and an EU-level Regulation are in force that require quite detailed data provision. The scope (list of gases to be reported) of Govt. Decree 14/2015. on fluorinated gases is the same as the scope of 517/2014/EC Regulation of the EU on F-gases, which is the same as the UNFCCC (before February 2015, the Govt. Decree 310/2008. and the Regulation No 517/2014/EC were in force in Hungary).

Amendments adopted by the European Parliament on 30 March 2023 on the proposal for a regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014 includes a number of changes that will have an impact on the use of F-gases in the future.

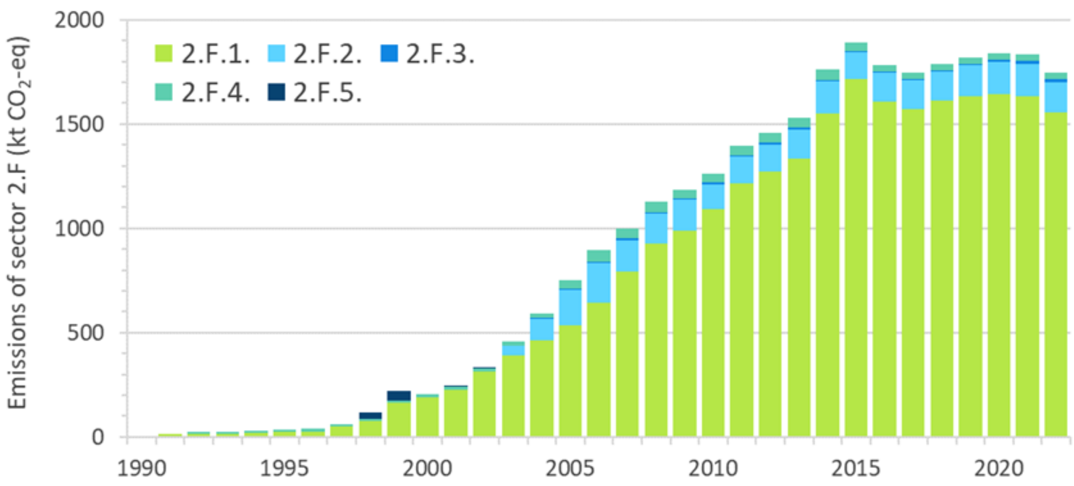


Figure 4.9.1 *Trend of emission from 2.F.1 between 1990 and 2022 (kt CO_2-eq)*

Emission of F-gases has stagnated for the last few years and increasing emission seems to be stalling. In average a four-fifths (it is between 60-90% for the whole time series) of category 2.F come from the operation of refrigeration and air-conditioning equipment containing F-gases. In 2022, this category accounts for 89% of total 2.F emissions. The second largest subsector is 2.F.2. (Foam blowing agent), which is accounts for 8 percent of total 2.F emissions. Continuous regulation of high GWP gases is also expected to reduce the emissions in this sector. Even though many refrigeration systems are operated with higher GWP gases, disposal practices are also becoming increasingly important, so emissions from equipment containing F-gases will not continue to increase significantly.

Emissions are to be reported by gas in the inventory (***Figure 4.9.1***), so the blends/preparations containing different F-gases need to be proportionated.

Trend of emissions of fluorinated greenhouse gases is presented in ***Table 4.9.2.***

***Table 4.9.2** Emission from 2.F by subcategories between 1990 and 2022*

	2.F.1.	2.F.2.	2.F.3.	2.F.4.	2.F.5.	SUM
			kt CO_2-equivalent			
1990	0.002	NO	NO	NO	NO	**0.00**
1991	13.760	NO	NO	NO	NO	**13.76**
1992	14.071	NO	NO	9.125	NO	**23.20**
1993	14.316	NO	NO	9.573	NO	**23.89**
1994	17.870	NO	NO	10.071	NO	**27.94**
1995	22.620	NO	NO	10.617	NO	**33.24**
1996	27.626	NO	NO	11.393	NO	**39.02**
1997	49.306	NO	NO	12.223	NO	**61.53**
1998	74.106	NO	NO	13.200	28.346	**115.65**
1999	164.250	NO	NO	12.612	43.161	**220.02**
2000	189.903	NO	0.321	14.628	NO	**204.85**
2001	224.888	NO	0.510	16.232	3.922	**245.55**
2002	311.191	NO	0.862	17.562	3.922	**333.54**
2003	388.418	47.197	1.636	19.150	NO	**456.40**
2004	465.165	102.008	3.286	20.681	NO	**591.14**
2005	534.551	171.898	5.735	39.438	NO	**751.62**
2006	641.313	192.637	6.395	53.580	NO	**893.92**
2007	791.826	152.048	6.435	49.027	NO	**999.34**
2008	926.260	145.306	6.314	47.338	NO	**1125.22**
2009	986.655	149.205	7.076	42.250	NO	**1185.19**
2010	1090.486	121.698	8.077	42.081	NO	**1262.34**
2011	1214.273	128.497	8.407	44.310	NO	**1395.49**
2012	1272.470	130.180	8.359	46.721	NO	**1457.73**
2013	1335.315	137.414	8.192	51.123	NO	**1532.04**
2014	1550.923	152.277	7.953	52.353	NO	**1763.51**
2015	1715.323	126.595	7.787	41.114	NO	**1890.82**
2016	1608.736	135.058	7.477	30.418	NO	**1781.69**
2017	1571.035	138.744	7.245	30.942	NO	**1747.97**
2018	1609.590	139.400	6.960	31.406	NO	**1787.36**
2019	1633.382	146.357	7.069	31.835	NO	**1818.64**
2020	1643.720	154.896	10.330	31.792	NO	**1840.74**
2021	1632.965	156.423	12.150	30.645	NO	**1832.18**
2022	1554.577	146.478	15.785	31.371	NO	**1748.21**

Methodological issues

The following table summarizes the methodologies used for each subcategory in 2.F. Detailed information of these methods are explained in the following chapters.

Table 4.9.3 *Overview of methods, emitted gases and emission factors used in category 2.F.*

	CRF Code	Emitted gases	Method	EF
Refrigeration and Air-Conditioning	2.F.1	HFCs, PFCs	Tier2	CS, D
Foam blowing agents	2.F.2	HFCs	Tier2	CS
Fire protection	2.F.3	HFCs	Tier1	D
Aerosols	2.F.4	HFCs	Tier2	CS, D
Solvents	2.F.5	HFCs, PFCs	Tier2	CS

4.9.2 Refrigeration and Air-Conditioning (2.F.1)

4.9.2.1 Source Category Description (2.F.1)

Emission from 2.F.1 is depicted on ***Figure 4.9.2*** The major share 43% in the range of actual emissions for year 2022 belongs to the subcategory 2.F.1.a. Subcategory 2.F.1.c, 2.F.1.e, 2.F.1.f. 2.F.1.d and 2.F.1.b accounts for 22.42%, 6.4%, 20.1%, 10.5 % and 0.0% of total 2.F.1 emissions, respectively.

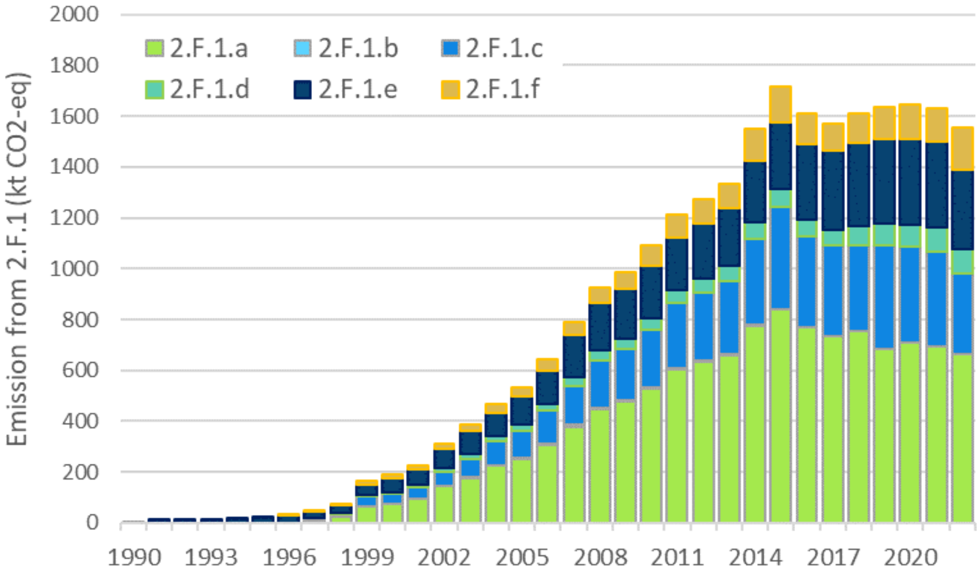


Figure 4.9.2 *Emission from 2.F.1 by subcategories*

Table 4.9.4 *Emission from 2.F.1 by subcategories*

YEARS	2.F.1.a	2.F.1.b	2.F.1.c	2.F.1.d	2.F.1.e	2.F.1.f	SUM
	kt CO_2-equivalent						
1990	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
1991	0.00	0.00	0.00	0.00	13.76	0.00	**13.76**
1992	0.00	0.02	0.00	0.00	14.05	0.00	**14.07**
1993	0.00	0.04	0.00	0.00	14.28	0.00	**14.32**
1994	0.00	0.06	0.00	0.00	17.81	0.00	**17.87**
1995	0.00	0.08	0.00	0.00	22.54	0.00	**22.62**
1996	0.53	0.09	0.48	0.04	26.23	0.26	**27.63**
1997	10.32	0.10	7.82	0.90	27.11	3.06	**49.31**
1998	25.19	0.11	10.25	2.82	32.13	3.62	**74.11**
1999	66.71	0.12	37.97	6.51	39.66	13.28	**164.25**
2000	76.24	0.12	36.38	7.35	56.79	13.03	**189.90**
2001	96.63	0.13	41.79	9.30	62.27	14.76	**224.89**
2002	144.92	0.14	56.00	14.12	77.35	18.66	**311.19**
2003	177.70	0.83	73.99	16.94	93.71	25.25	**388.42**

2004	225.14	0.83	94.80	21.09	91.11	32.20	**465.17**
2005	249.24	5.76	108.58	23.01	110.44	37.51	**534.55**
2006	305.82	5.30	129.89	28.29	127.64	44.36	**641.31**
2007	379.21	5.32	154.73	35.40	165.42	51.76	**791.83**
2008	445.21	5.66	186.20	41.20	185.42	62.56	**926.26**
2009	479.87	4.07	198.85	43.77	193.05	67.04	**986.66**
2010	529.80	2.43	227.11	47.45	203.44	80.26	**1090.49**
2011	605.13	2.39	256.36	54.15	206.42	89.82	**1214.27**
2012	635.29	2.60	269.42	55.88	214.62	94.67	**1272.47**
2013	659.32	2.08	291.14	57.43	226.42	98.93	**1335.31**
2014	776.70	1.56	338.77	67.88	241.86	124.15	**1550.92**
2015	841.08	1.13	399.07	74.12	260.77	139.16	**1715.32**
2016	767.89	1.15	357.08	66.25	295.54	120.82	**1608.74**
2017	732.11	0.44	357.23	62.59	313.00	105.66	**1571.03**
2018	754.25	0.14	335.34	76.38	329.58	113.90	**1609.59**
2019	683.45	0.02	408.07	84.54	334.09	123.21	**1633.38**
2020	711.48	0.01	374.63	86.84	338.13	132.62	**1643.72**
2021	693.06	0.03	373.92	93.22	337.18	135.55	**1632.97**
2022	663.76	0.00	316.43	99.00	312.23	163.15	**1554.58**

Share of emissions within category 2.F.1 is shown in the following Figure. Use of HFCs started in the beginning of 1990s, first in mobile air-conditioners and household refrigerators. Then the use of HFCs as a refrigerant in household refrigerators has strongly declined (for example the only Hungarian producer of household refrigerators uses exclusively R600 (isobuthane) for years), and commercial, industrial refrigeration and air-conditioning became more and more important.

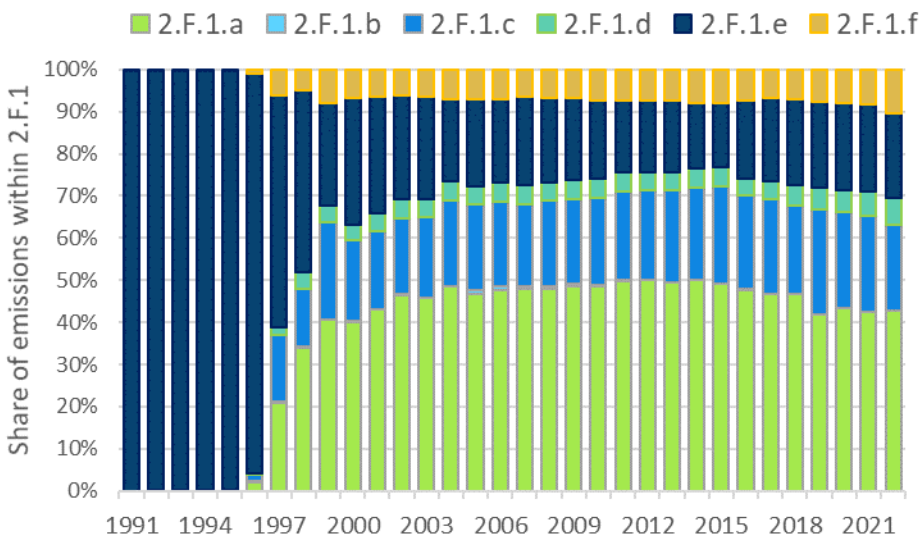


Figure 4.9.3 *Share of emissions within category 2.F.1 (%)*

4.9.2.2 Methodological issues (2.F.1)

Table 4.9.5 *Emission factors used for calculations*

Subcategory	QG	Emitted gases	Lifetime	Emission factor	
			[years]	Lifetime (x) [%]	Initial charge remaining (p) [%]
Commercial Refrigeration	2.F.1.a	HFCs, PFCs	15	35.0	50.0
Domestic Refrigeration	2.F.1.b	HFC	15	0.3	95.6
Industrial Refrigeration	2.F.1.c	HFCs, PFCs	20	25.0	70.0
Transport Refrigeration	2.F.1.d	HFCs, PFCs	15	50.0	20.0
Mobile Air-Conditioning	2.F.1.e	HFCs	15	15.0	16.7
Stationary Air-Conditioning	2.F.1.f	HFCs, PFCs	12	15.0	80.0

Emission factors, summarized in previous table have been determined based on expert estimates and 2019 Refinement to the 2006 IPCC Guidelines. *Emission factor x* is the average annual leakage and average annual emissions during servicing (%). *Emission factor p* is the residual charge of HFC in equipment being disposed (expressed in percentage of full charge, %).

The leakage rate of 1 percent of production was determined with the help of experts a few years ago. After the 2021 review, Hungary tried to collect more data. According to one of Hungary's largest car manufacturers the leakage rate is zero. Although, IPCC default range is 6–9 years (lifetime) in the Refinement 2019 to the 2006 IPCC Guidelines (vol. 3, p.7.52) for subcategory 2.F.1.d, the experience in Hungary shows that it is significantly longer.

History of improvements

Before submission 2019, Hungary used the mass-balance approach for the estimation of emissions from the whole 2.F.1 category. So, Equation 7.9 from Vol.3 of the 2006 IPCC Guidelines was applied, where data on annual sales of new refrigerant; total charge of new equipment, original total charge of retiring equipment and amount of intentional destruction is needed.

During the 2017 submission, the ERT recommended that instead of Tier1, Hungary use the Tier 2 method for 2.F.1 category. Instead of dividing sector 2.F.1 to sub-categories based on a study, Hungary should collect more data by sub-categories. In order to follow the recommendations and to obtain the most reliable data for the estimates of HFCs and PFCs emissions from this category including emissions from F-gases imported and exported in bulk and also in equipments, the following changes were implemented for submission 2019:

For years the mass-balance approach and the ’top-down’ approach were applied for all sub-categories in 2.F.1. For the following applications a ’bottom-up’ approach had been applied relying on statistics and expert estimations:

- Domestic Refrigeration (2.F.1.b)
- Mobile Air -Conditioning (2.F.1.e)

The amount of HFC-134a used for fill and refill products in subcategories Mobile Air-Conditioning and Domestic refrigerator was subtracted from the amount of imported and exported chemicals in bulk (for HFC-134a), as these amounts are already accounted for.

For the other four sub-categories, Hungary used chemical sales which is based on the amount of exported and imported F-gases. In these sub-categories Hungary used the same approach as before completed with an estimation of exported and imported F-gases in equipments, so disposal emissions from prefilled equipment appear in the inventory. So, Hungary was used the combination of Tier 1 and Tier 2 approach for the estimation of emissions until submission 2021.

Up to submission 2020, recovery of refrigerants was not considered in the calculations. Previous submission, according to the ERT recommendation recovery efficiency was developed for subcategories of 2F1. Therefore, the amount of emission from disposal was recalculated based on the amount of fluid in operating systems. For these sub-categories we used the same allocation of refrigerants as in previous submissions except for HFC-134a. For the latter, the proportion of the amounts in operating systems as contained in the F-gas database was taken into account.
The calculation of recovery efficiency was based on data from the F-gas database, which has been operating since 2010. Generally, according to the Hungarian experts, recovery efficiency has been increasing over the past years. As before 2010 Hungary has no further information about the efficiency of disposal, it was supposed that before 2010 recovery was negligible. To consider the imported products and equipment containing F-gases in the calculations the following method was applied previous submissions: the Hungarian 'F-gas database' includes the amount of imported F-gases in prefilled equipment since 2015. The most relevant blend contained in imported equipment is R410A (50% HFC-32 and 50% HFC-125) based on the Hungarian 'F-gas database'. Imported F-gases contained in equipment is calculated according to the database. The rate of the amount of fluid in operation systems and the amount of imported R410A in equipment are taken into consideration in the calculations. The calculated percentages for the amounts of F-gases contained in net imported products are 22% and 7% for HFC-32 and 125, respectively.

Activity data

Annual sales data is calculated as the difference of import and export of bulk chemicals. Documented, consistent time-series of import-export exists since 1992, thanks to the fact that the former Ministry for Environment, Nature and Water collected this data together with annual sales data of ozone depleting substances directly from the wholesaler companies. HMS has always been in a strong cooperation with the Ministry, so this data was used for the calculation of the inventory, together with the additional information collected directly by HMS when it was necessary.

By entry into force of Govt. Decree 310/2008 (XII.20.) the task of data collection was transferred to the Hungarian Monitoring Body for Certification (HMBC) as it is described in 2.F General chapter above. HMS receives the data needed from the HMBC database for the preparation of the inventory still through the ministry responsible for environment (Ministry for Agriculture). Consistency of the time series is ensured by the fact that it was checked that the wholesale companies reporting to the Ministry of that time are the same companies that report to the HMBC database too (except for the natural changes of the market, like cessations and entries of course).

The Hungarian Monitoring and Certification Body was also appointed for certification of persons required by 842/2006/EC ("EU F-gas Regulation"). HMBC and the database were maintained by the Association of Cooling and Air Conditioning Businesses. Govt. Decree 310/2008. (XII.20.) was replaced by Govt. Decree 14/2015 (II.20) that moves the responsibilities of HMBC to the newly established National Climate Protection Authority. With the adoption of Government Decree No 14/2015. (II.10.) on the conditions of activities with fluorinated greenhouse gases and ozone depleting substance the Authority was established on February 18, 2015 and its tasks were defined. HMBC database was renamed as 'F-gas database'.

Examining data exist in F-gas database, Hungary has realized that data by sub-application are accurate only from 2017. Amount of HFCs and PFCs banked in existing systems per sub-application serves as the basis for the calculations.

Actual method

In order to develop a Tier 2 methodology, further data collection and detailed data analysis were required. In addition to the above, it was recommended to Hungary uses the emission factor (Tier2a) approach in this sector. As, availability of data has not expanded enough to Hungary use top-down approach in every subcategory (in 2.F.1), data on chemical sales also plays an important role in the calculations. In subcategories, where top-down approach was improved in earlier years, there was some changes in the calculation method in order to meet the emission factor approach. These changes and the emission factors will be specified in the relevant chapters.

In general, the equation 7.10-7.14 of Chapter 7.5.2.1 on Choice of method from 2019 IPCC Refinement Guidelines was used:

$$E_{total,\,t} = E_{charge,\,t} + E_{lifetime,\,t} + E_{end\text{-}of\text{-}life,\,t}$$

where:

- $E_{charge,\,t}$: the emission during system assembly (as in Hungary manufacturing of refrigerators and air-conditioning systems is not appears, only assembly losses are taken into account),
- $E_{lifetime,\,t}$: the amount of F-gas emitted during system operation,
- $E_{end\text{-}of\text{-}life,t}$: the amount of HFC and PFC emission at system disposal in year t.

$E_{containers}$ have been left out of the equation, due to emission related to management of refrigerant containers is typically less than 0.05% in Hungary (according to a Hungarian expert of the biggest F-gas distributor). Hungary would like to improve this value by several experts later.

Previous equation consists of the following terms:

1. <u>Refrigerant charge emissions of new equipment:</u>

$$E_{charge,t} = M_t \cdot \frac{k}{100}$$

where:

- M_t : amount of HFC charged into new equipment in year t (per sub-application), kg

- k : emission factor of assembly losses of the HFC charged into new equipment (per sub-application), %

2. Emission during lifetime (operation and servicing):

$$E_{lifetime,t} = B_t \cdot \frac{x}{100}$$

where:

- B_t : amount of HFC banked in existing systems in year t (per sub-application), kg
- x : annual emission rate of HFC of each sub-application bank during operation accounting for average annual leakage and average annual emissions during servicing , %

3. Emissions at end-of-life:

$$E_{end-of-life,t} = M_{t-d} \cdot \frac{p}{100} \cdot \left(1 - \frac{\eta_{rec}}{100}\right)$$

where:

- $E_{end-of-life,t}$: amount of HFC emitted at system disposal in year t (per sub-application), kg
- M_{t-d} : amount of HFC initially charged into new systems installed in year (t-d), kg
- p : residual charge of HFC in equipment being disposed of expressed in percentage of full charge , %
- η_{rec}: recovery efficiency at disposal, %

To make a consistent timeseries the following assumptions and methods was used:

- Hungary uses the real quantity of banked existing systems per sub-application between 2017 and 2019 for subcategories 2.F.1.a/c/d/f
- It is important to highlight, according to the legislation, all applications that are subject to leak testing are included is also required to register in the F-gas database. Refrigeration and air-conditioning equipment containing 3 kg or more of F-gases are subject to leak testing. Due to this fact smaller mobile air-conditioning systems are not obligatory to reported. Some undertaking report air-conditioning equipment in database, but this value is negligible.
- For that 3 years, rate of gases existing systems per sub-application can be quantifiable. ***Table 4.9.6*** includes these values.
- As less variability can be detected in the data, Hungary was used the average of that 3 years in further calculations.
- Refrigerant quantities in equipment are available as aggregated data for the whole 2.F.1 sector from 2010. These data are still unreliable at the beginning of the time series, as significant changes took place in the institutions responsible for data collection, so this data was used

only from 2012. According to this, Hungary provided a timeseries by subcategory based on the percentages summarized in ***Table 4.9.6***, to estimate the amount of gas in equipment.

- For years before 2012, data based on the balance of import and export. Since 2010, database contains data on how much gas was used for filling and refilling into new appliances. Hungary calculated ratios from these values between 2010 and 2015. From these 6 years an average was obtained. A share of 36% is charged to new equipment (installation) and 64% for servicing.
- These data are in proportion to the total amount of gas aggregated, not for each gas.
- 1% of the amount calculated as total charge of new equipment was taken into account as prompt emission.
- Recovery efficiency: amount of regenerated gases in year t / original total charge of retiring equipment (amount of fluid remained in products at decommissioning)
- Determination of original total charge of retiring equipment is the total charge of new equipment lifetime years ago multiplied by the emission factor initial charge remaining (p), according to the equation 3 in this chapter.
- These efficiencies were calculated using data from the F-gas database, which was created in 2010. According to national experts, recovery efficiencies have been increasing over the past few years. As Hungary has no further information about the efficiency of the disposal of refrigerants prior to 2010, recovery was assumed to be negligible prior to this time. For 2018–2021, the average of these four years was used to estimate the recovery efficiencies and, assuming negligible recovery prior to 2010, calculated a linear trend between 2010 and 2017.

Table 4.9.6 *Rates of gases existing systems per sub-application*

	2.F.1.a	2.F.1.c	2.F.1.d	2.F.1.f	SUM
HFC-23	0%	84%	0%	16%	100%
HFC-32	9%	38%	1%	53%	100%
HFC-125	41%	34%	3%	21%	100%
HFC-134a	14%	66%	1%	19%	100%
HFC-143a	77%	16%	6%	1%	100%
HFC-152a	4%	30%	4%	62%	100%
PFC-116	1%	92%	0%	8%	100%
PFC-218	44%	15%	38%	3%	100%

The following table contains the values of recovery efficiency:

Table 4.9.7 *Recovery efficiencies between 2010 and 2021 by gas (%)*

	2010	2011	2012	2013	2014	2015	2016	2017	2018-2021
Recovery efficiency	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0

4.9.2.3 Domestic refrigeration (2.F.1.b)

In Hungary, there is only one relevant household refrigerator manufacturer. Although the ban of the placing on the market of domestic refrigeration appliances containing F-gases with a GWP >150 entered into force on 1 January 2015 according to the Regulation 517/2014 (Annex III) in this factory instead of HFC-134a, R600 was used since 2008 for filling refrigerators.

The following method was applied to calculate emission from domestic refrigerators:

- The number of manufactured refrigerators and the amount of refrigerants filled in new products are available directly from the producer.
- Equations in Chapter 4.9.2. was used, emission factors are summarized in *Table 4.9.5.*
- Number of prefilled (imported) products is available from HCSO statistics.
- For calculating the charge of manufactured and prefilled domestic refrigerators, a value of 20 g is used.
- Lifetime of domestic refrigerators is 15 years and a value of 0.3% annual leakage rate was determined (according to the table 7.9).
- The refrigerant stock is determined according to the number of sold refrigerators in Hungary. The amount of F-gases used for servicing (refill) is calculated from the amount of filled fluid multiplied by the annual leakage rate.
- Emissions from manufacturing are not applicable (NA) because the factory used an isolated system for filling new refrigerators.

For sub-category 2.F.1.b, disposal loss factor of 100% is used until submission 2019 to avoid underestimation of emission from this category. For submission 2020 Hungary was developed the value of this factor. In Hungary there are programmes in place in order to reform labor-saving devices since 2014 and the successfulness of this exchange program was summarized in studies. The programs are declared by Ministry for Innovation and Technology. The main target of them to households use more energy-saver devices, like refrigerators and washing machines in order to people can exchange their appliances in a more economy way. The number of changes are summarized in several studies, which are the base of used percentages by Hungary to calculate emissions from domestic refrigerators. Due to the programme has started in 2014, data are reliable for years between 2015 and 2018. An average amount (piece of 30000) of exchanged refrigerators was multiplied by the average charge of refrigerant (20 g). The rate of this value and the amount of fluid in operating systems was used. According to the information recovery before 2005 was negligible, between 2005 and 2010 values were interpolated. So, according to the ERT recommendation recovery was taken into account.

Hungary used a higher value of initial charge remaining for category domestic refrigeration than it is determined in the IPCC Guideline, because of the low refrigerant losses that occur during the use phase (0.3% per year). If Hungary assumes that 0.3% of the initial charge leaks in every year, 95.6% of the initial value will remain in the equipment over 15 years. In this case, Hungary used this value because there were no other expert estimates and range of 0 to 80% is very wide.

4.9.2.4 Mobile Air-conditioning (2.F.1.e)

As for Hungary, a database about the number of cars equipped with air-conditioning systems is not available, it's necessary to use more activity data for the calculations. The number of manufactured cars, the stock of road vehicles, the number of road vehicles registered for the first time in Hungary and the rate of cars equipped and not-equipped with air-conditioning systems was used in the calculations. The rate for the whole time series is based on the European vehicle categories. The following table includes the used percentages of vehicles with air-conditioning systems in manufactured cars and for stock of road vehicles.

Table 4.9.8 *Percentages of cars equipped with air-conditioning systems.*

Year	new cars equipped with air-conditioning systems	registered cars equipped with air-conditioning systems	Year	new cars equipped with air-conditioning systems	registered cars equipped with air-conditioning systems
1991	5%	5%	**2007**	95%	45%
1992	5%	5%	**2008**	95%	50%
1993	30%	5%	**2009**	100%	53%
1994	30%	5%	**2010**	100%	56%
1995	30%	7%	**2011**	100%	57%
1996	60%	8%	**2012**	100%	59%
1997	60%	8%	**2013**	100%	61%
1998	60%	10%	**2014**	100%	62%
1999	60%	12%	**2015**	100%	64%
2000	85%	16%	**2016**	100%	72%
2001	85%	17%	**2017**	100%	74%
2002	85%	20%	**2018**	100%	76%
2003	85%	23%	**2019**	100%	78%
2004	85%	28%	**2020**	100%	80%
2005	85%	33%	**2021**	100%	82%
2006	95%	37%	**2022**	100%	82%

The following method was applied for calculate emission from mobile air-conditioning for cars:

- The number of manufactured cars is available directly from the manufacturers. The emission from manufactured cars is calculated by multiplying percentages of new cars with air-conditioning systems and the refrigerant charge of cars.
- The average refrigerant charge is between 700 g and 550 g (in the earlier years more refrigerant was required for mobile air-conditioners in cars, according to one of the biggest manufacturer, the typical charge 15 years ago was 0.7 kg, but as of 2020 was 0.4 kg, resulting in an average refrigerant charge of 0.55 kg for the intermediate period of 2004– 2019).

- As the use of HFC-1234yf is more and more significant, the inventory includes the emission of HFC-1234yf from submission 2017. *Figure 4.9.4* shows the rate of HFCs in automobiles according to an expert estimation.
- A value of 1% for leakage rate of manufacturing was used in the calculations.
- The refrigerant stock are determined according to the number of registered cars on the road which are available from national statistics. Cars are divided according to their classification to European emission standards.
- The annual quantities of refrigerants in operating systems are calculated by multiplying the number of cars and the percentages of vehicles with air-conditioners and the average charge.
- Amount of F-gases used for servicing (refill) is calculated from the number of passenger cars multiplied by a leakage rate of 15% (following the recommendation of national experts which is in accordance with the 2019 IPCC Guidelines (from table 7.9 on page 7.52 of the 2019 IPCC Guidelines).
- Finally, the average lifetime is 14 years in the calculations. So, disposal emission was determined using the annual total charge of vehicles 14 years before.
- In the category mobile air-conditioning systems (2.F.1.e), emissions also from buses and railways were taken into account in this submission (until now the inventory included solely emissions from automobiles in this sub-category). In addition, activity data were revised because of clarifying the number of air-conditioned cars.
- Equations in Chapter 4.9.2 was used, emission factors are summarized in *Table 4.9.5.*

During the review 2021, ERT recommends that Hungary explain the main reason of the reduction of emissions for 2.F.1.e. Refrigerant charge in cars, was updated from 0.7 kg for the whole time series to 0.55 kg for 2004–2019. According to one of the biggest manufacturer, the typical charge 15 years ago was 0.7 kg, but as of 2020 was 0.4 kg, resulting in an average refrigerant charge of 0.55 kg for the intermediate period of 2004– 2019.

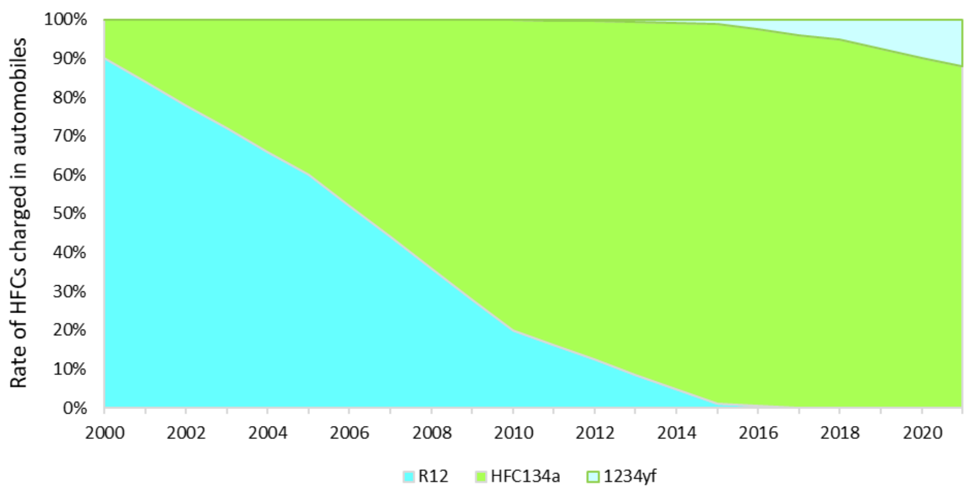


Figure 4.9.4 *Rate of quantity of HFC charged for automobiles between 2000 and 2021 (%)*

Calculation method for automobiles:

- the activity data is available from national statistics (number of buses: number of manufactured buses, stock of road buses/coaches. number of road vehicles registered for the first time);
- moreover, some information (number of air-conditioned coaches and charge of the mobile air-conditioners, the refrigerant type in these vehicles) are available directly from the biggest transport companies, like Volánbusz Transport Company and BKK (Centre for Budapest Transport);
- emission from buses are calculate from 1995, because before this year Hungary has not relevant data, moreover according to existing data it is negligible because of small rate of air-conditioned vehicles (1-2%);
- the refrigerant used in automobiles is HFC-134a;
- the average charge is 8kg for long-distance buses, 10kg for local buses according to the companies;
- a value of 15% for leakage rate was used for a year;
- a value of 16.7% for initial charge remaining (p) was used;
- the average lifetime is 14 years in the calculations, so disposal emission was determined using the annual total charge of vehicles 14 years before;
- amount of F-gases used for servicing (refill) is calculated from the quantity of refrigerant charge in air-conditioners, number of air-conditioned buses multiplied by a leakage rate of 15% (according to the 2006 IPCC Guidelines (from table 7.9 on page 7.52 of the 2019 IPCC Guidelines).

Calculation method for trains:

- data on stock of trains and the used refrigerant type and the refrigerant quantity are available from the company which has the main activity in railway passenger transportation;
- for every kind of trains the type and the quantity of charged refrigerant data is available directly from the aforesaid company (12 kg, 41 kg and 27 kg);
- in mobile air-conditioners of trains HFC-134a, HFC-422D are charged (90% is HFC-134a);
- emission from disposal is not occurring ;
- leakage rate is 15 % for this sub-category.

Up to now, emission of HFC-1234yf was not considered in the calculations. In this submission, an expert estimation was applied to refine the emission from automobiles.

Calculation method for trams:

- data on stock of trams and the used refrigerant type and the refrigerant quantity are available from the company which has the main activity in urban public transport
- trams (so-called Combino) were put into service in 2006 but these were basically non air-conditioned, air conditioning systems were installed into the vehicle only in 2008

- trams (CAF) were put into service in 2015-2016, and from 2019;
- mobile air-conditioners of trams in Hungary use R-407C and R-410A, both which contain HFC-32;
- emission from disposal is not occurring;
- leakage rate is 15 % for this sub-category .

4.9.2.5 Uncertainties and time-series consistency

Uncertainties are estimated taking into account the uncertainty of a legally binding data provision of the companies.

Uncertainty	AD	EF	Combined
2.F.1 Refrigeration and Air Conditioning Equipment - HFC+PFC	10	10	14.14

4.9.3 Foam Blowing (CRF sector 2.F.2)

Emitted gases: HFC 134a, HFC-152a, HFC-227ea, HFC-365mfc
Methods: T2
Emission factors: CS
Key sources: none

4.9.3.1 Source category description (2.F.2.)

Hydrofluorocarbons have been used in foam blowing industry, mainly as replacements for CFCs and HCFCs. There are 2 types of foam blowing, which are open-cell and close-cell products. The main characteristic of the open-cell foam is emission occur during the manufacturing process and shortly after it.

On the other hand, HFC emission from close-cell foams occurs throughout the products lifetime (during use). These products are polyurethane foams and extruded polystyrene foams (XPS) and these are used mainly for insulating applications.

4.9.3.2 Methodological issues (2.F.2.)

Country specific method is applied using activity data derived from PRODCOM statistics and emission factors from the 2006 IPCC Guidelines. This method has been developed due to the requirement of ERT during 2012 review and has been checked during the EU MS Support Project.

The new method of 2006 IPCC Guidelines is basically different because it encourages the inclusion of emissions from decommissioning and recovery. Please note that no decommissioning losses and destroyed quantity are reported currently but at the moment no product have yet reached the estimated (default) end of lifetime and no specific information is available on any destructed quantity or recycling technology.

Emissions of different gases from 2.F.2 Foam blowing sector are summarized in ***Figure 4.9.5.***

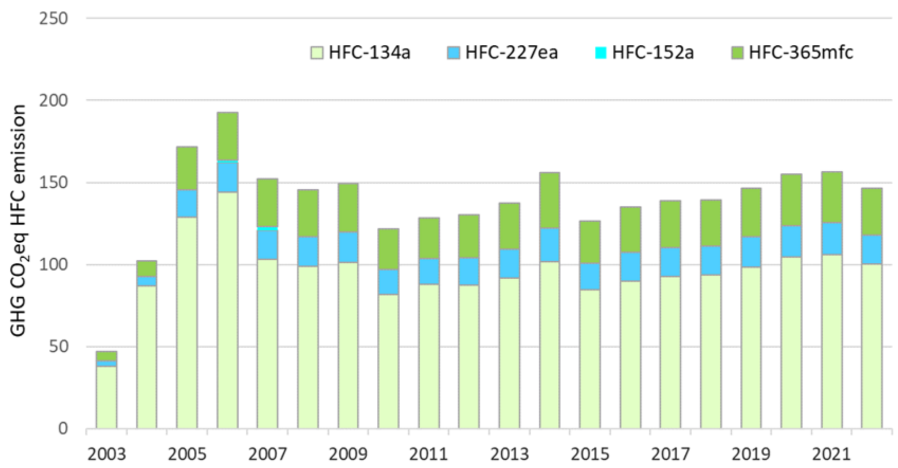


Figure 4.9.5 *Emission of different gases from 2.F.2 Foam blowing (kt CO_2-eq)*

At the moment, we have no information on the use of HFC-245fa as foam blowing agent in Hungary. Until 2013 there was no reporting on any import or export of this gas into Hungary and the emission estimation method in 2.F.2 subsector does not include this gas either.

4.9.3.3 Activity data (2.F.2)

As it is stated in both Guidelines and NIRs of other parties: „it is extremely difficult to collect activity data...” Indeed, no direct data or statistics are available on the HFCs imported in products, neither on the amount of HFCs present in products. So, there was only the possibility to start from the viewpoint of the foam products, as it was discovered that in fact PRODCOM statistics (Statistics on the production of manufactured goods published on the website of EUROStat and Hungarian Central Statistical Office) contain both import-export and production data of two foam types.

These are: 22214120 - Cellular plates, sheet, film, foil and strip of polymers of styrene (containing XPS) and 22214150 - Cellular plates, sheets, film, foil and strip of polyurethanes (PUR).

In order to get the amount of HFC blown into foam products, the percentage of blowing agent within foam products, proportion of HFCs within foam blowing agents and proportion of type of HFC is also needed, as it follows:

Chemical used in Foam Manufacture (HFC filled in new products) = domestic production of year t of foam product (t) * blowing agent/ foam type (%) * HFC blowing agent / all blowing agents (%) * HFC-type / all HFC (%)

(***Chemical used in Foam Manufacture*** data is to be multiplied by “first year loss” EF in order to calculate the **emissions from manufacturing**.)

Chemical emitted during the lifetime of closed cell foams (HFC charged into the product) = production + import - export of the foam type (t) * blowing agent/ foam type (%) * HFC blowing agent / all blowing agents (%) * HFC-type / all HFC (%)

(***Chemical emitted during the lifetime of closed cell foams*** data is to be accumulated as many years as the lifetime of the foam product and to be multiplied by “annual loss” EF in order to calculate the **emissions from stocks**.)

In this way. ***Chemical used in foam manufacture*** and ***Chemical emitted during the lifetime of closed cell foams*** required by eq. 7.7 of the 2006 IPCC Guidelines has been expressed, so default EF-s from Table 7.5 and 7.6 could be used. In this method both the amounts imported in bulk (*Chemical used in foam manufacture*) and in products (within *Chemical emitted during the lifetime*) are accounted. The double usage of statistical data of foam production does not result double count in emissions, since in the first case it is used to determine the emissions from manufacturing occurred in Hungary even if the product is exported and in the second case it is needed to determine the amount of foam products remaining in the country responsible for the emissions from stocks.

The following ***table*** summarizes the values and their references used in the calculation.

Table 4.9.9 *Summary of factors used by the calculation in 2.F.2*

	XPS	PUR	Reference
domestic production of year t of foam product (t)	Prodcom Statistics		http://epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/data/database
production+import-export of the foam type (t)			
blowing agent/ foam type (%)	6%	8%	Revised IPCC1996 page2.59 (6-15%) and IPCC/TEAP study (please see References)
HFC blowing agent / all blowing agents (%)	40% and decreasing *until 20%*	20% and decreasing *until 10%*	DG Climate F-gases Reg.Review Study and IPCC/TEAP study (please see References) and suggestion received during EU MS Support Project

Within PRODCOM 22214120 polystyrene foams category, only XPS (extruded polystyrene) type foam might be blown with HFCs. The proportion of XPS foam within polystyrene foams in the Hungarian market is estimated to be 10% by the Hungarian Association of EPS Insulating Foam Producers and another expert architect.

PRODCOM data of PUR production of 2005 to 2008 and XPS production data of 2004 and 2005 were averaged in order to avoid negative production+import-export values in the years 2006 to 2008 and to reflect better the trend. (Production data of the mentioned years are summed and divided by number of years).

HFC are used as blowing agent in foams mainly after 2003 as substitutes of ODS after the ban of CFCs and HCFCs under Montreal Protocol. Nowadays also HFCs are substituted by materials with less GWP (CO_2, Hydrocarbons, HFO, etc.) The background study of F-gases Regulation Review of DG Climate states the ratio of HFCs among the blowing agents is 40% for XPS and 20% for PUR between 2003 and 2011.

HFC use in foam blowing started in 2003 based on data reported by the intermediate material producer company (BASF).

The DG Climate study estimated that the final year of significant HFC use in foam blowing would be in 2011. However, our assumption for Hungary is 2015 (instead of 2011) based on suggestion of the IPCC/TEAP study (IPCC/TEAP. 2005), which seemed more realistic.

During the EU MS Support Project, the expert noted that the elimination of HFC blowing agent by 2015 is still not realistic and suggested to apply 20% for XPS foams and 10% for PUR foams after 2011 as well. HFC emissions of year have been recalculated based on this suggestion in sector 2.F.2.Foam.

Table 4.9.10 *Proportions of HFC foam blowing agents applied by calculation in 2.F.2*

		2007	2008	2009	2010	2011-2022
% of HFC blowing agent usage/All blowing agent usage in the case of	XPS products	35.6	31.1	26.7	22.2	20.0
	PUR products	17.8	15.6	13.3	11.1	10.0

The proportion of the different types of HFCs is based on the historical data reported by the intermediate material producer company (BASF). The average result is 10% HFC-227a and 90% HFC-134a. HFC-365mfc is reported the same as HFC-227ea because the company reported the use of a blend containing precise proportion of HFC -227ea and HFC-365mfc. So, HFC-365mfc is reported by multiplying the amount for HFC-227ea by this appropriate proportion. This method is the same as HFC-365mfc had been reported as cross cutting info in previous inventory submissions.

The proportion of soft foams and hard foams within PUR foams is also based on the historical data reported by the intermediate material producer company (BASF). The average result is: 10% soft foam and 90% hard foam. All soft foam is accounted as open cell foam (using eq. 7.8 of the 2006 IPCC Guidelines) and all hard foam is accounted as closed cell foam (using eq.7.7 of the 2006 IPCC Guidelines).

Please note that in addition to the abovementioned method, also a directly reported experimental usage of HFC-152a solely in the years 2006 and 2007 is included within the soft foam subcategory.

4.9.3.4 Emission factors (2.F.2)

Default emission factors from Table 7.6 of the 2006 IPCC Guidelines are used for XPS and general default emission factors from 7.5 of the 2006 IPCC Guidelines are used for PUR as the proportion of the different types of PUR foams is not known. Used values are summarized in ***Table 4.9.11.***

Table 4.9.11 *Default emission factors used from 2006 IPCC Guidelines*

	XPS	PUR
lifetime	50 years	20 years
first year loss	40%	10%
annual loss	3%	4.5%

In the case of soft foams (all accounted as open-cell foam) equation 7.8 of 2006 IPCC Guidelines is used, so ALL the filled amount is emitted during manufacture.

Please note that the IEF (in CRF) is changing through the years due to the fact that EF of the Guidelines is determined by foam type. while IEF in the CRF is determined by HFC type.

4.9.3.5 Source specific recalculations, QA/QC activities, uncertainties and planned improvements (2.F.2)

It is a planned improvement and also a further recommendation of MS Support Project to get in touch directly with producers and to verify whether HFC blowing agents have been used in Hungary at all, the country specific proportion of foam types and HFC types used.

Uncertainty	AD	EF	Combined
2.F.2 Foam Blowing – HFC	50	21	54.23

4.9.4 Fire Extinguishers (CRF sector 2.F.3)

Emitted gases: HFC 125, HFC-227ea, HFC-134a
Methods: T1
Emission factors: D
Key sources: none

4.9.4.1 Source Category Description (2.F.3)

Until the beginning of 1990s, halon systems were the second wide-spread fire extinguishers after dry chemical powder extinguishing systems. Because halons do not contain hydrogen, these are inflammable. According to the Montreal Protocol these substances were phased out. Nowadays fire protection equipment is filled with HFCs as partial replacement for halons. In Hungary, mainly HFC-125 and HFC-227ea gases are the most widespread in fire extinguishing systems.

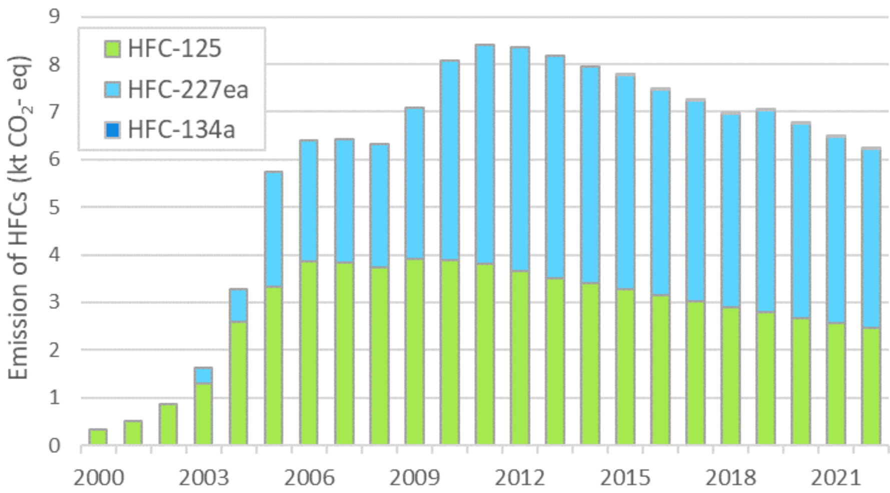


Figure 4.9.6 *Emission of different gases from 2.F.3 Fire Extinguishers from year 2000 (kt CO_2-eq)*

4.9.4.2 Methodological issues (2.F.3)

Activity data for this subcategory is collected by the Fire Protection Department of the National Directorate General for Disaster Management. Ministry of the Interior as part of the yearly national statistical data collection program. This data is available from 2000 and ensures the full coverage of the country on installed fire protection equipment. In addition, it includes the amount of import in products; however, it is not possible to separate from import in bulk.

The consumptions of the years are accumulated as a "bank", and emissions of a given year is calculated as a certain (default) percent of this "bank".

After submission 2020, Hungary has contacted with an expert who highlighted that lifetime of these devices in Hungary is usually 20 years (in agreement with IPCC Guidelines - the Guideline recommends to use years between 15 and 20 for lifetime years.). Moreover, Hungarian legislations incudes this fact for fire extinguishers. Therefore, for submission 2021 March this factor had been changed (from 15 to 20 years), so the first year when the disposal emission appears will be in 2020. In addition, as there are no accurate statistics on the recovery rate in this sector, this factor is still considered to be zero, based on the IPCC Guidelines (Chapter 7.6.2.2) and Hungary try to make further efforts to estimate recovery efficiency.

The following default emission factors have been applied:

Annual operational emission % per installed base	4%
Lifetime years	20

(source: 2006 IPCC Guidelines chapter 7.6.2.2. Tier 1 methodology)

4.9.4.3 Recalculations, QA/QC activities, uncertainties and planned improvement

Uncertainties are estimated based on the 2006 IPCC Guidelines chapter 7.6.4 regarding activity data and chapter 7.6.2.2 regarding the emission factor where it is stated: "*factor range of 2 to 6 percent (that is 4 % +/-2%)"*

Uncertainty	AD	EF	Combined
2.F.3 Fire extinguishers - HFC	20	2	15.13

Due to the changed GPW values of HFC-125 and HFC-227ea emission of this subcategory was reduced by between -0.03 and -0.3 kt CO_2-equivalent between 2000 and 2019.

There was no recalculation for submission 2024.

4.9.5 Aerosols and Metered Dose Inhalers (CRF sector 2.F.4)

Emitted gas: HFC-152a, HFC-134a
Methods: T2
Emission factors: CS, D
Key sources: none

This category includes metered-dose inhalers (MDI) which are used in medical products and general-purpose aerosols. Most aerosol packages contain mainly hydrocarbons (HC) as propellants, but in a small fraction also HFCs are used, especially HFC-134a in industrial, household and medical applications. The graph below ***(Figure 4.9.7)*** shows the emission of F-gases from this sub-category. The main substance is HFC-134a. Emission of HFC-152a from general-purpose aerosols is almost negligible.

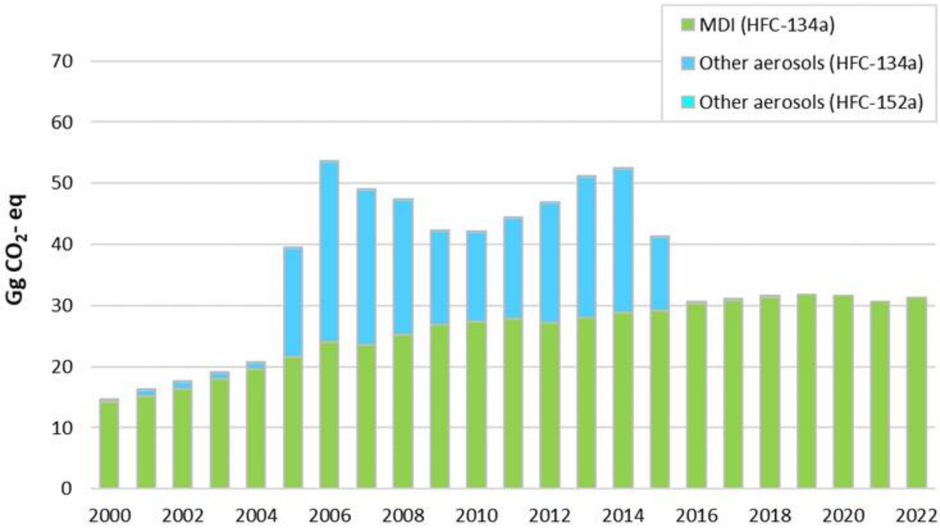


Figure 4.9.7 *Trend of emission in sector 2.F.4 Aerosols and MDI*

4.9.5.1 Metered-dose inhalers (2.F.4.a)

Emitted gas: HFC-134a
Methods: T2
Emission factors: CS
Key sources: none

4.9.5.1.1 Source Category Description (2.F.4.a)

Metered-dose inhalers are used in medical appliances primarily for the treatment of asthma and CODP (Chronic Obstructive Pulmonary Disease). As for medical aerosols, F-gases are today only used in MDIs, not in nebulizers. These medical products with HFC propellant first reached the Hungary market in 1992.

4.9.5.1.2 Methodological issues (2.F.4.a)

In the MDI sector the Tier2a method, i.e. the user-based approach was applied. Activity data of metered-dose inhalers subcategory was the consumption of MDIs. So, data on production was not used here. The emissions are calculated from the number of MDIs (HFC quantities) sold per year in Hungary. Emissions from aerosols should be calculated using the same method for each year in the time series. For the early years in the time series the splicing technique, the overlap method was applied to form a complete time series (find detailed description in the following chapter).

4.9.5.1.3 Activity data (2.F.4.a)

Data of annual sales from National Institute of Pharmacy and Nutrition was used between 2006 and 2015. The number of total consumption and the filled quantity in every aerosol was available. The typical charge contained in product is between 5 and 18 g. Before 2006 and after 2015 the overlap technique was applied to complete the time series. To estimate emissions for these years, the relationship between the consumption and the number of asthma and CODP (patients) cases was used applying the method of the 2006 IPCC Guidelines chapter 5.3.3.1.

Equation 5.1 from the 2006 IPCC Guidelines was applied.

$$y_t = x_t \cdot \frac{\sum_{i=m}^{m} y_i}{\sum_{i=m}^{m} x_i}$$

where: $\boldsymbol{y_t}$ – the estimated AD (the amount of the HFC quantities) in year t

$\boldsymbol{x_t}$ – the number of patients in year t

$\boldsymbol{y_i}$ – the amount of the HFC quantities in year i

$\boldsymbol{x_i}$ – the number of patients in year i.

As the difference between the average of the overlap for these 10 years (2006-2015) (19.6%) and the overlap of the first year (2006) (16.3%) is significant and the latter is more representative. we have chosen to use the overlap for the first year. For years between 2016 and 2018 the overlap of year 2015 was used (21.2%). The graph ***(Figure 4.9.8)*** below shows the relationship between the quantity of the gas and the number of patients.

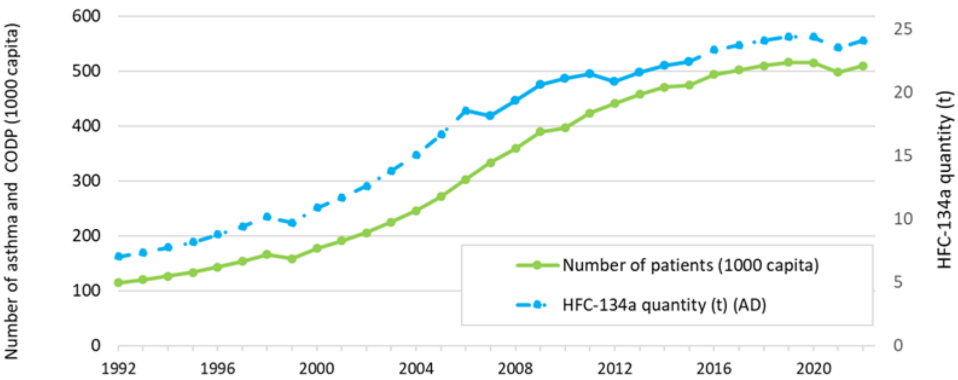


Figure 4.9.8 *Activity data of the 2.F.4.a subcategory*

In the CRF table the activity data „In operation system" (the annual average stocks) and „Emission from stocks" is the same amount, because the time period between sales and use is short (product lifetime is one year). Hungary uses notation key 'NO' in CRF for 'filled into new manufactured products', as Hungary uses the user-based approach.

4.9.5.1.4 Emission factors (2.F.4.a)

In the calculations, instead of the manufactured inhalers, the purchased aerosols were used. MDIs are prescription medicine and in Hungary it is rigorously regulated. In the calculations, it was assumed that the emission level corresponded to 100% of usage (i.e. purchased aerosols), because the time period between sales and use is short. Moreover, inhaled gases are emitted into the atmosphere without undergoing any changes (according to the IPCC specifications (2006 IPCC Guidelines, Vol. 3, p. 7.28)). In consequence, a country-specific emission factor was used (EF=1).

4.9.5.1.5 Recalculations, QA/QC activities, uncertainties and planned improvements (2.F.4.a)

There was no recalculation in this year.

4.9.5.2 Other aerosols (2.F.4.b)

Emitted gas: HFC-134a, HFC-152a
Methods: T2
Emission factors: D
Key sources: none

4.9.5.2.1 Source Category Description (2.F.4.b)

Other aerosols include personal care products, household products, special cleaning sprays etc. In these cans HFC-134a, HFC-152 and HFC-227 are the most prevalent gases.

4.9.5.2.2 Methodological issues (2.F.4.b)

For 2F4b (other aerosols) the Tier 2a method was applied from IPCC2006 Guidelines, which means that 'half of the chemical charge escapes within the first year and the remaining charge escapes during the second year' (chapter 7.3.2.2. of the IPCC2006). A 50% emissions in use of aerosols is assumed.

4.9.5.2.3 Emission factors (2.F.4.b)

In line with Chapter 7.3.2.1 of the IPCC2006 the equation 7.6 was used in the course of emission calculations:

$$Emission_t = S_t \cdot EF + S_{t-1} \cdot (1 - EF),$$

where S_t is the sum of the purchases of the current year and the previous year, and *EF* is the emission factor (EF= 0.5). So, the sum of half of the purchases of the current year and half of the purchases of the previous year was considered. The equation above was applied to each chemical individually.

4.9.5.2.4 Activity data (2.F.4.b)

In subsector Aerosols, annual sales data is directly reported by the producers. So, the activity data was the consumption of purchased aerosols and the HFC quantities of aerosol cans.

In Hungary manufacturing of aerosols is not occurring. While the amount of "filled into new manufactured products" was not estimated (NE). the amount of "in operating system" was filled in as the HFC quantity of sold aerosol cans in the current year and the half the sales of the previous year.

4.9.5.2.5 Recalculations, QA/QC activities, uncertainties and planned improvements (2.F.4.b)

There was no recalculation in this year.

Uncertainties are estimated based on chapter 7.3.3 of 2006 IPCC Guidelines and taking into account that activity data is provided on one hand by individual companies, on the other hand national statistics are used.

For HFC-134a and HFC-152a in 2.F.4.b subcategory 'NE' was reported in CRF for 'filled into new manufactured products' as activity data. During the review 2019, ERT's question was referred to why this notation key was used by Hungary. In response to the recommendation Hungary has changed notation key 'NE' to 'NO' because in Hungary manufacturing of aerosols is not occurring.

Uncertainty	AD	EF	Combined
2.F.4 Aerosol + MDI(HFCs)	10	50	50.99

4.9.6 Recalculations, QA/QC activities, uncertainties and planned improvements (2.F.)

The overall effect of recalculation for category 2.F is summarized in the following table:

	Submission 2023	Submission 2024	Difference
	kt CO_2 equivalent		
1990	0.00	0.00	0.00
1991	13.76	13.76	0.00
1992	23.20	23.20	0.00
1993	23.89	23.89	0.00
1994	27.94	27.94	0.00
1995	32.77	33.24	0.46
1996	38.31	39.02	0.71
1997	60.85	61.53	0.68
1998	114.95	115.65	0.70
1999	219.48	220.02	0.55
2000	204.20	204.85	0.65
2001	244.89	245.55	0.66
2002	332.85	333.54	0.69
2003	455.73	456.40	0.67
2004	590.66	591.14	0.48
2005	750.51	751.62	1.11
2006	892.92	893.92	1.01
2007	998.56	999.34	0.78
2008	1122.83	1125.22	2.39
2009	1182.44	1185.19	2.74
2010	1262.58	1262.34	-0.24
2011	1394.86	1395.49	0.63
2012	1457.24	1457.73	0.49
2013	1530.81	1532.04	1.23
2014	1760.51	1763.51	3.00
2015	1888.93	1890.82	1.88
2016	1779.02	1781.69	2.67
2017	1746.22	1747.97	1.74
2018	1783.35	1787.36	4.01
2019	1824.37	1818.64	-5.73
2020	1850.33	1840.74	-9.59
2021	1864.22	1832.18	-32.04

For submission 2022 March, two subcategories of 2.F.1 was recalculated. First, production data of activity data (PRODCOM) have been updated for the year 2021 for sub-category 2.F.2.

Second, following changes have been made within the MAC category:

- In the case of the output of trains, the entire time series has been recalculated for this submission, as more detailed data have been received from the largest Hungarian railway company.
- For buses, trams and cars emission values only for recent years have been corrected.

The overall effect of this recalculation on total emission including LULUCF is -0.04%.

4.10 Other products manufacture and use (CRF sector 2.G)

4.10.1 SF_6 use in Electronics industry (CRF sector 2.G.1)

Emitted gases: SF_6
Methods: T1
Emission factors: D
Key sources: none

4.10.1.1 Methodological issues (2.G.1)

SF_6 is mainly used as an insulation gas in electrical equipment, such as switchboards, switchgears. It was further used in the past as intermediate gas in double-glass heat insulation windows and production of optical bodies, etc. and in electronics industry for several years. In Hungary SF_6 is not used as a cover gas in coloured metal foundries.

The application of the 2006 IPCC Guidelines causes a major change within this sector although still the basic Tier 1 method is applied. Old Tier 1 calculation method accounted only for potential emissions, while the new Tier 1 method estimated actual emissions. As it was expected, emissions are lower using the new method *(see **Figure 4.10.1**)*.

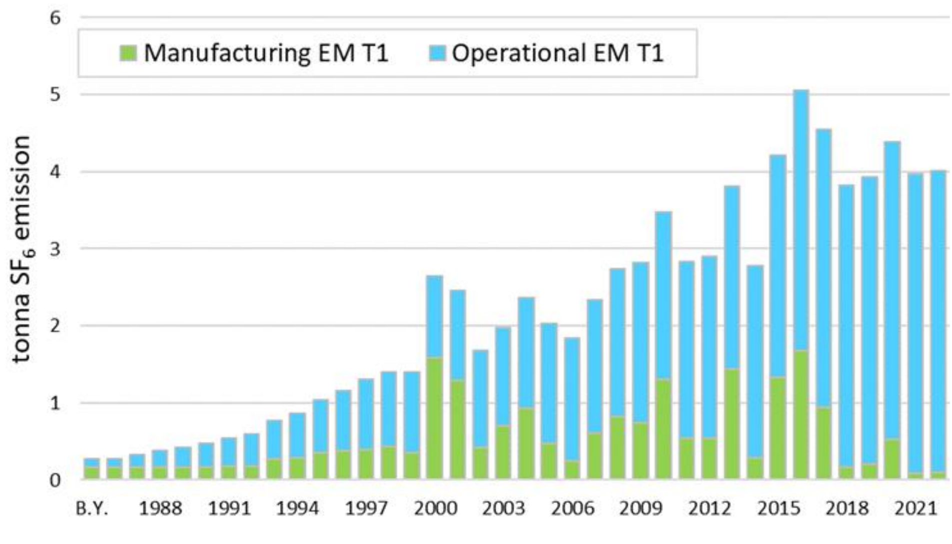


Figure 4.10.1. *Trend of SF_6 emissions in 2.G.1 Electrical equipment sector (t)*

4.10.1.2 Activity data (2.G.1)

Annual sales data is the basis for the calculation in the new method, as well. Data was collected from both manufacturers and the Hungarian Electrotechnical Association. The latter was appointed to data collection by 310/2008. Govt. Decree for data collection on import-export of SF_6. This is the same time-series of annual sales data that had been used by the old calculation of potential emissions in previous submissions. However, during the review of time-series it came out that the largest equipment manufacturer did not report any export before 1998. Therefore, export data has been extrapolated using the import/export proportion of the last reported year (1998).

310/2008. Govt. Decree has now been replaced by 14/2015 (II.14) Govt. Decree that moves the responsibilities and the handling of the database to the newly established National Climate Protection Authority.

4.10.1.3 Emission factors (2.G.1)

Default emission factor from Tables 8.2, 8.3 and 8.4 of the 2006 IPCC Guidelines are applied. As there is no information in the country what percent of electrical equipment are sealed pressure electrical equipment (MV switchgear) or closed pressure electrical equipment (HV switchgear) or gas insulated transformers, always the higher EFs are taken into consideration as conservative estimation.

Table 4.10.1. *Emission Factors used in 2.G.1 sector*

Manufacturing Emission Factor	0.085
Use Emission Factor	0.026
Fraction of SF_6 remaining at retirement	0.930
Lifetime (years)	35

4.10.1.4 Recalculations, QA/QC activities, uncertainties and planned improvements

General QA/QC procedures apply. Emission factors (and resulting time-series) have been verified with those included in *"Update on global SF_6 emissions trends from electrical equipment – Edition 1.1 Ecofys Emission Scenario Initiative on Sulphur Hexafluoride for Electric Industry (ESI-SF6)"*. Latter EFs are lower than the EFs in the 2006 IPCC Guidelines but it is planned to potentially include in the calculation method this more up-to-date information after further verification. Uncertainties are estimated based on Table 8.5 of 2006 IPCC Guidelines, taking the highest value as conservative estimation. Activity data’s uncertainties are estimated taking into account that activity data is provided by individual companies based on a legally binding data provision requirement.

Uncertainty	**AD**	**EF**	**Combined**
2.G Other Product Manufacture and Use - SF_6	3	40	40.11

4.10.2 Other applications (CRF sector 2.G.2.)

Emitted gas: SF_6
Methods: T1, T2
Emission factors: D
Key sources: none

4.10.2.1 Source category description (2.G.2)

SF_6 used mainly as an insulating medium in the radar systems of AWACS, in equipment in university and research particle accelerator, industrial and medical accelerators, adiabatic applications and in sound-proof windows. SF_6 used for sound-proof window production (only in the past due to the ban introduced by 842/2006/EC), scientific research and other non-defined purposes is included in sector 2.G.2.

4.10.2.2 Methodological issues

Equation 8.23 from the 2006 IPCC Guidelines is applied, so emissions are considered as 'prompt' emissions that is recommended in the case of any other applications. This means that emissions are distributed within two years, *"because both sales and emissions are assumed to be continuous over the year; that is, chemical sold in the middle of year t-1 is not fully emitted until the middle of year t."(*Chapter 8.3.2.2 of the 2006 IPCC Guidelines). Emission from sound-proof windows and particle accelerators are estimated separately.

The activity data (and consequently the emissions calculated with present methodology, too) show strong annual variations throughout the whole time series.

Soundproof windows

Recommendation by ERT already had been drafted at review 2017. This was about reporting of emission from use of double-glazed sound-proof windows. The application of SF_6 in windows began in 1975, but in Hungary it may appeared later. The average lifetime is 25 years because the annual leakage rate of 1 percent is assumed. Emission was calculated according to the 2006 Guidelines (equations 8.20 to 8.22). Annual leakage rate of 1 percent is assumed and a rate of 33 percent for the filling operations.

As Hungary has no data about the whole amount of targeted windows, emission was established from produced data. Data about manufactured double-glazed windows are available from 1996, moreover Hungary has information about domestic trade from one of the biggest SF6 wholesaler. For years 2007 and 2008 data are also available from the wholesaler by companies. From these data it could be concluded how much SF_6 companies were used for windows.

According to the years 2007 and 2008 the used SF_6 gas for windows is a percent of 7.5 of the whole amount of sold SF_6 gas. So, before 2007 this rate was considered in the calculations. This amount of SF_6 gas was filled to the sound-proof windows in Hungary.

The stock was established by summarized the annual filled quantity of the gas.

SF_6 is reported in 2.E sector between years 2001-2005 based on the data provision of a semiconductor manufacturer company. They also declared that the SF_6 has been acquired domestically, so the amount was allocated from the time-series of annual sales of "SF_6 for other use" in order to avoid double-counting. The SF_6 wholesaler company reports the list of their customer too. So, the intended use of SF_6 might be determined based on the sector of the activity of the customers.

Particle accelerators

As detailed data and individual accelerator charges are not available for this category, Hungary used the Tier 1 method (country-level method).

Equation 8.14 from the 2019 Refinement to the 2006 IPCC Guidelines was applied.

$$Emissions = Number\ of\ accelerators * SF6\ Use\ Factor * SF6\ Charge\ Factor * EF$$

where:

- *Number of accelerators: the total number of university and research particle accelerators in the country,*
- *SF_6 Use Factor is 0.33 (approximately one third of these accelerators use SF_6 as an insulator,*
- *SF_6 Charge Factor is 2400 kg (the average SF_6 charge in a university and research particle accelerator,*
- *EF is 0.7 (because the average annual university and research particle accelerator emission rate as a fraction of the total charge).*

Number of accelerators in Hungary is shown in the following table.

	1990-1995	*1996-2009*	*2010-2013*	*2010-2022*
Number of accelerators	*4*	*5*	*6*	*8*

In Hungary (in 2022) a cascade accelerator, a Cyclotron, an Electron Cyclotron Resonance (ECR) ion source, a Tandetron and three Van de Graaff generator.

4.10.2.3 Recalculations, QA/QC activities, uncertainties and planned improvement

General QA/QC procedures apply.

Uncertainties are estimated together with sector 2.G.2.

Emission from sound-proof windows was taken into account separately in response to the ERT's recommendation previous submission In submission 2021, recalculation was implemented because during last year's submission sound-proof windows were double-counted in category 2.G.2. So, the estimated amount of SF_6 charged into windows was not subtracted from the total amount of SF_6 used in 2.G.2 during the previous recalculation.

Category 2.G has been recalculated for this submission. Emissions from subapplication particle accelerators are reported. A first estimate is included in this submission.

4.10.3 Use of N_2O (CRF sector 2.G.3)

Emitted gas: N_2O
Methods: T3
Emission factors: CS, PS
Key sources: none

4.10.3.1 Source category description

This sub-sector includes emissions of N_2O from different product uses and the manufacturing (and other) losses from the production of these products. One of the two main important purposes is bulk N_2O use as an anaesthetic gas. Another is the use by household whipped cream cartridges. In Hungary, making whipped cream in siphons using N_2O cartridges was highly popular at the beginning of the time-series.

N_2O from these products is emitted directly into the atmosphere, so all the filling of these products used should be considered as emission.

The largest manufacturer of the region of bulk N_2O is operating in Hungary. The manufacturers of the whipped cream cartridges acquire the bulk N_2O also from this manufacturer.

4.10.3.2 Methodological issues

Emissions are reported using plant-specific data. Production and domestic sales data for both bulk N_2O and N_2O in whipped cream cartridges are available from the manufacturers for the whole time-series (presented in Figure 4.10.3). N_2O used for the preparation of whipped cream cartridges (2.G.3.b.i) is subtracted from bulk domestic N_2O use (2.B.b.ii), as the manufacturer declared that they acquire the gas from the manufacturer of bulk N_2O.

Manufacturing losses for the whole time-series is also available in the case of whipped cream cartridges. While in the case of bulk N_2O production data on losses is available only from 2008. In this year, extrapolation was performed in order to include emissions from losses for the years before 2008 too, for the improvement of the consistency of the time-series. Extrapolation was performed using data on losses from 2008 (as trend of the losses is decreasing later in time) and N_2O production as surrogate data. Please find the trend of production and emissions on the following figure ***(Figure 4.10.2).***

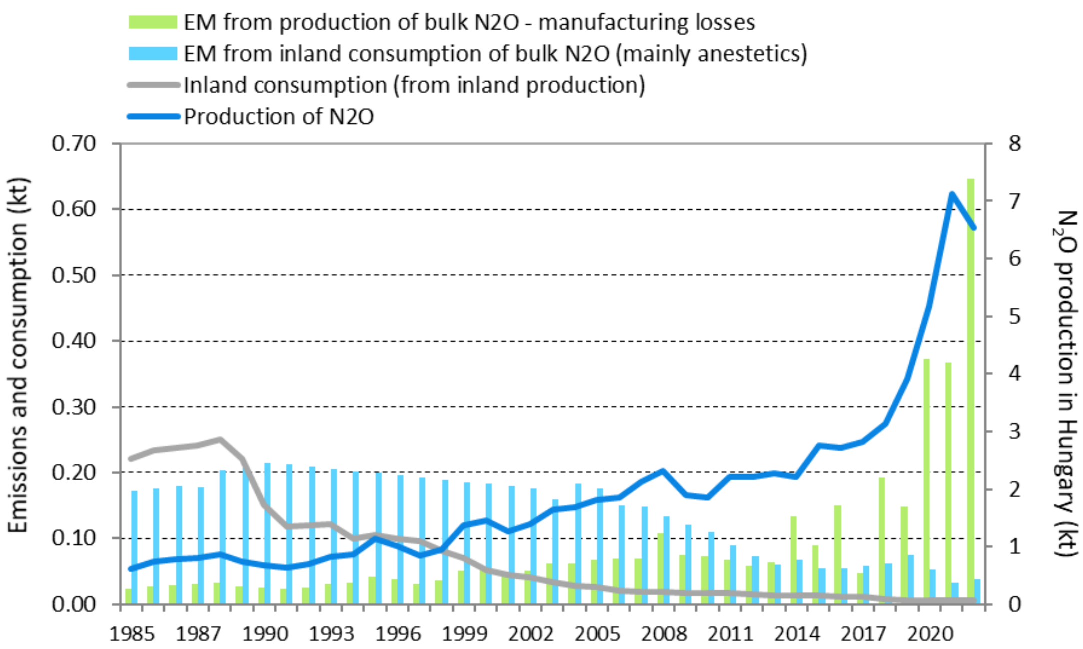


Figure 4.10.2 *Trend of N_2O production and N_2O emissions from Product Uses*

In 2014, an expert from the manufacturer of whipped cream chargers (cartridges) containing N_2O provided an estimate for the share of imported products on the Hungarian market, as well. In the 2014 submission, this amount has been included in the time-series. So, imports are estimated only within the subsector whipped cream, however in the case of other subsector (2.G.3.b.ii bulk use mainly for anaesthetics) imports are even less significant, as there is no notable bulk import as the Hungarian producer is the most important producer of the whole region. In addition, the wholesalers having a valid wholesaling authorization for products containing nitrous-oxide issued by the National Institute of Pharmacy (the agency responsible for licensing and control of drugs) have been identified. Most of them have already declared that they acquire N_2O domestically (from the Hungarian producer).

The strong interannual variations are due to the interannual variations of the reported data, which is related to the production of the company and the volatility of the market.

The significant decrease on inland consumption (and consequently the emissions from inland consumption) was also reported by the companies which was investigated in this submission. The producer of N_2O has reported separately the consumption data of the firm producing N_2O cartridges and other inland consumption for the last four years. The previous assumption - “inland consumption” is equal to the total inland consumption – was not correct, because most of the N_2O leave Hungary in cartridges produced by a Hungarian company. Upon the new data request the producer company has provided the separated consumption data back to 2002.

In case of „Propellant for pressure and aerosol products” emission during charging of cartridges intended for export was not covered before. As the inland consumption is less year after year meanwhile export rises dramatically as it turned out from the corrected inland consumption data. it was necessary to include charging loss of it. Unfortunately, data about loss of N_2O charging of export cartridges is available since 2009. Until 2002 this emission could be calculated from the new consumption data of the company (amount of N_2O in cartridges for inland consumption is known for the whole time-series) combined with implied emission factor for 2009. It was assumed that N_2O

cartridges were made only for inland consumption for the period 1985-1990. Before 2002 until 1990 linear interpolation was used for calculating other N_2O consumption (bulk use mainly for anaesthetics), and the rest of the inland consumption was assumed to be the consumption of the company producing cartridges. Inclusion of this new source resulted significant changes of emission in this subcategory. Data sources are summarized in the following table.

Table 4.10.2 *Summary table of data sources in 2.G.3 sector*

<table>
<tr><th>Data source for different periods</th><th>1985-1990</th><th>1991-2001</th><th>2002-2007</th><th>2008-2013</th><th>2014-</th></tr>
<tr><td>1 - NN_2O production</td><td colspan="5">Directly from the producer</td></tr>
<tr><td>2 – Inland consumption of bulk N_2O</td><td colspan="4">Directly from the producer</td><td>Sum of “3” and “4”</td></tr>
<tr><td>3 - Inland consumption for producing cartridges</td><td>Equal to “5”</td><td>Difference of “2” and “4”</td><td>Directly from the producer</td><td colspan="2">Directly from the company</td></tr>
<tr><td>4 - Other inland consumption</td><td>Difference of “2” and “5”</td><td>Linear interpolation between 1990 and 2002</td><td colspan="3">Directly from the producer</td></tr>
<tr><td>5 – N_2O amount used for charging cartridges for inland consumption</td><td colspan="5">Directly from the company</td></tr>
<tr><td>6 - Emission from charging cartridges for inland consumption</td><td colspan="5">Directly from the company</td></tr>
<tr><td>7 - Emission from charging cartridges for export</td><td>Assumed to be null</td><td colspan="2">Difference of “3” and “5” (using average EF from period 2009-2014)</td><td colspan="2">Directly from the producer</td></tr>
</table>

4.10.3.3 Uncertainties and time-series consistency

Production data is quite reliable because they are obtained directly from manufacturers. based on a legally binging data provision requirement, therefore the uncertainties are estimated as follows:

Uncertainty	AD	EF	Combined
2.G Other Product Manufacture and Use - N_2O	3	3	4.24

4.10.3.4 Recalculations, QA/QC activities, uncertainties and planned improvement

General QA/QC procedures apply.

Further investigation of data regarding imported products (especially whipped cream cans) might be performed. However, this source is reported only by few countries at the moment and the amount are expected to be insignificant compared to emissions reported under 2.G.3.b.ii. (production and domestic use of bulk N_2O) by Hungary. Results of recalculation are shown in the following table.

	submission 2023	submission 2024	difference
	kt CO_2 - equivalent		
1990	12.387	17.443	5.056
1991	13.470	18.526	5.056
1992	19.090	24.146	5.056
1993	30.038	35.094	5.056
1994	38.135	43.191	5.056
1995	51.048	56.104	5.056
1996	62.938	69.258	6.320
1997	77.939	85.523	7.584
1998	90.653	98.237	7.584
1999	72.154	79.738	7.584
2000	81.592	89.176	7.584
2001	79.166	86.750	7.584
2002	63.138	70.722	7.584
2003	73.955	81.539	7.584
2004	90.494	98.078	7.584
2005	88.395	95.979	7.584
2006	101.022	108.606	7.584
2007	100.570	108.155	7.584
2008	84.158	91.742	7.584
2009	77.441	85.026	7.584
2010	91.550	100.398	8.848
2011	77.591	85.660	8.070
2012	77.052	85.492	8.440
2013	97.850	105.923	8.073
2014	84.139	83.120	-1.020
2015	118.342	113.974	-4.368
2016	128.450	129.249	0.799
2017	113.842	117.017	3.175
2018	96.563	100.125	3.562
2019	101.138	102.221	1.083
2020	107.631	112.771	5.140
2021	94.149	103.698	9.549

4.11 Other production (CRF 2.H)

4.11.1 Source category description

Emitted gas: NMVOC

In accordance with the NRF report of Hungary, indirect NMVOC emissions from category 2.H are reported in CRF tables. From category 2.H only NMVOC emissions are reported. NMVOC is emitted from 2.H.1 (Pulp and paper) and 2.H.2 (Food and beverages industry).

The calculation methodology for NMVOC emissions is described in detail in the current IIR report.

In review 2020 TERT notes, that Hungary reports certain emission data and recovery in subcategory 2.H but without creating the relevant subcategory 2.H.3 Other. This leads to problems in the assessment tool. For these indirect emissions, Hungary has created subcategories 2.H.1., 2.H.2 and 2.H.3 and these cells has filled with appropriate values for submission 2024 March.

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5 AGRICULTURE (CRF sector 3)

5.1 Overview of sector

Agriculture production contributed to the greenhouse gas emission through the following processes:

- 3.A Enteric Fermentation by domestic livestock (CH_4).
- 3.B Manure Management (CH_4 and N_2O).
- 3.C Rice Cultivation (CH_4).
- 3.D Agricultural Soils (N_2O).
- 3.F Field Burning of Agricultural Residues (CH_4 and N_2O).
- 3.G Liming (CO_2).
- 3.H Urea application (CO_2).
- 3.I Other carbon containing fertilizers (CO_2).

Category 3.E Prescribed Burning of Savannas is not relevant to Hungary therefore notation key 'NO' is used relating to all associated emissions in the CRF Tables. In spite of this, the NIR contains a chapter on 3.E, following a recommendation from the UNFCCC annual review conducted in 2013.

The main greenhouse gas emissions from Agriculture are CH_4 and N_2O. Although CO_2 emissions from carbonate containing materials are also reported in the Agriculture sector, these emissions are less significant compared with non-CO_2 emissions. Other CO_2 emissions associated with agricultural production as energy consumption of agricultural activities (heat production, agricultural vehicles, and machinery) are reported in the Energy sector (1.AA.4C Energy, Agriculture/Forestry/Fishing), while CO_2 emissions from agricultural soils are included in the LULUCF sector.

To give an overview of Hungarian agriculture the main characteristics are as follows:

Due to national conditions agriculture played a definitive role in the Hungarian economy in the past and even today. In recent years, the largest decline in the output volume of the agricultural sector in Hungary occurred in 2022, so it could not contribute to GDP growth in that year. The volume of the total output of agriculture (its value at the previous year's prices) was down by 16% in 2022 compared to 2021. The largest contributors to the decline in the output were cereals (accounting for 11 percentage points) and industrial crops (accounting for 3.9 percentage points) (HCSO, 2023a). The agricultural land area was 55% of the total (HCSO, 2023b).

According to the data of the General Agricultural Census, 2020 (HCSO, 2021c), the number of agricultural holdings in 2020 was 241 000, a reduction of 31% since 2010, with those using agricultural land less than those keeping livestock. In the crop structure, the share of cereals has decreased while that of industrial, fodder crops, and vegetables has increased. The largest share of agricultural land was used by those with 5 hectares or more but less than 300 hectares. The reduction in subsistence farming has led to a concentration of livestock production. Between 2010 and 2020, the cattle population increased by 32%. The number of pigs has fallen by 7.4% compared to 2010, and the sow herd has shrunk by a quarter. There are still many farms with at most a few poultry, but production is more concentrated than in 2010.

The main characteristics for trends are as follows:

In Hungary, agricultural production practically stopped growing in the late 1980s. This was followed by a dramatic drop in the 1990s, as a result of the economic and political transition taking place in the country. The gross value of agricultural production decreased by 20% to 40% from the level of the 1980s. The drop was smaller for crop production (10-30%) than for animal husbandry. The output of the latter was only two thirds or less of the level of 1990 (Laczka and Soós, 2003). The volume index of gross agricultural production in 1993 reached a minimum of 69.1% of the 1990 level. The crop production has fluctuated considerably since 1993. It fell in 2002-2003 and 2007 due to drought. In contrast, agricultural production was relatively high due to the significantly high crop production in 2004 and 2008. Animal husbandry remained at a low level between 1993 and 2004 and has been decreasing steadily since the year of the European Union accession (2004) (Laczka, 2007). In recent years swine population decreased further, while cattle population increased as a result of the state incentives to promote the recovery of livestock sector. The volume of the total output of agriculture (its value at the previous year's prices) was down by 16% in 2022. The largest contributors to the decline in the output were cereals (accounting for 11 percentage points) and industrial crops (accounting for 3.9 percentage points) (HCSO, 2023a).

5.1.1 Emission trends

In 2022, the agriculture sector contributed 10% to Hungary's total GHG emissions (excluding LULUCF). The trend in emissions (Figure 5.1.1) shows a decrease of 48.1% from the base year (BY, average of 1985-1987) to 2022 as a result of a drop in activity data (Figure 5.1.2). The bulk of this decline occurred between 1985 and 1995, when agricultural production fell by more than 30%, and livestock numbers underwent a drastic decrease. Between 1996 and 2008, agricultural emissions had stagnated around 6.1 Mt CO_2-eq with fluctuations of up to 4%. Agricultural emissions decreased both in 2009 and 2010, hitting the lowest point in 2010. There was a slight increase in emissions in 2011 reflecting the higher fertilizer use and crop production. Since 2012, agricultural emissions have mainly increased due to the increasing cattle livestock, milk production, and fertilizer use. The increasing N-input from crop residues also contributed to the upward trend in emissions.

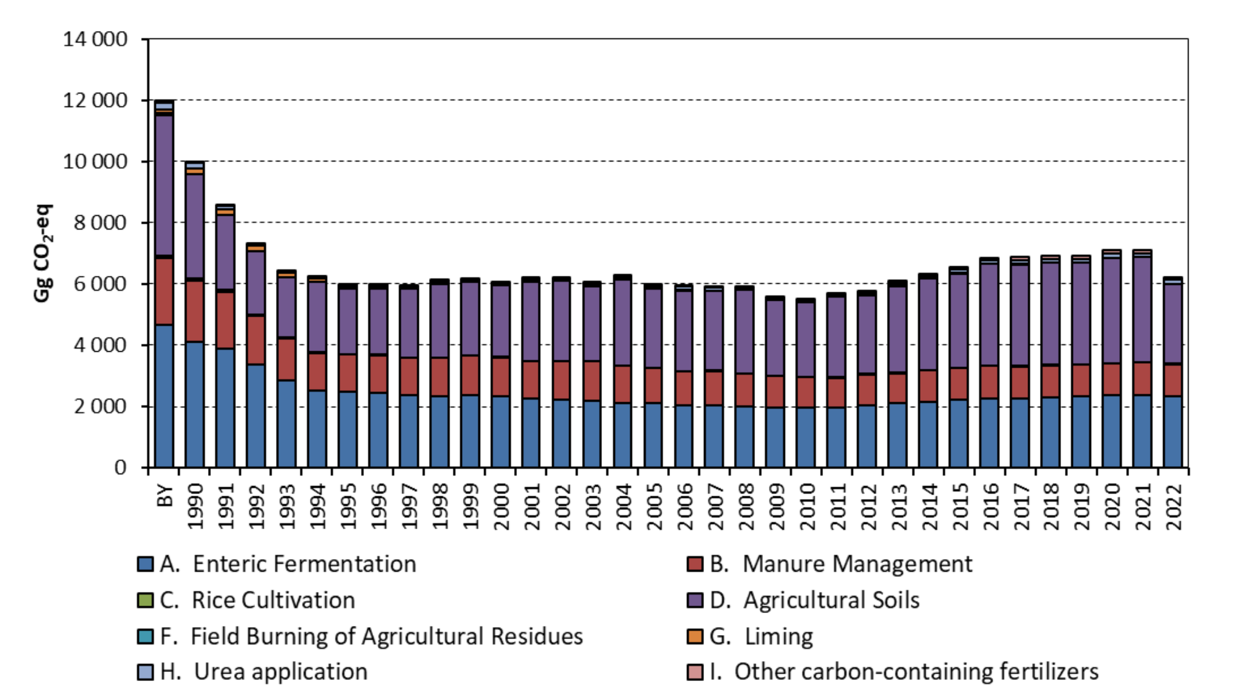

Figure 5.1.1 Trends in emissions from Agriculture BY and 1990-2022

Note: emissions from 3.C, 3.F, 3.G, 3.H and 3.I are small, but not zeros.

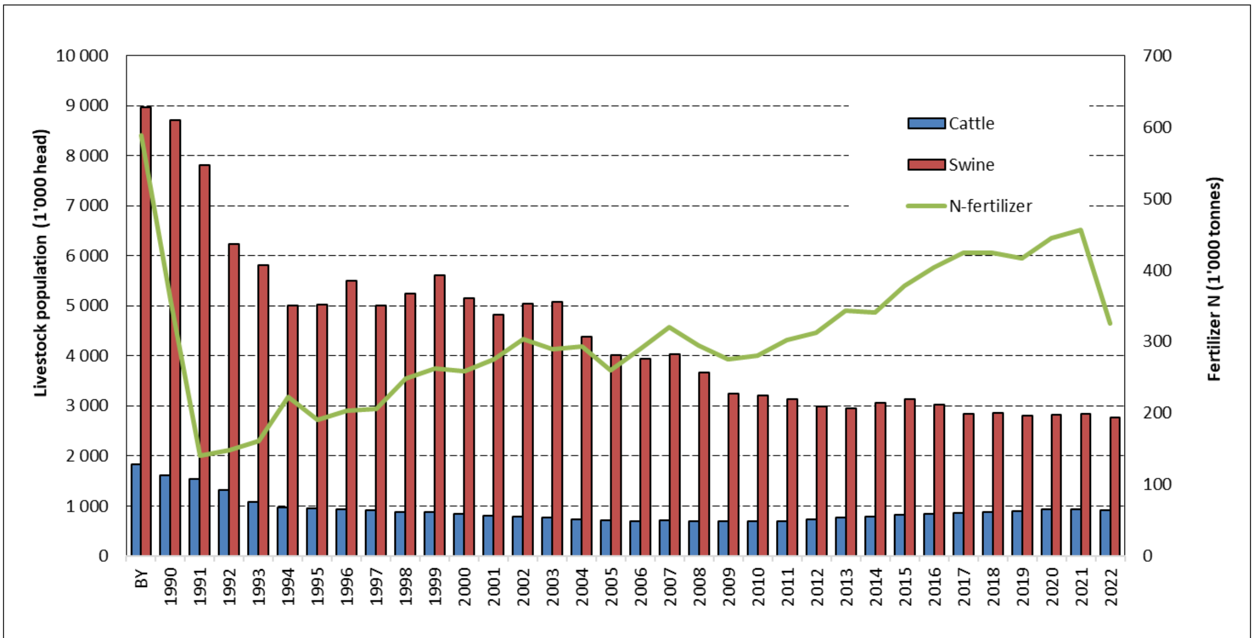

Figure 5.1.2 Main drivers of Agricultural emissions BY and 1990-2022

5.1.2 Emission trends by gas

From the BY to 2022, CH_4, N_2O and CO_2 emissions from agriculture decreased by 51.0%, 44.7% and 48.1%, respectively.

The decrease in CH_4 emissions is even more significant than N_2O, because CH_4 emissions are driven by the type and numbers of livestock. In Hungary's case, the amounts are largely determined by cattle and swine population. In 2022 cattle and swine accounted for 78.8% and 10.7% of combined total of emissions of CH_4 from enteric fermentation and manure management, respectively. After the sudden drop of in the livestock population at the beginning of the 1990s, it remained at that low level. Thus, CH_4 emissions had dropped by 46% from the base year level of 6 160 Gg CO_2-eq to 3 318 Gg CO_2-eq in 1994, when it reached a plateau. In 2004, which is the year of the European Union accession for Hungary, livestock started to decrease moderately again, leading to the lowest level of CH_4 emissions at 2 600 Gg CO_2-eq in 2010, representing a reduction of 58% from the level of the BY. Since 2012 cattle populations increased resulting in a moderate increase in the CH_4 emissions to 3 016 Gg CO_2-eq in 2022.

Emissions of N_2O show similar trends to those of CH_4 because the change of the regime resulted in a significant reduction in emissions. Agricultural N_2O emissions were 5 404 Gg CO_2-eq in the BY and decreased by 54% to 1993 to reach the lowest level in emissions at 2 480 Gg CO_2-equivalent. But unlike the livestock sector, there was a slight recovery in crop production and nitrogen fertilizer use at the beginning of the second half of the 1990s, resulting in a moderate increase in the emissions in the period between 1993 and 2004. Subsequently, in spite of the slightly increasing trends in nitrogen fertilizer use, N_2O emissions fluctuated, rather than increased, because the effect of the decreasing livestock overbalanced the increasing emissions from synthetic fertilizers. As a result, emissions amounted to 2 986 Gg CO_2-eq in 2022, representing a reduction of 45% on the BY level. N fertilizer use produces the bulk of agricultural N_2O emissions, accounting for 22% of the total emissions of the Agriculture sector in 2022.

Agricultural CO_2 emissions have dropped by 48.1% over the inventory period, which is the effect of the fall in urea use and liming. However, Agricultural CO_2 emissions are of low importance in the overall emissions, accounting for 0.5% of the national total CO_2 emissions (excluding LULUCF).

The trends in emissions by gas are presented in Table 5.1.1 . Trends by gas and sub-categories are shown in Figure 5.1.3, Figure 5.1.4 and Figure 5.1.5.

Table 5.1.1 Emissions of CH_4, N_2O and CO_2 from Agriculture BY and 1990-2022

Year	GHG emissions (Gg)		
	CH_4	N_2O	CO_2
BY	220	20	407
1990	194	16	385
1991	183	12	274
1992	157	10	237
1993	134	9	195
1994	119	10	159
1995	116	10	117
1996	116	10	105
1997	112	10	95
1998	112	11	96
1999	114	11	95
2000	113	11	104
2001	108	12	108
2002	108	12	117
2003	108	11	127
2004	104	12	151
2005	102	11	142
2006	98	11	144
2007	98	11	149
2008	96	12	91
2009	94	11	98
2010	93	11	106
2011	92	11	129
2012	96	11	142
2013	97	12	174
2014	100	13	169
2015	103	13	203
2016	105	14	209
2017	105	14	223
2018	107	14	214
2019	107	14	217
2020	109	14	240
2021	110	14	236
2022	108	11	211
Share of Hungarian total in BY	**42.1%**	**54.6%**	**0.5%**
Share of Hungarian total in 2022	**34.5%**	**81.4%**	**0.5%**
Trend BY-2022	**-51.0%**	**-44.7%**	**-48.1%**

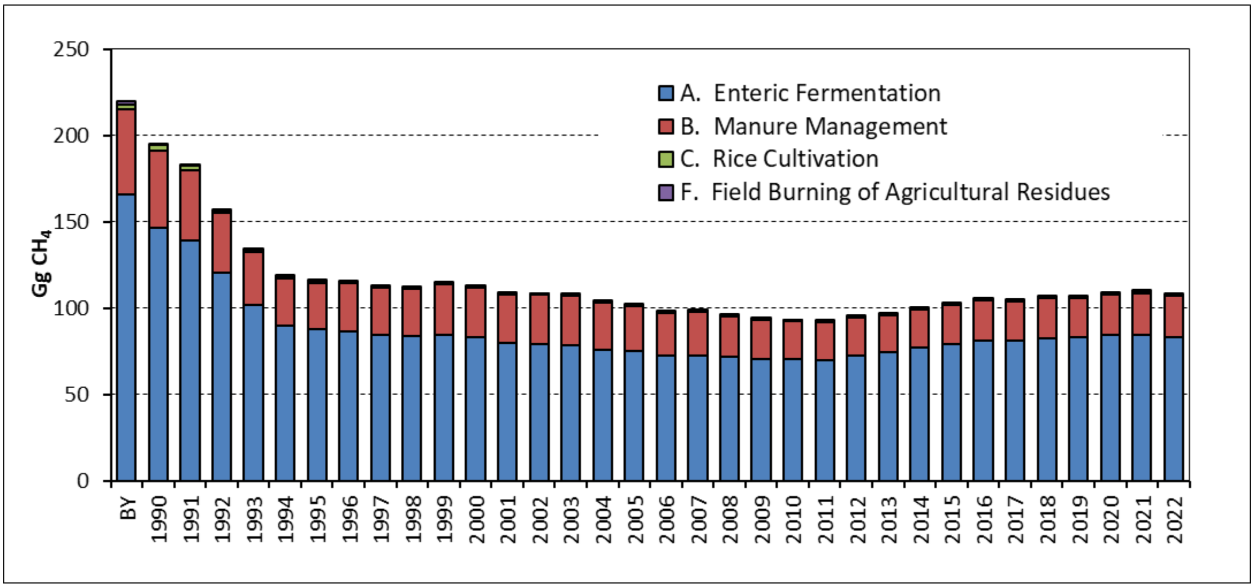

Figure 5.1.3 CH_4 emissions from Agriculture BY and 1990-2022

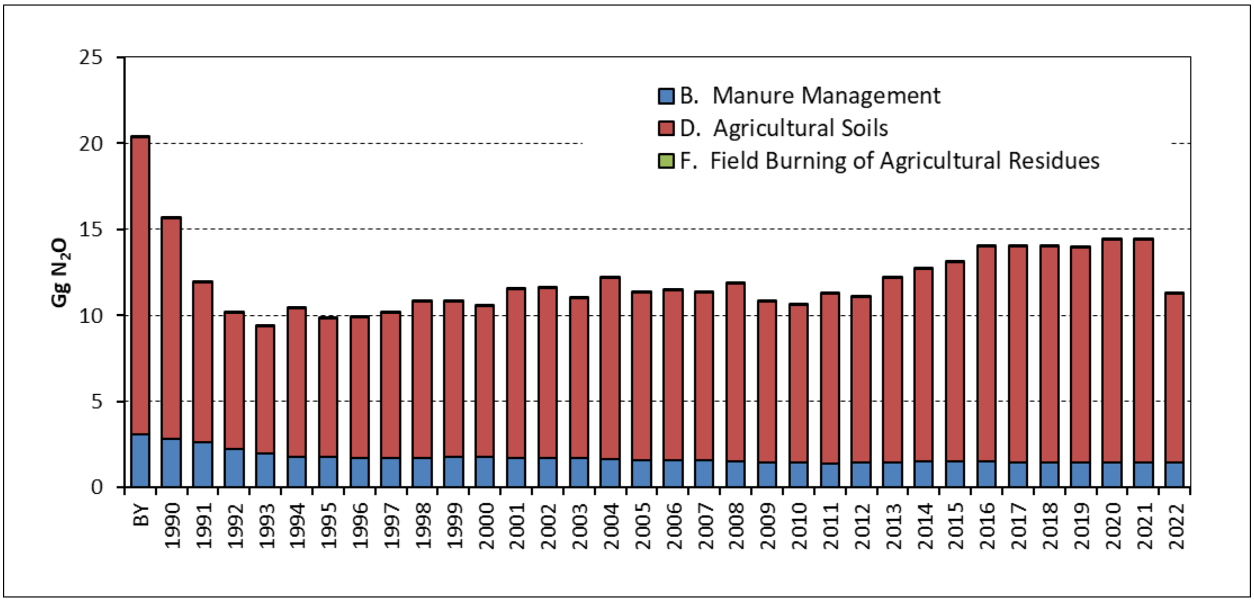

Figure 5.1.4 N_2O emissions from Agriculture BY and 1990-2022

Note: emissions from 3.C, 3.F, 3.G, 3.H and 3.I are small, but not zeros

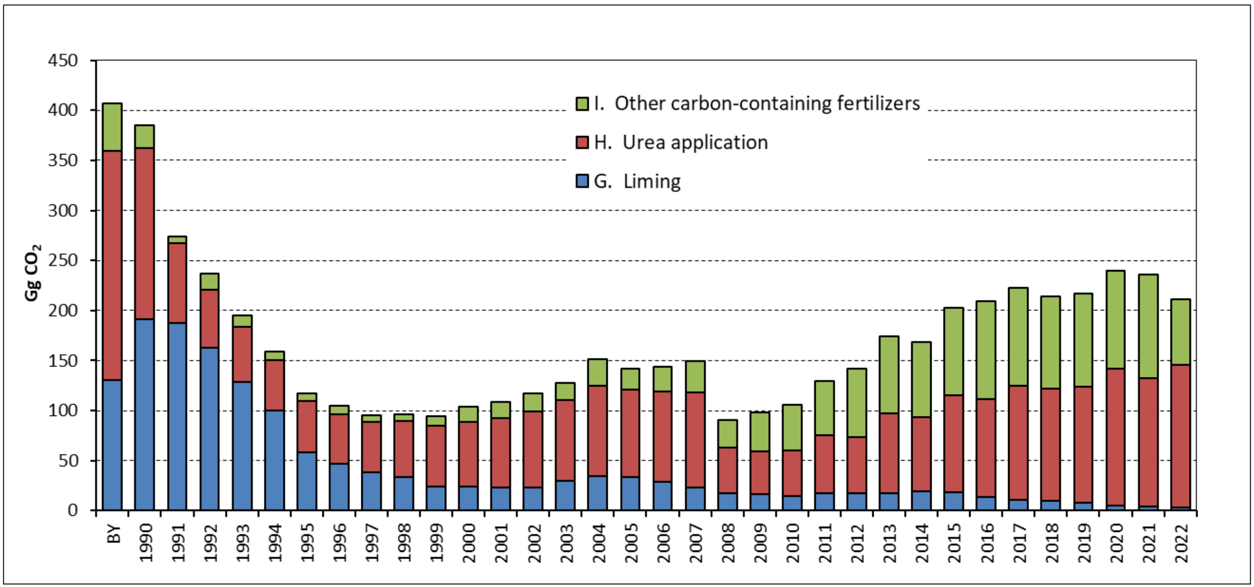

Figure 5.1.5 CO_2 emissions from Agriculture BY and 1990-2022

5.1.3 Emission trends by sub-category

Agricultural GHG emissions amounted to 11 971 Gg CO_2-eq in the BY and 6 213 Gg CO_2-eq in 2022, which means a reduction of 48.1%. Total emissions from the Agriculture sector in 2010, at 5 519 Gg CO2-eq, were the lowest level in the entire time series.

Table 5.1.2 shows the trends in GHG emissions by source categories as well as their contribution to the overall national emissions (excluding LULUCF). The most important category is 3.D Agricultural Soils at 4.4%, followed by 3.A Enteric Fermentation at 3.9% and 3.B Manure Management accounting for 1.8% of national total GHG emissions in 2022. CRF category 3.C Rice Cultivation accounts for less than 0.1% of the national total. As revealed from the Figure 5.1.3-Figure 5.1.5 emissions from all categories are decreasing between the BY and 2022 except for category 3.I. The reason for the declining trend in the emissions from Enteric Fermentation and Manure Management is the decrease in livestock numbers, especially cattle and swine. The total emissions from the Livestock, which equals the combined total of emissions from 3.A Enteric fermentation and 3.B Manure management (including Indirect emissions), expressed in CO_2 equivalents, were 6 841 Gg CO_2-eq in the BY. This decreased by 45% to reach 3 752 Gg CO_2-eq in 1994 and subsequently decreased by 10% to 3 375 Gg CO_2 -eq in 2022. Livestock accounted for 54% of GHG emissions in agriculture in 2022. The biggest contributor to Livestock emissions is cattle, with 31% share of agricultural total emissions.

Over the period BY-1993 emissions from 3.D Agricultural soils had dipped sharply from 4 567 Gg CO_2-eq in the base year to 1 957 Gg CO_2-eq, representing a decrease of 57% from the BY to the 1993 level. This was attributed to the halt in state subsidies on fertilizers and the decrease in animal manure due to the decreasing livestock numbers. Emissions totalling 2 609 Gg CO_2-eq in 2022 represent a reduction of 43% from the base year level. The significant decrease in emissions from agricultural soils in 2022 compared to 2021 is mainly due to the decrease in nitrogen fertilizers use, and the yields of major crops were also lower than in 2021.

The trends of emissions from liming, urea application and carbon-containing fertilizers slightly differ from those of the other sectors. Emissions from all of the CO_2 relevant sectors decreased at the beginning of the time series, but emissions from urea application and carbon-containing fertilizers started to increase at the end of the 1990s due to the increasing fertilizer use, while emissions from liming after a slight increase to mid-2000s decreased again continuously. The reason for the second drop in emissions from urea use was the economic crisis in 2008, when the price of the urea increased, leading to a sharp decline in urea application. Emissions from urea and carbon-containing fertilizers increased again over the period 2009-2022.

Table 5.1.2 GHG emissions BY and 1990-2022 from agriculture by subcategories

Year	**GHG emissions (Gg CO_2-eq)**								
	3	3.A	3.B	3.C	3.D	3.F	3.G	3.H	3.I
BY	11 971	4 650	2 191	91	4 567	64.71	130	229	48
1990	9 968	4 108	1 998	91	3 387	1.18	191	171	23
1991	8 538	3 897	1 848	68	2 449	0.63	188	80	7
1992	7 315	3 377	1 570	38	2 093	0.46	163	57	16
1993	6 422	2 854	1 378	38	1 957	0.39	128	55	12
1994	6 239	2 518	1 234	38	2 290	0.46	100	50	8
1995	5 961	2 466	1 221	30	2 127	0.38	58	51	8
1996	5 968	2 428	1 246	24	2 165	0.21	47	49	9
1997	5 928	2 370	1 211	17	2 234	0.22	38	51	7
1998	6 097	2 338	1 240	17	2 405	0.23	34	56	6
1999	6 163	2 364	1 288	17	2 400	0.22	24	60	10
2000	6 053	2 335	1 267	24	2 323	0.31	24	65	15
2001	6 193	2 242	1 230	18	2 595	0.23	23	69	16
2002	6 212	2 216	1 258	16	2 606	0.29	23	76	18
2003	6 062	2 192	1 274	19	2 449	0.33	30	80	17
2004	6 286	2 130	1 195	21	2 788	0.28	34	91	26
2005	5 985	2 110	1 140	20	2 572	0.28	33	87	22
2006	5 929	2 031	1 109	18	2 627	0.23	28	91	24
2007	5 909	2 037	1 112	20	2 591	0.29	24	95	31
2008	5 919	2 005	1 067	19	2 736	0.30	17	46	27
2009	5 588	1 976	1 007	21	2 486	0.35	16	43	39
2010	5 519	1 967	998	15	2 434	0.07	14	46	45
2011	5 702	1 958	981	20	2 613	0.26	18	58	54
2012	5 757	2 037	997	22	2 557	0.35	18	56	69
2013	6 113	2 094	980	20	2 845	0.32	18	79	77
2014	6 338	2 160	1 011	18	2 979	0.29	19	75	75
2015	6 550	2 215	1 041	21	3 069	0.28	18	97	87
2016	6 860	2 264	1 057	22	3 308	0.34	13	99	97
2017	6 867	2 274	1 029	21	3 320	0.37	11	113	99
2018	6 914	2 313	1 036	22	3 329	0.40	10	112	92
2019	6 903	2 321	1 035	20	3 309	0.33	8	116	93
2020	7 099	2 363	1 037	23	3 436	0.35	5	136	98
2021	7 115	2 364	1 067	21	3 428	0.28	4	128	104
2022	6 213	2 326	1 050	18	2 609	0.30	3	142	66
Share of HU total in BY	**10.8%**	**4.2%**	**2.0%**	**0.1%**	**4.1%**	**0.1%**	**0.1%**	**0.2%**	**0.0%**
Share of HU total in 2022	**10.4%**	**3.9%**	**1.8%**	**0.0%**	**4.4%**	**0.0%**	**0.0%**	**0.2%**	**0.1%**
Trend BY-2022	**-48.1%**	**-50.0%**	**-52.1%**	**-80.7%**	**-42.9%**	**-99.5%**	**-97.4%**	**-37.8%**	**36.2%**

5.1.4 Key Categories

Key category analysis is presented in Chapter 1.6. Table 1.2 contains the key categories of the agriculture sector.

5.1.5 Methodological issues

Methodologies of the 2006 IPCC Guidelines have been implemented throughout the agricultural inventory. However, in some cases, where there are gaps in the 2006 IPCC Guidelines, methodologies provided in the 2019 Refinement were applied.

IPCC Tier 2 methods were used for the following categories:

- 3.A Enteric Fermentation in Cattle.
- CH_4 emissions from 3.B Manure Management associated with all livestock categories, except Rabbits.
- N_2O emissions from 3.B for Cattle, Swine, Poultry (Laying hens and Broilers) and Indirect emissions.
- N_2O emissions from 3.D.1.5 Mineralization/immobilization associated with loss/gain of soil organic matter.
- Indirect N_2O emissions from 3B and 3D are reported in line with the national NH_3 and NO_x inventories, which also meets the requirements of a Tier 2 methodology.

For the other categories IPCC Tier 1 methods were applied. Country-specific emission factors were used whenever sufficient information was available, otherwise the IPCC default factors were used. See the individual categories for further details.

5.1.6 Uncertainties and time series consistency

The following chapter gives an overview of uncertainty estimates for CH_4, N_2O and CO_2 emissions from Agriculture.

Uncertainty estimates were performed using the Tier 1 approach based on the error propagation. Error propagation was calculated independently for the lower (2.5 percentile) and for the upper (97.5 percentile) range to treat the asymmetric confidence ranges. Uncertainties were combined in accordance with 2006 IPCC Guidelines Equation 3.1 and 3.2. The results of the Tier 1 approach are shown in Table 5.1.4.

The uncertainty of the activity data was calculated based on the available data from the Hungarian Central Statistical Office (hereafter HCSO), the EMEP/EEA Guidebook (EEA, 2023) and expert judgement. The uncertainty of the emission factors was calculated following the 2006 IPCC Guidelines. The uncertainty of the livestock population data for 2022 is presented according to the uncertainty assessment of the HCSO, in Table 5.1.3. The overall weighted mean of the uncertainties in the livestock population is ±0.8% The uncertainty in the Other livestock population is the lowest at 0.5%, while the uncertainty in Mules and Asses populations is the highest at approximately 10.7%.

In the Hungarian agricultural GHG inventory, the uncertainties of N_2O emissions from agricultural soils are the highest. These high values derive from the uncertainties of the emission factors. The uncertainty and the distribution of these emission factors (EF_1, EF_4 and EF_5) strongly influence the uncertainty and the distribution of the agricultural emissions as well as the overall uncertainty of the Hungarian GHG inventory. For these emission factors default confidence limit ranges and lognormal distributions have been applied according to the 2006 IPCC Guidelines.

Table 5.1.3 Uncertainty of animal population data for 2022 (HCSO)

Livestock categories	2021 Dec	2022 Jun	2022 Dec	Annual mean	Uncertainty of the annual mean u(AD$_i$)	Weighted annual mean
	95% Confidence Interval (+/- 1 000 head)				%	1 000 head
Dairy Cattle	12.00	9.79	9.16	6.18	2.52	245
Non-Dairy Cattle	22.46	20.14	18.83	12.45	1.83	679
Buffalo	0.93	0.98	1.32	0.63	8.06	8
Sheep	89.75	77.36	74.84	48.47	5.17	937
Goats	5.28	4.48	4.52	2.83	5.59	51
Horses	3.84	3.95	4.02	2.42	4.06	59
Mules and Asses	0.56	0.49	0.63	0.32	10.73	3
Swine	39.41	25.27	18.65	16.69	0.59	2 837
Poultry	770.02	346.26	391.78	276.81	0.69	40 244
Rabbit	9.03	10.38	7.93	6.00	0.51	1 183
Overall (weighted mean)					0.81	

Table 5.1.4 Uncertainties of activity data, emission factors and emissions for key and particularly significant categories by Tier 1 approach for 2022

3 Agriculture	GHG	Uncertainty of activity data	Uncertainty of Emission Factor	Combined uncertainty of emissions
			%	
3.A Enteric Fermentation	CH_4	±0	±13	±13
3.A.1 Enteric Fermentation/ Cattle	CH_4	±0	±14	±14
3.A.2 Enteric Fermentation/ Sheep	CH_4	±5	±40	±40
3.B Manure Management	CH_4	±0	±13	±13
3.B.1 Manure Management/ Cattle	CH_4	±0	±14	±14
3.B.3 Manure Management/ Swine	CH_4	±1	±30	±30
3.B Manure Management	N_2O	±0	-36/+130	-36/+130
3.B.13 Manure Management/ Other	N_2O	±21	-50/+100	-54/+102
3.B Manure Management/ Indirect	N_2O	±0	-85/+399	-85/+399
3D Agricultural Soil Emissions	N_2O	±0	-66/+187	-66/+187
3.D.a.1 Direct Soil Emissions/ Synthetic Fertilizer	N_2O	±5	-70/+200	-70/+200
3.D.a.4 Direct Soil Emissions/ Crop residues	N_2O	±25	-70/+200	-74/+202
3.D.3 Indirect Emissions	N_2O	±0	-81/+357	-81/+357

Note: In accordance with the 2006 IPCC Guidelines particularly significant categories are those which contribute together more than 60% to the key category.

5.1.7 Quality Assurance and Quality Control

The agricultural greenhouse gas inventory is compiled by the HMS. The used activity data is mainly derived from the official database of the HCSO, in cases where HCSO's data are not available the

EUROSTAT's, NFCSO's or the Institute of Agricultural Economics Nonprofit Kft. (hereafter AERI) data are applied.

Data and documentation are archived by the Unit of National Emissions Inventories of the Hungarian Meteorological Service. The annual sector specific QA/QC procedures are as follows:

- Check of activity data for transcription and rounding errors, comparison with original data sources.
- Re-check of activity data, comparison with the latest submission of the activity data (following the revision of the data by data supplier).
- Check of reasons for data gaps.
- Verification of activity data with other data sources if it is possible.
- Consistency check of time series of the activity data and the estimated emissions (reasons for jumps).
- Consistency check, following the methodological changes of the data collection.
- Check of the time series consistency of the applied livestock characterization.
- Cross-check of data sources of the activity data if it is possible (e.g., total annual milk yield per cow, and total dairy cow population).
- Cross-check of the applied activity data between the different sub-categories.
- Check of emission factors, comparison with the IPCC default ones and comparison with the values applied by other countries (especially EU member states) according to the EU's NIR and S&A report of the UNFCCC.
- Check of the methodologies used for the development of county-specific emission factors, comparison with the IPCC methodologies or other methodologies if it is available.
- Check of the correct use of the units in the calculation sheets.
- Check for transcription errors between the calculation sheets and the CRF tables.
- Consistency check of sub-categories with totals.
- Check of recalculation differences.
- Listing of QA/QC findings and the actions taken in the spreadsheets.
- Recording of sources of activity data and equations in the spreadsheets.

Details of other source-specific quality checks can be found in the respective sub-chapters.

Since 2011 the Unit of National Emissions Inventories of the HMS has also been participated in the preparation of the Air Pollution Emission Inventory under the Convention on Long-range Transboundary Air Pollution of the United Nations Economic Commission for Europe (UNECE/LRTRAP). (As a party to the UNECE/LRTRAP Convention Hungary is required to report annually data on emissions of air-pollutants covered in the Convention.) This provides an additional opportunity to cross-check the activity data and emissions with the GHG-inventory to ensure the consistency between the two inventories.

Hungary as a member state of the EU has additional reporting obligations (e.g., Nitrate Directive and Nutrient Balance) arising from different Community policies. In some cases, the same data and coefficients are required for the background calculation of these reports. As an additional QA procedure, these data and methodologies are compared in the course of regular expert meetings.

Checks and reviews of national emission inventories reported by EU Member States under the Monitoring Mechanism Regulation (MMR) is also considered as a quality assurance activity.

In-depth reviews required by the 406/2009/EC EU Effort Sharing Decision are performed in every two years by external experts contracted by the EU, which covers the full inventory. The first review was performed in 2012. The last comprehensive audit was in 2020, during which there were no recommendations for the agriculture sector.

5.1.8 Recalculations

The main reasons for changes in GHG emissions from Agriculture (CRF sector 3) are as follows:

- Updating the climate data from 1981-2010 to 1991-2020 provided by the Hungarian Meteorological Service (HMS),
- Upgrading VS calculation for swine,
- Revision of the nitrogen content of biogas feedstocks, especially in case of poultry manure and processing industrial by-products.

The overall effect of the recalculations in sector 3. Agriculture resulted in emissions changes ranging from -122.35 kt CO_2-eq to -71.1 kt CO_2-eq for the period 1985-2021, representing a percentage change ranging from -1.81% to -0.71%.

Reasons for recalculations by CRF categories are as follows:

3.B MANURE MANAGEMENT

3.B.1 CH_4 emissions and 3.B.2 N_2O emissions from Manure Management

The update of climate data has an impact on the entire time series The annual average temperature was higher between 1991 and 2020 than between 1981 and 2010, resulting in a higher methane conversion factor for liquid/slurry. In addition to updating the climate data, the livestock distribution by county also has been revised based on HCSO's censuses for the year 2020.

The revision of N content of biogas feedstocks resulted in minor changes in N_2O emissions form manure management, primarily due to the revised distribution of manure management technologies.

3.B.1.3 CH_4 Emissions from Manure Management – Swine, whole time series

The VS calculation method was extended to Tier 2 method in case of swine, resulting in significant reduction in CH_4 emission.

3.B.1.1 (CH_4), 3.B.1.2 (CH_4), 3.B.1.4 (CH_4), 3.B.2.1 (N_2O), 3.B.2.2 (N_2O) and 3.B.2.4 (N_2O) CH_4 and N_2O Emissions from Manure Management – Non-dairy Cattle, Sheep and Poultry in 2021

Correction of calculation errors regarding the manure management system of non-dairy cattle (<1 year), sheep, and geese in 2021 resulted in only minor changes in CH_4 and N_2O emissions.

3.B.1.1 CH_4 and 3.B.2.1 N_2O Emissions from Manure Management – Dairy Cattle in 2020

A correction of a calculation error resulted in minor changes in the feeding of dairy cattle, slightly reducing gross energy intake, nitrogen excretion etc. for the year 2020, which led to slight decrease in CH_4 and N_2O emissions.

The overall changes in CH_4 emissions from 3.B.1 Manure management ranged from a -94.52 kt CO_2-eq to -52.31 kt CO_2-eq for the period 1985-2021. The percentage changes varied between -12.00% and -4.18%. This decrease is primarily attributed to the extended calculation of VS for swine. The overall changes in the N_2O emissions from 3.B.2 Manure management are negligible between 2004 and 2021 (below 0.1%), except for the year 2020, when the change was -0.52% due to the recalculation of feeding of dairy cattle.

3.D AGRICULTURAL SOILS

3.D.1 Direct N_2O Emissions from Managed Soils

3.D.1.1 Inorganic N Fertilizers for the period 2013-2021

The amount of N fertilizers has been revised for the period 2013-2021, resulting in an insignificant increase in the N-inputs from N fertilizers.

3.D.1.2.c Other Organic Fertilizers Applied to Soils for the period 2004-2021

The emission slightly increased for the period 2004-2021 due to the revision of N content of biogas feedstock by expert and minor data revision for year 2017 provided by the Hungarian Energy and Public Utility Regulatory Authority (MEKH).

3.D.1.4 Crop Residues for the period 2016-2021

The grass yields have been revised between 2016 and 2021 based on data from Hungarian Central Statistical Office (HCSO), resulting in a negligible change in N_2O emission from crop residues.

The overall change in 3.D.1 Direct N_2O Emissions from Managed Soils due to recalculations varied between -1.14 kt CO_2-eq and 0.71 kt CO_2-eq for the period 2004-2021. These changes are below 0.05%.

3.D.2 Indirect N_2O Emissions from Managed Soils

3.D.2.1 Atmospheric Deposition, whole time series

The 3.D.AI.1 Fraction of synthetic fertilizer N applied to soils that volatilises as NH_3 and NO_x has increased significantly due to the change of NH_3 emission factors of fertilizers, following the 2023 EMEP/EEA Guidebook.

The 3.D.AI.2 Fraction of livestock N excretion that volatilises as NH_3 and NOx slightly increased due to the changes in the 2023 EMEP/EEA Guidebook. Additionally, NH_3 emissions from crop residues have been included as a new emission category. Although the name of the indicator '3.D.AI.2 Fraction of livestock…', may be misleading, it encompasses indirect emissions from crop residues, leading to a slight increase in emissions in this category.

The correction of the NH_3 emissions from sewage sludge and other organic fertilizers in the national air pollutant emission inventory for the year 2021 resulted in only minor changes. However, the decrease in Nex of dairy cattle in 2020 has also influenced the changes.

3.D.2.2 Nitrogen Leaching and Run-off, whole time series

The update of climate data and the change in methodology have impacted the entire time series. The definition of wet climate used in the latest inventory aligns with the 2019 Refinement, requiring less detailed data (no need for monthly data) compared to the method in IPCC 2006 Guidelines. Additionally, the ratio of annual precipitation to reference evapotranspiration between 1991 and 2020 is significantly lower compared to the period 1981-2010.

The proportion of irrigated area on agricultural lands has been revised for the years 2020 and 2021 based on HCSO data. Additionally, changes in the NH_3 emissions from sewage sludge and other organic fertilizers in 2021, as well as changes in the Nex of the dairy cattle in 2020, have also contributed in a minor way to the overall change.

The overall change in emissions in the 3.D.2 Indirect N_2O Emissions from Managed Soils is quite large, ranging from -31.72 kt CO_2-eq to -11.96 kt CO_2-eq for the period 1985-2021. The percentage change varied between -14.42% and -4.00%. This remarkable change arises from the update of climate data.

3.I OTHER CARBON-CONTAINING FERTILIZERS, FOR THE PERIOD 2013-2021

The revision of N fertilizers for the period 2013-2021 resulted in a negligible change (<0.00%) in CO_2 emissions from CAN fertilizers.

5.1.9 Planned improvements

Participation in the EU review mechanisms, which is part of the QA/QC processes for compiling EU inventory, provides an opportunity for examination of individual IPCC sectors and particular issues relating to methodologies, country-specific emission factors and coefficients. Issues of planned improvements will be assigned largely in accordance with the outcome of the EU and UNFCCC review processes.

N-excretion rates for the main animal categories such as Swine and Poultry are also planned to be updated based on the availability and processing of the data from the livestock feeding monitoring program. We also plan to extend the calculation of N_2O emissions from crops residues to include cover crops and green manure.

5.2 Enteric fermentation (CRF sector 3.A)

Enteric fermentation in animals is considered as a significant source of CH_4. The most important process of CH_4 generation is anaerobic cellulose degradation in the rumen of ruminants. Some CH_4 is generated in the colon of horses and rabbits, and in the caecum of poultry. In Hungary, the leading CH_4 emitters are cattle and sheep, with the most important category being non-dairy cattle. In addition to the number of animals, the level of production and feeding practices are the factors which primarily influence the amount of CH_4 from enteric fermentation.

In 2022 77.1% of the total CH_4 emissions from agriculture derived from this source category.

5.2.1 Source Category Description

Emitted gas: CH_4
Methods: T1, T2
Emission factors: D, CS
Key source: Yes
Particularly significant sub-categories: Cattle

Figure 5.2.1 presents the estimates of CH_4 emissions for *3.A Enteric Fermentation* by livestock categories. Emissions amounted to 166 Gg CH_4 in the base year and have reduced by 50.0% to 83 Gg in 2022 due to the decrease in cattle livestock. The bulk of this decrease occurred between 1985 and 1994, during which Hungary experienced a period of unprecedented drop in the agricultural production resulting in a dramatic decrease in animal populations. Despite the continuous decrease in the livestock populations, emissions stagnated in the years between 1995 and 2000, because the improving cow productivity overbalanced the effect of declining cattle population (Figure 5.2.2). In the period 2000 to 2010 emissions slightly decreased again reaching their lowest level in 2011. This decrease reflects the further decline in Cattle livestock. Since 2012, emissions started to increase, following the slightly rising cattle population and milk production. Emissions from 3.A mostly depend on cattle population and milk production. Enteric fermentation in Cattle produced 83% of emissions from 3.A in 2022.

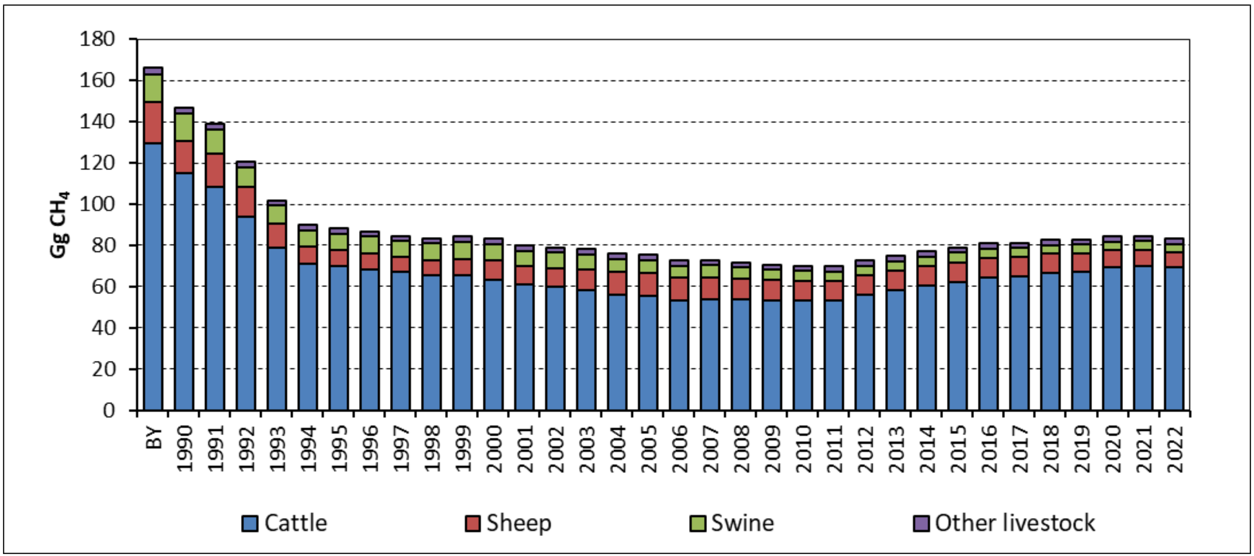

Figure 5.2.1 Trend in emissions from 3.A Enteric Fermentation by livestock categories BY and 1990-2022

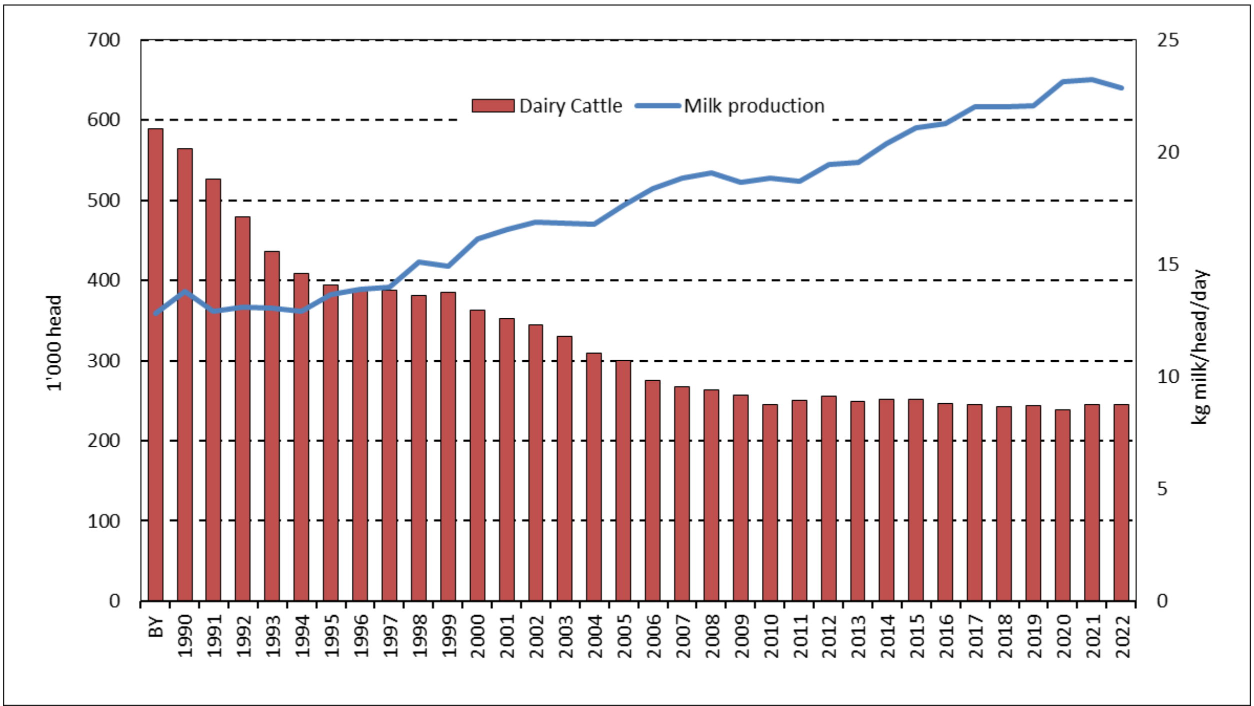

Figure 5.2.2 Dairy Cattle population and daily milk production per cow BY and 1990-2022

5.2.2 Methodological issues

Emissions from enteric fermentation were calculated using the Tier 1 method of 2006 IPCC Guidelines, except for the Dairy Cattle and the Non-Dairy Cattle categories, where country-specific emission factors were used in accordance with the Tier 2 method of 2006 IPCC Guidelines.

5.2.2.1 Activity Data - Livestock Population

The HCSO provides national livestock survey data to the emission estimate.

Following a recommendation of the centralized review conducted in 2014 the HCSO has provided livestock data rounded to the nearest hundred instead of nearest thousand. The HCSO has been producing two censuses of animal numbers per year since 2009. One survey is conducted in June and the other in December. The annual average population for a year t was calculated by using the chronological mean of surveys data, as follows:

$$NoA_t = \frac{0.5 \cdot NoA_{Dec,t-1} + NoA_{June,t} + 0.5 \cdot NoA_{Dec,t}}{2}$$

(Equation 5.1.)

Where:

NoA_t = chronological mean of the annual population of a livestock category in a year t (1 000 head)
$NoA_{Dec,t-1}$ = population of a livestock category in December of the year t-1 (1 000 head)
$NoA_{June,t}$ = population of a livestock category in June of the year t (1 000 head)
$NoA_{Dec,t}$ = population of a livestock category in December of the year t (1 000 head)

The method delineated above was suggested by the HCSO's expert (Tóth, 2004) to smooth out the seasonal changes in the livestock population.

Until the end of 2008 the HCSO collected data on animal livestock population three times a year, namely April, August and December. For the calculation of the annual average population for the years before 2009 the chronological mean was used similarly, based on the three surveys data.

The annual average livestock populations calculated as the *chronological means of the total animal population*s are reported in the CRF tables. Trends in livestock populations are provided in Table 5.2.1.

In the case of Non-dairy Cattle and Poultry enhanced characterization for livestock populations were used according to the requirements of the IPCC methodology. The annual average populations for these livestock were determined by sub-categories. Detailed livestock data by sub-categories for Cattle and Poultry are shown in Table 5.2.2 and Table 5.2.3.

Table 5.2.1 Livestock populations and trends BY and 1990-2022 (1 000 head)

Year	Dairy cattle	Non-dairy cattle	Sheep	Swine	Buffalo	Goats	Horses	Mules and Asses	Poultry	Other (Rabbit)
BY	589.5	1 233.6	2 498.3	8 963.0	0.1	19.3	98.7	5.0	81 738.8	2 536.5
1990	563.6	1 053.0	1 958.3	8 708.5	0.1	35.1	79.8	4.5	70 325.6	2 587.2
1991	526.6	1 017.8	2 008.7	7 809.1	0.1	39.3	84.0	4.3	58 827.4	2 629.5
1992	479.5	833.9	1 867.3	6 237.4	0.1	50.0	78.8	4.3	52 168.4	2 389.5
1993	436.3	648.5	1 457.7	5 805.4	0.1	60.6	74.6	4.3	43 429.1	2 149.5
1994	408.5	554.4	1 089.0	5 006.9	0.1	71.3	85.1	4.3	44 477.4	1 909.4
1995	394.5	548.8	997.7	5 023.0	0.2	76.1	74.6	4.3	44 874.5	1 669.4
1996	389.4	545.9	930.0	5 493.5	0.3	80.9	73.5	4.3	38 537.7	1 148.9
1997	387.8	520.8	900.9	5 012.7	0.4	85.7	75.6	4.3	40 416.6	1 071.3
1998	381.3	493.8	954.5	5 246.7	0.5	90.5	76.7	4.3	42 707.6	1 051.8
1999	385.0	488.5	980.7	5 609.0	0.6	95.3	77.7	4.3	40 260.3	1 040.4
2000	362.8	479.2	1 192.2	5 146.2	0.7	96.6	77.8	3.6	48 562.1	942.5
2001	353.0	443.3	1 162.8	4 823.3	0.8	107.2	67.5	3.5	51 074.0	1 087.2
2002	344.5	433.7	1 138.2	5 050.0	0.9	96.7	63.2	3.4	51 333.7	1 179.7
2003	330.0	433.2	1 226.5	5 077.5	1.0	94.5	62.5	3.3	52 486.2	1 088.8
2004	309.3	424.3	1 380.2	4 385.0	1.1	84.5	64.5	3.2	50 492.0	1 181.7
2005	299.8	419.7	1 446.7	4 021.7	1.2	77.8	67.0	3.0	46 404.7	1 002.7
2006	275.2	428.2	1 358.2	3 943.7	1.3	81.2	64.8	2.3	44 653.3	1 084.3
2007	267.5	442.3	1 300.7	4 039.0	1.4	71.5	59.0	2.1	43 159.7	1 055.0
2008	263.8	436.2	1 269.7	3 664.7	1.4	72.8	58.3	2.0	45 032.7	903.5
2009	257.5	444.3	1 260.8	3 248.0	1.5	65.0	59.8	1.9	44 789.3	871.3
2010	244.5	454.0	1 203.0	3 208.0	2.5	79.3	65.5	3.1	46 587.0	916.3
2011	250.6	440.2	1 159.1	3 131.3	3.7	83.8	73.0	3.5	46 283.8	949.1
2012	256.0	474.8	1 179.3	2 981.5	3.4	86.0	76.2	3.5	43 063.7	1 367.1
2013	248.5	518.7	1 204.9	2 943.9	3.7	85.2	66.1	2.7	41 674.3	1 560.1
2014	252.0	538.5	1 222.6	3 064.9	3.7	76.7	63.0	2.1	42 683.1	1 643.2
2015	252.1	562.8	1 193.9	3 127.0	3.7	79.5	61.3	2.5	44 459.1	1 610.4
2016	247.0	592.2	1 189.3	3 020.8	5.4	84.0	56.5	3.2	44 907.6	1 300.4
2017	244.8	617.7	1 160.3	2 847.6	6.1	85.0	53.7	4.1	42 711.1	1 149.9
2018	242.7	635.8	1 145.6	2 865.1	6.6	75.3	51.9	4.6	43 136.9	1 204.6
2019	243.9	660.0	1 100.3	2 796.4	6.9	69.0	51.6	5.0	42 875.1	1 195.7
2020	238.4	688.7	997.9	2 831.1	7.8	56.1	58.0	4.4	37 835.1	1 218.4
2021	245.4	679.2	936.9	2 837.2	7.9	50.8	59.5	3.0	40 244.0	1 183.2
2022	244.7	664.9	915.2	2 763.2	7.9	48.0	56.0	2.4	39 588.7	1 176.4
Trend BY-2022	**-58.5%**	**-46.1%**	**-63.4%**	**-69.2%**	**7800.0%**	**148.5%**	**-43.2%**	**-52.4%**	**-51.6%**	**-53.6%**
Trend 2005-2022	**-18.4%**	**58.4%**	**-36.7%**	**-31.3%**	**558.3%**	**-38.3%**	**-16.3%**	**-19.1%**	**-14.7%**	**17.3%**

Table **5.2.2 Livestock population and trends for non-dairy cattle BY and 1990-2022 (1 000 head)**

Year	<1 year		1-2 year		>2 year			
	Bovines for slaughter and other calves (male)	Bovines for slaughter and other calves (female)	Bovines (male)	Heifers for slaughter and other heifers	First calf heifers	Mature Non-Dairy (male)	Heifers for slaughter	Beef Cow
BY	256.9	264.3	226.0	277.7	72.0	20.4	19.6	96.8
1990	212.6	241.2	169.6	256.9	65.6	17.1	15.7	74.4
1991	204.7	237.8	162.2	251.9	61.8	16.4	14.9	67.9
1992	164.1	206.5	110.7	219.5	55.1	13.1	11.0	54.0
1993	128.7	162.9	86.2	170.9	44.7	9.7	7.0	38.5
1994	109.1	143.9	68.3	151.2	41.2	8.0	5.0	27.8
1995	107.4	143.4	65.9	149.1	42.7	7.9	4.9	27.5
1996	105.5	139.3	70.1	144.3	43.8	7.8	4.8	30.3
1997	99.5	133.0	63.5	138.8	47.3	7.4	4.3	27.0
1998	98.7	131.8	41.5	137.5	49.5	6.9	3.7	24.3
1999	97.4	130.1	47.8	135.7	44.3	6.8	3.6	23.0
2000	96.0	132.6	36.2	136.7	41.9	5.8	2.7	27.4
2001	88.0	125.9	29.4	131.4	37.1	4.8	2.7	24.0
2002	85.0	124.7	27.0	130.0	37.2	4.7	2.2	22.9
2003	87.8	121.4	26.6	124.4	36.0	4.5	2.3	30.1
2004	81.5	113.7	25.3	122.4	34.2	6.0	2.7	38.5
2005	84.7	109.2	22.6	119.1	32.8	5.8	2.0	43.4
2006	84.6	106.5	30.3	116.9	30.6	5.5	2.5	51.3
2007	86.6	106.2	37.0	116.4	33.0	6.2	2.2	54.7
2008	78.9	109.5	32.1	114.7	32.0	6.0	2.3	60.6
2009	81.5	108.2	31.7	120.2	32.5	6.5	2.0	61.7
2010	75.7	108.2	35.0	120.7	35.5	7.2	3.2	68.5
2011	74.5	105.6	26.4	115.7	35.6	7.0	2.6	72.8
2012	86.9	113.5	31.8	117.5	35.6	7.0	4.2	78.3
2013	89.1	119.6	41.5	130.1	35.3	8.2	4.3	90.5
2014	90.2	122.9	44.2	131.2	37.0	8.4	2.7	101.9
2015	90.3	129.9	43.2	135.7	38.3	9.2	3.7	112.5
2016	98.6	133.3	38.3	138.1	39.1	10.1	4.7	129.9
2017	104.0	138.9	37.8	137.4	37.8	10.5	5.2	146.2
2018	107.8	140.7	43.0	140.4	34.0	11.3	3.3	155.3
2019	107.4	146.7	44.9	146.4	33.3	11.1	4.3	166.0
2020	115.9	149.0	51.4	142.3	35.7	13.6	5.7	175.2
2021	116.6	159.4	39.2	129.6	27.8	16.8	19.1	170.7
2022	113.2	158.9	33.5	123.5	24.1	16.4	22.0	173.4
Trend BY-2022	**-55.9%**	**-39.9%**	**-85.2%**	**-55.5%**	**-66.6%**	**-19.8%**	**12.4%**	**79.1%**
Trend 2005-2022	**33.7%**	**45.6%**	**47.9%**	**3.7%**	**-26.6%**	**180.7%**	**1001.8%**	**299.1%**

***Table* 5.2.3 Livestock population and trends for Poultry BY and 1990-2022 (1 000 head)**

Year	Animal Population					
	Laying hens	Broilers	Turkey	Ducks	Geese	Guinea Fowls
BY	24 484.7	50 939.4	1 420.2	2 717.6	1 814.1	362.8
1990	22 735.0	40 178.1	1 772.6	2 463.6	2 926.5	249.8
1991	23 460.1	29 487.6	1 252.7	2 216.7	2 167.5	242.6
1992	20 187.3	27 392.8	916.7	1 969.9	1 459.2	242.6
1993	19 314.4	19 289.5	1 080.1	2 008.4	1 494.1	242.6
1994	17 092.6	21 666.5	1 288.8	2 339.1	1 854.9	235.5
1995	15 732.5	23 349.4	1 599.1	2 144.6	1 833.9	215.0
1996	16 368.0	16 430.5	1 979.1	1 955.3	1 616.4	188.3
1997	15 491.1	18 816.0	2 156.9	2 139.8	1 634.8	178.0
1998	15 824.0	20 158.3	2 156.9	2 725.7	1 623.8	219.0
1999	15 255.0	17 749.4	2 084.3	3 222.1	1 689.9	259.6
2000	13 744.3	24 223.7	4 029.8	3 249.5	3 080.3	234.4
2001	15 396.5	25 290.0	3 449.3	3 790.2	2 915.5	232.5
2002	16 051.5	23 327.7	3 789.8	4 490.0	3 474.3	200.3
2003	16 384.8	23 645.2	3 495.8	4 770.7	3 986.3	203.3
2004	15 398.8	23 187.2	4 637.3	3 898.0	3 177.3	193.3
2005	14 232.3	22 058.3	4 036.5	3 704.0	2 183.2	190.3
2006	14 424.7	20 268.5	4 270.3	3 117.3	2 387.3	185.2
2007	13 063.8	20 359.0	4 430.8	2 780.5	2 374.5	151.0
2008	13 376.3	21 865.8	4 071.2	3 070.0	2 487.8	161.5
2009	12 732.3	22 364.5	3 422.3	3 736.3	2 384.8	149.3
2010	12 544.5	23 163.5	3 365.0	5 155.0	2 211.3	147.8
2011	11 453.4	23 878.3	3 152.8	5 208.1	2 455.5	135.9
2012	11 088.8	22 003.7	3 023.6	4 489.2	2 311.0	147.4
2013	11 839.9	19 959.2	2 432.8	4 533.1	2 774.7	134.6
2014	11 291.9	21 505.5	2 692.7	4 781.3	2 280.7	131.1
2015	11 722.5	22 963.7	2 928.3	4 687.6	2 027.5	129.6
2016	11 246.6	23 307.9	3 022.3	4 854.5	2 354.1	122.3
2017	10 748.7	22 990.4	2 888.4	3 952.7	2 016.1	114.8
2018	10 891.7	22 118.3	2 834.1	4 898.8	2 290.3	103.8
2019	10 732.0	22 176.7	2 825.0	4 768.1	2 270.9	102.6
2020	9 312.4	21 176.9	3 013.8	2 829.6	1 404.9	97.6
2021	8 647.6	23 326.2	2 912.5	3 756.7	1 532.8	68.2
2022	8 627.7	23 258.2	2 736.3	3 471.9	1 446.9	47.8
Trend BY-2022	**-64.8%**	**-54.3%**	**92.7%**	**27.8%**	**-20.2%**	**-86.8%**
Trend 2005-2022	**-39.4%**	**5.4%**	**-32.2%**	**-6.3%**	**-33.7%**	**-74.9%**

5.2.2.2 Emission Factors

5.2.2.2.1 Cattle

CH_4 emissions from enteric fermentation in Dairy Cattle and Non-dairy Cattle categories were calculated using the Tier 2 method (2006 IPCC Guidelines, Equation 10.21):

$$EF = \frac{GE \cdot \frac{Y_m}{100} \cdot 365}{55.65}$$

(Equation 5.2)

Where:

EF = CH_4 emission factor (kg CH_4 head^{-1} yr^{-1})
GE = gross energy intake (MJ head^{-1} day^{-1})
Y_m = methane conversion rate (MJ MJ^{-1})
365 = days of year (day yr^{-1})
55.65 = energy content of methane (MJ kg^{-1} CH_4)

5.2.2.2.1.1 Gross Energy Intake in Dairy Cattle

Tier 2 emission estimate requires feed intakes expressed in terms of gross energy (MJ/head/day), which is the amount of energy an animal needs for maintenance, activity, lactation, and pregnancy. In the calculation of net energy requirements Holstein-Friesian and Hungarian Simmental cattle were distinguished, which are the most widespread dairy cattle breeds in Hungary.

To calculate the daily net energy requirements of cows the Hungarian Nutrition Codex (2004) was generally applied, which contains standards of livestock feeding for Hungary. In Hungary, the American energy requirement system was adapted in 1986 with some minor changes, thus the Hungarian and the IPCC equations for the calculation of net energy requirements are basically very similar. The main difference between the Hungarian and the IPCC methodology is that the Hungarian system does not differentiate the net energy for maintenance and activity, thus both energy requirements are taken into account in the net energy for maintenance. To ensure the closest conformity with the IPCC methodology and to avoid underestimate of emissions it was decided to take also into account the net energy for activity based on the IPCC methodology, using the Eq. 10.4 of 2006 IPCC Guidelines.

Calculation of net energy for lactation according to the Hungarian standards also differs from the IPCC methodology. For this reason, it was determined based on both equations. Use of Hungarian standards indicated higher values than the IPCC methodology. Thus, the net energy for lactation was calculated using the Hungarian standards for the inventory purposes, because it was assumed that it is more reliable for the Hungarian species.

The net energy requirement for pregnancy was also determined based on the standards of the Hungarian Nutrition Codex (2004) as well as the IPCC methodology, and it revealed that there is no difference between the outcomes of the two methodologies. As a consequence, Eq. 10.4 of 2006 IPCC Guidelines was applied for the sake of simplicity.

The Equation 10.16 of 2006 IPCC Guidelines was applied to transform net energy requirements into gross energy intake. The value of digestible energy (DE%) was calculated as weighted average of digestibility of components in the diet to the use of the aforementioned equation. Composition of the diet was taken from the dataset of the Farm Accountancy Data Network (FADN). This dataset provides annual data on the composition of the diet per 1000 kg milk basis, from which the feed intake can be calculated using the annual milk yields. This statistical data was combined with expert judgement on the composition of the diet and the seasonal changes in the feeding practices. Digestibility values for the different fodder crops in the diet were taken from the 'feed database' provided in the Hungarian Nutrition Codex (2004). This database contains results of laboratory measurements for feeds used for livestock nutrition in Hungary.

Parameters and equations used to estimate the gross energy intake for dairy cattle and their sources are listed in Table 5.2.4.

Calculation of net energy requirements requires further statistical data and parameters, which are summarized in Table 5.2.4. Net energy for maintenance depends on the average body mass of dairy cattle, which was determined for each year of the time series based on the change of livestock composition and characteristics of species. In the 1970s the Hungarian cattle herd consisted mainly of double used cows (Hungarian Simmental) and partly dairy cattle having smaller body mass (Jersey, Ayrshire). Since 1970 this cattle herd has been changed, continuously, crossing the above-mentioned species with Holstein Friesian cattle. In 1985 the Hungarian cattle herd consisted mainly of Holstein-Friesian and Holstein-Friesian Cross-bred, but the Hungarian Simmental also had an importance. Proportions of Jersey and Ayrshire can be considered as negligible. Since 1985 proportion of Hungarian Simmental species has been dropped and as a result the annual milk yield increased from 4671 kg to 6429 kg in the period BY-2005, together with this change the average body weight in the herd also increased. The annual average body mass was calculated from the typical body mass of the two main species and their proportions in the certain year based on HCSO statistics. The typical body mass of Holstein-Friesian and Hungarian Simmental is assumed to be 650 and 550 kg in the calculation. The resulted body weights by years are shown in Table 5.2.6

Table 5.2.4 Parameters and equations used to estimate the GE for Dairy Cattle

Activity data, parameters and coefficients	Unit	Source	Values/ Notes
Weight	kg	Kovács (2013)	Calculated annually, based on the ratio and the body mass of typical Hungarian breeds.
$C_{pregnancy}$		Table 10.7 of IPCC (2006)	0.1
Digestible energy intake (DE)	%	Kovács (2013)	Calculated annually, based on feeding statistics from FADN and laboratory measurements (Hungarian Nutrition Codex, 2004).
C_a		Table 10.5 of IPCC (2006)	0 for stall, 0.17 for pasture
Proportion for grazing		HCSO, agricultural surveys, NFCSO's Nitrate database	See also Chapter 6.3.
NE_m= 2.96 + FM * 4.25 + W * 0.06 where, **FM = farming method** (1 = stalled; 2 = farming on good pasture; 3 = farming on average pasture) **W = live weight of Cow, kg**	MJ/day	Hungarian Nutrition Codex (2004)	Country-specific methodology according to the Hungarian net energy requirements standards. Calculated separately for Holstein-Friesian and Hungarian Simmental
NE_a	MJ/day	Eq. 10.4 of IPCC (2006)	Calculated
NE_l=$NE_{l,milk}$* kg of milk per day **$NE_{l,milk}$ = 1.45 + 38.45 * Milk fat + 3.02 * Milk protein, where** **Milk fat = Fat content of milk, %** **Milk protein = Protein content of milk, %**	MJ/day	Hungarian Nutrition Codex (2004)	Country-specific methodology according to the Hungarian net energy requirements standards.
Ne_p	MJ/day	Eq. 10.13 of IPCC (2006)	Calculated
REM		Eq.10.14 IPCC (2006)	Calculated
GE	MJ/day	Eq. 10.16 of IPCC (2006)	Calculated

Net energy for lactation depends on the amount of daily milk production and fat content of milk. The daily average milk yield was calculated based on the HCSO's annual milk yield statistics. In 2022 the daily average milk production was 22.8 kg of milk per cow (Table 5.2.6). Data on fat content of milk was taken from the Eurostat statistics for the period 1998-2011, while for the period 1985-1997 the average of the values calculated for the period 1998-2003 were assumed due to lack of statistical data. Since 2004 this data has been taken from the Market Price Information System of the Institute of Agricultural Economics Nonprofit Kft. (hereafter AERI). (The legal background of the price transmission is laid down in the Commission Implementing Regulation (EU) 2019/1746 and in the national regulation Degree of Ministry of Rural Development 127/2013. According to the national regulation notification is mandatory for dairy processors exceeding 10 000 tons of raw milk delivery in the previous year.)

5.2.2.2.1.2 Methane Conversion Rate for Dairy Cattle

Following a recommendation from the annual review conducted in 2013 country-specific value of Y_m for Dairy Cattle were developed based on the data on composition of diet used for the estimation of GE. Laboratory measurements on Y_m, similarly to most of the other country, is unavailable in Hungary. Therefore, until the 2019 submission country-specific values were calculated based on conclusions of the related publication of Soliva (2006). As a result of a question raised during the UNFCCC Review, 2019, for this submission the Y_m values were revised according to the latest scientific publications.

According to the most recently published scientific publications, Y_m values depend on factors such as feed type, quality and animal characteristics such as breed and genetics. In Hungary the most typical dairy cattle breed is Holstein-Friesian (87.5%) while the remaining Jersey, and Ayrshire, which breeds were mainly examined in the studies of Niu *et al.* (2018) and Hellwing *et al.* (2016). In the study of Niu *et al.* (2018) 68% of the data examined related to Holstein cows. In the publication of Hellwing *et al.* (2016) Holstein and Jersey cows were studied.

In line with these publications and the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019), the annual value of the Y_m was determined based on the country-specific values of milk yield (MY), digestibility (DE) and Neutral Detergent Fiber (NDF) as a percentage of the dry matter intake (DMI).

Hungarian cattle are considered as low producing cows ($MY<5000$ kg yr^{-1}) at the beginning of the time series and medium producing cows (5000 kg $yr^{-1}<MY<8500$ kg yr^{-1}) since 1996. Proportions of concentrate in the diet have changed in a range between 21% and 38%; while digestibility has changed within a narrow range, between 68.3% and 70.7% over the time series, due to the good-quality forage crops. (Hungarian cattle's diet contains mainly maze silage as forage.)

According to Niu *et al.* (2018) information on neutral detergent fiber (NDF) improves the prediction of the enteric methane (CH_4) production from cattle. Therefore, to obtain a more accurate estimate of Y_m, the values of NDF were determined based on the diet for the whole time series. The percentage of NDF in DMI varied between 42% and 35% over the time series.

The annual values of Y_m were determined as shown in Table 5.2.5 .

Table 5.2.5 Assumptions made to estimate Methane Conversion Rates (Y_m) for Dairy Cattle

Milk Yield (MY) kg head^{-1} yr^{-1}	Digestibility (DE) %	Neutral Detergent Fiber (NDF) %	Enteric Methane Conversion Factor (Y_m) %
<5000	68%<DE<70%	40%<NDF	6.5
5000<MY<8500	68%<DE<70%	37%<NDF	6.3
5000<MY<8500	DE<70%	35%<NDF≤37%	6.2
5000<MY<8500	DE≤70%	NDF≤35%	6.1

Time series of background data to the estimation of the Y_m and the resulted values are shown in Table 5.2.6.

Table 5.2.6 Methane Conversion Rates for Dairy Cattle BY and 1990-2022

Year	Body Mass, Average	Milk Yield (MY)	Digestibility (DE)	Gross Energy Intake	Neutral Detergent Fiber (NDF)	Forage in the diet	Enteric methane conversion factor Y_m	Emission Factor for 3.A
	kg head^{-1}	kg head^{-1} yr^{-1}	%	MJ head^{-1}day^{-1}	%	%	%	kg CH4 head^{-1} yr^{-1}
BY	628	4 671	68.5	254	41.8%	78%	6.5	108
1990	633	5 031	69.3	255	40.7%	72%	6.3	105
1991	636	4 711	69.3	246	41.0%	72%	6.5	105
1992	639	4 780	69.4	246	41.3%	71%	6.5	105
1993	641	4 757	69.4	244	41.4%	71%	6.5	104
1994	641	4 716	69.4	243	41.5%	71%	6.5	104
1995	641	4 991	69.9	247	40.2%	68%	6.5	105
1996	640	5 064	69.9	249	39.8%	68%	6.3	103
1997	640	5 112	70.0	250	39.6%	68%	6.3	103
1998	641	5 513	70.3	257	39.0%	66%	6.2	105
1999	639	5 454	70.2	257	38.6%	66%	6.2	105
2000	641	5 886	70.5	264	38.4%	64%	6.2	107
2001	641	6 051	70.6	267	37.9%	64%	6.2	109
2002	641	6 155	70.6	270	37.6%	64%	6.2	110
2003	642	6 154	70.6	271	37.6%	64%	6.2	110
2004	642	6 131	70.4	269	37.4%	64%	6.2	109
2005	642	6 429	70.5	275	37.1%	63%	6.2	112
2006	642	6 706	70.6	280	36.8%	62%	6.1	112
2007	643	6 874	70.7	285	36.7%	63%	6.1	114
2008	643	6 972	70.5	288	36.6%	65%	6.1	115
2009	642	6 815	70.4	286	36.6%	65%	6.1	115
2010	642	6 877	70.3	289	36.3%	66%	6.1	116
2011	640	6 835	70.0	290	35.8%	68%	6.1	116
2012	639	7 104	70.1	297	35.4%	67%	6.1	119
2013	641	7 135	70.2	298	35.6%	66%	6.1	119
2014	641	7 443	70.4	302	35.4%	64%	6.1	121
2015	642	7 702	70.0	308	35.4%	69%	6.1	123
2016	643	7 768	69.9	313	35.5%	71%	6.2	127
2017	643	8 038	70.1	316	35.1%	70%	6.1	126
2018	643	8 031	69.6	319	36.9%	75%	6.2	130
2019	643	8 048	70.1	315	35.2%	73%	6.1	126
2020	643	8 447	70.2	323	37.4%	73%	6.2	131
2021	640	8 478	69.0	331	36.9%	77%	6.2	134
2022	639	8 338	68.8	325	37.3%	77%	6.3	134

5.2.2.2.2 Gross Energy Intake for Non-Dairy Cattle

Gross energy intakes for non-dairy cattle were derived from the study of Kovács (2013), where the typical Hungarian diets for each sub-category of non-dairy cattle was determined. Besides, the seasonal changes in the diets were also taken into account for each sub-category. In the calculation the available data, the Hungarian dietary standards and expert judgments were combined to get the most reliable results. Similarly, to the dairy cattle values of net energy requirements and net energy for lactation for other cattle were calculated according to the Hungarian standards. Table 5.2.7

summarizes the parameters and equations used to estimate the gross energy intake for non-dairy cattle.

***Table* 5.2.7 Parameters and equations to estimate gross energy intakes for Non-dairy cattle**

Activity data, parameters and coefficients	Unit	Sources	Values/ Notes
Weight	kg	Kovács (2013)	Calculated based on the livestock composition.
Weight Loss			NO
WG (daily weight gain)	kg	Kovács (2013)	1 for male<1 year, 0.73 for female<1 year, 0.65 for heifers, 0.9 for bovines 1-2 years, 0 for mature
C, Coefficient		Eq. 10.6 of IPCC (2006)	0.8 for females, 1.2 for bulls, 0 for mature
$C_{pregnancy}$		Table 10.7 of IPCC (2006)	0.1
Digestible energy intake (DE%)	%	Kovács (2013)	Calculated based on fed diets and laboratory measurements
C_a		Table 10.5 of IPCC (2006)	0 for stall, 0.17 for pasture
Proportion for grazing		HCSO, agricultural surveys, NFCSO's Nitrate database	
NE_m	MJ/day	Hungarian Nutrition Codex (2004)	Country-specific methodology according to the Hungarian standards of net energy requirements
NE_a	MJ/day	Eq. 10.4 of IPCC (2006)	calculated
NE_l	MJ/day	Hungarian Nutrition Codex (2004)	Country-specific methodology according to the Hungarian standards of net energy requirements
Ne_g	MJ/day	Eq. 10.6 of IPCC (2006)	Calculated
Ne_p	MJ/day	Eq. 10.13 of IPCC (2006)	Calculated
REM		Eq. 10.14 of IPCC (2006)	Calculated
REG		Eq. 10.15 of IPCC (2006)	Calculated
GE	MJ/day	Eq. 10.16 of IPCC (2006)	Calculated

Net energy for maintenance depends on the live weight, which was determined based on the study of Kovács (2013). The typical body mass for each sub-category as well as the resulted gross energy intake and the emission factors for the BY and the year 2022 are shown in Table 5.2.8 and Table 5.2.9.

Table 5.2.8 Gross energy intakes and emission factors by Non-dairy cattle subcategories for the base year (BY)

BY		<1 year		1-2 year		>2 year			
		Bovines for slaughter and other calves (male)	Bovines for slaughter and other calves (female)	Bovines (male)	Heifers for slaughter and other heifers	First calf heifers	Mature Non-Dairy (male)	Heifers for slaughter	Beef Cow
Live weight	kg	195	170	415	370	515	575	530	600
Digestible Energy	%	69	71	62	62	69	66	67	69
N-excretion	kg N / head year	42	41	40	36	61	56	53	70
Gross Energy Intake	MJ/ head day	94	92	156	160	200	192	185	157
Concentrate ratio	%	31	33	10	12	18	17	17	16
Y_m	%	5.51	5.47	7.03	7.00	6.87	6.90	6.89	6.90
Emission Factor for 3.A	**kg CH_4 / head year**	**24**	**23**	**72**	**73**	**90**	**87**	**84**	**71**

***Table* 5.2.9 Gross energy intakes and emission factors by Non-dairy cattle subcategories for the year 2022**

		<1 year		1-2 year		>2 year			
2022		**Bovines for slaughter and other calves (male)**	**Bovines for slaughter and other calves (female)**	**Bovines (male)**	**Heifers for slaughter and other heifers**	**First calf heifers**	**Mature Non-Dairy (male)**	**Heifers for slaughter**	**Beef Cow**
Live weight	kg	195	170	415	370	515	575	530	600
Digestible Energy	%	69	70	61	62	68	65	65	67
N-excretion	kg N / head year	44	42	46	41	66	60	57	75
Gross Energy Intake	MJ / head * day	94	94	161	163	192	199	191	162
Concentrate ratio	%	30	33	10	12	18	17	17	17
Y_m	%	5.53	5.48	7.03	7.01	6.87	6.90	6.89	6.90
Emission Factor for 3.A	**kg CH_4 / head year**	**24**	**24**	**74**	**75**	**87**	**90**	**86**	**73**

Methane conversion rate for Non-dairy cattle

Methane conversion rate for non-dairy cattle was calculated by linear interpolation in dependency of the proportion of concentrate in the dry matter intakes. In case of 'Bovines < 1 year' for the period of consuming only milk methane conversion rate zero was assumed in accordance with the 2006 IPCC Guidelines. The time of consuming only milk for juveniles was assumed to be 60 days, which is in line with the Hungarian standards.

5.2.2.2.3 Other livestock categories

Detailed information required to develop the Tier 2 emission factor is not available for other important livestock category in Hungary, such as sheep. Therefore, the Tier 1 methodology for enteric fermentation for all livestock categories other than cattle is applied. The emission factors used are the IPCC default ones provided for developed countries in Table 10.10 of the 2006 IPCC Guidelines. In the case of Rabbit and Poultry the IPCC methodologies do not provide emission factors. Emissions from enteric fermentation in rabbits are relatively small, accounting for 0.1% of the total emissions from enteric fermentations in all livestock, so development of a country-specific emission factor does not seem to be reasonable. The emission factor provided by the Italian NIR (2008) is used, because Italy is the nearest neighbour of Hungary, which reports emissions from rabbits. It is assumed that the Hungarian housing and feeding practices do not differ from the Italian ones. Emission factor for poultry was taken from the literature, due to lack of IPCC default values. Sources of emission factors per livestock species are summarized in Table 5.2.10.

Table 5.2.10 Emission factors used for the calculation of the methane emissions from enteric fermentation

Animal category	CH_4-emission factor kg head^{-1} yr^{-1}	Comments
Buffalo	55	IPCC default value for developed countries
Sheep	8	IPCC default value for developed countries
Goats	5	IPCC default value for developed countries
Horses	18	IPCC default value for developed countries
Asses & Mules	10	IPCC default value for developed countries
Swine	1.5	IPCC default value for developed countries
Poultry	0.015	expert judgement, according to Minonzio *et al.* (1998)
Rabbits	0.08	expert judgement, according to the NIR of Italy, 2008

5.2.3 Uncertainties and time series consistency

Uncertainty of activity data (animal population) was estimated based on the confidence intervals for each animal category and livestock survey provided by the HCSO. The uncertainty of the mean annual averages was estimated according to the error propagation rules. (See Table 5.1.3) For the uncertainty of the country specific EFs ±20% were assumed, while for the default EFs ±40% were applied in accordance with the 2006 IPCC Guidelines. The combined uncertainty in emissions from the 3.A sector is ±13%. CH_4 EF for dairy cattle was estimated based on data for milk production and GE, for which uncertainties could be estimated to be less than ±3% and ±10%, respectively. Data on milk production is readily available while the GE is checked against cattle feeding requirements arising from the biology of ruminants (e.g., ratio of crude protein, dry matter intake and proportion of silage in the diet).

5.2.4 Source specific QA/QC information

Consistency of Animal Populations

Since the centralized review conducted in 2014, the HCSO has provided animal populations rounded to the nearest hundred instead of nearest thousand (according to the recommendation of the ARR, 2014 para 47). Until 2014 the HCSO provided animal populations rounded to the nearest thousand; data for each livestock subcategory as well as the total livestock population were rounded by the HCSO.

It was not feasible to provide new animal populations rounded to the nearest hundreds for the full time series. The HCSO provided revised animal numbers backward to 2011.

In the case of animal categories for which enhanced livestock characterization is used rounding can cause slight differences between the rounded totals and the sum of the rounded values of subcategories.

As the IPCC methodology requires annual average animal populations, this fact can cause further seeming discrepancies in the case of enhanced livestock characterization, because of the error propagation.

To avoid inconsistencies in NIR tables arising from rounding and the use of annual average animal populations the following correction is used:

- The HCSO has provided animal numbers rounded to the nearest hundred since the inventory year 2011. However, using rounded values to the nearest hundred instead of nearest thousand the error propagation cannot be completely avoided; only reduced.
- An adjustment of animal numbers of Non-dairy cattle and Swine subcategories was applied to the chronological means of totals to eliminate the differences between the chronological means of totals and the sum of the chronological means by subcategories for those years when a slight difference occurred. It is worth noting, that the aforementioned discrepancy also exists in the case of the inventory year 2011, because the chronological means contain the livestock population in December of the previous year (i.e., 2010).

In the next figures we present an example of processing and adjustment of HCSO's livestock populations to get the required activity data to the emission estimate. The method used to derive Dairy cattle and Non-dairy cattle average annual populations for the year 2011 are outlined in the following steps below:

- STEP1 HCSO provides annual population survey data by subcategories (*Figure 5.2.3*).
- STEP2 Chronological means are calculated for each subcategory, as well as the total (*Figure 5.2.4*). See also Section 5.2.2.1.
- STEP3 Adjustment to the HCSO's total Cattle livestock is applied (*Figure 5.2.5*).

STEP 1 Data provided by the HCSO (1'000 head)			
	12/1/2010	**6/1/2011**	**12/1/2011**
Bovines less than one year old			
Calves for slaughter, male	40.0	46.7	47.8
Calves for slaughter, female	12.0	10.9	12.0
Other calves, male	26.0	30.6	29.5
Other calves, female	92.0	93.0	98.5
Bovines aged between one and two			
Male	30.0	25.6	24.5
Female for slaughter (heifers)	18.0	7.2	4.9
Other heifers	105.0	106.1	108.1
Bovines of two years and over			
Male	8.0	6.7	6.4
Female for slaughter (heifers)	3.0	2.6	2.2
Other heifers	37.0	35.2	34.8
Cows, dairy	193.0	206.0	196.9
Cows, beef	70.0	71.9	77.2
Cows, dual purpose	47.0	49.3	54.7
Cattle, total	**682.0**	**691.7**	**697.4**
Cattle, SUM OF SUBCATEGORIES	681.0	691.8	697.5
Difference	-1.00	0.10	0.10
Dairy Cattle	240.0	255.3	251.6
Other Cattle	442.0	436.4	445.8
Cattle, total	**682.0**	**691.7**	**697.4**
Cattle, SUM OF SUBCATEGORIES	681.0	691.8	697.5
Difference	-1.00	0.10	0.10

Figure 5.2.3 *Cattle populations survey data provided by the HCSO for the inventory year 2011*

	2011			
Bovines less than one year old				
Calves for slaughter, male	45.3			
Calves for slaughter, female	11.5			
Other calves, male	29.2			
Other calves, female	94.1			
Bovines aged between one and two				
Male	26.4			
Female for slaughter (heifers)	9.3			
Other heifers	106.3			
Bovines of two years and over				
Male	7.0			
Female for slaughter (heifers)	2.6			
Other heifers	35.6			
Cows, dairy	200.48			
Cows, beef	72.8			
Cows, dual purpose	50.08			
Cattle, total	**690.7**			
SUM OF CHRONOLOGICAL MEANS	690.5			
Difference for Cattle	-0.17			
Dairy Cattle	250.6	reported in the CRF Table		
Other Cattle	440.2	reported in the CRF Table		
Cattle, total	**690.7**	**consistent with the HCSO's total**		
Other Cattle SUM OF CHRONOLOGICAL MEANS	440.0			
Difference for Non-dairy Cattle	-0.18			

Figure 5.2.4 Chronological means for Cattle, 2011

STEP 3 Adjustment and conversion to activity data	**2011**		
<1 year	Original	Adjusted	*Difference*
Calves, male	74.5	74.5	*0.03*
Calves, male	105.6	105.6	*0.04*
1-2 year			
Bovines (male)	26.4	26.4	*0.01*
Heifers for slaughter and other heifers	115.7	115.7	*0.05*
>2 year			
Mature Non-Dairy (male)	7.0	7.0	*0.00*
Mature Non-Dairy (female)	2.6	2.6	*0.00*
First calf heifers	35.6	35.6	*0.01*
Beef Cow	72.8	72.8	*0.03*
Non-dairy Cattle	**440.2**	**440.2**	*0.00*
Non-dairy Cattle, SUM OF SUBCATEGORIES	440.0	440.2	*0.17*
Dairy Cattle	**250.6**	**250.6**	0.00
Cattle, total	**690.7**	**690.7**	**0.00**

Figure 5.2.5 Adjustment of average annual populations for Non-dairy cattle, 2011

The country specific value of the gross energy intake for Dairy Cattle was verified using values reported by the EU member states. Verification revealed the Hungarian value of 325 MJ head^{-1} d^{-1} for the year 2022 was consistent with the reported values by other EU member states. The average gross energy intake for the EU-28 member states was slightly lower, 323 MJ head^{-1} d^{-1} according to the EU's NIR 2023 submission. The milk yield in Hungary was slightly higher in 2022 than in the EU-28 in 2021. The milk production for the year 2021 was 21.2 kg for the EU-28, while 22.8 kg for Hungary in 2022. The feed digestibility was 71.4% in the EU-28 in 2021, while 68.8% in Hungary in 2022.

5.2.5 Source-specific recalculations

There was no recalculation in this category.

5.2.6 Planned improvements

See Section 5.1.9.

5.3 Manure management (CRF sector 3.B)

Emitted gases: CH_4, N_2O
Methods: T1, T2
Emission factors: D, CS
Key source: Yes
Particularly significant sub-categories, CH_4: Swine and Cattle
Particularly significant sub-categories, N_2O: Other AWMS and Indirect emissions

Animal manure is an important source of CH_4 and N_2O. The amount of CH_4 and N_2O emitted from the manure to the atmosphere depends on the conditions of manure management and use as well as on the composition of released excrements. CRF category 3.B comprises direct and indirect emissions during storage and treatment of manure before it is applied to land.

5.3.1 Source Category Description

In 2022 22.3% of agricultural CH_4 and 12.6% of agricultural N_2O emissions arose from the 3.B Manure management. The bulk of emissions were generated in cattle and swine husbandry, accounting for 587 Gg CO_2-eq and 244 Gg CO_2-eq direct emissions in 2022, which equates to 56% and 23% of total GHG emissions from 3.B, respectively), due to the considerable share of deep bedding and liquid manure. The main sources of CH_4 emissions from 3.B are Swine and Cattle manure (Figure 5.3.1), and most of N_2O emissions are generated in the solid and 'other' systems containing 'Cattle and Swine deep bedding' and 'Poultry manure with or without litter'. Indirect emissions contributed 11% to the total GHG emissions from 3.B. The uncovered manure tanks and the cattle housing are the main sources of the significant amount of N_2O emissions from volatilization of N in form of NH_3 and NO_x.

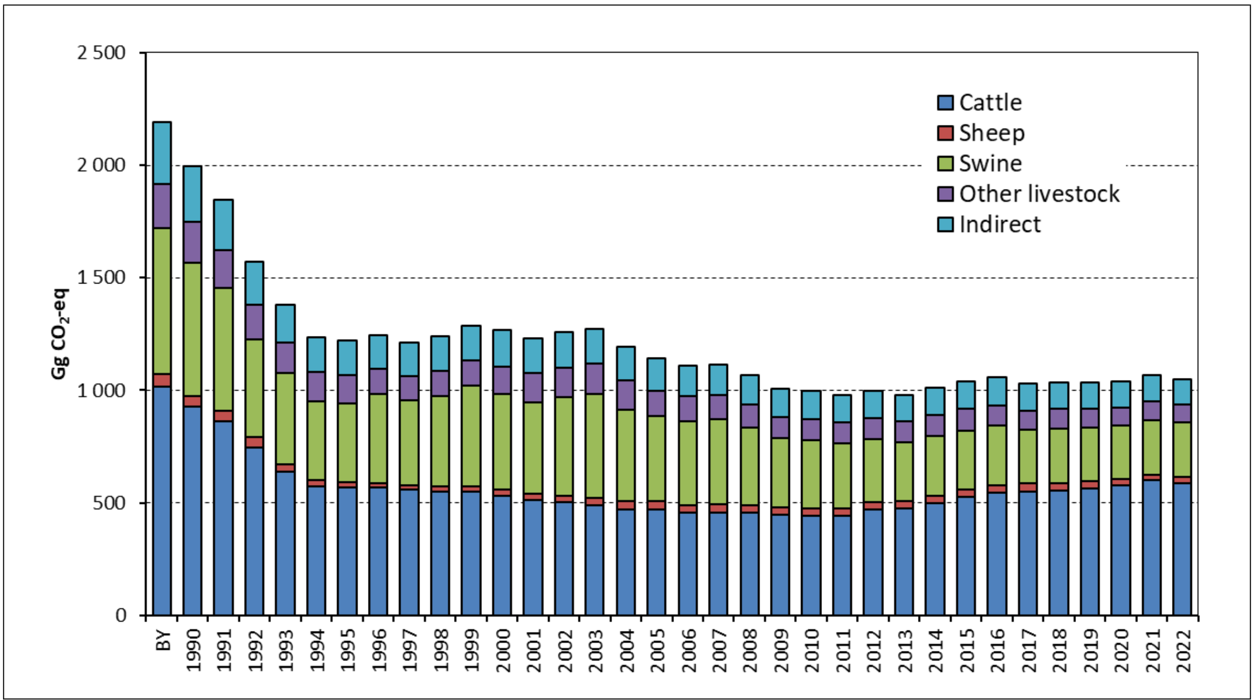

Figure 5.3.1 Emissions from 3.B Manure management by sources BY and 1990-2022

Emissions from 3.B Manure management have decreased by 52% since the BY. Considering CH_4 and N_2O emissions separately, they have decreased by 51% and 54% over the inventory period, respectively. The significant decrease in the emissions reflects the decreasing swine and cattle livestock between 1985 and 1994. In the period 1995-2003 emissions fluctuated to some extent on a yearly basis, following the annual changes in swine population. Emissions decreased again in the period 2004 to 2010 reflecting again the falling swine livestock numbers over that period. Since 2011 emissions from 3.B slightly increased due to the increasing non-dairy cattle livestock. CH_4 and N_2O emissions from 3.B are shown in Table 5.3.1 and Table 5.3.2.

Indirect N_2O emissions due to leaching decreased continuously over the time series. The decrease in the emission levels reflects the drop in livestock population and the effect of measures to reduce nitrate leaching during manure storage.

Table 5.3.1 Trend in CH_4 emissions from 3.B Manure Management by livestock categories BY and 1990-2022

Year	CH_4 emissions from 3.B				
	Dairy-Cattle	Non-Dairy Cattle	Sheep	Swine	Other livestock
BY	15.15	11.72	0.74	17.67	3.54
1990	14.28	10.01	0.58	16.16	3.25
1991	12.86	9.62	0.60	14.84	3.08
1992	11.63	7.82	0.56	11.89	2.68
1993	10.49	6.08	0.43	11.06	2.48
1994	9.76	5.18	0.32	9.59	2.38
1995	9.44	5.14	0.30	9.59	2.28
1996	9.37	5.16	0.28	10.93	2.21
1997	9.35	4.95	0.27	10.41	2.20
1998	9.37	4.62	0.28	11.26	2.26
1999	9.49	4.58	0.29	12.67	2.19
2000	9.06	4.44	0.35	12.07	2.40
2001	8.93	4.09	0.35	11.66	2.49
2002	8.81	4.00	0.34	12.65	2.58
2003	8.45	3.99	0.36	13.56	2.60
2004	7.98	3.97	0.41	11.93	2.49
2005	7.95	3.90	0.43	11.07	2.19
2006	7.46	4.00	0.40	10.86	2.09
2007	7.42	4.13	0.38	11.14	1.91
2008	7.35	4.11	0.37	10.19	1.83
2009	7.06	4.26	0.37	8.96	1.68
2010	6.72	4.46	0.35	8.84	1.68
2011	6.83	4.35	0.34	8.54	1.60
2012	7.19	4.78	0.35	8.12	1.50
2013	6.72	5.31	0.36	7.57	1.38
2014	6.92	5.71	0.37	7.60	1.40
2015	7.20	6.18	0.36	7.57	1.43
2016	7.21	6.68	0.36	7.75	1.41
2017	7.24	6.83	0.35	7.08	1.32
2018	7.39	6.94	0.34	7.18	1.34
2019	7.34	7.15	0.32	7.02	1.33
2020	7.45	7.37	0.29	7.10	1.22
2021	8.36	7.22	0.27	7.27	1.26
2022	8.00	7.20	0.27	7.32	1.22
Share in 3B CH_4 in BY	**31.0%**	**24.0%**	**1.5%**	**36.2%**	**7.3%**
Share in 3B CH_4 in 2022	**33.3%**	**30.0%**	**1.1%**	**30.5%**	**5.1%**
Trend BY-2022	**-47.2%**	**-38.5%**	**-63.1%**	**-58.6%**	**-65.6%**

Table 5.3.2 Trend in N_2O emissions from 3.B Manure Management by sources BY and 1990-2022

Year	N_2O emissions from 3.B						
	Direct					Indirect	
	Dairy-Cattle	Non-Dairy Cattle	Sheep	Swine	Other livestock	Atmospheric deposition	Nitrogen leaching and run-off
BY	0.48	0.51	0.14	0.57	0.37	0.99	0.04
1990	0.49	0.44	0.11	0.53	0.35	0.90	0.04
1991	0.45	0.43	0.11	0.48	0.32	0.81	0.04
1992	0.41	0.35	0.10	0.39	0.29	0.69	0.03
1993	0.38	0.27	0.08	0.36	0.25	0.60	0.03
1994	0.35	0.23	0.06	0.31	0.25	0.55	0.02
1995	0.37	0.23	0.06	0.31	0.23	0.56	0.02
1996	0.37	0.24	0.05	0.34	0.19	0.55	0.02
1997	0.37	0.23	0.05	0.31	0.19	0.53	0.02
1998	0.38	0.22	0.05	0.33	0.19	0.55	0.02
1999	0.38	0.21	0.06	0.35	0.19	0.56	0.02
2000	0.37	0.21	0.07	0.33	0.21	0.58	0.02
2001	0.37	0.19	0.07	0.30	0.22	0.57	0.02
2002	0.36	0.19	0.07	0.32	0.22	0.57	0.02
2003	0.34	0.19	0.08	0.32	0.22	0.58	0.02
2004	0.33	0.19	0.09	0.28	0.22	0.55	0.02
2005	0.33	0.19	0.09	0.26	0.20	0.52	0.02
2006	0.31	0.19	0.09	0.25	0.20	0.50	0.01
2007	0.31	0.20	0.09	0.26	0.19	0.50	0.01
2008	0.30	0.20	0.09	0.23	0.19	0.49	0.01
2009	0.29	0.20	0.09	0.21	0.18	0.46	0.01
2010	0.27	0.21	0.09	0.20	0.18	0.47	0.01
2011	0.27	0.21	0.09	0.20	0.18	0.46	0.01
2012	0.28	0.23	0.09	0.19	0.20	0.45	0.01
2013	0.27	0.25	0.09	0.18	0.21	0.44	0.01
2014	0.28	0.26	0.10	0.19	0.21	0.45	0.01
2015	0.28	0.28	0.09	0.18	0.21	0.46	0.01
2016	0.28	0.30	0.09	0.18	0.19	0.46	0.00
2017	0.28	0.31	0.09	0.16	0.18	0.45	0.00
2018	0.26	0.32	0.08	0.16	0.18	0.45	0.00
2019	0.28	0.33	0.08	0.15	0.18	0.45	0.00
2020	0.28	0.34	0.07	0.15	0.17	0.43	0.00
2021	0.28	0.33	0.06	0.15	0.17	0.44	0.00
2022	0.27	0.34	0.07	0.15	0.17	0.43	0.00
Share in 3B N_2O in BY	**15.3%**	**16.5%**	**4.5%**	**18.5%**	**12.0%**	**31.9%**	**1.3%**
Share in 3B N_2O in 2022	**19.1%**	**23.6%**	**4.9%**	**10.3%**	**11.6%**	**30.3%**	**0.3%**
Trend BY-2022	**-42.8%**	**-34.6%**	**-50.0%**	**-74.6%**	**-55.5%**	**-56.6%**	**-91.4%**

*We note that the ‘0.00’ values are due to the rounding of small numbers rather than inferring those emissions are zeros.

5.3.2 Methodological issues

5.3.2.1 Calculation method

CH_4 emissions from manure management were estimated using Tier 2 methodology, except Rabbit, which contribution is less than 1% to the source category. Direct N_2O emissions were calculated using Tier 2 method for the important livestock categories in Hungary, such as Dairy cattle, Non-dairy cattle, Swine and Poultry. For these livestock categories, country-specific nitrogen excretion rates were applied, but IPCC default values of emission factors were used. For the other livestock categories Tier 1 method was adopted. Indirect N_2O emissions were estimated based on the national air pollutant emissions inventory (i.e., reported NH_3 and NO_x emissions), which meet the requirement of the IPCC Tier 2 method. A detailed description of the methods applied for the calculation of NH_3 and NO_x emissions is given in the report 'Hungary's Informative Report, 2024' – Submission under the UNECE/CLRTAP.

5.3.2.2 Activity Data

5.3.2.2.1 Animal Waste Management System Distribution

Activity data on allocation of manure to animal waste management systems is based on processing and synthesizing of statistics from the HCSO's General Agricultural Censuses conducted in 2000, 2010 and 2020, Farm Structure Surveys, conducted in 2003, 2005, 2007, 2013, 2016, annual data for the period 2004-2022 from the Nitrate Database, statistics on agricultural wastes treated in biogas plants provided by the Hungarian Energy and Public Utility Regulatory Authority. Expert judgments were drawn on to the further stratification of primary data e.g., to stratify deep litter by mixing and frequency of removals.

In Hungary the first comprehensive study on animal waste management system distribution for emission inventory purposes was carried out by Ráky in 2003 (Ráky, 2003) based on the HCSO's General Agricultural Census 2000. This study focused on product producer farms and provides data by farm-size structure. The results of the HCSO's General Agricultural Census 2010 and 2020 provided comprehensive information on the manure management system distribution again. The censuses provide data on housing practices for cattle, swine and laying hens, and in addition on grazing for all animal species. The surveyed housing systems are as follows:

Cattle:

- Tied and loose housing solid systems
- Tied and louse housing liquid systems
- Other systems

Swine:

- Partly slatted floors (liquid systems)
- Fully slatted floors (liquid systems)
- Solid systems
- Deep litter systems
- Other systems

Poultry:

- Deep litter
- Cage with manure belt
- Cage with pit
- Battery cage with stilt house
- Other battery cage
- Aviary (without litter)
- Other

Farm Structure Survey data was applied to get representative activity data from the different datasets published by farm size structure, and it was applied as surrogate data to the interpolation of the 2000-2010 and 2010-2020 time series. Farm structure survey conducted in 2013 and 2016 contained a more detailed data collection on grazing than former surveys. This data on proportion of grazing animals as well as grazing period was also taken into account in the inventory preparation.

Agricultural census is taken every 10 years, thus for the recent years statistics from the Nitrate Database provides the most reliable data on animal waste management system distribution. Annual statistics from the Nitrate Database are supplied by the National Food Chain Safety Office (NFCSO) to the inventory. Data collection for the Nitrate Database is based on the Decree of the Ministry of Agriculture and Rural Development No. 59/2008 (IV. 29). The Annex 6 of the Decree contains a questionnaire, which is the basis of the data collection. Data supply obligation is prescribed for farmers, whose animal production exceeds the household requirements. The first version of this Decree (Government Decree No. 49/2001 (IV. 3)) entered into force in 2001. The collected data have been stored in a database since 2003. This database contains data on cattle and swine by sub-categories, poultry (laying hens, cocks and broilers, ducks, geese, turkey), sheep and goats, horse. Six different management systems were distinguished: liquid, solid, deep litter, grazing, farmyard/paddock and other. Amendments of this decree in 2008 resulted in a minor change in the structure of the data collection. Until 2007 only the livestock numbers for six housing systems were collected, while since 2008 the amount of manure has also been surveyed. In 2009 a more detailed livestock characterization was introduced for cattle and swine. At the same time sheep and goats were separated into two different categories. The former paper questionnaires were replaced by on-line forms in 2014. This measure contributed to the improvement of compliance with data provision obligations. In 2013, Hungary revised the area of the so-called 'Nitrate Vulnerable Zones' (hereafter NVZs). Thus, the areas designated as NVZs increased to approximately 68-69% of the country from the former 47%, further increasing the number of farms under the data provision obligations. In 2016 the data provision obligations of farmers were amended. The new regulations were developed in line with the data needs of emission inventories. The former six categories of management systems were improved by more detailed categories.

The number of the questionnaires received has been increasing since 2003, although the representativeness of this sample varies between different years and livestock categories. The dataset is most representative for cattle and poultry, about 80-90% of these livestock are covered. This data collection covers about 70-75% of the pig livestock. It is least representative for goats and horse with 10-15% coverage.

The applied data sources sometimes contain information on housing practices rather than manure management storage systems in many cases, therefore additional qualitative information was needed to define the relationship between the housing and manure management systems. Two studies

(Mészáros, 2005 and Pazsiczky *et al.*, 2006) were applied to get additional information. Data on sheep and goats were updated by a survey for sheep and goats in 2011 (Borka *et al.*, 2010).

The 2006 IPCC Guidelines require data on liquid manure to be disaggregated by manure storage coverage. The Nitrate Database has provided data on covered manure tanks, including formation of natural crust from the year 2015 onwards. This database was used to determine the proportion of covered and uncovered manure stores for the period 2015-2022. In Hungary, regulations on the construction of manure storage facilities have been in place since 2001, and covered slurry storage facilities have been built since then. Therefore, before 2001, only natural crust cover was considered, other types of cover were considered as 0. Between 2001 and 2015, linear interpolation was used. Table *5.3.3* shows the proportions of the covered cattle and swine slurry tanks in Hungary.

***Table* 5.3.3 Proportions of covered cattle and swine slurry tanks**

	1990	1995	2000	2005	2010	2015	2020	2022
Cattle	52%	52%	52%	54%	57%	59%	54%	56%
Swine	53%	53%	53%	55%	56%	58%	64%	61%

Expert judgments of Mészáros (2015) were drawn on to the further stratification of deep litter by mixing and frequency of removals.

ANAEROBIC DIGESTION

In Hungary, the first biogas plant utilizing animal manure was established in 2004, so the inventory takes into account the amount of manure treated in the biogas plants from 2004 onwards. For the period before that, we report notation key 'NO' in the CRF tables. Detailed data on agricultural wastes treated in biogas plants have been collected by the Hungarian Energy and Public Utility Regulatory Authority based on Regulation No 11/2017. (VIII. 25.) since 2017. However, according to the Hungarian Statistical Act (Act CLV of 2016 on Official Statistics), these detailed feedstock statistics are confidential, i.e., some feedstocks are used by less than three plants. Based on the amount of manure used in biogas plants, we determine the proportion of slurry and farmyard manure (FYM) treated in biogas plants for the calculation of emissions from 3.B Manure management and based on this data collection we also calculate the emissions from the application of biogas digestate for the 3Da2c sector. In order not to violate the statistical law, but to comply with the transparency requirement of the GHG inventory, in Table 5.3.4 we report the proportion of slurry and solid manure used in the biogas plant, by animal species.

Table 5.3.4 Proportions of slurry/solid manure used for biogas production

	2000	2005	2010	2015	2020	2021	2022
Swine, slurry	0.0%	*0.2%*	*2.6%*	5.6%	5.9%	4.4%	3.3%
Swine, solid	0.0%	*0.0%*	*0.1%*	0.3%	0.5%	0.5%	0.2%
Cattle, slurry	0.0%	*4.1%*	*29.9%*	39.7%	26.3%	20.9%	23.7%
Cattle, solid	0.0%	*0.1%*	*0.8%*	1.6%	1.7%	1.5%	1.5%
Broiler, solid	0.0%	*0.0%*	*0.4%*	1.2%	1.4%	1.5%	1.3%
Turkey, solid	0.0%	*0.0%*	*0.1%*	0.3%	0.6%	0.0%	0.0%
Laying hen, solid	0.0%	*0.0%*	*0.1%*	0.1%	0.0%	0.0%	0.0%

Values in italics are estimates based on "other biogas" production and feedstock consumption statistics for 2017-2021.

The amount of "other biogas" production and the biogas production potential from the feedstock were verified, ensuring consistency of data between the energy, waste, and agriculture sectors in terms of emissions from anaerobic digestion. Based on this verification, we found that on average about 25%

of other biogas produced in Hungary comes from animal manure. We used this verification for gap filling for the period 2004-2016 and estimated the amount of manure used in biogas plants based on the amount of "other biogas" produced as follows. From the data spanning 2017-2021, it was found that the manure N used for biogas production averaged 7.7 tones N per TJ. The N from manure used for biogas production for each year was estimated and allocated among different animal species based on the data from 2017-2021.

TRENDS IN DATA ON ANIMAL WASTE MANAGEMENT SYSTEM DISTRIBUTION

The most significant change occurred in the poultry manure management. From 2000 to 2022, the proportion of the liquid manure had dropped from 26% to almost zero for laying hens. Previously, the semi-solid manure was diluted by water and handled as liquid manure, but recently the semi-solid manure is rather dried than diluted and handled as solid manure. Thus, the liquid manure technology has been replaced by the drying technology as a result of environmental restrictions (Pazsiczky *et al.*, 2006). The other notable change in the poultry manure management is the decrease of the proportion of grazing for geese. As a result of the avian influenza pandemic, the animals are kept in barn rather than pastures.

For pigs, and in particular dairy cattle, there is an increase in slurry farming practices, which is also linked to an increase in the concentration of production. A growing proportion of the herd is concentrated on large farms where slurry farming is the dominant practice. At the same time, since 2004 part of the slurry has been used in biogas plants.

The share of manure used in biogas plants peaked in 2018 and has declined slightly in recent years, on one hand due to a decrease in other biogas production (see also 5B2) and the other hand due to a decrease in the share of animal manure in other biogas production compared to other agricultural and food waste.

In case of non-dairy cattle, the AWMS data show an increase in grazing. This can be explained by the increase in the proportion of beef cattle in the non-dairy cattle population, as in Hungary the most common type of beef cattle farming is deep-litter housing and grazing.

Activity data for the base year and 2022 are presented in Table 5.3.5 and Table 5.3.6, respectively. In case of cattle and swine extrapolation and surrogate data were used to complete the time series. For the other livestock categories data for the year 2000 were used for the period 1985-1999 due to lack of information.

***Table* 5.3.5 Animal waste management distributions for the base year per livestock categories**

BY	Liquid	Solid	Pasture	Anaerobic digesters	Other	Deep litter	Yard	Poultry manure with bedding	Poultry manure without bedding
Dairy Cattle	3.6%	40.9%	8.0%	NO	47.5%	44.0%	3.4%	-	-
Non-Dairy Cattle	2.5%	39.8%	16.1%	NO	41.6%	38.3%	3.3%	-	-
Swine	39.5%	59.0%	0.0%	NO	1.5%	0.0%	1.5%	-	-
Poultry	8.2%	22.0%	0.1%	NO	69.7%	-	-	58.0%	11.7%
Sheep	0.8%	44.9%	54.2%	NO	0.0%	-	-	-	-
Goats	0.8%	55.7%	43.4%	NO	0.0%	-	-	-	-
Horses	0.0%	60.0%	40.0%	NO	0.0%	-	-	-	-

Table 5.3.6 Animal waste management distributions for the year 2022 by livestock categories

2022	Liquid	Solid	Pasture	Anaerobic digesters	Other	Deep litter	Yard	Poultry manure with bedding	Poultry manure without bedding
Dairy Cattle	18.8%	29.3%	3.9%	6.8%	41.2%	32.6%	8.6%	-	-
Non-Dairy Cattle	2.1%	16.0%	22.6%	1.6%	57.6%	46.9%	10.7%	-	-
Swine	69.7%	19.2%	0.0%	2.4%	8.7%	7.0%	1.7%	-	-
Poultry	0.1%	19.2%	0.0%	0.4%	80.3%	-	-	65.8%	14.6%
Sheep	0.0%	61.3%	38.7%	0.0%	0.0%	-	-	-	-
Goats	0.0%	63.4%	36.6%	NO	0.0%	-	-	-	-
Horses	0.0%	60.3%	39.7%	NO	0.0%				

5.3.2.2.2 Livestock Number

Livestock population data provided by the HCSO are used for the estimation. For more details on the calculation of the annual average population and the activity data see section 5.2.2.1. The enhanced livestock characterization was used for the key categories according to the IPCC methodology. The livestock population data for swine by sub-categories are shown in Table 5.3.7.

***Table* 5.3.7 Swine population and trends from the BY and 1990- 2022 (1 000 head)**

Year	Animal Population						
	Piglets under 20 kg	Young pigs, 20-50 kg	Pigs for fattening over 50 kg	Breeding boars	Breeding sows	Guilts not yet mated	Sows mated for the first time
BY	2 015.2	1 718.2	4 341.0	25.2	690.9	76.1	96.4
1990	1 953.1	2 626.3	3 239.6	27.2	657.5	116.3	88.5
1991	1 612.3	2 349.7	3 090.6	25.1	563.0	104.0	64.4
1992	1 310.1	1 844.5	2 436.3	20.4	486.7	81.7	57.8
1993	1 222.7	1 744.1	2 245.4	18.0	446.0	77.2	52.0
1994	1 050.0	1 499.5	1 958.4	15.4	372.5	66.4	44.8
1995	1 107.2	1 458.5	1 921.6	15.3	404.7	64.6	51.1
1996	1 256.8	1 523.9	2 146.8	15.7	429.8	67.5	53.0
1997	1 187.5	1 302.1	2 039.4	14.3	356.3	56.7	56.3
1998	1 247.4	1 407.0	2 073.5	14.0	364.0	65.0	75.8
1999	1 281.3	1 503.1	2 299.8	14.8	396.9	56.3	56.8
2000	1 208.0	1 302.8	2 143.5	14.2	359.8	56.7	61.2
2001	1 260.5	1 108.0	1 984.5	12.5	342.2	54.7	61.0
2002	1 361.2	1 136.7	2 043.0	12.8	368.0	60.3	68.0
2003	1 281.8	1 157.8	2 150.9	12.0	362.3	56.0	56.7
2004	1 064.3	1 015.0	1 885.3	9.8	309.2	50.0	51.3
2005	998.7	916.5	1 701.9	10.0	291.5	50.7	52.5
2006	976.0	933.1	1 635.4	8.7	282.2	54.8	53.5
2007	1 015.3	934.2	1 700.3	7.8	279.0	52.0	50.3
2008	877.5	848.3	1 595.3	6.8	249.7	46.3	40.7
2009	757.4	795.4	1 374.1	6.0	226.5	45.0	43.5
2010	763.4	751.7	1 374.1	6.5	225.2	42.2	44.7
2011	751.5	748.6	1 326.9	5.7	217.6	43.4	37.8
2012	707.1	726.7	1 256.8	5.0	205.8	42.0	38.1
2013	724.0	683.6	1 250.4	4.8	194.2	44.1	42.8
2014	761.3	725.0	1 288.5	4.9	198.5	43.5	43.2
2015	784.2	741.4	1 308.3	4.7	201.1	44.8	42.5
2016	710.9	665.9	1 370.3	4.2	184.9	43.7	40.9
2017	683.0	636.8	1 271.5	3.4	175.0	41.0	36.9
2018	695.9	633.9	1 275.1	3.0	176.6	44.1	36.4
2019	690.2	626.4	1 228.9	2.7	167.9	45.3	35.0
2020	730.6	574.1	1 277.3	2.7	164.2	46.1	36.1
2021	736.7	596.0	1 254.5	2.4	163.4	48.3	36.0
2022	727.7	592.8	1 196.7	2.3	159.8	48.0	36.0
Trend BY-2022	**-63.9%**	**-65.5%**	**-72.4%**	**-90.9%**	**-76.9%**	**-36.9%**	**-62.7%**
Trend 2005-2022	**-27.1%**	**-35.3%**	**-29.7%**	**-77.0%**	**-45.2%**	**-5.2%**	**-31.5%**

5.3.2.2.3 Annual Average Nitrogen Excretion Rates (N_{ex})

For the values of annual average nitrogen excretion rates country specific (Tier 2) coefficients derived based on the Equation 10.31 of the 2006 IPCC Guidelines were used for Dairy Cattle, Non-dairy Cattle, Swine, Laying hens and Broilers.

In the calculation for breeding sows three different stages as gestation, lactation, and the period 'between weaning and mating' were distinguished. The daily nitrogen intake/retention was determined for each period and annual values were calculated as the weighted mean using the length of the periods as weighting factors. According to the Hungarian practices the length of gestation and lactation are 114 and 21 days, respectively. While the period between two successive farrowing decreased gradually across the time series. Annual values are provided in Table 5.3.11.

For broilers four-phase feeding was assumed for the period 2005-2018 and three phases from 2004 backwards. Time series consistency was ensured based on the time series overlap approach of the 2006 IPCC Guidelines (Volume 1, Chapter 5). Therefore, for the years 2005-2007 the three- and four-phase feeding systems were assumed, parallelly.

There was no need to distinguish between different stages in case of laying hens.

NITROGEN INTAKE

To the above equation Nitrogen intakes were determined from the crude protein content of the dietary components for all subcategories of these animals. The crude protein intakes were multiplied by 0.16, which is the fraction of nitrogen in protein, to convert the protein content into nitrogen. In the case of cattle and swine subcategories (breeding sows and breeding boars excepted) crude protein content in the diet was calculated from the feed ingredients. Data on crude protein contents of each component were taken from the so-called 'feed database' containing the laboratory measurements of all kinds of feed used for livestock nutrition in Hungary. The feed database is available in the Hungarian Nutrition Codex, 2004. In the case of cattle, nitrogen intakes were determined in conjunction with the examination of gross energy intake (see also section 5.2.2.2).

In respect of breeding swine, laying hens and broilers data on crude protein content of the feed (CP%) in proportion of dry matter intake (DMI) was provided from the livestock feed monitoring system operated by the AERI. Therefore, the nitrogen intake for a certain animal subcategory and stage was calculated using the Equation 10.32A of the 2019 Refinement:

$$N_{intake(T,i)} = DMI_{T,i} \cdot \left(\frac{\frac{CP\%_{T,i}}{100}}{6.25} \right)$$

(Equation 5.3)

Where:

$N_{intake(T,i)}$= daily N consumed per animal of category T and stage i (kg N animal^{-1} day^{-1})
$DMI_{T,i}$ = dry matter intake per animal in a certain stage (kg DMI animal day^{-1})
CP% $_{T,i}$= percent crude protein in dry matter
6.25 = conversion from kg of dietary protein to kg of dietary N, kg feed protein (kg N)$^{-1}$

In Hungary a feed monitoring system started to operate in 2016, with a retrospective data collection for the year 2005. For the year 1990 standards of the DMI and CP% intakes taken from the Hungarian Nutrition Codex, 1990 were applied and interpolation was used to complete the time series. According to the expert opinions and the depth interviews of the AERI, the Hungarian Nutrition Codex provided the most appropriate values of DMI and CP% for swine. While for broiler and laying hens the breeder's guides seemed to be the most reliable sources before 2005. However, as the research of the AERI revealed, in the years between 2005-2007, the crude protein content of the laying hen and broiler diet could be slightly lower than as it is suggested in the breeder’s guides. Therefore, time series overlapping was applied to avoid the time series inconsistency arising from the use of data from two different sources.

Table 5.3.8 shows the trends in the crude protein content in the diet of breeding sows and breeding boars. These trends in the CP% for sows are the result of two opposite effects. The rising productivity resulted in an increase in the protein demand and the nitrogen intake. This rising trend was maintained to 2010 after which the amino acid supplements lead to decreasing trends in the crude protein content in the breeding sow diet. Trends in the CP% for breeding boar shows a slight increase over the inventory period.

The trend in the N-intake of broiler is also driven by the abovementioned two contrary effects. The growing living weight result in an increase in the protein demand and the nitrogen intake. In 2007 the N-intake reached a peak. After that N-intake decreased gradually, due to the amino acid supplements. Finally, the N-intake started to increase slightly again in the last two years. The CP% of the diet which was the source of the N-intake estimate are provided in Table 5.3.9.

The overall slightly decreasing trend in the N-intake of laying hens reflects the improvement of the feeding practices and the importance of the amino acid supplements (*No data were available for 2022, therefore, data from 2021 were used in Table 5.3.10).

Table 5.3.8 Crude protein content in the diet of breeding sow and breeding boar in proportion of DMI BY and 1990-2022

Year	Gestating sow	Lactating sow	Weighted average for breeding sow	Breeding boar
	%			
BY	13.8	16.1	14.1	15.0
1990	13.8	16.1	14.1	15.0
1991	13.8	16.2	14.1	15.1
1992	13.9	16.2	14.2	15.1
1993	13.9	16.3	14.2	15.2
1994	13.9	16.4	14.2	15.2
1995	14.0	16.5	14.3	15.3
1996	14.0	16.5	14.3	15.3
1997	14.0	16.6	14.3	15.4
1998	14.1	16.7	14.4	15.4
1999	14.1	16.8	14.4	15.5
2000	14.1	16.8	14.5	15.5
2001	14.2	16.9	14.5	15.6
2002	14.2	17.0	14.5	15.6
2003	14.2	17.1	14.6	15.7
2004	14.3	17.1	14.6	15.7
2005	14.3	17.2	14.7	15.8
2006	14.3	17.2	14.7	15.8
2007	14.3	17.2	14.7	15.9
2008	14.3	17.2	14.7	15.9
2009	14.3	17.2	14.7	16.0
2010	14.3	17.2	14.7	16.0
2011	14.3	17.0	14.6	16.1
2012	14.0	17.1	14.4	16.1
2013	13.9	17.2	14.3	16.2
2014	13.7	16.9	14.1	16.2
2015	13.6	16.7	14.0	16.3
2016	13.4	16.7	13.8	16.3
2017	13.3	16.9	13.8	16.4
2018	13.4	16.9	13.9	16.4
2019*	13.4	16.9	13.9	16.4
2020*	13.4	16.9	13.9	16.4
2021*	13.4	16.9	13.9	16.4
2022*	13.4	16.9	13.9	16.4

Source: AERI

*No data were available for 2019-2022, therefore, data from 2018 were used.

Table 5.3.9 Crude protein content in the diet of broilers in proportion of DMI BY and 1990-2022

Year	Crude protein content, % (breeder's recommendation)			Year	Crude protein content, % (AERI data collection)			
	starter	grower I.	finisher		starter	grower I.	grower II.	finisher
BY	23.0	20.0	18.5	**2005**	22.1	20.3	20.2	19.4
1990	23.0	20.0	18.5	**2006**	22.0	20.3	20.0	19.2
1991	23.0	20.0	18.5	**2007**	22.0	20.3	19.9	19.1
1992	23.0	20.0	18.5	**2008**	22.0	20.3	19.7	19.0
1993	23.0	20.0	18.5	**2009**	21.9	20.3	19.6	18.9
1994	23.0	20.0	18.5	**2010**	21.9	20.3	19.5	18.7
1995	22.9	20.0	18.6	**2011**	21.9	20.2	19.2	18.6
1996	22.9	20.1	18.6	**2012**	21.6	20.1	19.0	18.4
1997	22.8	20.1	18.7	**2013**	21.4	19.9	19.1	18.3
1998	22.8	20.2	18.8	**2014**	21.3	19.8	19.0	18.5
1999	22.7	20.2	18.8	**2015**	21.1	19.9	18.9	18.3
2000	22.7	20.3	18.9	**2016**	21.2	19.8	19.0	18.2
2001	22.6	20.3	19.0	**2017**	21.4	20.0	19.3	18.3
2002	22.6	20.4	19.1	**2018**	21.5	20.1	19.4	18.5
2003	22.5	20.4	19.1	**2019**	21.4	20.0	19.2	18.4
2004	22.5	20.5	19.2	**2020**	21.5	21.5	21.5	21.5
2005	*22.4*	*20.5*	*19.3*	**2021**	21.6	20.1	19.3	18.5
2006	*22.4*	*20.6*	*19.3*	**2022***	21.6	20.1	19.3	18.5
2007	*22.3*	*20.6*	*19.4*					

*No data were available for 2022, therefore, data from 2021 were used

Table 5.3.10 Crude protein content in the diet of laying hens in proportion of DMI BY and 1990-2022

Year	Crude protein content (breeder's recommendation)	Year	Crude protein content (AERI data collection)
	%		%
BY	17.4	**2005**	17.2
1990	17.4	**2006**	17.2
1991	17.5	**2007**	17.2
1992	17.6	**2008**	17.1
1993	17.6	**2009**	17.1
1994	17.7	**2010**	17.1
1995	17.8	**2011**	17.4
1996	17.6	**2012**	17.5
1997	17.5	**2013**	16.8
1998	17.4	**2014**	16.7
1999	17.4	**2015**	16.7
2000	17.4	**2016**	16.7
2001	17.4	**2017**	16.6
2002	17.4	**2018**	16.4
2003	17.4	**2019**	16.7
2004	17.4	**2020**	16.6
2005	*17.4*	**2021**	16.5
2006	*17.3*	**2022***	16.5
2007	*17.2*		

*No data were available for 2022, therefore, data from 2021 were used

N retention

N retained by gestating sows and lactating sows were calculated using the Equation 10.33A and 10.33B of the 2019 Refinement:

$$N_{(retention,i)} = N_{(gain,i)} + N_{(piglets,i)}$$

(Equation 5.4)

Where:

$N_{retention,i}$= amount of N retained by the sow in the stage i (head day^{-1})
$N_{gain,i}$= amount of N retained in the sow in the stage i (head day^{-1})
$N_{piglets,I}$ = amount of N in piglets in the stage i (heads day-1)
i=stage (i=1: gestation, i=2: lactation, i=3: period 'between weaning and mating')

$$N_{piglets,i} = 0.0256 \cdot LITSIZE_i \cdot WG_{piglets,i}$$

(Equation 5.5)

Where:
$LITSIZE_i$ = litter size, in the stage i, heads;
$WG_{piglets,I}$ = weigh gain of piglets, in the stage i, head·day-1;
0.0256 = N content of weight gain (kg/kg) Lfl, 2013

For sows in the period between two successive farrowing and breading boars the nitrogen retention was calculated based on the daily weight gain.

Background data as litter size, weaning weight and days between two successive farrowing are provided in Table 5.3.11.

Data was compiled by the HMS, based on the annual yearbooks of 'Results of Pig Breeding' 1985-2018, published by the NFCSO. Piglets weight at birth was assumed to be 1.3 kg.

Table 5.3.11 Background data to the calculation of nitrogen retention rate of breeding sows BY and 1990-2022

Year	Piglet weight at weaning	Number of piglets at birth	Number of piglets at weaning	Period between two successive farrowing
	kg	heads	heads	days
BY	5.9	9.8	8.9	178.4
1990	6.3	10.1	8.8	178.1
1991	6.2	10.1	8.9	178.8
1992	6.2	10.2	8.8	181.2
1993	6.2	9.8	8.5	181.2
1994	6.2	9.8	8.4	182.2
1995	6.4	10.0	8.4	181.3
1996	6.5	10.1	8.5	181.0
1997	6.5	10.1	8.5	182.9
1998	6.2	10.2	9.1	181.6
1999	6.2	10.3	9.3	178.6
2000	6.3	10.4	9.3	180.2
2001	6.4	10.3	9.2	173.4
2002	6.5	10.2	9.1	173.3
2003	6.3	10.2	9.2	172.1
2004	6.4	10.2	9.2	170.7
2005	6.6	10.2	9.2	170.6
2006	6.7	10.3	9.2	170.4
2007	6.8	10.3	9.4	169.1
2008	7.0	10.4	9.4	168.9
2009	7.3	10.4	9.5	167.5
2010	7.6	10.5	9.5	166.6
2011	7.7	10.6	9.6	166.0
2012	7.7	10.7	9.8	162.6
2013	7.7	10.9	9.9	162.2
2014	7.7	11.1	10.0	162.0
2015	7.8	11.2	10.1	161.9
2016	7.8	11.3	10.2	161.8
2017	7.8	11.5	10.3	161.4
2018	7.9	11.4	10.2	161.8
2019*	7.9	11.4	10.2	161.8
2020*	7.9	11.4	10.2	161.8
2021*	7.9	11.4	10.2	161.8
2022*	7.9	11.4	10.2	161.8

Source: NFCSO

*No data were available for 2019-2022, therefore, data from 2018 were used.

N retention for laying hens was calculated from the production data using the Equation 10.33D of the IPCC Refinement:

$$N_{retention} = \left[N_{LW} \cdot DWG + \left(\frac{N_{EGG} \cdot EGG}{1000}\right)\right]$$

(Equation 5.6)

Where:

$N_{retention}$ = daily nitrogen retention of laying hens (kg N·head^{-1} ·day^{-1})

N_{LW} = average content of nitrogen in live weight, kg N·kg head^{-1}. Default value of 0.028 provided in the 2019 Refinement was applied;

DWG = average daily weight gain (kg·head^{-1}·day^{-1})

N_{EGG} = average content of nitrogen in eggs (kg N·kg egg^{-1}). Default value of 0.0185 provided in the 2019 Refinement was used.

EGG = egg mass production (g egg·head^{-1} day^{-1})

Data on egg production was obtained from the HCSO (Table 5.3.12). Average daily weight gain (DWG) was calculated from the daily weight gain of the typical laying hen breeds, as Tetra, Lohman and Hy-Line. Data on the distribution of typical breeds in Hungary were provided by the Hungarian Poultry Board. The average egg weight was calculated similarly, based on the egg weight of the typical laying hen breeds.

Table 5.3.12 Background data to the calculation of nitrogen retention rate of laying hens BY and 1990-2022

Year	Egg production egg·head^{-1}·year^{-1}
BY	206
1990	206
1991	189
1992	206
1993	218
1994	227
1995	220
1996	200
1997	212
1998	207
1999	202
2000	208
2001	213
2002	212
2003	210
2004	212
2005	208
2006	205
2007	218
2008	215
2009	215
2010	218
2011	214
2012	217
2013	208
2014	214
2015	218
2016	225
2017	227
2018	233
2019	240
2020	273
2021	293
2022	282

Source: HCSO, 2023

Nitrogen retention for broilers was calculated using the Equation 10.33E of the 2019 Refinement:

$$N_{retention} = \frac{(BW_{Final} - BW_{Initial}) \cdot N_{gain}}{Productin\ period}$$

(Equation 5.7)

Where:

$N_{retention}$= amount of N retained in animal (head) day^{-1}
BW_{Final} = Live weight of the animal at the end of the stage (kg)
$BW_{Initial}$ = Live weight of the animal at the beginning of the stage (kg)
N_{gain} = the fraction of N (kg) retained per kg BW gain (kg kg^{-1})
Production period = length of time from chick to slaughter (fattening duration)

N_{gain} was assumed to be 0.0304 kg kg^{-1} based on Haenel *et al.* (2018) and Haenel and Dämmgen (2009). This value relates to the 40 days fattening duration, but in order to ensure the time series consistency this value was applied for the whole inventory period. Data on BW_{Final} was obtained from the slaughterhouse statistics of the AERI. This statistic provides data on living weight before slaughtering. The value of $BW_{initial}$ was estimated to be 0.042 kg based on expert judgement. The fattening period was estimated to be 49, 42 and 40 days for the years 1994, 2007 and 2018 based on the Breeders Management Manuals of Arbor Acres and Aviagen, respectively; and interpolation was used to complete the timeseries. Background data to calculate nitrogen retention rate for broilers are shown in Table 5.3.13.

Table 5.3.13 Background data to the calculation of the nitrogen retention rate in broilers BY and 1990-2022

Year	BW_{final}	Production period (fattening duration)
	kg	day
BY	1.9	49.0
1990	1.9	49.0
1991	1.9	49.0
1992	1.9	49.0
1993	1.9	49.0
1994	1.9	49.0
1995	1.9	48.5
1996	1.9	47.9
1997	1.9	47.4
1998	1.9	46.8
1999	2.0	46.3
2000	2.0	45.8
2001	2.0	45.2
2002	2.0	44.7
2003	2.1	44.2
2004	2.0	43.6
2005	2.0	43.1
2006	2.1	42.5
2007	2.1	42.0
2008	2.1	41.8
2009	2.2	41.6
2010	2.2	41.3
2011	2.3	41.1
2012	2.3	40.9
2013	2.3	40.7
2014	2.4	40.4
2015	2.4	40.2
2016	2.4	40.0
2017	2.5	40.0
2018	2.5	40.0
2019	2.5	40.3
2020	2.6	40.6
2021	2.6	40.9
2022	2.6	40.9

Source: AERI, 2023

Values of fraction of annual N-intakes that is retained by animals ($N_{retention}$) and their sources are summarized in Table 5.3.14. The resulted values of N-excretion for Dairy Cattle and Non-dairy Cattle are provided in Table 5.2.4, Table 5.2.8 and Table 5.2.9, respectively, while values of N excretion for Swine are presented in Table 5.3.15.

Table 5.3.14 $N_{retention}$ rates and their sources

Animal species	**$N_{retention}$** (kg N retained/animal/day) (kg N intake/animal/day)$^{-1}$	**Source**
Dairy Cattle	0.20	Table 10.20 of IPCC (2006)
Non-Dairy Cattle	0.07	Table 10.20 of IPCC (2006)
Swine		
Piglets under 20 kg	0.48	Fébel and Gundel (2007)
Young pigs, 20-50 kg	0.34	Fébel and Gundel (2007)
Pigs for fattening over 50 kg	0.34	Fébel and Gundel (2007)
Breeding sows, weighted mean	0.34	*country-specific (calculated based on the Hungarian production data)*
Gestating Sows	*0.30*	country-specific
Lactating Sows	*0.42*	country-specific
Sows between weaning and mating	*0.26*	country-specific
Breeding boars	*0.08*	*country-specific (calculated based on the Hungarian production data)*
Guilts not yet mated	0.34	Fébel and Gundel (2007)
Sows mated for the first time	0.34	Fébel and Gundel (2007)
Laying hens	0.34	*country-specific (calculated based on the Hungarian production data), 2022*
Broilers	0.70	*country-specific (calculated based on the Hungarian production data), 2022*

Table 5.3.15 Annual average Nitrogen excretion rates (N_{ex}) for Swine

Sub-categories	N_{ex}
	kg $head^{-1}$ $year^{-1}$
Piglets under 20 kg	3.0
Young pigs, 20-50 kg	8.6
Pigs for fattening over 50 kg	12.3
Breeding sows (weighted average, BY)	**15.9**
Gestating Sows	*13.2*
Lactating Sows	*35.3*
Sows between weaning and mating	*13.4*
Breeding sows (weighted average, 2022)	**15.8**
Gestating Sows	*12.5*
Lactating Sows	*37.9*
Sows between weaning and mating	*12.9*
Breeding boars (BY)	24.4
Breeding boars (2022)	22.1
Guilts not yet mated	9.9
Sows mated for the first time	13.8
Swine, weighted average (BY)	**9.9**
Swine, weighted average (2022)	**9.3**

For other livestock categories the default values of nitrogen excretion provided in Table 10.19 of the 2006 IPCC Guidelines were used except Buffalo for which the EMEP/EEA Guidebook (EEA, 2023) were applied (Table 3.9). It should be noted that in the case of nitrogen excretion rate of Buffalo the 2006 IPCC Guidelines refer to the EEA, 2002, thus the use of the EMEP/EEA Guidebook (EEA, 2023), which is the most up-to-date emission inventory guidebook of the EEA, seems to be reasonable. Nitrogen excretion rates for 'Other animals' and the related body weights are shown in Table 5.3.16 and Table 5.3.17.

Table 5.3.16 Annual average Nitrogen excretion rates (N_{ex}) for 'Other livestock'

Animal Category	N_{ex} kg head^{-1} year^{-1}	Source
Buffalo	82.00	Table 3-9 of EMEP/EEA Guidebook (EEA, 2023)
Sheep	15.93	Table 10.19 of IPCC (2006)
Goats	17.99	Table 10.19 of IPCC (2006)
Horses	41.28	Table 10.19 of IPCC (2006)
Asses & Mules	14.24	Table 10.19 of IPCC (2006)
Poultry (2022)	0.66	Weighted average for 2022
Laying hens (2022)	*0.72*	*Country-specific, calculated annually*
Broilers (2022)	*0.48*	*Country-specific, calculated annually*
Turkey	*1.84*	Table 10.19 of IPCC (2006)
Ducks	*0.82*	Table 10.19 of IPCC (2006)
Geese	*0.55***	Table 3-9 of EMEP/EEA Guidebook (EEA, 2023)
Guinea Fowls	*0.36*	as default for Broilers provided in the Table 10.19 of IPCC (2006)
Rabbit	8.10	Table 10.19 of IPCC (2006)

*2006 IPCC GLs refer to the 2002 EMEP/EEA GB. Therefore, the EMEP/EEA Guidebook (EEA, 2023) as the more updated version of the GB was applied.

**There is no value provided in the IPCC (2006)

Typical animal weights to calculate the annual N-excretion per head are provided in Table 5.3.17.

Table 5.3.17 Typical animal mass (TAM) for other livestock

Livestock	Weight kg	Source/Note
Buffalo	380.0	Table 10A-6 of 2006 IPCC GLs
Sheep	48.5	Table 10A-9 of 2006 IPCC GLs
Goats	38.5	Table 10A-9 of 2006 IPCC GLs
Horses	377.0	Table 10A-9 of 2006 IPCC GLs
Asses and Mules	130.0	Table 10A-9 of 2006 IPCC GLs
Poultry	2.2	*Weighted average for 2022*
Laying hens (2022)	*2.0**	*Country-specific, calculated annually*
Broiler (2022)	*1.6**	*Country-specific, calculated annually*
Turkey	*6.8*	Table 10A-9 of 2006 IPCC GLs
Ducks	*2.7*	Table 10A-9 of 2006 IPCC GLs
Geese	*3.5*	Table A1.5 of EMEP/EEA Guidebook (EEA, 2023)
Guinea fowls	*0.9*	Default for Broilers provided in the Table 10A-9 of 2006 IPCC GLs
Rabbit	1.6	Table 10A-9 of 2006 IPCC GLs

*Please note that Tier 2 is applied, therefore TAM is not used in the calculation. These values are reported for information.

5.3.2.3 Estimation of CH_4 emissions

5.3.2.3.1 Emission factors for CH_4

As Manure Management is a key source the Tier 2 method was applied to calculate the CH_4 emission factors, except Rabbit, for which a default value of 0.08 is given in the Table 10A-9 of 2006 IPCC Guidelines was used. According to the Equation 10.23 of 2006 IPCC Guidelines, development of country-specific emission factors involves determining a weighted average methane conversion factor (MCF) using the estimates of the manure managed in each AWMS and the volatile solid excretion (VS), which means the organic material in livestock manure. The CH_4 emission factor also depends on the maximum methane producing capacity (B_o) for the livestock categories. The values of these components in the above-mentioned equation were calculated as it is delineated in the following sub-sections.

5.3.2.3.1.1 Volatile solid excretion per day (VS)

Country-specific values of VS for Cattle, Laying hens and Broilers were calculated according to the Equation 10.24 of 2006 IPCC Guidelines. Values needed for this calculation are the gross energy intake (GE), and its fractional digestibility, DE. The estimation of these values is detailed in Chapter 6.2.2.2. Metabolizable and digestible energy of feed for Laying hens and Broilers were calculated similarly, based on feeding practices. Forage composition parameters were taken from the Hungarian Nutrition Codex (2004).

For the ash content of the manure the IPCC default value (8%) was applied due to lack of country-specific values. Similarly, the urinary energy which is also required to the Equation 10.24 was calculated as 0.04·GE according to the 2006 IPCC Guidelines.

Table 5.3.18 contains the values of volatile solid excretion rate and the emission factors for non-dairy cattle sub-categories for the BY and 2022, respectively.

Table 5.3.18 Volatile solid excretion rate and CH_4-Emission Factor for Non-Dairy Cattle in the BY and 2022

Non-dairy cattle sub-categories		BY		2022	
		VS excretion	**CH_4-Emission Factor**	**VS excretion**	**CH_4-Emission Factor**
		$kg\ DM \cdot head^{-1} \cdot day^{-1}$	$kg \cdot head^{-1} \cdot yr^{-1}$	$kg\ DM \cdot head^{-1} \cdot day^{-1}$	$kg \cdot head^{-1} \cdot yr^{-1}$
<1 year	Bovines for slaughter and other calves (male)	1.6	4.7	1.6	6.9
	Bovines for slaughter and other calves (female)	1.5	4.3	1.6	6.8
1-2 year	Bovines (male)	3.2	13.3	3.4	17.3
	Heifers for slaughter and other heifers	3.3	13.3	3.4	14.7
>2 year	First calf heifers	3.4	14.7	3.5	14.5
	Mature Non-Dairy (male)	3.6	15.5	3.9	16.2
	Heifers for slaughter	3.5	14.7	3.7	15.3
	Beef Cow	2.8	10.6	3.0	11.5

For the other livestock categories, such as Swine, Buffalo, Sheep, Horses, Asses and Mules, Ducks and Geese the IPCC default values provided for Eastern Europe or Developed countries in the Table 10A-6-10A-9 in the 2006 IPCC Guidelines was used. IPCC default values for geese and guinea fowls are not available; hence values for ducks and broilers were used, respectively.

In the case of swine, the country specific (Tier 2) VS used for market swine and breeding swine categories were based on Dammgen *et al.* (2011). The reasons for applying the Dammgen *et al.* (2011) methodology were as follows: Equation 10.24 of the 2006 IPCC Guidelines contains inaccuracies; for instance, it includes organic matter excreted in the urine, which is erroneous, because urea, the primary component of urine organic matter, does not produce methane due to bacterial breakdown. Additionally, the gross energy content of swine feeds in dry matter is not constant (18,45 MJ/kg d.m.) for the entire time series.

The VS excretions for swine are calculated with the national procedure of Dammgen *et al.* (2011):

$$VS_i = m_{feed,DM,i} \cdot (1 - X_{DOM,i}) \cdot (1 - X_{ash,feed})$$

(Equation 5.3)

Where:

VS_i = VS excretions for animal category i (in kg place^{-1} d^{-1})
$m_{feed,DM,i}$ = Dry-matter intake for animal category i (in kg place^{-1} d^{-1})
$X_{DOM,i}$ = Digestibility of organic matter for animal category i (in kg kg^{-1})
$X_{ash,i}$ = Ash content of feed for animal category i (in kg kg^{-1})

Based on the time-series data collection for assessing the nutrient content of AERI swine feeds monitoring system (2005, 2010-2022), the results of the Hungarian Feed Code (1990 and 2004) and the FADN feed intake and weight gain, the time series result between 1990 and 2022 was determined and compiled.

Table 5.3.19 contains the values of volatile solid excretion rate and the emission factors for swine sub-categories for the BY and 2022, respectively.

Table 5.3.19 Volatile solid excretion rate and CH_4-Emission Factor for Swine in the BY and 2022

Swine sub-categories		BY		2022	
		VS excretion	CH_4-Emission Factor	VS excretion	CH_4-Emission Factor
		kg DM·head^{-1}·day^{-1}	kg·head^{-1}·yr^{-1}	kg DM·head^{-1}·day^{-1}	kg·head^{-1}·yr^{-1}
Market swine	Piglets, under 20 kg	0.08	0.31	0.06	0.28
	Young pigs, 20-50 kg	0.20	0.82	0.18	0.86
	Pig for fattening, over 50 kg	0.34	1.37	0.28	1.35
Breeding swine	Boars	0.39	1.57	0.49	2.35
	Breeding sows	0.38	1.53	0.36	1.79
	Guilts (not yet mated)	0.23	0.94	0.27	1.30
	Sows (first mated)	0.21	0.86	0.45	2.18
Swine		0.26	1.97	0.21	2.65

5.3.2.3.1.2 Maximum CH_4 producing capacity (B_o) values

Due to lack of country-specific data default values listed in Tables 10A-4-10A-9 of the 2006 IPCC Guidelines were applied.

5.3.2.3.1.3 Methane conversion factors (MCF)

Default MCFs for different manure management systems by average annual temperatures provided in Table 10.17 of 2006 IPCC Guidelines were used. The annual mean temperature in most parts of Hungary is between 10 and 11 °C. Thus, MCFs values provided for cool climate zone were applied for Pasture/Range/Paddock, Solid and both Poultry manure.

The choice of MCFs for liquid manure and deep litter required the disaggregation of livestock categories by annual average temperatures. However, Hungary does not have either large animal populations or multiple climate regions. To the further stratification the annual mean temperature and livestock data by counties were used. The detailed climate data (i.e., annual mean temperatures for 19 counties of Hungary) were extracted from the HMS climate database for the period 1991-2020, while the detailed livestock data from the General Agricultural Censuses, conducted in 2020. The resulted proportion of animal population by average annual temperature and livestock categories are provided in Table 5.3.20. In the previous submissions, climate data from 1981 to 2010 were utilized, resulting in significantly lower average annual temperatures compared to the period from 1991 to 2020. Nevertheless, this update of climate data was essential to ensure the use the most current data.

Table 5.3.20 **Distribution of main livestock categories by average annual temperatures**

Average annual temperature	Proportion of animal population				
	Dairy Cattle	Other Cattle	Swine	Laying Hens	Broiler
≤10°C	16%	14%	5%	14%	12%
11°C	78%	80%	92%	81%	86%
12°C	6%	5%	3%	5%	2%

Beyond the average annual temperature, the IPCC methodology differentiates between liquid manure with ‘natural crust cover’ and without, as well as ‘deep litter < 1 month’ and ‘deep litter > 1 month’. According to the expert opinion of the NARIC Institute of Agricultural Engineering (Mészáros, 2015), duration of deep litter is generally longer than one month in Hungary.

To determine the MCF for pig and cattle slurry, the proportion of covered and uncovered manure stores was determined (see also Section 5.3.2.2.1) and the IPCC default values for these were weighted according to the proportion of covered and uncovered manure tanks.

Anaerobic digestion

The technological specificities of the use of animal manure in biogas plants were investigated by AERI in 2021. The study was financed by the Ministry of Agricultural and a report an “The Hungarian biogas plants technological survey” was submitted to the Ministry. The AERI’s project found that in Hungary, most manure is treated in agricultural biogas plants and not in centralized ones. Consequently, emission losses during transport and storage of manure are not typical. Thus, slurry used in biogas plants is not stored on livestock farms, either on the site of the biogas facilities. In the biogas plant, manure is fed continuously, so the manure is transported via pipeline to the biogas plant, which is mostly located on the farm. Most of the solid manure treated in biogas plants comes from calves and is stored for up to two weeks before being used in biogas plants.

The MCFs for manure treated in anaerobic digesters were determined based on the 2019 Refinement Tier 2 methodology using equations provided in the Annex 10A.4 of the 2019 Refinement. The 2019 Refinement provides a much more detailed and scientifically more improved methodology for calculating the MCF for anaerobic digestion than the 2006 IPCC Guidelines. I.e., it separates the MCF from the digester during pre-storage and storage of digestate, allowing open and covered storage to be taken into account. Therefore, we believe, that the 2019 Refinement methodology reflects better the Hungarian circumstances than the 2006 IPCC Guidelines.

The following assumptions were used in the calculations, and the parameters required for the calculations were determined as follows:

For the leakage rate of digester (L_{dig}) the default value of 0.01 was assumed, presuming high quality biogas digesters. This assumption is also supported by the verification calculation carried out, as the estimated biogas yields are in good agreement with the amount of biogas produced, confirming that there should not be any significant loss from the digester. The value of 0.046 is used for relative amount of residual gas (μ_{rg}), because in Hungary the mesophilic digestion is dominant. In accordance with the report of the AERI the share of gastight storage of the digestate (x_{gts}) was 21% in Hungary, in 2020. No data was available on the leakage rate of the storage ($L_{sto,gt}$), therefore $L_{sto,gt}$= L_{dig} was assumed. Methane conversion factor for the non-gastight storage of digestate, (MCF_{ngts}) a value of 11% was assumed, similarly to the country-specific value of open cattle slurry tank with natural crust, because the viscosity of the digestate is similar to the cattle liquid manure and the co-fermented crop residues allow the formation of natural crust. Values of methane conversion factor for the non-gastight storage of digestate (MCF_{ps}) were calculated based on the values of the MCFs for manure not treated in biogas plants, considering the significantly lower length of manure storage.

IPCC Guidelines provide no methane conversion factor for Yard therefore the MCF of Solid was applied for yard manure. Methane conversion factors used in the inventory are provided in Table 5.3.21.

Table 5.3.21 Methane conversion factors for manure management systems

Manure Management System	**MCF** **%**
Pasture range and paddock	
Poultry	2.0
Other livestock	1.0
Solid storage and dry lot	2.0
Liquid system (2022)	
Cattle	14.4
Swine	14.1
Poultry	18.8
Other AWMS (2022)	
Dairy cattle	6.3
Non-dairy cattle	15.7
Swine	15.6
Poultry	1.5
Anaerobic digestion (2022)	
Cattle	2.2
Swine	1.4
Poultry	1.4
Dairy cattle deep bedding	18.7
Non-dairy cattle deep bedding	18.8
Swine deep bedding	18.9
Yard	2.0
Poultry manure with litter	1.5
Poultry manure without litter	1.5

5.3.2.4 Estimation of direct N_2O emissions from Manure Management

Default emission factors from 2006 IPCC Guidelines were used. In the case of cattle and swine liquid manure covered and uncovered manure tanks were distinguished, similarly to the selection of MCF values (see section above for further details). Mixing of cattle and swine deep bedding does not occur in practice in Hungary (expert judgement, Fenyvesi, 2015). Therefore, for cattle and swine deep bedding 'no mixing' was assumed.

In the IPCC Guidelines emission factor is unavailable for Yard, therefore the emission factor for solid manure was applied. Emission factors used in the inventory to estimate N_2O emissions from manure management are listed in Table 5.3.22. In response to a recommendation from the UNFCCC review 2019, Table 5.3.15 was supplemented with the sources of the emission factor indicating where weighted averages of the IPCC default values were applied.

Table 5.3.22 Emission factors used for the estimation of N2O emissions

Manure management system	N_2O-N emission factors kg N_2O-N kg^{-1} N_{ex}	Source
Solid storage and dry lot	0.005	Table 10.21 of the IPCC (2006)
Liquid system		
Cattle (2022)	0.003	Weighted average depending on the ratio of covered to uncovered slurry tanks
Swine (implied, 2022)	*0.003*	Weighted average
Sows (2022)	0.003	Weighted average depending on the ratio of covered to uncovered slurry tanks
Fattening pigs (2022)	0.003	Weighted average depending on the ratio of covered to uncovered slurry tanks
Poultry	0.000	Table 10.21 of the IPCC (2006) (without natural crust cover)
Other AWMS		
Cattle deep bedding	0.010	Table 10.21 of the IPCC (2006)(No mixing)
Swine deep bedding	0.010	Table 10.21 of the IPCC (2006)(No mixing)
Yard	0.005	As solid due to lack of default value provided in the IPCC (2006)
Poultry manure with litter	0.001	Table 10.21 of the IPCC (2006)
Poultry manure without litter	0.001	Table 10.21 of the IPCC (2006)

5.3.2.5 Estimation of indirect N_2O emissions from Manure Management

5.3.2.5.1 Indirect N_2O emissions through volatilization losses from manure management

Following the 2006 IPCC Guidelines, indirect N_2O emissions due to volatilization of N from manure management were calculated using the Tier 2 methodology.

The country-specific value of fraction of N that is volatilized as NH_3 and NO_x ($Frac_{GASMS}$) was calculated based on the NH_3 and NO_x emissions from 3.B Manure management reported to the UNECE under the LRTAP Convention. Hungary applies the EMEP/EEA Guidebook (EEA, 2023) to calculate emissions of air pollutants from agriculture. Tier 2 and Tier 3 methodology is applied for Cattle, Sheep, Swine, Laying hens and Broiler and Tier 1 for other livestock categories. NO_x emissions are calculated based on Tier 1 method. Derivation of the amount of manure nitrogen that is lost due to the volatilization of NH_3 and NO_x based on the Hungarian air pollutant emission inventory under the UNECE/LRTAP Convention is demonstrated in Table 5.3.23 Volatilized N as NH3 and NOx from manure management systems for 2022 for the year 2022. Time series of volatilization losses were calculated similarly for all years of the inventory period (Table 5.3.23).

Table 5.3.23 Volatilized N as NH3 and NOx from manure management systems for 2022

CRF code	Long name	NO_x (as NO_2)	NH_3	Total N volatilized kg N
3B1a	Manure management - Dairy cattle	0.14	7.08	5 872 974
3B1b	Manure management - Non-dairy cattle	0.14	7.40	6 132 977
3B2	Manure management - Sheep	0.01	1.49	1 230 386
3B3	Manure management - Swine	0.03	7.31	6 025 351
3B4a	Manure management - Buffalo	0.00	0.03	28 175
3B4d	Manure management - Goats	0.00	0.02	15 995
3B4e	Manure management - Horses	0.00	0.39	323 521
3B4f	Manure management - Mules and asses	0.00	0.01	4 152
3B4gi	Manure management - Laying hens	0.12	1.26	1 074 207
3B4gii	Manure management - Broilers	0.63	3.78	3 303 685
3B4giii	Manure management - Turkeys	0.07	1.53	1 284 402
3B4giv	Manure management - Other poultry	0.08	2.00	1 675 064
3B4h	Manure management - Other animals (Rabbit)	0.00	0.55	455 704
3B	**Manure management**	**1.23**	**32.85**	**27 426 593**

*We note that the ‘0.00’ values are due to the rounding of small numbers rather than inferring those emissions are zeros.

Table 5.3.24 NH_3-N and NO_x-N volatilization losses of manure management systems BY and 1990-2022

Year	Total N volatilized	$Frac_{GasMS}$
	kg N	%
BY	63 133 402	22
1990	57 141 728	22
1991	51 699 038	21
1992	44 054 276	21
1993	38 278 031	21
1994	35 134 016	21
1995	35 513 648	22
1996	34 816 168	22
1997	33 927 278	22
1998	35 103 031	22
1999	35 561 008	22
2000	37 080 190	23
2001	36 035 342	23
2002	36 429 539	23
2003	36 744 763	23
2004	34 987 565	22
2005	33 022 693	22
2006	31 935 768	22
2007	31 657 112	22
2008	30 916 929	22
2009	29 433 181	22
2010	29 633 251	22
2011	28 985 498	22
2012	28 402 598	21
2013	27 775 095	21
2014	28 683 937	21
2015	29 381 713	21
2016	29 396 782	21
2017	28 431 758	21
2018	28 489 664	21
2019	28 360 217	21
2020	27 411 791	21
2021	28 140 720	22
2022	27 426 593	21

To ensure transparency of reporting the volatilization losses, agricultural NH_3 emissions and NO_x emissions from 3.B Manure management are reported in CRF Table 6.

To estimate the indirect N_2O emissions from volatilization default value of 0.01 kg N_2O-N (kg NH_3-N + kg NO_x-N volatilized)$^{-1}$ for EF_4 given in Table 11.3 of 2006 IPCC Guidelines was used.

5.3.2.5.2 Indirect N_2O emissions through N-leaching and run-off from manure storage

In Hungary there are strict environmental obligations concerning the manure storage arising from the Nitrates Directive (91/676/EEC). The current regulations require to prevent/decrease N-leaching. Therefore, N-leaching from housing and manure storage systems not falling within the scope of nitrate regulations, and nitrogen leaching before the compliance deadlines of the regulations are reported here.

Information concerning Hungarian animal housing and manure storage systems was derived from the Nitrate Database, data from the national Farm Structure Survey (FSS), Codes of Good Agricultural Practice (GAP) and nitrate regulations.

National regulations concerning N-leaching from manure storage systems are as follows:

- Government Decree 27/2006. (II. 7.) on the protection of waters against pollution caused by nitrates from agricultural sources (Nitrate Decree), amending Government Decree 49/2001(IV.3);
- Decree 59/2008 (IV. 29.) FVM on the detailed rules of the action program required for the protection of waters against pollution caused by nitrates from agricultural sources and on the procedures for data provision and registration (hereafter GAP Decree; database established from data provided under the regulation is called Nitrate Database);
- Decree 43/2007. (VI.1.) FVM on Designation of nitrate vulnerable zones by MePAR blocks (MePAR is the abbreviation of the Hungarian Land Parcel Identification System).

The watertight construction of animal housings and manure storage systems is generally required under the GAP Decree. The use of impermeable barriers on the underlying strata, to prevent nitrate leaching is needed to ensure the compliance with the Nitrate Decree.

Areas and farms falling within the scope of Nitrate Decree are as follows:

- Farms operating on designated nitrate vulnerable zones and producing more than household needs. (Household needs is here defined as five livestock unit (LSU) or three LSU in the case of poultry; LSU is here defined as 500 kg live weight);
- Farms under the Environmental Permitting Regulations (EPR);
- Large livestock farms (defined in Decree 41/1997/. (V. 28.) FM);
- Areas of manure storage systems and manure processing.

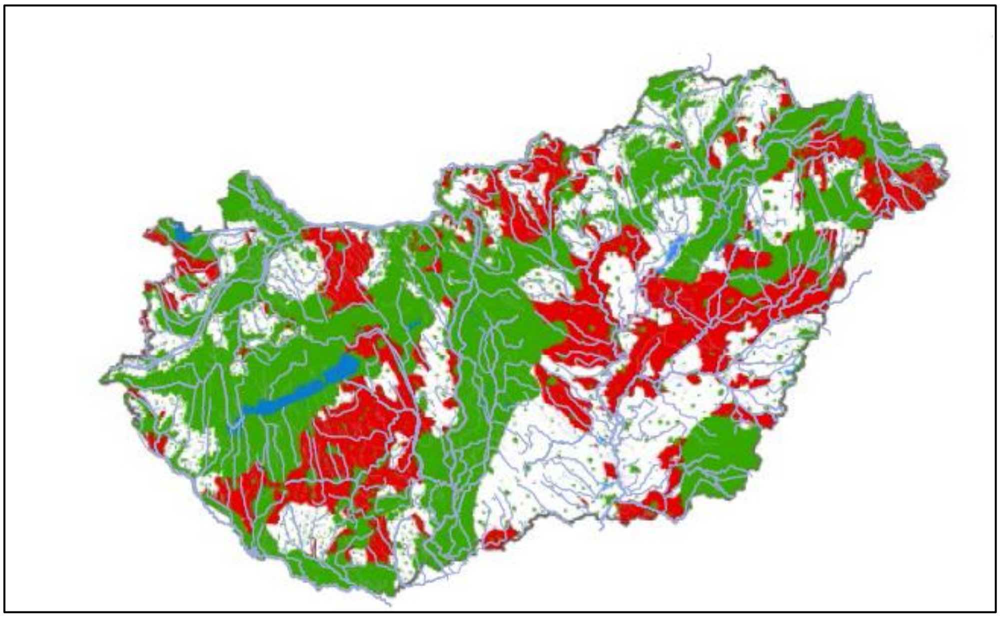

Figure 5.3.2. Maps of areas under the regulation of Nitrate Decree

Legend: nitrate vulnerable zones designated in 2007 are marked with green color, while areas under the regulations of Nitrate Decree since 2013 are marked with red color

The compliance deadline for nitrate regulations was 31 December 2014 for liquid/ slurry, and 22 December 2015 for solid manure storage systems in accordance with the amended Nitrate Decree.

(The Government Decree 49/2001(IV.3) contained earlier deadlines, between 2006 and 2014, which were extended in the amended regulation.)

Arising from the nitrate regulations amount of nitrogen leached was determined using the following assumptions:

- Measures for preventing N-leaching from manure management systems should have been started in 2001.
- Measures to improve manure management systems in order to prevent/ decrease N-leaching should have been finished according to the extended deadlines in the amended Nitrate Decree (i.e., at the end of 2014 or 2015).
- After the compliance deadline N-leaching could only occur on small farms (<5 LSU; or <3 LSU for poultry).

To summarize, N-leaching could occur from solid manure and deep litter of animals housed on small farms; and from solid manure, deep litter of animals housed on large farms before the compliance deadlines of nitrate regulations.

In 2000, one year before the introduction of the new legislation, a comprehensive survey was conducted to measure the proportion of farms where actions were needed to ensure compliance with the nitrate regulations. The results of the survey were published in the study of Ráky (2003). For the year 2000 livestock on farms where N-leaching could occur was estimated based on this study in the emission estimate.

For each year between 2000 and 2016 the livestock housed on farms with less than five or three LSU was determined based on FSS data. Besides, the fraction of non-compliance was estimated using linear interpolation between 2000 and the deadline of full compliance. (Smooth implementation of the nitrate regulations was assumed.) For the period 1985-1999 data for the year 2000 was applied due to lack of reliable statistics.

Annual amount of manure nitrogen that leached from manure management systems was determined according to the Eq 10.28 of the 2006 IPCC Guidelines, modified for the Hungarian legal circumstances as follows:

$$N_{leaching-MMS} = \sum_{S}\left[\sum_{T}\left[\left(N_{(T)} \cdot Nex_{(T)} \cdot \left(\frac{Frac_{Small} + Frac_{NC}}{100}\right)_{(T)} \cdot MS_{(T,S)}\right) \cdot \left(\frac{Frac_{leachMS}}{100}\right)_{(T,S)}\right]\right]$$

(Equation 5.8.)

Where:

$N_{leaching\text{-}MMS}$= amount of manure nitrogen that leached from manure management systems (kg N yr^{-1})
$N_{(T)}$= number of head of livestock species/category T in the country
$Nex_{(T)}$=annual average N excretion per head of species/category T (kg N $animal^{-1}$ yr^{-1})
$MS_{(T,S)}$=fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, dimensionless
$Frac_{leachMS}$=percent of managed manure nitrogen losses for livestock category T due to runoff and leaching during solid and liquid storage of manure
$Frac_{Small}$ = percent of livestock on small farms (<5 LU; or <3 LU for poultry)
$Frac_{NC}$ =percent of livestock on large farms (>5 LU; or >3 LU for poultry), not meeting the requirements of nitrate regulations.

In the case of Buffalo, Goat, Horse, Mule and Asses, Guinea Fowls and Rabbit, which livestock categories have small share to the total emissions, the whole livestock was assumed to be farmed on small farms ($Frac_{Small}$=100).

Time series of percent of livestock on small farms ($Frac_{Small}$) or large farms, which do not meet the requirements of nitrate regulation ($Frac_{NC}$), by livestock categories, are shown in Table 5.3.25.

Table 5.3.25 Fractions of livestock on small farms ($Frac_{Small}$) or large farms, which do not meet the requirements of nitrate regulation ($Frac_{NC}$) for 2000-2022

Year	Swine	Dairy Cattle	Non-Dairy Cattle	Sheep	Laying hens	Geese	Broiler	Turkey	Ducks
	Solid/ Deep litter	Solid/ Deep litter	Solid/ Deep litter	Solid	Solid	Solid	Solid	Solid	Solid
2000	49	100	100	53	72	21	29	29	97
2001	47	95	94	51	71	20	28	27	92
2002	44	89	89	48	70	19	26	26	87
2003	42	83	82	46	69	18	24	24	81
2004	39	78	76	44	67	17	22	22	76
2005	36	72	70	43	65	16	20	21	71
2006	33	65	64	39	66	15	18	19	66
2007	30	59	58	35	68	15	17	17	61
2008	29	53	52	34	61	14	15	16	56
2009	27	47	47	32	55	13	13	14	51
2010	26	42	42	30	47	12	11	12	46
2011	24	35	36	27	46	10	10	11	40
2012	22	29	29	25	45	8	8	10	35
2013	20	23	23	22	43	7	6	8	29
2014	18	16	16	20	38	6	4	6	22
2015	16	9	10	17	32	4	2	4	15
2016	14	3	3	15	26	3	0	2	9
2017	12	2	2	15	23	3	0	2	9
2018	11	2	2	15	19	3	0	1	10
2019	9	2	2	15	16	3	0	1	10
2020	8	2	2	15	13	3	0	1	11
2021	8	2	2	15	13	3	0	1	11
2022	8	2	2	15	13	3	0	1	11

The 2006 IPCC Guidelines provide a range of 1-20% for the default value of $Frac_{leachMS}$, but there is no animal and manure management specific default values available in the IPCC methodology. However, the difference of $Frac_{LossMS}$ and $Frac_{GasMS}$ given in Tables 10.23 and 10.22 seems to be as a proxy for $Frac_{leachMS}$, but according to the footnote of the Table 10.23, this difference contains the leaching losses as well as the N_2 emissions, therefore cannot be used as default values in the estimation.

In the submissions before 2021, the default ($EF\__{leachateN}$=12.0 as a proportion of TAN entering storage) provided for solid manure in the Table A1.12 of the EMEP/EEA Guidebook (EEA, 2016) was applied for $Frac_{leachMS}$, due to lack of country-specific measurements on the leaching losses from manure management systems and considering the low share of this emission. In line with the 2006 IPCC Guidelines, as well as the EMEP/EEA Guidebook (EEA, 2016) N leaching from liquid/slurry was not assumed as a source of leachate. In the most up to date EMEP methodology, in the EMEP/EEA Guidebook (EEA, 2023) N-leaching is no longer taken into account in the N-flow, thus the related EF was omitted from the Guidebook. Therefore, to calculate the indirect N_2O emissions from Manure Management due to leaching/runoff in this submission the methodology and the default value of $Frac_{LeachMS}$ provided in the 2019 Refinement was applied (2% for solid and 3.5% for deep litter).

In accordance with the Table 11.3 of 2006 IPCC Guidelines the default value of 0.0075 kg N_2O-N (kg N leaching and run off)$^{-1}$ for EF_5 was applied to estimate the indirect emissions from leaching/ run off.

5.3.3 Uncertainties and time series consistency

5.3.3.1 CH_4 emissions

Uncertainty of activity data (animal population) was estimated based on the confidence intervals for each animal species and livestock survey provided by the HCSO. The uncertainty of the mean annual averages was estimated according to the error propagation rules.

Uncertainty of EFs for CH_4 emissions from manure management was assumed to be ±20% for Cattle and ±30% for all livestock categories except rabbit, for which ±50% was applied. The 2006 IPCC Guidelines provide ±30% for T1 and ±20% for T2 methods, thus the estimated uncertainties are in line with the IPCC values. The Tier1 uncertainty analysis gives an overall uncertainty of ±13 % for the CH_4 emission from manure management.

5.3.3.2 Direct N_2O emissions

Uncertainties of ±25% are assumed relating to the N excretion of dairy cattle, non-dairy cattle, and swine, for which country-specific values are used. Uncertainties of ±30% are assumed for Poultry because country-specific N excretion rates are applied for Broiler and Laying hens, and ±50% for the other livestock categories in accordance with the 2006 IPCC Guidelines. The uncertainty of the manure management system usage ($MS_{T,S}$) data was assumed to be ±25% in accordance with the default value provided by 2006 IPCC Guidelines. The uncertainty of the EFs are -50%/+100% according to the 2006 IPCC Guidelines, therefore the lower combined uncertainty of the direct N_2O emissions from Manure management is 35% and the upper one is 67%.

5.3.3.3 Indirect N_2O emissions

Uncertainties in emission factor (EF_4) are likely to dominate these emissions, thus uncertainties in the volatilized nitrogen are comparatively less important in terms of emissions. Consequently, the default uncertainty ranges for the $Frac_{GasMS}$, and default uncertainty of the emission factor (EF_4), taken from the 2006 IPCC Guidelines were applied. The lower combined uncertainty of the indirect N_2O emissions from Manure management is 85% and the upper one is 399%.

The overall combined uncertainty in the N_2O emissions from 3.B is -36%/+130%.

5.3.4 Source specific QA/QC

Following the recommendation of the 2021 UN review (A.7, 2021), the following information has been added to this chapter:

The CH_4 IEF for swine for 1985-2000 is lower than the lowest value in the IPCC default range due to the higher proportion of solid manure in Hungary than accounted for in the IPCC default value for Eastern Europe. For 1985–2000, the proportion of solid manure ranged from 59.1% to 45.7%, while tables 10A-7–10A-8 of the 2006 IPCC Guidelines assume a proportion of 42% for Eastern Europe. Additionally, the IPCC default MMS usage assumes 3% anaerobic lagoon with methane correction factors of 66% and 68%, but anaerobic lagoons do not exist in Hungary. The extremely high methane correction factors for anaerobic lagoons significantly increase the IPCC default EF.

Nitrogen excretion rates for Cattle and Swine were verified using different calculation methodologies and compared with values used by other countries (EU Member States). For Dairy Cattle two different methodologies were used to verify the annual value of N-excretion. Firstly, the N-excretion was estimated based on the body mass and milk yields according to the methodology provided in Fébel and Gundel (2007). This methodology indicates a value of 124 kg N/head/year for the year 2019 and 149 kg N/head/year for the year 2020. This methodology also justifies a significant increase in the N-excretion factor in the inventory between 2019 and 2020, due to a significant increase in milk production.

In case of Non-Dairy Cattle and Swine the methodology provided in Fébel and Gundel (2007) indicates lower values. However, the difference for Swine is insignificant. Nitrogen excretion rates were compared with the values reported by other EU Member States. This verification revealed that the Hungarian values are in the range of values reported by EU Member States. The N_{ex} for non-dairy cattle was on average 52 kg N/head/year for the EU MS for the year 2020, which is very close to the Hungarian figure. The EU average of N-excretion rates for pigs was 10.7 kg N/head/year for the year 2020. The Hungarian value is slightly lower, but the Hungarian value is well within the range of EU values. The slightly lower value in Hungary is probably due to the lower fattening weights and the use of amino acid supplements.

Nitrogen excretion rate for Laying hens was compared with the default values provided in the 2006 IPCC Guidelines, 2019 Refinement and the EMEP/EEA Guidebook (EEA, 2023). Default IPCC values are given in kg N (1000 kg animal mass)$^{-1}$ day^{-1}), hence the 'typical animal mass' (TAM) is required to determine the annual N excretion. The table below summarizes the default values and the resulted annual N excretion.

Table 5.3.26 Comparison of N excretion rates for laying hens between the IPCC Guidelines and the EMEP/EEA Guidebook

Laying hen	IPCC Guidelines (2006)		IPCC Refinement (2019)		EMEP/EEA Guidebook (EEA, 2023)
	Eastern Europe	Western Europe	Eastern Europe	Western Europe	
Daily N excretion rate (kgN (1000 kg animal mass)$^{-1}$ day^{-1})	0.82	0.96	0.81	0.87	*0.96**
TAM (kg)	1.8	1.8	1.9	1.9	2.2
Annual N excretion (kg N head^{-1} yr^{-1})	0.54	0.63	0.56	0.6	0.77

*Calculated from the values provided in Table 3.9 and Table A1.5 of the EMEP/EEA (EEA, 2023) Guidebook.

The value of 0.70 kg N head^{-1} yr^{-1} used in the Hungarian inventory for the year 2021 is higher than the IPCC default values. The higher, 2.0 kg weight of laying hens in the Hungarian inventory justifies the higher annual N excretion rates. The EMEP/EEA Guidebook (EEA, 2023) also uses higher default weight than the IPCC Guidelines, resulting in similarly higher annual N excretion rate. The table above reveals that the value of 0.70 kg N head^{-1} yr^{-1} used in the Hungarian inventory is in the range of the default values provided in the different emission inventory guidelines.

Nitrogen excretion rates for broiler was also compared with the default values provided in the different emission inventory guidebooks. This comparison reveals that the most up-to-date guidebooks suggests higher values than the 2006 IPCC Guidelines due to the increase in the weight and the recently published defaults ranged from 0.4 to 0.5 kg N head^{-1}·yr^{-1}. However, the default daily N excretion rates combined with the country-specific TAM result in values ranging from 0.60 to 0.62 kg N head^{-1}·yr^{-1}, thus the value of 0.49 N head^{-1}·yr^{-1} for the year 2021 in the Hungarian inventory can be considered as consistent with the default values provided in the recently published emission inventory guidebooks.

Table 5.3.27 Comparison of N excretion rates for broiler between the IPCC Guidelines and the EMEP/EEA Guidebook

Broiler	IPCC Guidelines (2006)		IPCC Refinement (2019)		EMEP/EEA Guidebook (EEA, 2023)*
	Eastern Europe	Western Europe	Eastern Europe	Western Europe	
Daily N excretion rate (kgN (1000 kg animal mass)$^{-1}$ day^{-1})	1.1	1.1	1.12	1.14	1.1
TAM (kg)	0.9	0.9	1.1	1.2	1
Annual N excretion (kg N head^{-1} yr^{-1})	0.36	0.36	0.45	0.50	0.40

*Values are taken from the Manure Management N-flow tool.xlsx provided to the EMEP/EEA Guidebook (EEA, 2023)

N_2O emissions are calculated and reported consistently with the NH_3 and NO_x inventory under the UNECE/LRTAP convention. To calculate the NH_3 and NO_x emissions the EMEP/EEA Guidebook (EEA, 2023) was applied.

5.3.5 Source-specific recalculations

3.B.1 CH_4 emissions and 3.B.2 N_2O emissions from Manure Management

The update of climate data has an impact on the entire time series The annual average temperature was higher between 1991 and 2020 than between 1981 and 2010, resulting in a higher methane conversion factor for liquid/slurry. In addition to updating the climate data, the livestock distribution by county also has been revised based on HCSO's censuses for the year 2020.

The revision of N content of biogas feedstocks resulted in minor changes in N_2O emissions form manure management, primarily due to the revised distribution of manure management technologies.

3.B.1.3 CH_4 Emissions from Manure Management – Swine, whole time series

The VS calculation method was extended to Tier 2 method in case of swine, resulting in significant reduction in CH_4 emission.

3.B.1.1 (CH_4), 3.B.1.2 (CH_4), 3.B.1.4 (CH_4), 3.B.2.1 (N_2O), 3.B.2.2 (N_2O) and 3.B.2.4 (N_2O) CH_4 and N_2O Emissions from Manure Management – Non-dairy Cattle, Sheep and Poultry in 2021

Correction of calculation errors regarding the manure management system of non-dairy cattle (<1 year), sheep, and geese in 2021 resulted in only minor changes in CH_4 and N_2O emissions.

3.B.1.1 CH_4 and 3.B.2.1 N_2O Emissions from Manure Management – Dairy Cattle in 2020

A correction of a calculation error resulted in minor changes in the feeding of dairy cattle, slightly reducing gross energy intake, nitrogen excretion etc. for the year 2020, which led to slight decrease in CH_4 and N_2O emissions.

The overall changes in CH_4 emissions from 3.B.1 Manure management ranged from a -94.52 kt CO_2-eq to -52.31 kt CO_2-eq for the period 1985-2021. The percentage changes varied between -12.00% and -4.18%. This decrease is primarily attributed to the extended calculation of VS for swine. The overall changes in the N_2O emissions from 3.B.2 Manure management are negligible between 2004 and 2021 (below 0.1%), except for the year 2020, when the change was -0.52% due to the recalculation of feeding of dairy cattle.

5.3.6 Planned improvements

See Section 5.1.9.

5.4 Rice cultivation (CRF sector 3.C)

Emitted gas: CH_4
Methods: T1
Emission factors: D
Key source: none

5.4.1 Source Category Description

Hungary is situated on the north edge of the rice production area, where climatic conditions are generally unfavorable for rice cultivation. The production area of rice involves the poorer quality soils. Since the production volume is very low in Hungary, the contribution of rice cultivation to the greenhouse gas emissions is minimal, only 0.6% of the entire CH_4 emissions from agriculture sector.

5.4.2 Methodological issues

In Hungary the rice is cultivated on poorer quality soil, without organic amendments, the fields are intermittently flooded. Aeration is applied as a pest control during the cultivation (Apáti, 2003).

Methane emissions from rice cultivation were calculated according to the Equation 5.1 of 2006 IPCC Guidelines. As CH_4 emissions from rice cultivation are not a key category in Hungary, the Tier 1 methodology with default emission factors was applied. The adjusted daily emission factor to the above equation was calculated based on Equation 5.2 of 2006 IPCC Guidelines. The required values of baseline emission factor (EF_c), water regime (SF_w), water regime in the pre-season (SF_p) to this equation were taken from Tables 5.11-5.13 of 2006 IPCC Guidelines. The adjusted CH_4 emission scaling factor for organic amendment (SF_o) was calculated using the Eq. 5.3 of 2006 IPCC Guidelines. The value of conversion factor (CFOA) was taken from Table 5.14 of 2006 IPCC Guidelines. Due to lack of detailed information ‘straw incorporated shortly (<30 days) before cultivation’ was assumed as a conservative approach.

In response to a recommendation from the in-country review conducted in 2016, this section was supplemented with the Table 5.4.1 to present values of parameters used for calculating the EFs for irrigated rice cultivation.

Table 5.4.1 Parameters used for calculating the Emission Factors for CRF category 3.C

Parameters	Value	Unit	Source	Notes
$EF_{i,j,k}$, daily emission factor	1.86	kg CH_4 ha^{-1} d^{-1}	Eq. 5.2 of IPCC (2006)	
$t_{i,j,k}$, cultivation period, day	145	day	Calculated	Sowing: third ten days of April, or first ten days of May. Harvesting: between 10th of September and 10th of October
EF_c, baseline emission factor	1.3	kg CH_4 ha^{-1} d^{-1}	Table 5.11 of IPCC (2006)	
SF_w, water regime	0.78		Table 5.12 of IPCC (2006)	
SF_p, water regime, pre-season	1.22		Table 5.13 of IPCC (2006)	
SF_o, organic amendment	1.51		Eq. 5.3 and Table 5.14 for CFOA of IPCC (2006)	
$SF_{s,r}$, soil type, rice cultivar	1			There is no default value provided in the IPCC (2006). However, it should take into account if it is available according to the IPCC methodology.

As activity data, the total size of the production area was taken from the HCSO's statistics.

5.4.3 Uncertainties and time series consistency

For the uncertainty of the activity data, ±5% has been estimated by expert judgement. Uncertainties of scaling factors and the baseline emission factor were taken from the 2006 IPCC Guidelines. (SF_W ± 26%; SF_0 -4%/+5%; SF_p -14%/+15%, EF_c -63%/+69%) Combination of uncertainties listed above resulted in 69%/+75% combined uncertainty for the adjusted daily emission factor. Therefore, the overall lower and upper uncertainty of 69% and 76% can be calculated for the emissions from rice cultivation.

5.4.4 QA/QC Information

See 6.1.5.

5.4.5 Source-specific recalculations

There were no recalculations in this category.

5.4.6 Planned improvements

There are no further improvements planned.

5.5 N_2O emissions from Agricultural soils (CRF sector 3.D)

Emitted gas: N_2O
Methods: T1
Emission factors: D
Key source: Yes
Particularly significant sub-categories: Inorganic N fertilizers, Crop residue

5.5.1 Source Category Description

In 2022 agricultural soils emitted 87.4% of the total N_2O emissions from the agriculture sector, and 81.4% of the national total N_2O emissions are generated in agricultural soils (Table 5.5.1). Emissions from agricultural soils contributed 4.4% (2 609 Gg CO_2-eq) to the national total GHG emissions in 2022.

The overall trend in emissions is decreasing. However, trends in emissions from crop production related sectors as 3.D.a.4 Crop residues and 3.D.a.5 Mineralization are different from the other subsectors. Emissions from 3.D.a.4 fluctuated significantly depending on crop production, which is determined by the weather conditions. Trends for 3.D.a.5 also seem to be fluctuating. However, emission from this source is low and uncertain.

Table 5.5.1 Trends in emissions from 3. D Agricultural Soils by subcategories BY and 1990-2022

Year	N_2O emissions (Gg N_2O)									
	3.D.a	**3.D.a.1**	**3.D.a.2**	**3.D.a.3**	**3.D.a.4**	**3.D.a.5**	**3.D.a.6**	**3.D.b**	**3.D.b.1**	**3.D.b.2**
BY	15.75	9.25	3.24	0.37	2.50	0.005	NO	1.49	1.36	0.13
1990	11.64	5.63	2.97	0.29	2.39	0.005	NO	1.14	1.01	0.13
1991	8.49	2.20	2.77	0.30	2.89	0.005	NO	0.75	0.68	0.07
1992	7.24	2.33	2.38	0.28	1.97	0.005	NO	0.66	0.59	0.07
1993	6.77	2.53	2.09	0.23	1.70	0.005	NO	0.61	0.54	0.07
1994	8.00	3.49	1.88	0.18	2.25	0.005	NO	0.64	0.56	0.07
1995	7.42	3.00	1.86	0.16	2.19	0.005	NO	0.60	0.54	0.07
1996	7.56	3.19	1.81	0.16	2.20	0.005	NO	0.61	0.54	0.06
1997	7.84	3.24	1.75	0.15	2.50	0.005	NO	0.59	0.54	0.05
1998	8.41	3.90	1.78	0.16	2.37	0.005	NO	0.66	0.60	0.06
1999	8.40	4.12	1.81	0.17	2.12	0.005	NO	0.65	0.61	0.04
2000	8.06	4.05	1.82	0.19	1.80	0.005	NO	0.70	0.63	0.07
2001	9.08	4.32	1.79	0.19	2.60	0.005	NO	0.71	0.64	0.07
2002	9.08	4.76	1.82	0.18	2.14	0.005	NO	0.75	0.67	0.08
2003	8.49	4.54	1.83	0.18	1.75	0.005	NO	0.75	0.66	0.09
2004	9.76	4.60	1.77	0.20	3.00	0.005	NO	0.76	0.68	0.08
2005	9.03	4.09	1.69	0.20	2.87	0.000	NO	0.67	0.62	0.06
2006	9.21	4.54	1.67	0.19	2.64	0.000	NO	0.70	0.64	0.06
2007	9.03	5.03	1.66	0.17	1.98	0.000	NO	0.75	0.67	0.08
2008	9.67	4.62	1.62	0.17	3.07	0.000	NO	0.65	0.58	0.07
2009	8.78	4.32	1.56	0.16	2.54	0.000	NO	0.60	0.54	0.07
2010	8.57	4.42	1.57	0.15	2.24	0.000	NO	0.61	0.54	0.07
2011	9.23	4.74	1.57	0.15	2.57	0.004	NO	0.64	0.56	0.07
2012	9.00	4.92	1.60	0.15	2.11	0.010	NO	0.65	0.57	0.08
2013	10.02	5.39	1.65	0.14	2.61	0.010	NO	0.71	0.63	0.09
2014	10.52	5.36	1.70	0.14	3.07	0.011	NO	0.73	0.63	0.10
2015	10.80	5.95	1.73	0.14	2.72	0.011	NO	0.78	0.69	0.10
2016	11.67	6.35	1.70	0.14	3.21	0.011	NO	0.81	0.72	0.09
2017	11.67	6.67	1.67	0.14	2.89	0.011	NO	0.86	0.76	0.09
2018	11.71	6.67	1.65	0.14	2.94	0.012	NO	0.85	0.76	0.10
2019	11.65	6.54	1.64	0.14	2.99	0.015	NO	0.84	0.75	0.09
2020	12.07	7.00	1.62	0.13	2.97	0.015	NO	0.89	0.79	0.10
2021	12.05	7.17	1.63	0.13	2.77	0.016	NO	0.89	0.79	0.10
2022	9.10	5.12	1.61	0.11	1.95	0.019	NO	0.75	0.66	0.09
Share of Hungarian total N_2O emissions in BY	**42.2%**	**24.8%**	**8.7%**	**2.0%**	**6.7%**	**0.0%**	**NO**	**4.0%**	**3.6%**	**0.3%**
Share of Hungarian total N_2O in 2022	**65.7%**	**37.0%**	**11.6%**	**2.9%**	**14.1%**	**0.1%**	**NO**	**5.4%**	**4.8%**	**0.6%**
Trend BY-2022	**-42.2%**	**-44.7%**	**-50.3%**	**-70.0%**	**-22.1%**	**277.7%**	**NO**	**-49.7%**	**-51.3%**	**-33.6%**

The total emissions from 3.D Agricultural soils have reduced by 43% of the BY levels until 2022. A significant drop had occurred in the period 1985-1993 due to the significant decrease in synthetic fertilizer use and livestock population (organic manure applied) which resulted in less N-input. After reaching the lowest point of the emission levels in 1993 there was a slight increase until 1998 due to a small rise in synthetic fertilizer use. After that emission levels remained quasi stable in the period 1998-2013 as a result of compensatory processes between the different sources of N input. As the Figure 5.5.1 reveals emissions are primarily driven by the amount in synthetic fertilizer used. At the beginning of the time series the second most important source was the organic manure. In contrast, in the recent years N in crop residues has exceeded the amount of organic N, reflecting the restructuring in the Hungarian agricultural. Namely, the animal husbandry has declined in importance in the agricultural production, while crop production has become more meaningful. For more details on trends see also Section 5.1.1.

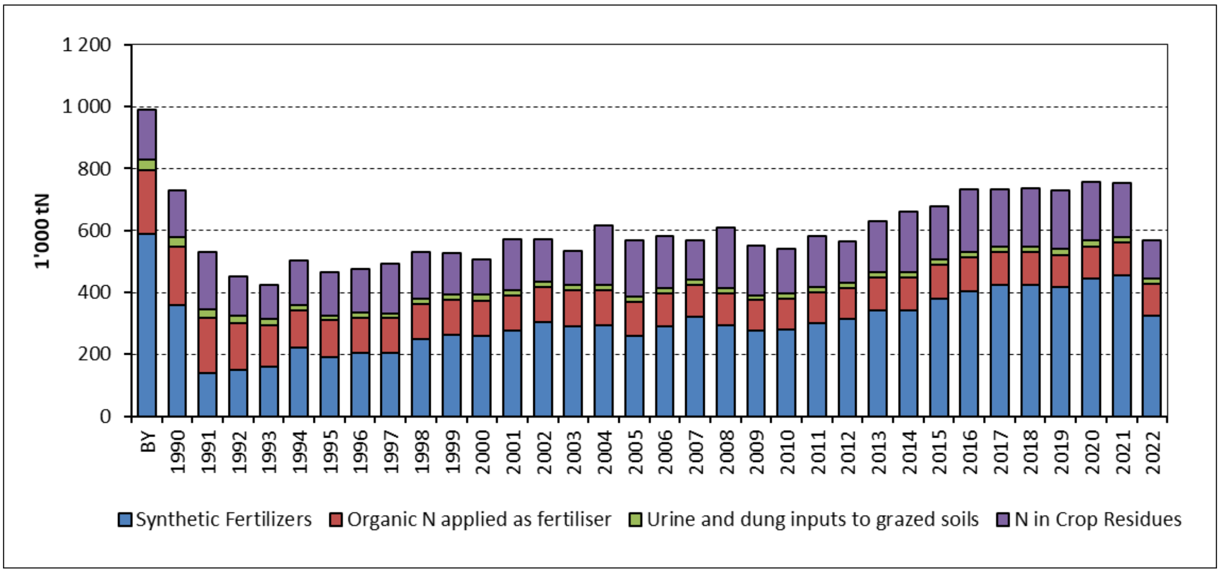

Figure 5.5.1 Trends in nitrogen input to soils BY and 1990-2022

5.5.2 Methodological issues

5.5.2.1 Direct soil (CRF sector 3.D.a)

Direct soil emissions are the main source of N_2O in the Hungarian inventory. In 2022, 65.7% of the national total N_2O emissions originated from this sector, which includes N inputs from synthetic N-fertilizer (3.D.a.1), organic manures as animal manure use and sewage sludge application (3.D.a.2), emissions from urine and dung N deposited on pasture (3.D.a.3) and crop residues (3.D.a.4). Emissions from N mineralization associated with loss of SOM (3.D.a.5) are rather low, but also was taken into account to meet the principle of completeness. In response to the recommendation of the ESD review in 2016, N_2O emissions form 3.D.2.c Other organic fertilizers applied to soils (compost) have been reported since the 2018 submission. Organic soils are protected, thus not cultivated in Hungary. Therefore, emissions from cultivation of histosols are not reported.

Emissions from these sources were calculated using Tier 1 methodology based on the Equation 11.1 of 2006 IPCC Guidelines. The N_2O-N was converted to N_2O by the factor (44/28) in line with the IPCC methodology. Terms of the Equation 11.1 were determined as it is detailed in the following sub-sections, while amounts of various N inputs to soils are provided in Table 5.5.7.

5.5.2.1.1 N input from synthetic fertilizer use (F_{SN})

Annual amount of synthetic N fertilizer applied to soils was estimated from the total amount of synthetic fertilizer sold to end users, annually. Collection of this data is executed according to the National Statistical Data Collection Program (OSAP) by the AERI. Although, this is sale statistics instead of consumption data, but so comprehensive survey on fertilizer consumption there is not available in Hungary. Moreover, this sale statistics contain the sold fertilizers by product line, which enables us to determine the amount of nitrogen applied to soils by fertilizer types, thus the detailed and more accurate calculation of volatilization and indirect emissions. Data on synthetic fertilizer applied (F_{SN}) for the period 1985-2022 are provided in Table 5.5.7.

5.5.2.1.2 Applied organic fertilizers (F_{ON})

The amount of organic N inputs applied to soils other than by grazing animals was calculated using Equation 11.3 of 2006 IPCC Guidelines. In Hungary, this includes animal manure, sewage sludge and composted sewage sludge, composted municipal solid waste and digestate from anaerobic digesters.

Animal manure applied to soils (F_{AM})

Annual amount of animal manure N applied to soils (F_{AM}) was calculated using the equation 11.4 of the 2006 IPCC Guidelines. In Hungary manure is not used as feed, fuel or for construction, therefore fractions ($Frac_{FEED}$, $Frac_{FUEL,}$ $Frac_{CNST}$) in the equation were assumed to be zero.

Consequently, annual amount of animal manure N applied to soils (F_{AM}) is corresponded to the managed manure nitrogen available for application to managed soils (N_{MMS_Avb}), which was calculated based on Eq. 10.34 of 2006 IPCC Guidelines. The first term of this equation is the managed manure N taking into account the losses in the manure management systems. Data and information on the calculation of managed manure N, volatilization, leaching and N_2O-N losses from manure management systems are provided in Chapter 5.3.

In the equation 10.34 reference is also made to $Frac_{LossMS}$, for which default values are provided in Table 10.23. According to the footnote b of this table, N_2 emissions are also taken into account in the N losses form the manure management systems. Thus, the losses in equation 10.34 covers the N_2 emissions for most manure management systems.

Hungary uses Tier 2 and country-specific values to calculate the volatilization and leaching losses from the manure management systems, therefore the default values provided in Table 10.22 and 10.23 are not used in the inventory. Nevertheless, accepting the concept that the default total N losses from manure management systems covers the N_2 emissions, the N_2 emissions were subtracted to get the N content of animal manure applied to soils.

As the IPCC methodology does not provide emission factors to calculate N_2 emissions from the storage of manure the default EFs given in the Table 3.10 of the EMEP/EEA Guidebook (EEA, 2023) was applied. (EF_{solid}=0.3 kg N_2/ kg TAN and 0.003 kg N_2/ kg TAN.) N_2 emissions are calculated in the N-flow tool used to calculate NH_3 emissions and published with the EMEP/EEA Guidebook (EEA, 2023).

The time series of N_2 emissions are shown in Table 5.5.2.

Table 5.5.2 N_2 emissions calculated to estimate F_{AM}, for the BY and the period 1990-2022

Year	N_2 emissions (kg) from manure management systems
BY	29 114 449
1990	26 199 192
1991	23 932 415
1992	20 594 325
1993	17 642 028
1994	16 212 676
1995	16 365 051
1996	15 852 307
1997	15 561 855
1998	15 952 601
1999	15 810 298
2000	16 524 508
2001	16 219 023
2002	16 100 270
2003	16 053 955
2004	15 644 499
2005	14 936 848
2006	14 452 653
2007	14 186 347
2008	14 096 724
2009	13 572 714
2010	13 602 617
2011	13 327 285
2012	13 091 134
2013	12 965 721
2014	13 234 598
2015	13 509 410
2016	13 432 410
2017	13 031 359
2018	12 728 559
2019	12 556 037
2020	11 977 992
2021	11 963 276
2022	11 666 413

The second term of the Equation 10.34 of the 2006 IPCC Guidelines is the N input from bedding materials. Straw N amounts depend on livestock population and the housing systems. The 2006 IPCC Guidelines provide default values on the nitrogen contained in organic bedding materials for Cattle and Swine, which were used in our calculation. For other livestock categories default values taken from the Table 3.7 of the EMEP/EEA Guidebook (EEA, 2023) were applied. Data used in the calculations to estimate N from bedding materials with their sources is provided in Table 5.5.3.

Table 5.5.3 Nitrogen in bedding materials by animal category and manure management systems

Animal category	N content of bedding materials by manure management systems kg N $head^{-1}$ yr^{-1}		Source
	Solid	Deep Litter	
Dairy Cattle	7.000	13.000	p.10.66 of IPCC (2006).
Non-Dairy Cattle	4.000	8.000	p.10.66 of IPCC(2006).
Buffalo	6.000	-	EMEP/EEA Guidebook (EEA, 2023)
Sheep	0.080	-	EMEP/EEA Guidebook (EEA, 2023)
Goats	0.080	-	EMEP/EEA Guidebook (EEA, 2023)
Horses	2.000	-	EMEP/EEA Guidebook (EEA, 2023)
Mules	2.000	-	EMEP/EEA Guidebook (EEA, 2023)
Swine	0.800	1.600	p.10.66 of IPCC (2006)
Poultry	0.022*	-	Expert judgments

**Poultry manure with bedding*

The time series of the resulted N inputs from bedding are shown in Table 5.5.5.

Sewage N (F_{SEW})

Data on annual amount of total sewage N that is applied to agricultural soils is available in the Urban Wastewater Information System (UWIS) since 2011. For the period 1994-2010 data were taken from the EUROSTAT statistics. The EUROSTAT provides data on sewage sludge disposal for agricultural use, but this statistic contains the sewage sludge disposal for recultivation as well as agricultural purposes. 40% of the reported disposed sewage sludge based on expert judgment was assumed to be applied on agricultural lands and the remaining 60% for recultivation. Activity data was extrapolated for the period 1988-1994. For the years 1988 backwards application of sewage was assumed to be 'not occurring', because of the low proportion of wastewater treatment in Hungary. The N content of sewage sludge was assumed to be 4.2% in the calculation. Following a recommendation from the centralized review 2019, country-specific value on the N content of the sewage sludge based on the measured data provided by the NFCSO were used in the estimate. Data on applied organic fertilizers (F_{ON}) was determined in coordination with the Waste sector.

Other organic waste including compost N (F_{COMP})

In this category, composted sewage sludge, composted municipal solid waste (MSW) and digestate from anaerobic digesters are reported.

Composted sewage sludge

For the calculation of emissions from the application of sewage sludge compost, the amount of composted sewage sludge reported as activity data in the NFR sector 5B1 is used. The Wastewater Sludge Processing and Use Strategy 2014-2023 (General Directorate of Water Management, 2013) shows that 38% of composted sewage sludge is used in agriculture. The N content of the sewage sludge compost was assumed to be 2% based on the Table 4.1 of the Vol. 5. Ch. 4 of the 2006 IPCC Guidelines.

Composted MSW

Activity data was taken from the NFR sector 5B1. The IPCC default parameters on moisture content and N in dry matter given in Table 4.1 of the Vol. 5. Ch. 4 of the 2006 IPCC Gls was used. According to the NHKV (National Coordination of Waste Management and Asset Management Plc.) reports for the last years, loss during composting approximately 25% and 50% of the sewage sludge compost generated is used for agricultural purposes (NHKV, 2020).

Digestate (other than animal manure and crop residues)

The N content of the biogas compost applied is calculated on the basis of the N content of feedstock. As biogas feedstock statistics are only available from 2017 onwards, the N consumption per TJ energy production was determined for the previous years' using the feedstock consumption in the period 2017-2020. N per TJ are estimated to 4.2 tones N per TJ based on average of N in feedstock and energy production in 2017-2020.

The resulted activity data for the period 1985-2022 are provided in Table 5.5.4

Table 5.5.4 Nitrogen applied to soils as organic waste including compost BY and 1990-2022

Year	Composted sewage sludge N	Composted MSW N	Digestate (other than animal manure and crop residues) N	Total N applied
	kg N			
BY	152 000	-	-	152 000
1990	152 000	-	-	152 000
1991	152 000	-	-	152 000
1992	152 000	-	-	152 000
1993	152 000	-	-	152 000
1994	152 000	-	-	152 000
1995	212 800	-	-	212 800
1996	220 400	54 000	-	274 400
1997	197 600	57 000	-	254 600
1998	174 800	54 000	-	228 800
1999	243 200	54 000	-	297 200
2000	228 000	51 000	-	279 000
2001	205 200	51 000	-	256 200
2002	281 200	141 000	-	422 200
2003	425 600	141 000	-	566 600
2004	182 058	116 199	224 417	522 673
2005	399 932	124 182	213 930	738 044
2006	326 414	177 321	270 558	774 293
2007	388 672	184 608	524 338	1 097 618
2008	469 573	246 075	1 027 702	1 743 350
2009	683 795	262 797	1 539 456	2 486 047
2010	624 935	396 942	1 883 421	2 905 298
2011	618 408	403 674	2 802 061	3 824 143
2012	685 342	463 623	2 317 573	3 466 537
2013	708 761	487 764	4 282 791	5 479 315
2014	739 125	596 301	4 228 259	5 563 686
2015	754 845	629 079	4 098 224	5 482 148
2016	773 726	656 496	4 121 295	5 551 516
2017	779 684	803 250	5 042 916	6 625 850
2018	749 154	863 802	4 578 435	6 191 391
2019	695 815	1 001 709	4 137 591	5 835 116
2020	704 836	1 077 990	4 269 339	6 052 165
2021	705 265	1 102 413	4 200 580	6 008 258
2022	669 963	1 072 677	4 184 307	5 926 947

5.5.2.1.3 Urine and dung from grazing animals (F_{PRP})

The term F_{PRP} is estimated using Equation 11.5. For the required values of the equation see Chapter 5.3. Annual amount of urine and dung nitrogen deposited by grazing animals on pasture, range and paddock (F_{PRP}) for the period 1985-2020 are provided in Table 5.5.7.

5.5.2.1.4 Crop residue N including forage/ pasture renewal (F_{CR})

Nitrogen input from crop residues was estimated in accordance with the Tier 1 methodology, Equation 11.7A of the 2006 IPCC Guidelines. Activity data on crop yields and annual area of harvested cops were taken from the HCSO. To estimate the N added to soils from crop residues and forage/pasture renewal mainly default parameters from the Table 11.2 of the 2006 IPCC Guidelines were used. Since yield statistics are reported as field-dry weight a correction factor was applied to estimate dry matter yields in accordance with Equation 11.7 of 2006 IPCC Guidelines. In the case of wheat parameters provided for grains were used, because the default values given for wheat in the 2006 IPCC Guidelines are inappropriate for Hungarian wheat species. For rapeseed and sunflower seed, for which default values are unavailable in the 2006 IPCC Guidelines, country-specific values of ratio of above-ground residues, dry matter to harvested yield crop and N content of above-ground residues for crop were used, while N contents of below-ground biomass for these crops were calculated using default values provided for 'beans and pulses' in the 2006 IPCC Guidelines. Dry matter contents of forage crops as lucerne-hay, red clover-hay, silo maize and grass hay were sourced from the Hungarian Nutrition Codex (2004). Input factors used to estimate the N added to soils from crop residues are provided in Table 5.5.6.

The 2006 IPCC method accounts for the effect of residue burning or other removal of residues. Annual areas of burning for cereals (Area $burnt_{(T)}$) were estimated based on expert judgement. It was taken into account for the years before 1990, because burning of crop residues has been banned since 1986 in Hungary. A decreasing proportion of illegal field burning for cereals was assumed for the period between 1986 and 1990. Since this submission emissions from rice field burning due to plant protection reasons have already been reported, for the estimation of area of burnt rice fields see in Chapter 5.7.

Equation 11.7 requires fractions of total area of crops that is renewed annually. For annual crops $Frac_{Renew}$=1 was assumed, while for Lucerne hay (Alfalfa) and Red clover hay 25%, as the area of these forage crops are renewed on average every four years. In addition, $Frac_{Renew}$=0.2 was assumed for the forage/pasture renewal, assuming five-year renewal frequency based on expert judgement (Monori, 2015).

In the fraction of above-ground residues of crops removed annually ($Frac_{Remove}$), straw used as bedding materials was taken into account. Proportion of straw used as bedding materials were subtracted here, to avoid double counting, as this N is taken into account in the term of F_{AM}. This fraction was calculated consistently with the 3.B Manure management and the 3.D.a.2 Annual amount of animal manure N applied to soils (F_{AM}). In response to a recommendation from the 2017 UNFCCC review, this section has been supplemented with the following information on the derivation of the value $Frac_{Remove}$.

According to the 2006 IPCC Guidelines, survey of experts in country is required to obtain data on $Frac_{Remove}$. If data for $Frac_{Remove}$ are not available, assume no removal. While, in accordance with the p. 10.64 of the IPCC Guidelines where organic forms of bedding material (straw, sawdust, chippings, etc.) are used, the additional nitrogen from the bedding material should also be considered as part of the managed manure N applied to soils. However, the 2006 IPCC Guidelines referring to the EEA, 2002 states, that the volatilization losses from bedding is zero. It should be noted that the most up-to-date version of the EMEP/EEA Guidebook (EEA, 2023) does consider the bedding material as a source of ammonia. Consequently, the use of Tier 2 for the volatilization losses entails the detailed characterization of the flow of nitrogen through the manure management. In housing systems with bedding the bedding material is generally straw and the bedding material should be considered as a part of the nitrogen budget.

As Hungary uses a N-flow approach to calculate the emissions from 3.B and 3.D, which is in line with the IPCC Guidelines, the N_2O emissions from straw used for bedding is reported in CRF 3.D.a.2 Animal manure applied to soils, and this amount of N was taken into account in the value of $Frac_{Remove}$. The value of $Frac_{Remove}$ was calculated for all year from the N content of straw used for bedding divided by the sum of the N content of the above-ground biomass of grain crops of which straw is used for bedding (wheat, barley, rye and oats). For other crops the value of $Frac_{Remove}$ was zero.

Table 5.5.5 Nitrogen in bedding materials and $Frac_{Remove}$ for the BY and 1990-2022

Year	N input from bedding materials kg	N content of above-ground biomass of grain crops used as bedding material kg	$Frac_{Remove}$ (for Wheat, Barley, Rye and Oat)
BY	18 570 123	45 816 497	41%
1990	16 288 098	54 154 798	30%
1991	14 942 494	53 999 172	28%
1992	12 581 264	38 806 951	32%
1993	10 876 230	32 929 235	33%
1994	9 783 694	48 318 199	20%
1995	9 689 709	44 110 126	22%
1996	9 784 246	37 435 227	26%
1997	9 433 348	48 700 129	19%
1998	9 366 668	45 877 198	20%
1999	9 541 831	28 788 874	33%
2000	9 400 809	34 985 052	27%
2001	8 875 423	47 729 049	19%
2002	8 872 012	38 049 930	23%
2003	8 740 600	30 688 130	28%
2004	8 192 855	53 247 162	15%
2005	7 747 942	45 797 614	17%
2006	7 497 937	40 484 154	19%
2007	7 513 448	38 025 633	20%
2008	7 282 140	50 820 104	14%
2009	7 040 604	40 763 617	17%
2010	7 083 717	35 366 925	20%
2011	7 031 319	37 476 309	19%
2012	7 084 451	37 608 560	19%
2013	7 150 026	44 180 338	16%
2014	7 341 011	46 829 467	16%
2015	7 485 618	47 625 106	16%
2016	7 563 557	50 157 836	15%
2017	7 385 178	46 362 040	16%
2018	7 354 679	44 676 710	16%
2019	7 287 976	46 831 375	16%
2020	7 117 545	45 684 704	16%
2021	7 113 771	47 860 493	15%
2022	7 008 247	42 018 399	17%

There is not comprehensive survey on the amount of crop residues burned as fuel in Hungary. Thus, no removal for burning of fuel was assumed. Amount of N in crop residues, including N-fixing crops, and from forage/ pasture renewal, returned to soils are shown in Table 5.5.7.

Table 5.5.6 Parameters used to estimate emissions from crop residues

Crops	Dry matter fraction of harvested product (DRY)	Slope	Intercept	N content of above-ground residues (N_{AG})	Ratio of below-ground residues to above-ground biomass (R_{BG-BIO})	N content of below-ground residues (N_{BG})
Wheat[1]	*0.880*	*1.09*	*0.88*	*0.0060*	*0.22*	*0.009*
Maize (corn)	0.870	1.03	0.61	0.0060	0.22	0.007
Rice	0.890	0.95	2.46	0.0070	0.16	0.009
Barley	0.890	0.98	0.59	0.0070	0.22	0.014
Rye	0.880	1.09	0.88	0.0050	0.22	0.011
Oats	0.890	0.91	0.89	0.0070	0.25	0.008
Bean	0.900	0.36	0.68	0.0100	0.19	0.010
Peas	0.910	1.13	0.85	0.0080	0.19	0.008
Soya-bean	0.910	0.93	1.35	0.0080	0.19	0.008
Green peas	0.910	1.13	0.85	0.0080	0.19	0.008
Potatoes	0.220	0.10	1.06	0.0190	0.20	0.014
Sugar beat	0.220	0.10	1.06	0.0190	0.20	0.014
Sunflower[2]	*0.800*	*NA*	*NA*	0.0057	0.19	0.008
Rape[2]	*0.700*	*NA*	*NA*	0.0033	0.19	0.008
Lucerne-hay[3]	*0.864*	0.29	0.00	0.027	0.40	0.019
Red Clover-hay[3]	*0.855*	0.29	0.00	0.027	0.40	0.019
Maize (silo)[3]	*0.317*	1.03	0.61	0.006	0.22	0.007
Meadows[3]	*0.874*	0.18	0.00	0.015	0.54	0.012

[1]2006 IPCC default for 'grains' was applied, as data for wheat are inappropriate for Hungarian species.
[2]Dry matter content and R_{AG} are country-specific based on Zsembeli *et al.* (2011). $R_{AGsunflower}$=3.0, R_{AGrape}=2.0.
[3]Values of DRY are country-specific, sourced from Hungarian Nutrition Codex (2004).

5.5.2.1.5 N mineralization associated with loss of SOM (F_{SOM})

F_{SOM} refers to the amount of N mineralized from loss in soil organic C in mineral soils through land-use change or management practices. To estimate the N mineralized as consequence of this loss of soil carbon the Equation 11.8 of 2006 IPCC Guidelines was applied. The activity data was the carbon loss from management changes under 4.B.1 cropland remaining cropland/ mineral soils.

CRF category 4.B.1 covers conversions of set-aside croplands and non-set-aside-croplands to each other in Hungary. Among these conversions non-set-aside croplands conversions to non-set-aside croplands and set-aside croplands conversions to non-set-aside croplands leads to carbon losses. These carbon losses calculated in the LULUCF sector based on the detailed land-use matrices were used as activity data to calculate the N-losses due to mineralization. (See also Section 6.6.2). According to the 2006 IPCC Guidelines, usage of disaggregated land-use categories of 4.B.1 cropland remaining cropland, in the calculation meets the requirement of Tier 2 methodology.

The default C:N ratio of the soil organic matter of 10 was used. The resulted annual values for F_{SOM} are provided in Table 5.5.7.

Table 5.5.7 Amount of N inputs to soils BY and 1990-2022

Year	Synthetic Fertilizers (F_{SN})	Organic N applied as fertilizer (F_{ON})			Urine and dung inputs to grazed soils (F_{PRP})	Crop Residues (F_{CR})	N mineralization associated with loss of SOM (F_{SOM})
		Animal manure (F_{AM})	Sewage (F_{SW})	Compost (F_{COMP})			
	1000t N						
BY	589	206	NO	NO	36	159	0.31
1990	358	189	0.2	0.2	30	152	0.33
1991	140	176	0.2	0.2	30	184	0.33
1992	148	151	0.3	0.2	27	126	0.33
1993	161	132	0.3	0.2	22	108	0.33
1994	222	119	0.4	0.2	18	143	0.33
1995	191	118	0.6	0.2	17	140	0.33
1996	203	115	0.5	0.3	16	140	0.33
1997	206	110	0.4	0.3	16	159	0.33
1998	248	113	0.5	0.2	16	151	0.33
1999	262	114	0.4	0.3	17	135	0.33
2000	258	115	0.5	0.3	18	115	0.33
2001	275	113	0.4	0.3	18	165	0.33
2002	303	115	0.5	0.4	17	136	0.33
2003	289	115	0.5	0.6	17	111	0.33
2004	293	112	0.6	0.5	18	191	0.33
2005	260	106	0.9	0.7	19	182	0.02
2006	289	104	0.9	0.8	18	168	NO
2007	320	104	0.8	1.1	17	126	NO
2008	294	101	1.0	1.7	17	196	NO
2009	275	96	1.1	2.4	16	162	NO
2010	281	96	1.0	2.8	16	142	NO
2011	302	95	0.9	3.7	16	163	0.25
2012	313	98	0.8	3.4	16	135	0.64
2013	343	99	0.6	5.4	16	166	0.66
2014	341	102	0.6	5.4	17	195	0.72
2015	378	104	0.6	5.4	17	173	0.72
2016	404	102	0.7	5.4	17	204	0.72
2017	424	99	0.7	6.4	18	184	0.72
2018	424	99	0.7	6.0	18	187	0.78
2019	416	98	0.7	5.7	19	191	0.93
2020	445	97	0.7	6.0	19	189	0.93
2021	456	97	0.6	5.9	19	176	1.02
2022	326	96	0.8	5.8	16	124	1.22

5.5.2.1.6 Area of drained/managed organic soils (F_{OS})

Cultivation of Histosols is not occurring in Hungary, therefore notation key 'NO' is reported for the N_2O emission in CRF Table 3.D. Following the recommendation in the 2013 annual review, and the 2016 in-country review, the NIR has been supplemented with the following justification.

In the Hungarian soil classification system Peat soils and Ameliorated peat soils could be identified as WRB Histosols. It should be noted that one of the features of the Hungarian genetic soil classification system is that the name of certain types of soils hints at the condition of the soil formation and not necessarily at their current characteristics. Thus, the translation of this name into English can cause some misunderstanding. I. e. words like 'swampy', or 'peat' in the name of the Hungarian genetic soil types does not definitely mean that the soil falls in the group of Histosols.

Total areas of Peat and Ameliorated peat soils are 41 612 and 90 685 ha based on AGROTOPO, the Hungarian agro-topographical map at scale of 1: 100 000. The delineated areas of Peat and Ameliorated Peat soils are shown on Figure 5.5.2.

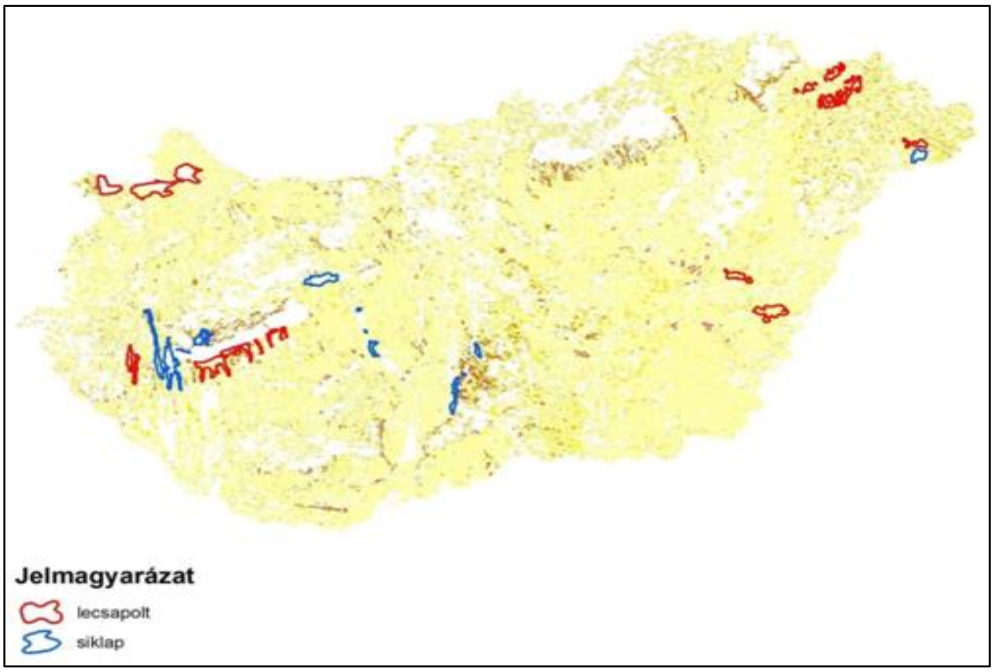

Figure 5.5.2 Peat soils and Ameliorated peat soils in Hungary

Source: Research Institute for Soil Science and Agricultural Chemistry (Hungary)

Note: 'lecsapolt' = Ameliorated peat soils, 'síkláp'=Peat soils

Peat soils form and can be restored under wetland conditions, which are 'exe lege' protected in Hungary in accordance with the Article 23 Paragraph (2) of the Act No LIII of 1996. (This law is in force currently, but Wetlands was protected decades ago.) Hungary also signed the Ramsar convention in 1971, thus the protection of wetlands is also encouraged based on this convention. As a consequence, areas of wetland soils are mainly national parks and landscape protection areas. **In summary, cultivation of organic soils/ Histosols is prohibited by law in Hungary.**

Before the 1950s attempts were made on the utilization of peat lands by draining them. The results of this activity are the Ameliorated peat soils. After draining, the organic carbon content of these soils declined resulting from the oxidization of organic matters during more than 60 years of continuous cultivation. Consequently, as it is proved by measurements, these cultivated Ameliorated peat soils have an average humus content of 6%, which do not meet the definition of 'Histosols' or 'organic soils' used in the IPCC Guidelines.

The FAO database on GHG emissions indicates 229.2 kha cultivated organic soil for Hungary based on the Harmonized World Soil Map and the Global Land Cover 2000 dataset, but this area exceeds the total area of Peat soils and Ameliorated peat soils in Hungary (i.e., 132.3 kha altogether) delineated based on higher resolution national soil map regardless of land cover and land use. This significant overestimation indicates the high uncertainty in the estimated area from the harmonized international databases. Areas of cultivated organic soils based on FAO GHG emission database are shown on Figure 5.5.3.

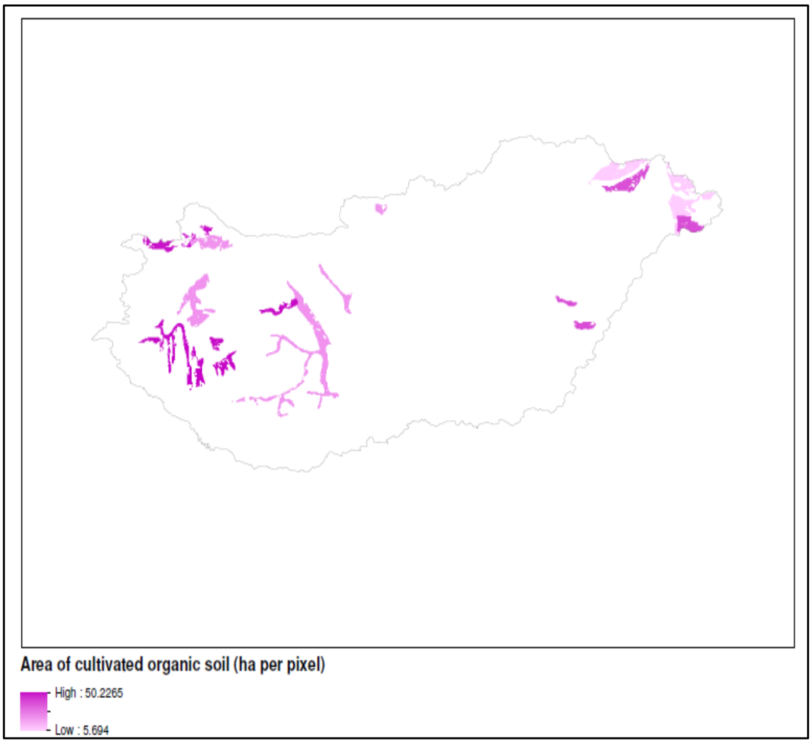

Figure 5.5.3 Cultivated Histosols in Hungary based on FAO GHG emission database

Source: FAO

The data of the Hungarian Soil Protection and Monitoring System (hereafter referred to as TIM) prove this fact, namely there are no cultivated organic soils in Hungary. Arising from the definition of Histosols in the 2006 IPCC Guidelines, the organic carbon contents of agricultural soils were analyzed to distinguish between Histosols (organic soils) and mineral soils.

The organic matter content of agricultural soils was derived from the measurements of the TIM. A summary about the TIM is also available in English, in Várallyay (2005). The measured humus content data for ***1014 sample points*** was received from the Plant, Soil and Agri-environmental Directorate of the National Food Chain Safety Office. The humus content data based on laboratory measurements are available for the year 1998 and 2000. According to the data of the TIM, the humus content of the soil does not reach 20%, the lower limit of humus content in organic soils, in any of the TIM points. The Table 5.5.8 summarizes the measured humus content data for Ameliorated peat soils and Peat soils.

Table 5.5.8 Measured humus content for Ameliorated peat soils and Peat soils based on TIM

Code	EOV_X	EOV_Y	Humus content	Humus content	Average humus content	Hungarian genetic soil types	IPCC soil type
			1998	2000	1998, 2000		
			%	%	%		
I0908	489320	258154	5.69	4.97	5.33	Ameliorated peat soils	Wetland
I1614	531672	149870	6.01	6.7	6.36	Ameliorated peat soils	Wetland
I1707	590004	203609	5.36	6.04	5.70	Ameliorated peat soils	Wetland
I3008	520145	273846	5.69	4.61	5.15	Ameliorated peat soils	Wetland
I3819	512187	219795	6.77	5.3	6.04	Ameliorated peat soils	Wetland
I4019	526785	166020	5.65	5.9	5.78	Peat soils	Wetland
I4715	901096	276942	2.83	2.44	2.64	Ameliorated peat soils	Wetland
S4920	504239	148173	5.25	5.85	5.55	Peat soils	Wetland
S5008	502087	262733	5.24	5.6	5.42	Ameliorated peat soils	Wetland
S6303	675522	115685	5.11		5.11	Peat soils	Wetland
S6515	901822	285368	12.05	11	11.53	Ameliorated peat soils	Wetland

Source: Soil and Agri-environmental Directorate of the National Food Chain Safety Office (NFCSO)

In 2009, the European Commission extended the periodic Land Use/Land Cover Area Frame Survey (LUCAS) to sample and analyse the main properties of topsoil in 23 Member States of the European Union (EU). The LUCAS Topsoil Data (EC JRC, 2013) providing measured organic carbon data for 20 000 sample points in Europe for the year 2009 were also analysed and confirmed that organic soils are not cultivated in Hungary.

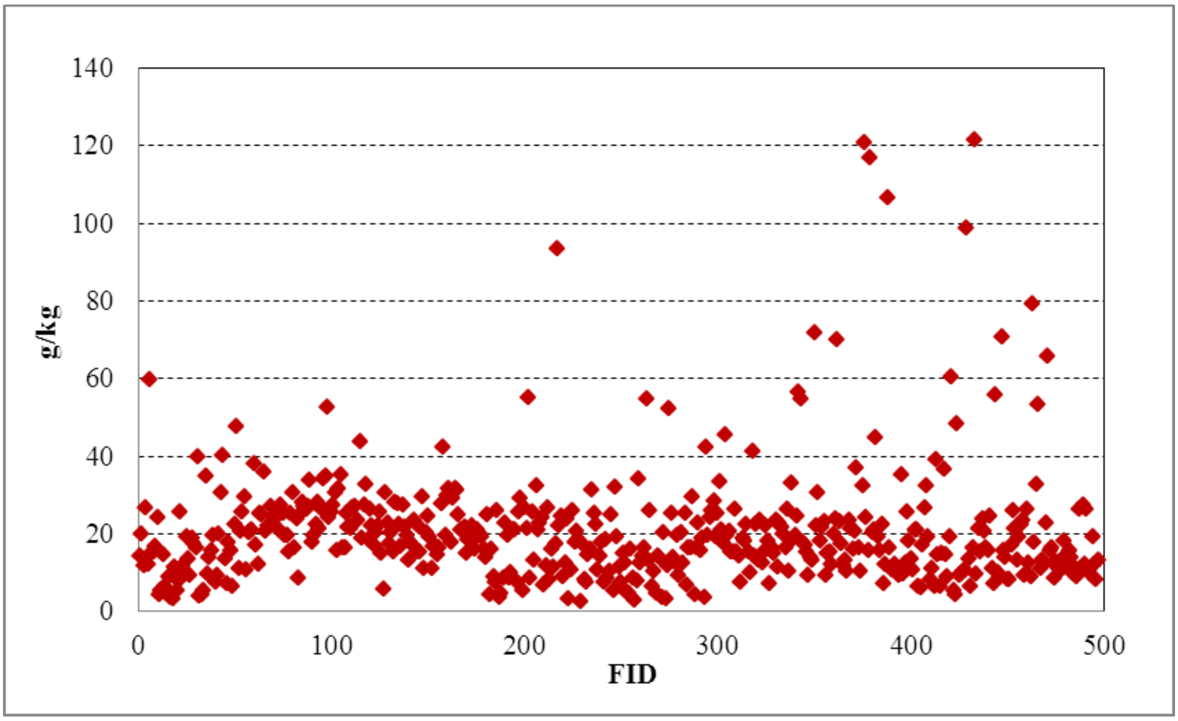

Figure 5.5.4 Organic carbon contents of soil samples in Hungary based on LUCAS Topsoil Survey, 2009

In the course of the LUCAS Topsoil Survey 497 samples were collected in Hungary, out of them 314 samples from annual croplands, 6 from permanent crops, 60 from woodlands, 4 from shrublands and 104 from grasslands. For more information on the survey and representativity issues see also Tóth G. *et al.* (2013). As the data on organic carbon content of soil samples revealed, only two samples have 12.06% and 12.15% organic carbon content which might be classified into the group of Histosols, but none of them was from cultivated cropland. (The point IDs of these samples are 49422714 and 48782686, respectively.) The resulted organic carbon contents expressed in terms of g/kg are shown on Figure 5.5.4. Photos of sample plots where the samples having about 12% organic carbon content were collected are shown in Figure 5.5.5. According to the LUCAS survey, the land cover of these plots is grassland without tree/ shrub cover (Code: E20). Therefore, cannot be disturbance leading to loss of organic matter stored in the soil.

Figure 5.5.5 Photos of sample plots where soil samples with 12% organic carbon content were collected in the course of LUCAS Topsoil Survey, 2009

As a consequence of the domestic legislation on one hand and based on data from soil surveys on the other, it can be confirmed that organic soils are not cultivated in Hungary. Soils in Hungary, which are classified as Histosols in international soil databases (e.g., FAO HWSD) are either on protected wetlands (Peat soils) or, if on managed croplands, they have lost most of their carbon content (Ameliorated peat soils) and cannot be classified as Histosols.

5.5.2.2 Indirect Emissions (CRF 3.D.b)

In addition to the direct emissions of N_2O from managed soils, emissions of N_2O also take place through two indirect pathways. The first of these pathways is the volatilization of N as NH_3 and NO_x, and the subsequent deposition of these gases and their products onto soils and water surfaces. The sources of N volatilization are not confined to agricultural fertilizers and manures, but also include fossil fuel combustion, biomass burning, and processes in the chemical industry. In the Hungarian inventory reporting of volatilization of N and the deposition of NH_3 and NO_x is confined to agricultural sources.

The second pathway of indirect emissions is the leaching and runoff from land of N from agricultural inputs.

5.5.2.2.1 Indirect N_2O emissions through atmospheric deposition of N volatized

In response to a recommendation from the in-country review conducted in 2016, this section was supplemented with information on the EMEP/EEA methodology used to derive $Frac_{GASF}$ and $Frac_{GASM}$ including the parameters and equation used.

The Hungarian national system takes advantage of parallel inventory preparation and reporting of air pollutants under the LRTAP Convention ensuring efficiency and consistency in the compilation of emission inventories, because a wide range of substances using common datasets and inputs. Hungary applies the most up to date EMEP/EEA Guidebook (EEA, 2023) to calculate the agricultural NH_3 and NO_x emissions. A detailed description of the method applied for NH_3 and NO_x is given in the report 'Hungary's Informative Report 2019 submitted under the UNECE Convention on Long-range Transboundary Air Pollution' (CLRTAP) (UNECE, 1999) and the National Emissions Ceilings Directive (EP and CEU, 2016).

The N_2O emissions from atmospheric deposition of N volatilized from managed soil was calculated based on Tier 1 methodology, following the Equation 11.9 of 2006 IPCC Guidelines. The activity data are the same as those under 3.D.a.

The method requires values for the fractions of N that are lost through volatilization ($Frac_{GASF}$, $Frac_{GASM}$) and the emission factor (EF_4). The volatilization rates for Hungary are country-specific based on the reported NH_3 and NO_x emissions.

Country-specific volatilization fraction of synthetic fertilizers ($Frac_{GASF}$) includes the NH_3-N and NO_x-N losses from fertilizers calculated by fertilizer types.

Country-specific volatilization fraction of applied organic N fertilizer materials and urine and dung N deposited by grazing animals ($Frac_{GASM}$) includes:

- NH_3-N and NO_x-N losses from livestock manure application on agricultural soils.
- NH_3-N and NO_x-N losses from dung and urine deposited by grazing livestock.
- NH_3-N and NO_x-N losses from sewage sludge applied to soils.
- NH_3-N and NO_x-N losses from compost applied to soils.

To calculate the NH_3-N losses the reported NH_3 emissions were multiplied by 14/17. In the air pollutant inventory NO_x is reported as NO_2; therefore, the NO_2 emissions were multiplied by 14/46 to get the NO_x-N losses.

NH_3-N and NO_x-N volatilization losses from mineral fertilizer application

The parallel and consistent emission inventory compilation enables the use of country-specific data, which is more accurate than the use of the IPCC default value of $Frac_{GASF}$.

NH_3 and NO_x emissions from Sector 3 Agriculture are estimated according to the EMEP/EEA Guidebook (EEA, 2023). For the calculation of NH_3-N losses from synthetic fertilizers the Tier 2 methodology was applied. This method uses specific NH_3 emission factors for different types of synthetic fertilizers depending on the soil acidity. To summarize, NH_3 emissions can be calculated by means of the following equation:

$$E_{fert\_NH3} = \sum_{i=1} \sum_{j=1} m_{fert_{i},j} \cdot EF_{i,j}$$

(Equation 5.9)

Where:

E_{fert_NH3}= NH_3 emission from fertilization (kg a^{-1} NH_3)
m_{fert_i}= mass of fertilizer type i consumed nationally (kg a^{-1} N)
$EF_{i,j}$ = EF for fertilizer type i in pH region j (kg NH_3 (kg N)$^{-1}$)

Proportion of soil with normal pH and high pH was determined based on the most up-to-date high resolution (250m) soils map (Tóth, G. *et al.*, 2015). Emission factors provided by soil pH in the EMEP/EEA Guidebook (EEA, 2023) were weighted by the resulted proportions and weighted national average emission factors, given in Table 5.5.9, were calculated for each fertilizer types.

Table 5.5.9 Country specific emission factors for ammonia emission from fertilizers

Fertilizers	IEF_i kg NH_3 kg^{-1} N
Ammonium nitrate	*0.041*
Anhydrous ammonia	*0.020*
Ammonium phosphate, NP mixtures	*0.145*
Ammonium sulphate	*0.145*
Calcium ammonium nitrate	*0.041*
Other straight N compounds	*0.145*
Nitrogen solutions	*0.131*
Urea	*0.201*
NK mixtures	*0.041*
NPK mixtures	*0.145*
Implied EF (2022)	**0.100**

Mass of fertilizer type i consumed nationally was derived from the sales statistics by product line.

Detailed data on fertilizer consumption by fertilizer types is not published in this report because of data confidentiality. However, main driver in the trend of NH_3 emissions from inorganic fertilizers is the urea consumption and the time series of urea use is published in this report.

For the calculation of NO_x emissions, the Tier 1 methodology of the EMEP/EEA Guidebook (EEA, 2023) was applied, by means of the following equation:

$$E_{pollutant} = AR_{N\_applied} \cdot EF_{pollutant}$$

(Equation 5.10)

Where:

$E_{pollutant}$ = amount of pollutant emitted (kg a^{-1})
$AR_{N\_applied}$=amount of N applied in fertilizer or organic waste (kg a^{-1})
$EF_{pollutant}$ EF of pollutant (kg kg^{-1})

Emissions were calculated as a fixed percentage of total fertilizer nitrogen applied to soil. For all types of mineral fertilizer, the default emission factor of 0.04 kg NO_2 per kg applied fertilizer-N was used (EEA, 2023).

In 2022 the value of $Frac_{GASF}$ was 0.09, which is slightly lower to the IPCC default value, reflecting the slightly below average proportion of Urea in the total fertilizer use. The proportion of Urea in Hungary in 2022 was 18%, which is slightly lower than the average of 20% as indicated in Table A1.1 of the EMEP/EEA Guidebook (EEA, 2023).

NH_3-N and NO_x-N volatilization losses from organic N fertilizers and N deposited by grazing animals

Similarly, to $Frac_{GASF}$, $Frac_{GASM}$ is also an annual implied value of N-losses referring to NH_3-N as well as NO_x-N losses from organic manure that is volatilized as NH_3 and NO_x.

NH_3-N volatilization losses from livestock manure application

For the calculation of NH_3 emissions from manure application, we partly used the EMEP/EEA Guidebook (EEA, 2023) Tier 1 and Tier 2 emission factors, on the other hand, the Tier 2 emission factors have been adjusted according to the specific NH_3 reduction technologies and their penetration, taking into account the measures for solid/liquid manure application. Information on the derivation of correction factors to account for NH_3 reduction technologies for the unabated emission factor is described in the 2024 submission of Hungary's Informative Inventory Report, 2022 (HMS, 2024). Emission factors and the level of the applied methodologies to calculate NH_3 emissions from manure application are shown in Table 5.5.10.

Table 5.5.10 Emission factors for NH_3 emissions from animal manure application

Livestock	Manure type	EF spreading kg NH_3-N (kg TAN)$^{-1}$	Applied methodology
Cattle	slurry	0.27	Tier 3
	solid	0.27	Tier 3
Fattening pigs	slurry	0.18	Tier 3
	solid	0.18	Tier 3
Sows	slurry	0.13	Tier 3
	solid	0.18	Tier 3
Sheep	solid	0.90	Tier 2
Horses, Mules and Asses	solid	0.90	Tier 1
Laying hens	solid/ slurry	0.18	Tier 3
Broilers	solid	0.15	Tier 3
Turkey	solid	0.54	Tier 1
Ducks	solid	0.54	Tier 1
Geese	solid	0.45	Tier 1

NO_X-N emissions from animal manure spreading

NO_x emissions were calculated using the default emission factors for 3.D.a.2 Animal manure applied to soils. The default emission factors were calculated on the basis that all manure is stored before surface application without rapid incorporation.

NH_3-N and NO_x-N volatilization losses from sewage sludge application

As with the application of animal manure, the emissions from the application of sewage sludge were calculated taking into account NH3 mitigation technologies. Therefore, the 'base' emission factor (0.13 kg NH3 per kg N applied) provided in the EMEP/EEA Guidebook (EEA, 2023) was adjusted according to the annual penetration of the applied NH3 abatement technologies. For more information see HMS (2021).

NO_x emissions were estimated using the default emission factor of 0.04 kg NO_2 per sewage sludge Nitrogen (EEA, 2023).

NH_3-N and NO_x-N volatilization losses from compost application

For the calculation of NH_3 emissions the default emission factor provided for other organic waste (0.08 kg NH_3 per kg N applied) was applied (EEA, 2023).

NO_x emissions were estimated using the default emission factor of 0.04 kg NO_2 per N applied (EEA, 2023).

Derivation of N losses from mineral fertilizer and applied organic N fertilizer materials including grazing from the Hungarian air pollutant emission inventory is demonstrated in Table 5.5.11 for the year 2022. The time series of the volatilization losses were calculated similarly for all years of the inventory period.

Annual NH_3-N and NO_x-N volatilization losses from synthetic fertilizers and organic N fertilizers (including grazing) for the BY and the period from 1990 to 2022 are provided in together with the resulted values of $Frac_{GASF}$ and $Frac_{GASM}$.

Table 5.5.11 Derivation of NH_3-N and NO_x-N volatilization losses from synthetic and organic N fertilizers (including grazing) for the year 2022

NFR code	Long name	NO_x (as NO_2)	NH_3	Total N volatilized kg N
3Da1	Inorganic N-fertilizers (also includes urea application)	13.02	32.66	30 861 905
3Da2a	Animal manure applied to soils	3.84	9.61	9 079 198
3Da2b	Sewage sludge applied to soils	0.03	0.04	45 848
3Da2c	Other organic fertilizers applied to soils (including compost)	0.24	0.47	462 635
3Da3	Urine and dung deposited by grazing animals	0.65	1.75	1 641 919
3Da4	Crop residues		0.02	14 900
3D	***Agricultural soils***	**17.78**	**44.56**	**42 106 405**

Table 5.5.12 NH_3-N and NO_x-N volatilization losses from synthetic and organic N fertilizers (including grazing) BY and 1990-2022

Year	N losses from mineral fertilizer	N losses from applied organic N fertilizer materials and grazing	$Frac_{GASF}$	$Frac_{GASM}$
	kg N	kg N		
BY	52 005 398	34 413 575	0.09	0.14
1990	33 102 866	31 186 683	0.09	0.14
1991	13 992 315	29 130 163	0.10	0.14
1992	12 626 166	24 843 823	0.09	0.14
1993	12 693 594	21 843 118	0.08	0.14
1994	16 066 688	19 736 843	0.07	0.14
1995	14 396 853	19 849 602	0.08	0.15
1996	14 579 264	20 017 355	0.07	0.15
1997	15 218 742	19 412 629	0.07	0.15
1998	18 415 002	20 025 644	0.07	0.15
1999	18 388 604	20 406 335	0.07	0.15
2000	19 1062 365	20 835 955	0.07	0.16
2001	20 365 312	20 333 662	0.07	0.15
2002	22 438 871	20 357 705	0.07	0.15
2003	21 989 998	20 275 462	0.08	0.15
2004	23 652 311	19 302 752	0.08	0.15
2005	20 983 565	18 192 933	0.08	0.14
2006	23 324 039	17 441 717	0.08	0.14
2007	25 582 569	16 981 560	0.08	0.14
2008	20 672 940	16 339 536	0.07	0.14
2009	18 697 039	15 378 794	0.07	0.13
2010	19 331 509	15 222 067	0.07	0.13
2011	21 155 300	14 790 648	0.07	0.13
2012	21 744 924	14 394 625	0.07	0.12
2013	25 694 003	14 127 678	0.07	0.12
2014	25 749 242	14 275 162	0.08	0.11
2015	29 460 963	14 308 635	0.08	0.11
2016	31 288 702	14 229 931	0.08	0.11
2017	34 744 774	13 744 152	0.08	0.11
2018	34 725 842	13 379 069	0.08	0.11
2019	34 537 725	13 120 017	0.08	0.11
2020	37 318 976	12 838 631	0.08	0.10
2021	37 740 408	12 307 201	0.08	0.10
2022	30 861 905	11 244 500	0.09	0.09

5.5.2.2.2 Leaching and runoff

The N_2O emissions from the N lost through leaching and runoff was calculated using the Tier 1 methodology and Equation 11.10 of 2006 IPCC Guidelines. The activity data are the same as those under 3.D.a.

In accordance with the 2006 IPCC Guidelines for humid regions and in regions where irrigation is used, the default value of $Frac_{LEACH-(H)}$, 0.3 was applied. For dryland regions, where precipitation is lower than evapotranspiration throughout most of the year, $Frac_{LECH}$ was assumed to be zero. According to the

IPCC methodology the determination of proportion of irrigated areas and humid regions are required. Thus, the Equation 11.10 of the 2006 IPCC Guidelines can be considered as the same as Equation 5.11.

$$N_2O_{(L)}N = (F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \cdot (Frac_{irr} + Frac_{wet}) \cdot Frac_{LEACH-(H)} \cdot EF_5$$

(Equation 5.11)

Where:

$N_2O_{(L)}$-N = annual amount of N_2O-N produced from leaching and run-off of N additions to managed soils in regions where leaching/runoff occurs, kg N_2O-N

F_{SN} = annual amount of synthetic fertilizer N applied to soils in regions where leaching/runoff occurs, kg N yr^{-1}

F_{ON} = annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to soils in regions where leaching/runoff occurs, kg N yr^{-1}

F_{PRP} = annual amount of urine and dung N deposited by grazing animals in regions where leaching/runoff occurs, kg N yr^{-1}

F_{CR}= amount of N in crop residues (above- and below-ground), including N-fixing crops, and from forage, pasture renewal, returned to soils annually in regions where leaching/runoff occurs, kg N yr^{-1}

F_{SOM}= annual amount of N mineralized in mineral soils associated with loss of soil C from soil organic matter as a result of changes to land use or management in regions where leaching/runoff occurs, kg N yr^{-1}

$Frac_{irr}$ = fraction of irrigated agricultural areas

$Frac_{wet}$ = fraction of humid agricultural areas

$Frac_{LEACH-(H)}$ =fraction of all N added to/mineralized in managed soils in regions where leaching/runoff occurs

EF_5 = emission factor for N_2O emissions from N leaching and runoff, kg N_2O-N (kgN leached and runoff)$^{-1}$.

Derivation of fraction of irrigated areas ($Frac_{irr}$)

Proportions of irrigated areas were derived annually from HCSO's statistics on irrigated, utilized, and total agricultural areas. The 2006 IPCC Guidelines require to distinguish the drip irrigated areas within the irrigated areas, because according to the methodology, N-leaching is assumed to be unlikely on drip irrigated areas. The HCSO publishes the total irrigated areas annually, which include the drip irrigated areas as well for the period 1989-2014. Unfortunately, the drip irrigated areas are not reported separately in this statistic. For the period before 1989 data on the total irrigated areas and within this the drip irrigated areas are available, separately. Therefore, since the 2016 submission it has been decided to account the total irrigated areas, i.e., areas of drip irrigation are not subtracted from the total irrigated areas, due to lack of reliable and consistent statistics on drip irrigation for the whole time series. As the fraction of drip irrigation was 1.5% of the total irrigated areas on average for the period 1985-1989, inclusion of drip irrigation in the emission estimation probably causes a negligible overestimation of emissions.

Because it is assumed that N is applied only on utilized agricultural areas, annual fractions of irrigated areas were calculated as a fraction of utilized agricultural areas. (Calculation of irrigated areas as fraction of the total agricultural areas could result in an underestimation of the amount of N leached and run-off.) Utilized areas were taken from the HCSO's censuses for the year 2000, 2010 and 2013. Annual areas for years between censuses data have been based on linear interpolation between data points. For the period before 1990 the total agricultural area was assumed to be utilized, as agricultural areas started to be abandoned as a result of the change of the regime in the 1990s.

In 2019 108.3 thousand hectares (2.3% of the utilized agricultural areas) were irrigated. Although, the National Water Authority indicates a total area with water right permit 190.0 ha (about 4% of total agricultural areas) for 2014, according to the HCSO's statistics 57% of the irrigable areas were irrigated in 2019. In 2020, the HCSO did not carry out a survey on irrigation, so the proportion of irrigated areas for 2020 was interpolated.

In Hungary the fraction of irrigated areas is significantly lower than the average of the EU Member States because of the limited and outdated irrigation system and the segmentation of irrigable areas. In 2010 5.8% of the Member States utilized agricultural areas were irrigated. In contrast this proportion was 2.4% for Hungary in that year according to the EUROSTAT statistics. Because of this low proportion of irrigation, the improvement of water management efficiency and irrigation systems are among the priorities of the Hungarian Rural Development Program for the period 2014-2020. Additionally, the large inter-annual fluctuations in the harvested crop productions also reflect the high dependence on weather conditions (e.g., droughts) partially due to the low proportion of irrigated areas.

The resulted fractions of irrigated areas are shown in Table 5.5.13.

Table 5.5.13 Derivation of activity data on irrigated agricultural areas, from the BY and 1990- 2022

Year	Total irrigated areas	Total agricultural areas	Utilized agricultural areas (UAA)	Irrigated areas as % of UAA
	ha	1000 ha	1000 ha	
BY	147 871	6 186	6 186	2.4%
1990	216 937	6 132	6 132	3.5%
1991	148 669	6 116	5 989	2.5%
1992	177 808	6 091	5 839	3.0%
1993	180 088	6 080	5 702	3.2%
1994	160 384	6 064	5 562	2.9%
1995	146 541	6 048	5 422	2.7%
1996	126 344	6 028	5 278	2.4%
1997	81 908	6 008	5 137	1.6%
1998	93 431	5 990	4 997	1.9%
1999	44 822	5 972	4 858	0.9%
2000	125 866	5 745	4 555	2.8%
2001	104 172	5 729	4 598	2.3%
2002	117 035	5 698	4 629	2.5%
2003	148 642	5 667	4 660	3.2%
2004	120 596	5 632	4 686	2.6%
2005	75 161	5 604	4 718	1.6%
2006	78 193	5 570	4 744	1.6%
2007	121 064	5 536	4 769	2.5%
2008	80 149	5 503	4 794	2.0%
2009	107 106	5 471	4 820	2.2%
2010	114 550	5 261	4 686	2.4%
2011	101 046	5 256	4 681	2.2%
2012	124 944	5 257	4 682	2.7%
2013	118 934	5 259	4 657	2.6%
2014	130 400	5 266	4 663	2.8%
2015	124 300	5 266	4 663	2.7%
2016	108 233	5 286	4 680	2.3%
2017	108 595	5 305	4 697	2.3%
2018	111 401	5 298	4 691	2.4%
2019	108 300	5 271	4 667	2.3%
2020	111 850	4 919	4 355	2.6%
2021	110 560	5 046	4 468	2.5%
2022	133 126	5 078	4 496	3.0%

Derivation of fraction of humid regions ($Frac_{wet}$)

Estimating the fraction of humid regions is also required to calculate the emissions from N-leaching. The proportion of humid regions was determined based on the analysis of the 30-year climate means (1991-2020) of the yearly precipitation and evaporation data from the HMS climate database. In previous submissions, the calculation of the proportion of humid regions was based on climate data from 1981 to 2010. The update of climate data necessitated the recalculation of estimates for humid regions as well. The definition of wet climate used in the latest inventory aligns with the 2019 Refinement, which requires less detailed data (no need for monthly data) than the method in IPCC 2006 Guidelines.

According to the 2019 IPCC Refinement, N-leaching could occur in areas where:

$$\sum P - \sum ET_0 > soil\ water\ holding\ capacity$$

(Equation 5.12)

Where:

P = precipitation,

ET_0 = reference evapotranspiration.

Because the soil water holding capacity is generally greater than zero, the following equation can be derived from Equation 5.12:

$$\sum P - \sum ET_0 > 0$$

(Equation 5.13)

Where:

P = precipitation,

ET_0 = reference evapotranspiration.

Evaporation is the process whereby liquid water is converted to water vapor and removed from the evaporating surface. Water evaporates from various surfaces, including water bodies, soil, and wet vegetation. In agricultural areas, the soil and plants serve as the evaporating surfaces. Thus, evaporation in agricultural areas depends on the weather conditions, soil properties, management practices, and crop types. As a consequence, potential evaporation (PE) could vary significantly within a country and cannot be adequately represented by a single value. To analyze the climatic conditions affecting leaching and run-off, the 30-year means yearly precipitation and reference evapotranspiration (ET_o) data from station data were determined by the HMS, provided at a 0.1° resolution grid over Hungary. It is important to note that the 2019 Refinement, as stated on p.11.26, also uses the potential evapotranspiration instead of potential evaporation to distinguish between dryland and humid regions.

The FAO Penman-Monteith method was employed to calculate ET_o. The definition and concept of ET_o are as follows:

'The evapotranspiration rate from a reference surface, not short of water is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ET_o. The reference surface is a hypothetical grass reference crop with specific characteristics. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. As water is abundantly available at the reference evapotranspiration surface, soil factors do not affect evapotranspiration (ET). Relating ET to a specific surface provides a reference to which ET from other surfaces can be related. It obviates the need to define a separate ET level for each crop and stage of growth. ET_o values measured or calculated at different locations or in different seasons are comparable as they refer to the ET from the same reference surface. The only factors affecting ET_o are climatic parameters. Consequently, ET_o is a climatic parameter and can be computed from weather data. ET_o expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The method has been selected because it closely approximates grass ET_o at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters.’ (FAO, ET_o calculator.)

Subsequently, areas where $\sum P-\sum ET_o>0$ were determined through GIS analysis of the gridded climate data. The resulting areas were then overlaid onto the CORINE 2018 land cover database. The use of the CORINE 2018 land cover database is also an update compared to the previous submission, which utilized the CORINE 2012 land cover database. From the CORINE 2018 land cover database, areas classified as croplands, grasslands, and agricultural mosaics (200<CLC codes<300) were considered as agricultural lands.

As a result of the GIS analysis of climate and land cover maps, the fraction of agricultural lands where N-leaching could occur due to the potential presence of precipitation surplus is 80 926 ha, which equates to 1.31% of the agricultural lands in the CORINE database (Table 5.5.14). This rate is significantly lower than the one used in the previous submission, which was 10.65%. This large difference is also confirmed by the Péczely climatic classification, which is based on average temperature during the vegetation and the aridity index. According to the Péczely classification, a large part of Hungary is categorized as warm-dry for the period 1981-2010 (Figure 5.5.*6*). However, the area of warm-dry regions significantly increased for the period 1991-2020 (Figure 5.5.7) compared to the period 1981-2010, which indicates, that the area of humid regions decreased significantly.

Table 5.5.14 Resulted areas from GIS analysis of climate and CLC, 2018 land cover databases

	Area	
	ha	**As % of the total area of the country**
Total area of humid regions	159 095	1.67%
Agricultural lands from CORINE, 2018	6 170 179	64.96%

	Area	
	ha	**As % of the total area of agricultural lands**
Total area of humid agricultural lands	**80 926**	**1.31%**

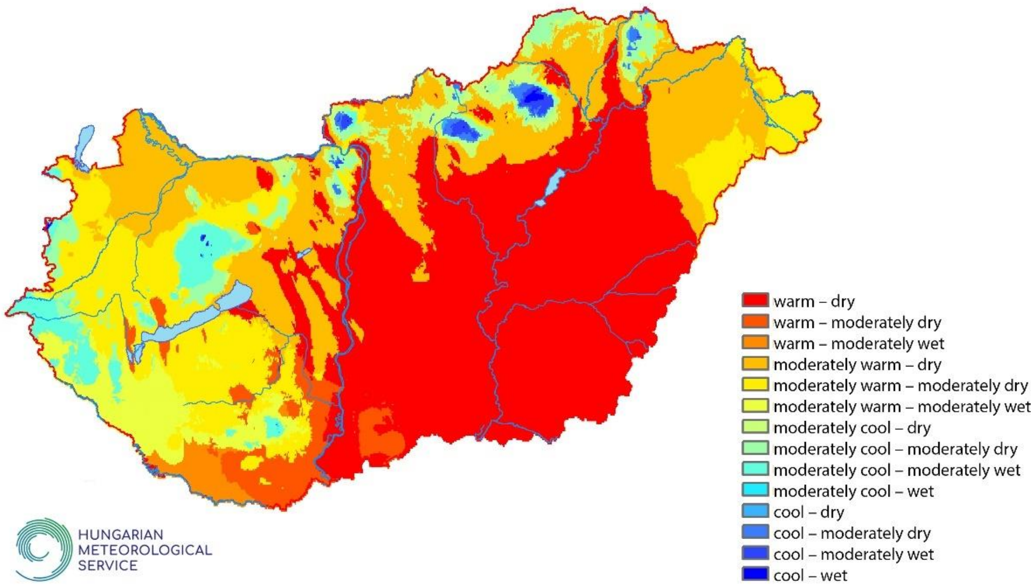

Figure 5.5.6 Climatic regions in Hungary (based on climate classification of György Péczely) for the period 1981-2010

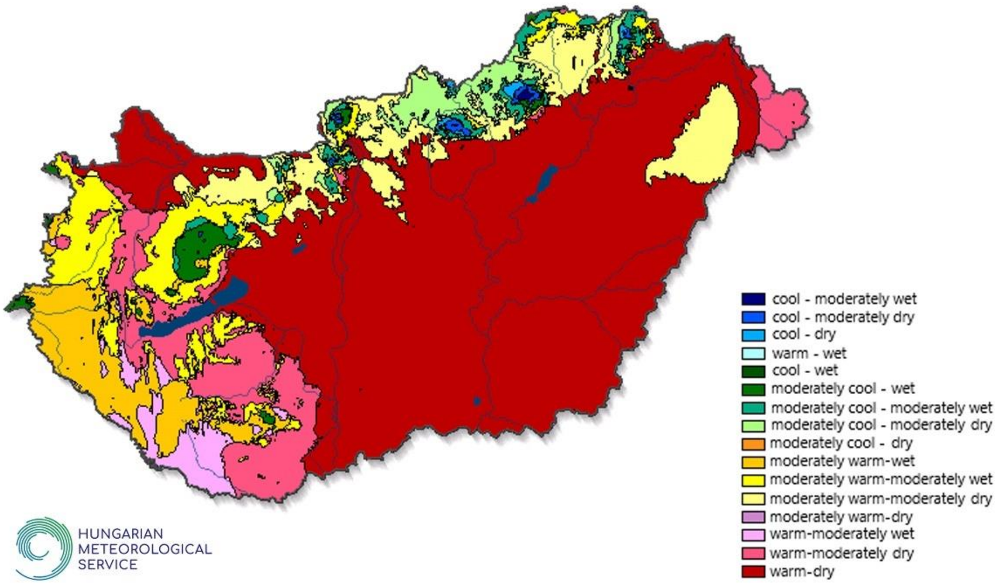

Figure 5.5.7 Climatic regions in Hungary (based on climate classification of György Péczely) for the period 1991-2020

5.5.3 Uncertainties and time-series consistency

Implementation of the methodologies provided in the 2006 IPCC Guidelines resulted in significant reduction in the uncertainties in 3.D N_2O Emissions from Agricultural Soils. Uncertainties in this category are driven by uncertainties related to the emission factors. For the default emission factor for direct emissions (EF_1), a range from -70% up to +200% is assigned by the 2006 IPCC Guidelines. This uncertainty range is significantly narrower than the former one provided in the GPG (IPCC, 2000), leading to significant reduction in the overall uncertainty in the N_2O emissions.

For the uncertainties in the activity data as F_{SN}, F_{ON}, F_{PRP}, F_{CRP}, F_{SOM} ±5%, ±37%, ±30%, ±25%, ±91% were calculated, respectively. The resulted combined uncertainty in the activity data for 3.D.a is ±9.0%, which is negligible compering with the uncertainty in the emission factor. The estimated combined uncertainties in the emissions from 3.D.a were -70%/+200%.

To estimate uncertainties in indirect emissions the same values of uncertainties were applied for activity data as in the calculation of direct emissions. These uncertainties were combined with the uncertainties in the $Frac_{GASF}$ (±50%) and $Frac_{GASM}$ (±75%). Uncertainty in $Frac_{GASF}$ was estimated based on the EMEP/EEA Guidebook (EEA, 2023). For the EF_4 the default uncertainty range provided in the 2006 IPCC Guidelines was applied. The resulting uncertainty for the indirect emission from agricultural soils ranges from -81% to +357%.

5.5.4 QA/QC Information and verification

Direct N_2O emissions

The main driver of the GHG-emissions from the agriculture sector is the N-fertilizer use in Hungary. Therefore, the verification of the amount of N-fertilizer applied is very essential in the QA/QC process in the Agriculture sector.

The amount of the N-fertilizer applied has been compared with the international statistics, namely FAO and IFA (International Fertilizer Industry Association). There is not any difference between the reported N-fertilizer used in the FAO statistics and the GHG-inventory. However, the IFA reports higher N-fertilizer use for the years before 2007. The reasons for it have already been investigated by the experts of the HCSO, the AERI and IFA's.

The fertilizer consumption data used in the GHG inventory derives from the HCSO's official statistics. HCSO gets these data from the data collection of the AERI. The AERI collects data on the sold amount of the different types of fertilizers. The IFA used an expert judgement for the estimation of fertilizer consumption data made by the Yara's (a Norwegian chemical company) experts, recently. The IFA's methodology for expert judgement is based on the sowing area of the main crops, such as cereals, maize and sunflower and so on. The estimation considered the area and the fertilizer need requirements of these crops. Unfortunately, the fertilizer consumption in Hungary is generally lower than the suggested amount, due to the high price of the fertilizer. So, this methodology of IFA resulted in an overestimation.

The HCSO's, the AERI's and the YARA's experts consulted on this issue in 2012, and consequently the IFA revised the applied methodology. So, as an outcome of this consultation the IFA's data for the years 2007 onwards are not higher than the official statistic of Hungary.

Indirect N_2O emissions due to volatilization

NH_3-N and NO_x-N losses are calculated in compliance to the obligations under UNECE/CLRTAP. To estimate the NH_3 and NO_x emissions from 3.D methodologies of EMEP/EEA Guidebook (EEA, 2023) were applied.

Indirect N_2O emissions due to leaching and run off

In response to a recommendation of the in-country review, conducted in 2016, this section was supplemented with verification information.

Verification of the applied data

Dry and humid/ irrigated regions were distinguished using the IPCC definitions, based on climate data and the HCSO's statistics on irrigated areas. Climate data was taken from the HMS's climate database. The HMS fulfil international and national quality standards concerning data collection and processing.

Statistics on irrigated areas was verified using data collection of different institutes and data on areas with irrigation license and drought affected areas.

In the frame of the National Statistical Data Collection Program (OSAP) the HCSO collects data on irrigated areas, annually. The HCSO provides another statistic on irrigated areas based on data collection of the Hungarian General Directorate of Water Management (OVF). Generally, the HCSO (OSAP) data indicates slightly higher irrigated areas compared to data from OVF data, as shown in Figure 5.5.8. The HCSO's, OSAP data was used to estimate the proportion of irrigated areas until 2013 and from 2020 onward. For the years 2014-2019, data from OVF was used data to avoid underestimation of emissions.

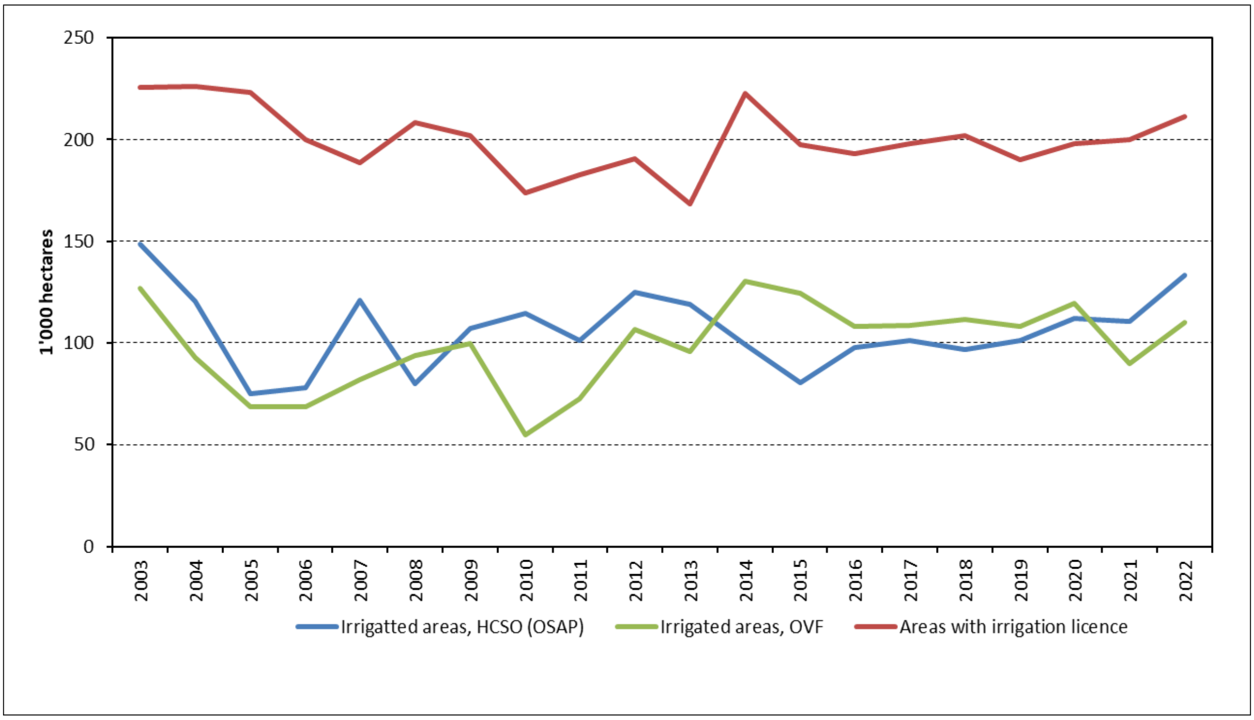

Figure 5.5.8 Irrigated areas and areas with irrigation license, 2003-2022

In Hungary the water use for agricultural purposes must be permitted; statistics on areas with irrigation license is published by the HCSO. Data on irrigated areas was compared to the areas with irrigation license to check the reliability of the applied data. Areas of irrigated lands highly depends on the weather. On average 48% of areas with irrigation license was irrigated in the period between 2003 and 2019. This proportion was the highest in 2015, when 63% of areas with irrigation license was irrigated due to the dry weather. Areas with irrigation license did not exceed the 4.8% of the utilized agricultural areas (Table 5.5.15). Therefore, indirect N_2O emissions from leaching and run off cannot be significantly underestimated due to underestimation of irrigated areas.

Table 5.5.15 Irrigated areas from different sources and areas with irrigation license in proportion to the utilized agricultural areas (2005,2010-2022)

	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Irrigated areas, HCSO (OSAP)	1.6%	2.4%	2.2%	2.7%	2.6%	2.1%	1.7%	2.1%	2.2%	2.1%	2.2%	2.6%	2.5%	3.0%
Irrigated areas, OVF	1.4%	1.2%	1.6%	2.3%	2.1%	2.8%	2.7%	2.2%	2.3%	2.4%	2.3%	2.7%	2.0%	2.5%
Areas with irrigation license	4.7%	3.7%	3.9%	4.1%	3.6%	4.8%	4.2%	4.1%	4.2%	4.3%	4.1%	4.5%	4.5%	4.7%

Verification with other countries

According to the European field experiments 2-8% or 1-16% of the applied N was lost by leaching (Füleky, 2014). Therefore, the IPCC default value of 30% for $Frac_{LEACH-H}$ is probably too high even for countries with higher annual precipitation than Hungary. Thus, accounting lower proportion of N addition than the default 30% in the light of climate data as well as the amount of N applied seems to be reasonable. In spite of this $Frac_{LECH\_H}$ was assumed to be 30% in this inventory submission due to lack of country-specific value. Although, taking into account the proportion of humid and irrigated areas the resultant fraction of all N added to/mineralized in managed soils for 2021 and 2022 is above 1%, which is in line with the results of the European field experiments.

For the general procedure of the QC see 6.1.5.

5.5.5 Source-specific recalculations

3.D.1 Direct N_2O Emissions from Managed Soils

3.D.1.1 Inorganic N Fertilizers for the period 2013-2021

The amount of N fertilizers has been revised for the period 2013-2021, resulting in an insignificant increase in the N-inputs from N fertilizers.

3.D.1.2.c Other Organic Fertilizers Applied to Soils for the period 2004-2021

The emission slightly increased for the period 2004-2021 due to the revision of N content of biogas feedstock by expert and minor data revision for year 2017 provided by the Hungarian Energy and Public Utility Regulatory Authority (MEKH).

3.D.1.4 Crop Residues for the period 2016-2021

The grass yields have been revised between 2016 and 2021 based on data from Hungarian Central Statistical Office (HCSO), resulting in a negligible change in N_2O emission from crop residues.

The overall change in 3.D.1 Direct N_2O Emissions from Managed Soils due to recalculations varied between -1.14 kt CO_2-eq and 0.71 kt CO_2-eq for the period 2004-2021. These changes are below 0.05%.

3.D.2 Indirect N_2O Emissions from Managed Soils

3.D.2.1 Atmospheric Deposition, whole time series

The 3.D.AI.1 Fraction of synthetic fertilizer N applied to soils that volatilises as NH_3 and NO_x has increased significantly due to the change of NH_3 emission factors of fertilizers, following the 2023 EMEP/EEA Guidebook.

The 3.D.AI.2 Fraction of livestock N excretion that volatilises as NH_3 and NOx slightly increased due to the changes in the 2023 EMEP/EEA Guidebook. Additionally, NH_3 emissions from crop residues have been included as a new emission category. Although the name of the indicator '3.D.AI.2 Fraction of livestock…', may be misleading, it encompasses indirect emissions from crop residues, leading to a slight increase in emissions in this category.

The correction of the NH_3 emissions from sewage sludge and other organic fertilizers in the national air pollutant emission inventory for the year 2021 resulted in only minor changes. However, the decrease in Nex of dairy cattle in 2020 has also influenced the changes.

3.D.2.2 Nitrogen Leaching and Run-off, whole time series

The update of climate data and the change in methodology have impacted the entire time series. The definition of wet climate used in the latest inventory aligns with the 2019 Refinement, requiring less detailed data (no need for monthly data) compared to the method in IPCC 2006 Guidelines. Additionally, the ratio of annual precipitation to reference evapotranspiration between 1991 and 2020 is significantly lower compared to the period 1981-2010.

The proportion of irrigated area on agricultural lands has been revised for the years 2020 and 2021 based on HCSO data. Additionally, changes in the NH_3 emissions from sewage sludge and other organic fertilizers in 2021, as well as changes in the Nex of the dairy cattle in 2020, have also contributed in a minor way to the overall change.

The overall change in emissions in the 3.D.2 Indirect N_2O Emissions from Managed Soils is quite large, ranging from -31.72 kt CO_2-eq to -11.96 kt CO_2-eq for the period 1985-2021. The percentage change varied between -14.42% and -4.00%. This remarkable change arises from the update of climate data.

5.5.6 Planned improvements

See Section 5.1.9.

5.6 Prescribed Burning of Savannas (CRF Sector 3.E)

Category 3.E Prescribed Burning of Savannas is not relevant to Hungary therefore notation keys 'NO' is used relating to all associated emissions in CRF Tables.

5.7 Field burning of agricultural residues (CRF Sector 3.F)

Emitted gases: CH_4, N_2O
Key source: none

5.7.1 Source Category Description

In Hungary, the first legislation in order to control field burning of agricultural residues entered into force in 1986. According to the regulation No. 21/1986. (VI. 2.) of the Council of Ministers a burning permit was required from the local authority for crop residue burning. This legislation had been in force until 2001, when the Government Decree No. 21/2001. (II. 14.) was issued. The new decree banned the field burning of agricultural crop residues, unless otherwise provided by law. Plant health emergency was the special exception, when burning of crop residues had been allowed. This Government Decree was amended at the end of 2010. The Government Decree No. 306/2010. (XII.23.) is currently in force, which explicitly ban the field burning of crop residues. According to this, field burning of standing crops and crop residues are prohibited unless otherwise provided by law. The only exception is if there is a plant disease on the agricultural field that can only be eliminated by field burning. In this case the plant protection authority – the county government office – in principle may issue a burn permit. In practice such permits are issued rarely. According to the information and data provided by the plant protection authority burn permits have been issued for only rice lands due to infection of Pyricularia oryzae or Helminthosporium oryzae.

In line with the legal legislation, it was assumed that field burning of crop residues has been not allowed in Hungary since 1986. According to the estimation of the regional inspectors of the Central (Budapest) Soil and Plant Protection Service, less than 1% of the area sown by crops (i.e., not the entire arable area) is affected by illegal burning (Sári 2003, verbal communication), therefore it was taken into account only between 1985 and 1989, and it was considered as negligible in the period after 1990.

However, field burning due to plant protection reason is practically negligible, to ensure the consistency with the reporting to the UNECE on CRTAP and NECD, emissions from this this source have been reported for the first time in the 2020 submission.

5.7.2 Methodological issues

Until the middle of the 1980s, field burning was quite widespread. In the lack of reliable and quantitative information, it was assumed that the rate of field burning in crop cultivation areas had been gradually decreasing between 1985 and 1989 and was essentially eliminated in 1990. Accordingly, for the mentioned period between 1985 and 1990 the following values for crops were used as the proportion of biomass burnt on field: $Frac_{BURN}$ = 0.11, 0.09, 0.07, 0.04 and 0.02 (it meant for all plants produced: $Frac_{BURN}$ = 0.05, 0.04, 0.03, 0.02 and 0.01). To the emission estimation Equation 2.27 of 2006 IPCC Guidelines was applied. As regards other parameters required for the calculation (dry matter, product/by-product ratio, C to N ratio), the default values given in Table 2.5 and Table 2.6 of 2006 IPCC Guidelines were used.

To estimate the emissions from rice field burning the plant protection authority provided data on the areas for which burn permits were issued for the period 2010-2016. Due to unavailability of data for other years the time series from the BY to 2009 was gap-filled by calculating an average proportion of the rice cropping area affected by plant diseases from the available data. The burnt areas for the years from 2017 onward were estimated using a similar approach.

IPCC default dry matter fraction and residue to crop ration was applied. Fraction burned on fields was estimated as 100% of the biomass available. Default combustion factor (C_f) from the Table 2.6 of the 2006 IPCC Guidelines was used.

In 2022, 770 ha was burnt In Hungary, which equates to 0.02% of the areas covered by crops in 2022.

Table 5.7.1 Activity data to calculate emissions from 3F field burning due to plant protection reasons BY and 1990-2022

Year	Rice field burnt ha
BY	3 985
1990	3 974
1991	2 980
1992	1 656
1993	1 656
1994	1 656
1995	1 325
1996	1 031
1997	726
1998	937
1999	748
2000	1 067
2001	775
2002	696
2003	848
2004	932
2005	882
2006	799
2007	867
2008	839
2009	898
2010	257
2011	882
2012	1 037
2013	1 089
2014	993
2015	932
2016	1 034
2017	916
2018	971
2019	877
2020	989
2021	900
2022	770

5.7.3 Uncertainties and time-series consistency

Uncertainty in activity data was assumed as 40%. Uncertainty in the EF as 50%. Uncertainty in the emissions is estimated to be ± 48.0%.

5.7.4 QA/QC Information

See 6.1.5.

5.7.5 Source-specific recalculations

There was no recalculation.

5.7.6 Planned improvements

There are no further improvements planned.

5.8 Liming (CRF Sector 3.G)

Emitted gases: CO_2
Methods: T1
Emission factors: D
Key sources: none

5.8.1 Source Category Description

Liming is a small source of CO_2 emissions in Hungary, which occur mainly from Limestone $CaCO_3$. The use of Dolomite $CaMg(CO_3)_2$ is rather low in Hungary, especially in the last decade. In Hungary the recommended methods for liming are as follows:

- Meliorative liming: chemical improvement of acidic soils, applying 5-15 tones carbonate lime per ha.
- Maintenance liming: low dose liming, improving the efficiency of meliorative liming and preventing the recurrence of soil acidity, with a dose of 1-2 tones carbonate lime per ha.
- Lime fertilization: improvement of the Ca supply of the regularly cultivated soil layer, preventing the development of soil acidity. Recommended doses: 1-2 tons per hectare.

In Hungary before the regime change meliorative liming was subsidized by the state, while maintenance liming and lime fertilization were not promoted. As a result, the maintenance liming and lime fertilization were rather rare activity in the large agricultural co-operatives and state farms. In the 1990s, after the liquidation of the large-scale agricultural companies, the regular state subsidization for soil melioration was practically removed, and the meliorative liming decreased significantly. Currently, liming with doses higher than 2 tons per hectare must be licensed with the Soil Conservation Authority (County Governmental Offices dept. of Plant Protection and Soil Conservation under the supervision of the National Food Chain Safety Office). The licenses are valid for five years (i.e., the licensed amount of carbonate lime is allowed to apply to soils within a five-year period). Licenses contain information on the amount and the type of the applied chemical amendment.

The most frequent substances used for the improvement of acidic soils in Hungary are as follows:

- Hard and soft limestone powder.
- Beet potash: the by-product of sugar production (especially at the beginning of the inventory period; currently only one sugar factory is operating in Hungary, thus the amount of beet potash used for soil melioration is low.).
- Bog or lake lime.
- Industrial waste products (e.g., lime sludge).

CRF sector 3.G is a minor source of emissions in Hungary, accounting for 0.1% and 0.01% of the national total emissions in the BY and 2022, respectively. Emissions from 3.G decreased by 97% between the BY and 2022. The bulk of this decrease occurred in the early 1990s, reflecting the dramatic drop in the agricultural production and the effect of suspension of state support for soil reclamation. After the period of change in the regime (i.e., the 1990s), agricultural production started to recover and the ownership feeling strengthened, promoting the soil conservation activities. In this period the carbonate lime usage slightly increased, leading to moderately growing emissions until peaking in 2004, when a slight decrease started again. In 2007, the economic downturn resulted in a further reduction in the applied lime and the resulted emissions, and emissions continued to decline until 2019. As Figure 5.8.1 reveals, this remarkably decreasing trend in the recent years can be explained by the significantly increasing trend in the use of 'Other carbonate containing fertilizers' (CRF category 3.H). Trends in emissions from 3.G Liming are shown in Figure 5.8.2.

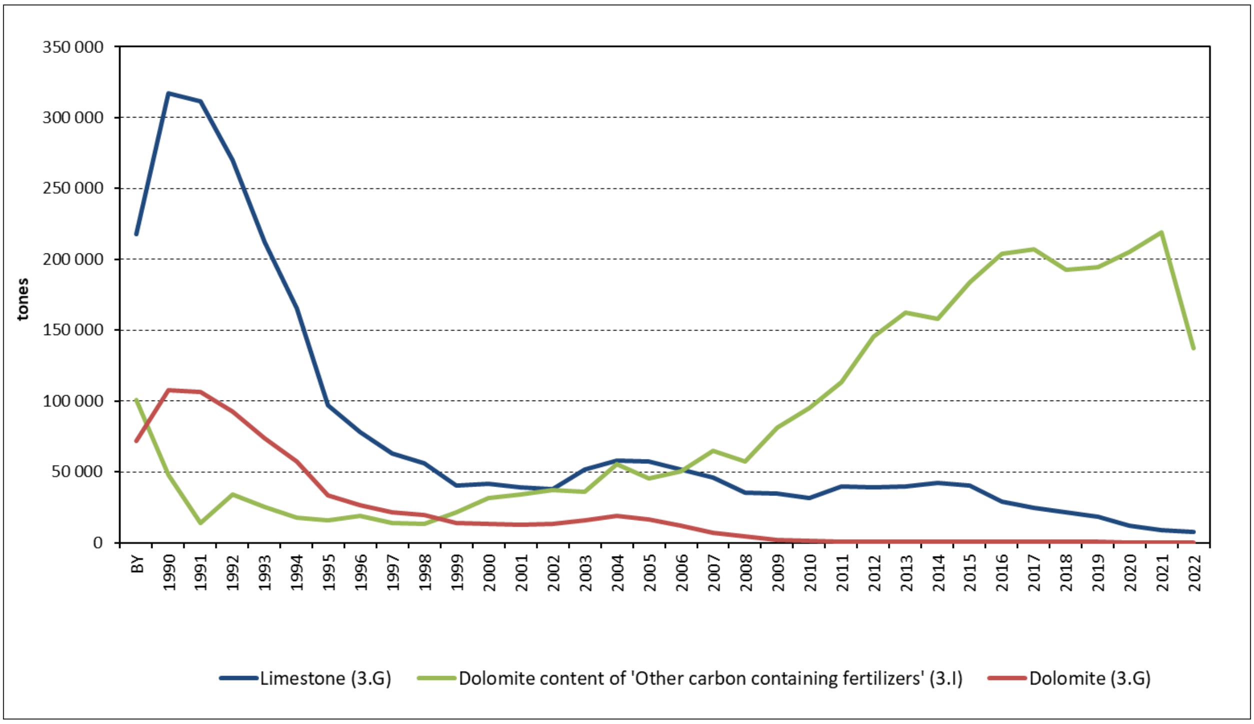

Figure 5.8.1 Trends in activity data for 3.G and 3.I BY and 1990-2022

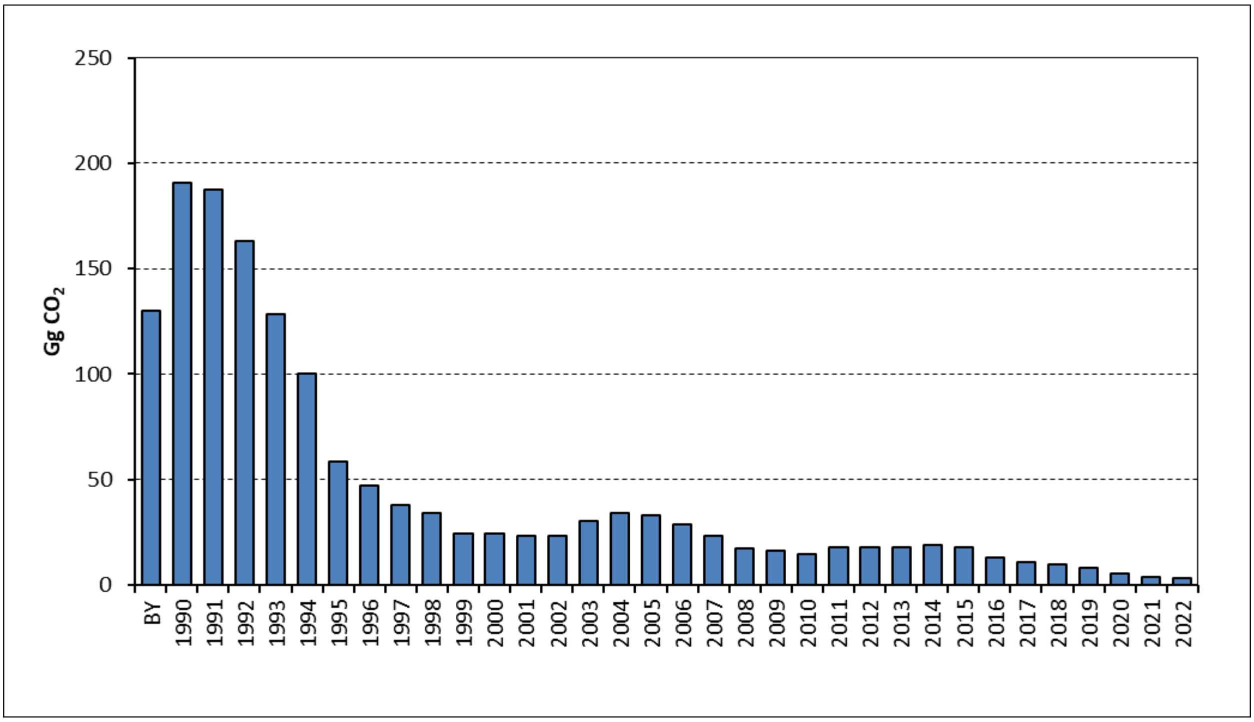

Figure 5.8.2 *Trends in CO_2 emissions from 3.G Liming BY and 1990-2022*

As a result of a recommendation arising from the in-country review conducted in 2017, this chapter was supplemented with detailed information on the activity data used and time-series consistency issues.

5.8.2 Methodological issues

5.8.2.1 Calculation method

Emissions from additions of carbonate limes were estimated using the Equation 11.12 of the 2006 IPCC Guidelines which is the Tier 1 method. Because of the relatively negligible share of liming in the national total GHG emissions the use of simple methodology is reasonable.

5.8.2.2 Activity Data

National usage statistics for carbonate lime is not available for the full timeseries in Hungary, which would be used optimally in accordance with the 2006 IPCC Guidelines, as activity data to determine the CO_2 emissions from additions of carbonate lime. Therefore, method was developed to acquire activity data from statistics providing direct inference on lime application to resolve data gap for the beginning of the inventory period.

Meliorative liming (high dose liming)

For the period 1985-2006 annual statistics on soil melioration by soil type (acidic soils, salt-effected soils, and sandy soils) was used to derive activity data to the emission estimate. For the period 1985-1999 areas of the improved soils were published annually in the statistical pocketbooks of the Hungarian Central Statistical Office. While for the years between 2000 and 2006 detailed statistics was available at the website of the AERI, including the areas as well as the amounts and the agent content of the applied chemical amendments by soil types. Nevertheless, the consistency and the representativity of the time series are ensured, as both institutions used the same data sources (regular national agricultural surveys that cover agricultural enterprises as well as private farms). Therefore, for the beginning of the inventory period experts of the Karcag Research Institute of the University of Debrecen, Centre for Agricultural and Applied Economic Sciences made expert judgment using the available statistics to provide activity data to the emission estimate. The main assumptions of the expert judgment were as follows:

- 67% of meliorated acidic sols were improved using limestone containing amendments.
- 27% of meliorated acidic soils were reclaimed by dolomite.
- 50% of meliorated salt-affected soils were reclaimed with limestone containing amendments.
- Liming was not assumed for sandy soils, as high organic matter containing amendments are added to these soils to increase their fertility, not carbonate containing materials.
- The average doses of lime and dolomite was applied (8 tones $CaCO_3$ and 7 tones $CaMg(CO_3)_2$ per hectares).

For the years between 2000 and 2006 the published usage data were taken into account, while the direct relationship between the reclaimed areas and the lime usage provided the basis for the expert judgment for the previous period (i.e., the overlap technique was used to ensure the time-series consistency). See also Section 5.8.4

Statistics used to derive annual amounts of limestone and dolomite content of liming matters for the period 1985-1999 are provided in Table 5.8.1. Data in bold show the original statistical data to distinguish from estimated amounts shown in italics in the Table 5.8.1.

Table 5.8.1 Statistics and calculated amount of limestone and dolomite use for the period 1985-2006

Year	Area				Amount of agent			Amount	
					Limestone	Dolomite	Limestone	Limestone	Dolomite
	Acidic	*Salt-affected*	*Sandy*	Total	on Acidic soils		on Salt-affected soils	Total	
	ha				tones				
1985	30 709	3 068	2 718	36 495	*164 600*	*58 040*	*12 272*	*176 872*	*58 040*
1986	34 476	3 538	1 507	39 521	*184 791*	*65 160*	*14 152*	*198 943*	*65 160*
1987	61 084	4 633	1 224	66 941	*327 410*	*115 449*	*18 532*	*345 942*	*115 449*
1988	57 867	4 753	2 095	64 715	*310 167*	*109 369*	*19 012*	*329 179*	*109 369*
1989	57 696	1 046	1 197	59 939	*309 251*	*109 045*	*4 184*	*313 435*	*109 045*
1990	73 013	2 073	3 025	78 111	*391 350*	*137 995*	*8 292*	*399 642*	*137 995*
1991	31 352	202	305	31 859	*168 047*	*59 255*	*808*	*168 855*	*59 255*
1992	25 342	569	49	25 960	*135 833*	*47 896*	*2 276*	*138 109*	*47 896*
1993	7 555	50	488	8 093	*40 495*	*14 279*	*200*	*40 695*	*14 279*
1994	13 580	1 754	0	15 334	*72 789*	*25 666*	*7 016*	*79 805*	*25 666*
1995	10 346	100	15	10 461	*55 455*	*19 554*	*400*	*55 855*	*19 554*
1996	13 873	0	0	13 873	*74 359*	*26 220*	*0*	*74 359*	*26 220*
1997	11 861	82	85	12 028	*63 575*	*22 417*	*328*	*63 903*	*22 417*
1998	1 206	5	23	1 234	*6 464*	*2 279*	*20*	*6 484*	*2 279*
1999	20	0	0	20	*107*	*38*	*0*	*107*	*38*
2000	9 894	266	1 751	11 911	56 283	14 805	231	56 514	14 805
2001	11 173	90	504	11 767	53 613	24 091	445	54 058	24 091
2002	10 097	20	383	10 500	50 715	25 645	145	50 860	25 645
2003	11 309	1 142	3 371	15 822	52 608	14 354	1 713	54 321	14 354
2004	6 443	1 318	2 171	9 932	19 864	14 737	1 954	21 818	14 737
2005	7 310	1 079	1 920	10 310	48 514	3 607	651	49 165	3 607
2006	7 279	1 077	764	9 120	15 660	2 892	1 702	17 362	2 892

No data on land reclamation are available after 2006; hence other sources had to be used to estimate the limestone and dolomite contents of the applied liming maters. In Hungary liming with higher doses of lime than 2 tons per hectare must be licensed by the Soil Conservation Authority (County Governmental offices dept. of Plant Protection and Soil conservation, National Food Chain Safety Office). Since 2007 the NFCSO has recorded the content of the issued license in an electronic database and provided data annually, on the quantity and type of the used liming maters and the affected areas for emission inventory purposes. (For the first year of the data collection the dataset was incomplete, therefore the County offices of the NFCSO collected supplementary data on the agent content of carbonate lime from the hard copies of the issued licenses. Thus, for 2007 only the agent contents of the applied liming maters are available.) Table 5.8.2 shows the quantities of liming material permitted per year based on the permits issued for liming (please note that the lime permits are for five years and the quantities permitted must be used by the farmer within five years).

Table 5.8.2 Carbonate lime usage for the period 2000-2022

Year	Liming maters							Amount	
	Beet potash	Dolomite	Lime sludge	Hard limestone powder	Calcareous moorland	Bog lime	Soft limestone powder	Total $CaCO_3$ content	Total $CaMg(CO_3)_2$
	tones								
2000	22 505	17 723	NO	48 038	NO	NO	NO	56 514	17 723
2001	36 767	30 170	NO	34 313	NO	10 721	NO	53 732	30 170
2002	55 276	32 000	NO	18 457	NO	4 812	NO	50 715	32 000
2003	62 850	18 884	NO	29 237	NO	833	NO	54 070	18 884
2004	28 552	18 998	NO	9 430	NO	162	NO	21 818	18 998
2005	34 364	5 312	285	42 905	NO	NO	NO	48 969	5 312
2006	31 303	4 228	45	2 898	NO	NO	NO	17 318	4 228
2007	NO	133	NO	*22 892*	NO	NO	NO	*20 603*	133
2008	NO	77	NO	12 870	2 239	NO	NO	12 898	77
2009	7 323	1 439	NO	16 319	2 639	NO	713	20 527	1 439
2010	1 157	491	NO	28 231	2 014	NO	450	28 362	491
2011	3 088	807	NO	45 955	2 007	NO	463	46 173	807
2012	1 452	278	NO	20 843	NO	NO	NO	20 527	278
2013	4 197	570	NO	10 321	3 693	NO	NO	13 011	570
2014	1 738	836	NO	31 391	NO	NO	NO	30 690	836
2015	NO	851	NO	21 309	NO	4	NO	20 246	851
2016	60	1 112	NO	11 176	NO	NO	NO	10 648	1 112
2017	6	192	NO	4 297	NO	NO	NO	5 032	192
2018	1 545	60	NO	2 003	NO	NO	NO	2 675	60
2019	NO	NO	NO	1 780	NO	NO	NO	21 210	NO
2020	NO	NO	NO	NO	NO	NO	NO	NO	NO
2021	NO	NO	NO	NO	NO	NO	NO	144	NO
2022	NO	NO	NO	NO	NO	NO	NO	984	NO

As mentioned, for the period 2000-2006 very detailed statistics are available on land reclamation which is consistent with the data used for the period 1985-1999 as well as the statistics for the period 2007-2016. Data for the period 2000-2006 are provided in the structure of the statistics for the period 1985-1999 as well as 2000-2017 to demonstrate the time-series consistency. Carbonate containing chemical amendments could also contain various amounts of inert materials, or other non-carbonated ingredients, which was also taking into account in the estimate. The assumed agent contents of liming maters appearing in the statistics are summarized in Table 5.8.3. The $CaCO_3$ content of liming maters were determined consistently between data from the literature and statistics for the period 2000-2006.

Table 5.8.3 $CaCO_3$ content of the applied liming maters

Liming materials	$CaCO_3$ content
Beet potash	50%
Bog lime	50%
Calcareous moorland	25%
Hard limestone powder	90%
Lime sludge	6%
Soft limestone powder	80%

Lime fertilization/ maintenance liming (low dose liming)

For the period 1985-1999 average doses of limestone and dolomite usage were assumed therefore additional liming as lime fertilization were not estimated. Besides, as mentioned, lime fertilization and maintenance liming were not typical in this period arising from the agricultural subsidization system. For the period 2000-2006 statistics on lime fertilization were available, while for the period 2007 to 2016 expert judgment was applied. The agent content of limestone applied for lime fertilization was assumed to be 53% of liming maters applied for soil reclamation.

Resulted activity data

Since meliorative and maintenance liming are periodic rather than annual activities, besides the liming licenses relates to five-year periods, activity data was calculated as five-year moving average of the statistical and the estimated usage data delineated above to smooth out inter-annual inequities.

5.8.2.3 Emission factors

IPCC default values of 0.12 for limestone, 0.13 for dolomite and 0.20 for urea were used.

5.8.3 Uncertainties and time-series consistency

Uncertainties in the activity data used to estimate emissions from 3.G, were estimated to be ±10%. Uncertainties in the emission factors were assumed to be ±20%. Thus, the estimated combined uncertainties in the emissions for 3.G is ±22%.

5.8.4 QA/QC Information

Time series consistency

In response to a recommendation from the in-country review conducted in 2016, this section has been supplemented with further information on addressing the time-series consistency issues arising from the use of different sources of activity data through the time series.

2006 IPCC Guidelines provide different splicing techniques to ensure time-series consistency. In the case of 3.G the applied methodology to form a complete time series is the overlap technique provided in the Chapter 5.3 of the 2006 IPCC Guidelines.

The areas of carbonate lime usage are available *consistently* for the full period of 1985-2006 from the same data collection. For the period 2000-2006 the areas as well as the amount of the carbonate lime usage are available, therefore the period of 2000-2006 is suitable for overlapping. To resolve data gap relationship observed between the areas and the applied amount (i.e., doses) during the period of overlap was applied. (In accordance with the 2006 IPCC Guidelines, the average of annual doses was used instead of the dose calculated from the total amount and the total areas over the period 2000-2006.)

Data on carbonate lime usage for soil *melioration* is available since 2000. However, data was sourced from different statistics. For the period 2000-2006 melioration statistics, while for the period since 2007 data acquired from liming licenses was applied. As the subject of liming licenses is liming with higher doses than 2 tons per hectare, which is the same as the definition of meliorative liming in the former statistics, consequently the data on meliorative liming are consistent for the full time series.

Data on lime fertilization for the period 2007-2016 are estimated using expert judgement based on the statistics of the previous period.

The following further source specific QA/QC procedures have been carried out:

- The missing data were elaborated by scientific experts from the Karcag Research Institute of University of Debrecen.
- Activity data is checked for plausibility.

5.8.5 Source-specific recalculations

There are no recalculations for this source category in this submission.

5.8.6 Planned improvements

Considering that agricultural CO_2 emissions are of minor importance in Hungary improvements are not planned.

5.9 Urea Application (CRF Sector 3.H)

Emitted gases: CO_2
Methods: T1
Emission factors: D
Key sources: none

5.9.1 Source Category Description

Adding urea to soils during fertilization leads to a loss of CO_2 that was fixed in the industrial production process. Reporting of CO_2 emissions from urea application is a new element of the 2006 IPCC Guidelines. This source category has been introduced because the CO_2 removal from atmosphere during urea manufacturing is estimated under the Industrial Processes and Product Use sector (IPPU).

CRF sectors 3.H is a minor sources of CO_2 emissions in Hungary, accounting for 0.3% of the national total CO_2 emissions in 2022. The overall trend in emissions from 3.H shows an overall decrease of 37.8% (Figure 5.9.1). CO_2 emissions from 3.H increased at the beginning of the inventory period until they peaked in 1988 and dropped by 82 % to 1996, reflecting the effects of the change in the regime and the suspension of agricultural subsidies. Between 1997 and 2007 emissions moderately increased, reaching a peak in 2007 due to the slightly rising fertilizer use.

The decline in the emission level and the drop in the urea use reflect the impact of the economic downturn in 2008, when the urea prices increased significantly on the world market as well as in Hungary. Besides, Péti Nitrogénművek Ltd., the only fertilizer producer in Hungary, came to a halt of the production due to the uncertain market conditions on 18th of October 2008. The production started again on 26th of February in 2009. (55% of the urea used in Hungary is produced by this company and 45% is import.) The loss of production also contributed to that the urea prices remained at a high level in Hungary in 2009 leading to further decline in urea consumption.

Fertilizer prices increased more than 60% because of the economic recession in 2008. In 2009 the fertilizer prices started to slightly decrease, but it remained at a high level in the first half of 2009, especially in spring, when the demand for fertilizers is the highest. Thus, the fertilizer consumption was significantly lower than in other years, additionally farmers favored the other fertilizers with lower N content and lower price than the urea which resulted in further decline in the urea use in 2009. Emissions have since increased.

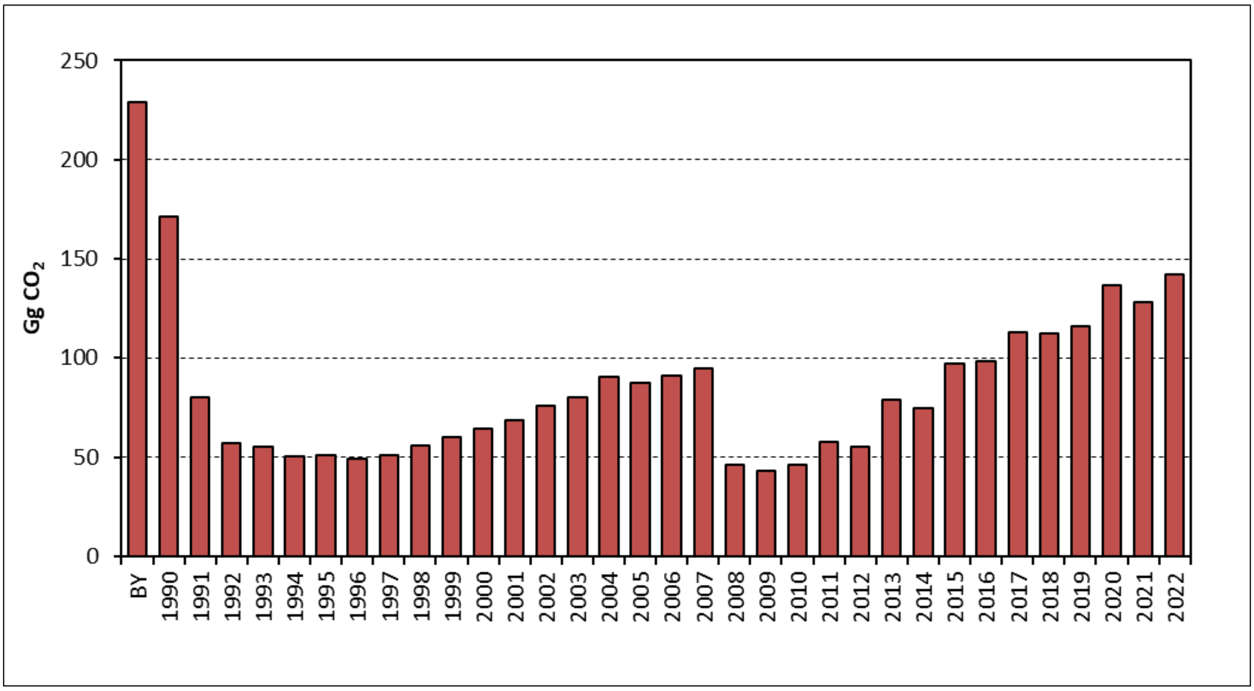

Figure 5.9.1 Trends in the CO_2 emissions from 3.H Urea use BY and 1990-2022

5.9.2 Methodological issues

5.9.2.1 Calculation method

Emissions from CO_2 emissions from urea fertilization were estimated using the Equation 11.13 of the 2006 IPCC Guidelines, which is the basic Tier 1 method. Because of the relatively negligible share of CO_2 in total agricultural GHG emissions the use of simple methodologies is reasonable.

5.9.2.2 Activity Data

Annual consumption of urea was derived from the sales statistics by products reported annually by the AERI. AERI's statistics contain the amount of Urea and other ammonium solutions (UAN) and urea ammonium sulphate (UAS) fertilizers. To calculate CO_2 emissions from urea application the annual activity data was derived as the sum of the amount of urea and the urea contents of UAN and UAS fertilizers (Table 5.9.1).

Table 5.9.1 Urea applied to soils, BY and 1990-2022

Year	3.H Solid Urea	3.H Urea in UAN and UAS
	tones	
BY	279 275	33 045
1990	223 511	9 875
1991	104 262	4 705
1992	73 913	4 301
1993	69 907	5 123
1994	61 536	7 291
1995	59 840	9 460
1996	58 906	7 958
1997	60 953	8 267
1998	64 530	11 709
1999	66 621	15 407
2000	64 955	23 191
2001	69 235	24 719
2002	76 284	27 236
2003	87 506	21 576
2004	105 415	18 289
2005	101 268	17 973
2006	102 229	21 930
2007	103 190	25 887
2008	30 114	32 394
2009	27 382	31 692
2010	35 211	27 840
2011	47 913	31 094
2012	41 874	33 850
2013	65 337	42 496
2014	52 618	48 993
2015	75 425	57 450
2016	74 761	59 665
2017	87 758	66 645
2018	74 769	78 460
2019	76 175	81 931
2020	93 040	93 058
2021	78 187	96 332
2022	129 064	65 082

5.9.2.3 Emission factors

IPCC default value of 0.20 was used.

5.9.3 Uncertainties and time-series consistency

Uncertainties in the activity data used to estimate emissions from 3.H were estimated to be ±5% for urea. Uncertainties in the emission factors were assumed to be ±20%. Thus, the estimated combined uncertainties in the emissions for 3.H were ±21%.

5.9.4 QA/QC Information

HCSO publishes the nitrogen content of synthetic fertilizers sold, which report is also based on the AERI's data collection. Consequently, data on the total annual amount of synthetic N fertilizer applied to soils (F_{SN}) under the category 3.D are consistent with data used to estimate emissions for CRF 3.H and 3.I.

Emissions from 3.H were cross-checked with the IPPU sector (CRF 2.B.1), to calculate emissions from urea manufacturing consistently.

5.9.5 Source-specific recalculations

There was no recalculation.

5.9.6 Planned improvements

Considering that agricultural CO_2 emissions are of minor importance in Hungary improvements are not planned.

5.10 Other carbonate containing fertilizers (CRF Sector 3.I)

Emitted gases: CO_2
Methods: T1
Emission factors: D
Key sources: none

5.10.1 Source Category Description

As some types of fertilizers contain liming matters to reduce the soil acidity and improve plant growth, CO_2 emissions from carbonate containing fertilizers has also been reported under the 3.I Other sector to ensure the completeness of the agricultural inventory.

Under the category *3.I Other Carbon containing fertilizers* CO_2 emissions from calcium ammonium nitrate (CAN) are reported. According to the sale statistics CAN fertilizers sold in Hungary are predominantly the so-called 'Pétisó', which is a mixture of ammonium nitrate and very fine dolomite powder (NH_4NO_3 + $CaMg(CO_3)_2$). This fertilizer is the main product of the 'Nitrogénművek Zrt.' (Information about this fertilizer is available on the website of the producer company:

https://genezispartner.hu/termekek-es-szolgaltatasok/mutragyak/nitrogen-mutragyak/genezis-petiso/

CRF sectors 3.I is a minor sources of CO_2 emissions in Hungary, accounting for 0.06% and 0.14% of the national total CO_2 emissions in the BY and 2022, respectively. However, this is the only one source-category in the Agriculture sector, from which emissions increased significantly, compared to the BY. CO_2 emissions from 3.I increased by 36% between the BY (49 Gg) and 2022 (66 Gg).

Emissions from carbonate containing fertilizers decreased sharply until 1991, reflecting the effect of suspension of state support of fertilizers. After the period of change in the regime emissions fluctuated annually, depending on the fertilizer's prices. Emissions reached the lowest level at -87% (6 Gg) in 1998. Emissions from other carbonate containing fertilizers grew steadily from 1999. The increase over the period 2008-2017 was largely, due to the increase in the production volume of Pétisó, thanks to investments at the producer company. Figure 5.10.1 shows the trend in CO_2 emissions from 3.I Other carbonate containing fertilizers for the BY and the period 1990 to 2022.

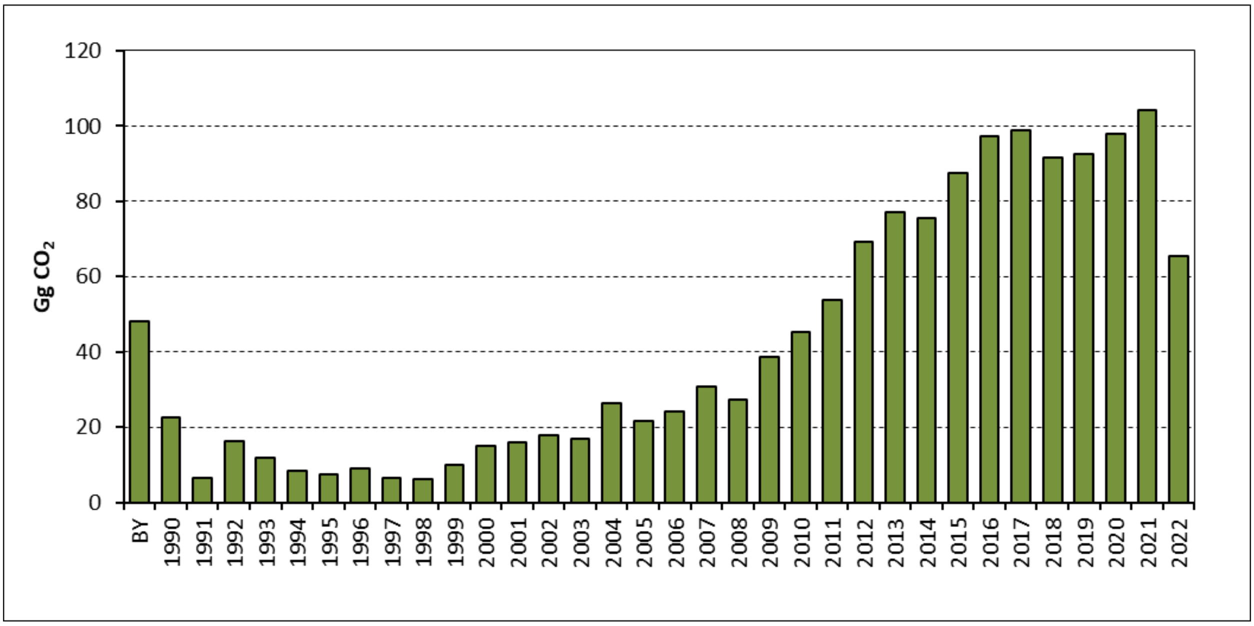

Figure 5.10.1 Trends in CO_2 emissions from 3.I Other carbonate containing fertilizers BY and 1990-2022

5.10.2 Methodological issues

5.10.2.1 Calculation method

Emissions from carbonate containing fertilizers were estimated using the Equation 11.12 of the 2006 IPCC Guidelines, because carbonate containing fertilizers contains dolomite in Hungary.

5.10.2.2 Activity Data

Annual consumption of fertilizers by fertilizer types such as carbon-containing fertilizers were derived from sales statistics by products reported annually by the Agricultural Economics Research Institute (AERI). AERI's statistics contain the amount of soled CAN fertilizers.

The activity data of the emission estimate was the average dolomite content of the soled CAN fertilizers, which was estimated as 25% of the amount of CAN fertilizers based on the chemical formula of 'Pétisó'.

Activity data used to estimate CO_2 emissions from categories 3.I are summarized in Table 5.10.1.

Table 5.10.1 Activity data for 3.I BY and 1990-2022

Year	3.I Carbon containing-fertilizers
	CAN fertilizers tones
BY	403 704
1990	190 768
1991	55 681
1992	137 037
1993	100 290
1994	71 020
1995	63 094
1996	76 704
1997	54 993
1998	52 513
1999	85 051
2000	126 920
2001	135 283
2002	149 058
2003	143 067
2004	221 375
2005	181 847
2006	202 130
2007	259 592
2008	230 307
2009	323 794
2010	379 529
2011	452 342
2012	580 401
2013	648 440
2014	632 993
2015	734 119
2016	816 018
2017	828 278
2018	769 126
2019	777 275
2020	821 327
2021	875 400
2022	549 956

5.10.2.3 Emission factors

IPCC default value of 0.13 for dolomite was used, as carbon content of calcium ammonium nitrate (CAN) fertilizers, which is reported here, is dolomite (see also the section above).

5.10.3 Uncertainties and time-series consistency

Uncertainties in the activity data used to estimate emissions from 3.I were estimated to be ±5% for carbon-containing fertilizers. Uncertainties in the emission factors were assumed to be ±20%. Thus, the estimated combined uncertainties in the emissions for 3.I are ±21%, respectively.

5.10.4 QA/QC Information

HCSO publishes the nitrogen content of synthetic fertilizers sold, which report is also based on the RIAE's data collection. Consequently, data on the total annual amount of synthetic N fertilizer applied to soils (F_{SN}) under the category 3.D are consistent with data used to estimate emissions for CRF 3.H and 3.I.

5.10.5 Source-specific recalculations

The revision of N fertilizers for the period 2013-2021 resulted in a negligible change (<0.00%) in CO_2 emissions from CAN fertilizers.

5.10.6 Planned improvements

Considering that agricultural CO_2 emissions are of minor importance in Hungary improvements are not planned.

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6 Land-Use, Land-Use Change and Forestry (CRF sector 4)

6.1 Overview of sector

The greenhouse gas inventory of the Land-use, Land-use Change and Forestry (LULUCF) sector covers both CO_2 emissions and removals due to gains and losses in the relevant carbon pools of the predefined six IPCC land-use categories and non-CO_2 emissions from biomass burning and disturbance of soils associated with land-use conversions.

Table 6.1.1. below reports all comments from the most recent Annual Review Report (ARR; unedited draft at the time of the submission of this NIR) and how they have been addressed.

Table 6.1.1. *Comments that were not considered "Resolved" by the ERT in the ARR of 2022 and how they have been addressed in this NIR.*

ID of comment in draft ARR of 2022	How the comment has been addressed in this NIR
L.2	(i) The uncertainty analysis for the forest-related categories has been completed and its results are included in section 6.11. (ii) The uncertainty analysis for the forest-related categories includes all major carbon pools, see section 6.11. (iii) The first year of the uncertainty analysis (i.e., 2005) is different from what the ARR suggests but is consistent with our treatment of the years before 1985, see section 6.11 and L.4 below.
L.4	For years before 2005, i.e., for the first year for which a complete time series of land-use change could be estimated for the default length of 20 years, net emissions are, as in the last year, reported as zero; see section 6.3.2 for details. By using this approach, we disagree with the review in 2022 (and some earlier reviews), but do agree with the option suggested by the review of 2021 that "the Party … , in the absence of reliable data, *assume* zero land-use changes for 1966–1985, which equates to zero CSC..." (italics are ours). It is clear that there may be bias in the time series of emissions until 2004 by using this approach, we are aware of that, and never stated otherwise (that is why the years before 2005 are excluded from the uncertainty estimation, see above). This bias is the direct consequence of the *assumption* that C pools were in equilibrium prior to 1985. However, as noted several times in our response to questions by ERTs earlier in various reviews: - the issue is of minor importance because, as we go on in time, what matters is the trend of the latest years, and the time series 2005-2021 already creates a good basis for trend analysis (with years backwards from this period could also be used to establish the trends, with increasing uncertainty of course); - if the above *assumption* were replaced by any other one, no better (=less biased) estimates could be produced because there is no way to know what happened before 1985 and how biased any possible assumption could be; - in fact, if trend analysis were conducted using data before 2005 for which *assumptions* are made, the trend developed could only reflect what is assumed, clearly creating circular reasoning, and thus using such assumptions as useless at best (and misleading at worst); - applying justified *assumptions* is nevertheless a legitimate approach in case there is clear lack of data or other knowledge; but we don't replace such data or knowledge with unjustified assumptions (and don't involve in trend analyses data for years before 2005 for which only assumptions are available); - there is a clear lack of country-wide domestic maps and databases for years before 1985 that could be used instead of any of the above assumptions, making it impossible to produce "better" estimates that we currently have; - there is a clear lack of national or international remote sensing products that could be used instead of the above maps etc. for the years concerned;

ID of comment in draft ARR of 2022	How the comment has been addressed in this NIR
	- it would not be "as far as practicable" to waste time and resources for an impossible task; - although we asked ERTs to suggest *scientifically sound* ways to address the task starting from the fact that no reliable, country-wide data can be estimated for the years before 1985), no ERT could so far suggest any such ways; - we strongly believe that we should concentrate on, and allocate resources to, the improvement (in cases replacement) of our current system for the years after 2004 so that we can develop more reliable data for more recent years. Because of all the above and after having considered options to generate data for the years 1966-1985 based on different assumptions, as reported to several ERTs during reviews, we strongly believe that, although not perfect at all, our time series (whose shortcomings have been clearly indicated in our NIRs) are the best "as far as practicable" that one can ever develop.
L.5	It is stated in the NIR that the CSCs of all FF are included in the net removals of the FL-FL category, and that the carbon stock of found forests is excluded from the estimation of carbon stock changes to avoid overestimating net sinks under FL-FL. See section 6.5.5.2.4. To increase transparency, we have attempted to estimate and report in this NIR carbon stock changes of FF with age of less than 21 years separately by origin and for each C pool, see section 6.5.5.2.4.
L.6	See L.5 above.
L.7	Information added to several sections, e.g., 6.5.1.1.
L.8, 10	The erroneous values in various Tables of the NIR have been corrected and match now the respective values in CRF table 4.A.
L.11	Hungary corrected the necessary AD and updated the emission and removal estimates and the NIR (see e.g. section 6.4.1).
L.12	See NIR section 6.7.2.3.
L.13	Improvements with regard to this issue have been implemented in this submission, see section 6.8.2.

6.1.1 Emission trends

We firstly note that the reported area of the non-forest land-use conversion categories, which is a key input for the estimation of emissions and removals, and which should include areas under conversion for the (default) period of 20 years, excludes areas that were converted before 1985. This is because no estimates are available before 1985 with regard to either the nature or the direction of trends of conversion areas before that year. Therefore, data for these years could only be generated using assumptions applied in simple mathematical models such as extrapolating the trend of later conversions backwards or keeping conversion rates in 1985 constant beforehand. However, there is no guarantee that any of these assumptions would yield realistic time series. The conversion rates generated by these models thus yield emission and removal estimates with very high uncertainties. Additionally, if trends after 2004 were analyzed by including emissions based on assumptions, then these trends may simply reflect those assumptions and not actual emissions. Therefore, we decided not to generate either area or emission and removal data for the years before 1985. An important consequence of this lack of data before 1985 is that we assume that carbon stock changes due to land-use changes are zero before 1985, and that the reported trend of both the areas and the calculated emissions and removals in the conversion categories before 2005 may involve artefacts. To avoid false conclusions arising from these artifacts, we only analyzed trends and report them in the below graphs beginning 2005. However, we report on the entire time series (i.e., for all years beginning 1985) of the area as well as emissions and removals of all LULUCF categories in the CRF tables.

The estimates of emissions and removals of our GHG inventory show that the LULUCF sector in Hungary has been a net sink for the last two decades. In 2022, total removals in the sector corresponded to over 10 per cent of total GHG emissions in Hungary (excluding LULUCF), with a rather high variability. This share has substantially increased since the base period because of the large drop of emissions in the non-land-use sectors. In general, Forest Land (FL) is the largest contributor to this net carbon sink, Wetlands (WL) and Settlements (SE) are net sources, whereas Grassland (GL) and Cropland (CL) are net sources in some years and net sinks in others (Figure 6.1.1). Depending on a category, the bulk of the emissions may be in either the “remaining” sub-category (e.g., Forest Land remaining Forest Land, or FL-FL) or in a land converted to another category (e.g., Land converted to Grassland, or L-GL).

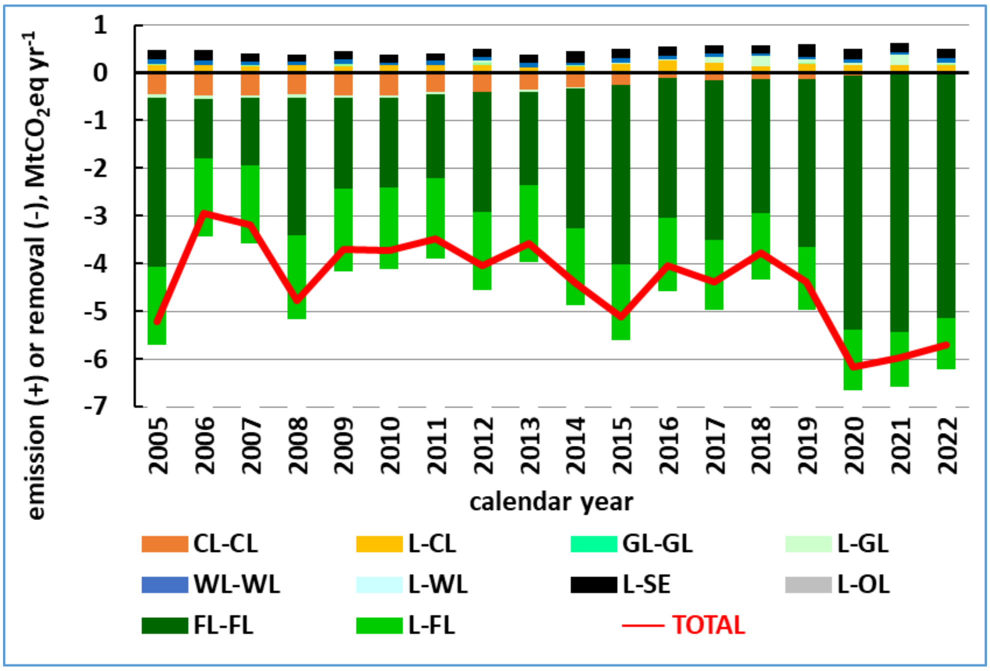

Figure 6.1.1 *Trends in estimated emissions/removals from the LULUCF sector by land-use and land-use change subcategories since 2005. (CL-CL: Cropland remaining Cropland; L-CL: Land converted to Cropland; GL-GL: Grassland remaining Grassland; L-GL: Land converted to Grassland; WL-WL: Wetland remaining Wetland; L-WL: Land converted to Wetland; L-SE: Land converted to Settlements; L-OL: Land converted to Other Land, FL-FL: Forest land remaining Forest land; L-FL: Land converted to Forest land. In other sub-categories, no emissions and removals are estimated, see text.*

Most removals are generated by biomass gains in the FL-FL and the Land converted to Forest Land (L-FL) categories. The net sink in the FL-FL category is mainly due to the fact that the forest area has been increasing, and that the total woody increment of the growing stock in forest land has been larger than the annual harvest for the last three decades (see Figures 6.5.1 and 6.5.4).

Although the reported levels of emissions and removals from the non-forest land-use categories are smaller than in the FL, soils in the Cropland and Grassland categories have added to the net sinks in the last decade or so (Figure 6.1.2) which reflects trends in land-use changes (see also section 6.3 and 6.6.4).

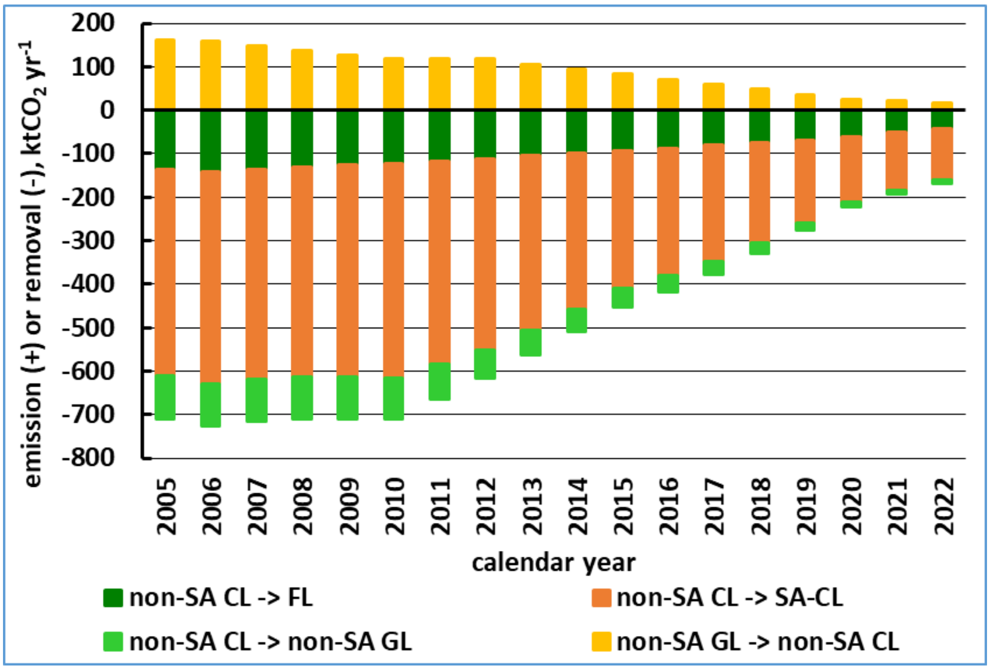

Figure 6.1.2. *Estimated emissions and removals in the most important land-use change categories due to soil carbon stock changes since 2005. (SA: set-aside.)*

6.1.2 Key categories

Key category analysis is presented in Chapter 1.6, whereas Table 1.6.1 contains the key categories of the LULUCF sector.

6.1.3 Completeness

In this submission, Hungary reports on carbon stock changes as well as greenhouse gas emissions and removals from all LULUCF sectors, i.e., Forest Land (CRF 4.A), Cropland (CRF 4.B), Grassland (CRF 4.C), Wetland (CRF 4.D) Settlements (CRF 4.E) and Other land (CRF 4.F). N_2O emissions from N in mineral soils that is mineralized/immobilized in association with loss of soil C are reported in CRF Table 3.D for CL-CL. CRF Table 4(III) reports N_2O emissions for all other land-use and land-use change categories. (Hungary does not report N_2O emissions from immobilization associated with gain of organic matter resulting from change of land-use or management of mineral soils because we apply a combination of Tier1/Tier 2 to estimate carbon stock changes in soils.) N_2O emissions from fertilization in Wetlands (CRF 4(I)) do not occur in Hungary; N_2O emissions from fertilization in other land-use categories, where relevant, are reported under the Agriculture sector (CRF 3). In addition, CO_2 emissions from liming are reported in CRF table 3G, whereas CO, CH_4, N_2O and NO_x emissions from biomass burning are reported in CRF table 4(V). Indirect N_2O emissions due to N mineralization associated with loss of soil organic matter resulting from change of land-use or management of mineral soils are also reported. (Of all the possible sources of such emissions, only those ones due to leaching/runoff occur.)

Apart from a few cases (conversions), emissions from OL (CRF 4.F) are not reported because, consistent with the national definition of this category, it contains unmanaged land for which it is only required to report area data, and because rather small areas are sometimes converted to OL, if any. CH_4 emissions from drainage of soils and Wetlands are not reported, either, because this is an optional reporting category, therefore, the notation key NA and NO were used in CRF Table 4 (II).

6.1.4 Recalculations

In this submission, we have implemented a number of recalculations. There are two main reasons for the recalculations. One is the correction of the land-use change matrix which resulted in small changes in some categories in Table 4.1. While the correct numbers were used for the emission calculations for the GHG inventory (as in previous reporting years), several incorrect area values used to be uploaded to the CRF Reporter system under categories 4.A-4.F due to technical reasons. This year, we have made efforts to correct all such errors. Another reason for the recalculations is the correction of some calculation errors, activity data or emission factor. With respect to the specific reason, method and scale of both the above and other recalculations at the category level, see the respective sections below.

6.1.5 Methodology

The description of the methodological details in the subsequent sections follows the structure of the national inventory reports as outlined in the Appendix to Annex I (Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: UNFCCC reporting guidelines on annual greenhouse gas inventories) of Decision 24/CP.19 (Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention).

In estimating emissions and removals, we have been using the 2006 IPCC Guidelines as a methodological basis since 2016.

In general, we apply Tier 2 methodology with country specific data where any such data is available. We also apply “best estimates”, i.e., we have made use of all data and information that exist within the country in relation to the GHG inventory. In all other cases, we refer to the source of the data applied (i.e., the 2006 IPCC GL for default data).

Due to the complexity of the LULUCF sector, the Hungarian national circumstances and data availability, the methodology of the estimation sometimes differs for the various land-use and land-use change categories, the various pools and emissions. Therefore, this report is completed with methodology matrices at the beginning of the section of each major land-use and land-use change sector which include information on the Tier applied, type of data (e.g., default or country-specific) for emission factors, where and how “included elsewhere”, if any, is treated, other major methodological information, or if a pool (e.g., organic soils) or non-CO_2 emissions are estimated or not. Subsequent methodological sections only provide more detailed methodological description for those pools and non-CO_2 emissions for which estimation has been done.

The estimated emissions and removals are generally only reported in the CRF tables, but they are often also shown in graphs for the major land-use and land-use change categories. In contrast, the time series of major activity data are often reported in this NIR.

6.2 Land-use definitions and classification systems

The land-use categories applied in the Hungarian inventory are consistent with the requirements of IPCC (2006), Volume 4, Chapters 2 and 3. Consistent also with the definitions of national land-use categories, the following definitions are used for the various land-use categories:

Forest land is defined, consistent with the domestic definition in the Forest Act, as land (1) under forestry land-use, (2) outside of settlements, and (3) spanning more than 0.5 hectares with trees of forest species higher than two meters and a canopy cover of more than 50 percent (or, in case of open forests, 30 percent), or trees able to reach these thresholds, and with a minimum width of 20 m measured as the distance between trees on edges, in situ. It does not include land that is predominantly under agricultural or urban land-use but, in addition to areas covered by trees, it includes areas under regeneration, roads and other areas that have no tree cover but are under forest management (see section 6.5.1 for details). Note that this definition is somewhat different from that reported earlier, however, the differences are very tiny (not affecting the time series of the total forest area) and the change is made only be consistent word-by-word with the domestic legal definition.

Cropland contains arable lands, kitchen gardens, orchards and vineyards, as well as set-aside croplands. *Arable lands* are any land area under regular cultivation irrespective of the rate or method of soil cultivation and whether the area is under crop production or not due to any reason, such as temporary inland waters or fallow. Areas under tree nurseries (including ornamental and orchard tree nurseries, vineyard nurseries, forest tree nurseries excluding those for the own requirements of forestry companies grown in the forest), permanent crops (e.g., alfalfa and strawberries), herbs and aromatic crops are included. *Kitchen gardens* are areas around residential houses where, in addition to meeting the owners' demand, owners may produce some surplus of low amount which is usually traded. *Orchards* are land under fruit trees and bushes that may include several fruit species (e.g.: apples, pears, cherries, etc.). Included are non-productive orchards and orchards of systematic layout in kitchen gardens if the area is 200 m² or above in case of berries and 400 m² or above in case of fruit trees. *Vineyards* are areas where grapes are planted in equal row width and planting space and include non-productive areas and vineyards in kitchen gardens (e.g., trellises) if grapes are planted in equal row width and planting space, and the size of the area is at least 200 m². *Set-aside cropland* is land that is temporarily unmanaged but not converted to any other land-use.

Grassland is land with predominantly or entirely grass vegetation (artificial planting included) that is not under either cropland or forest land. It includes meadows where the production is utilized by cutting, irrespective of whether it is used for grazing sometimes, and pasture that is utilized for grazing irrespective of whether it is cut sometimes or not. Grassland includes areas with trees below the thresholds discussed under Forest land (and which may be utilized for grazing) and set-aside grasslands (i.e., unmanaged grasslands) which are not in use for agricultural purposes.

Wetland includes the wetlands and water bodies as currently defined by the CORINE land-cover databases and contains inland marshes (low-lying land usually flooded in winter, and more-or-less saturated by water all year round), peat bogs (peat land consisting mainly decomposed moss and vegetable matter), water courses (natural or artificial water-courses including those serving as water drainage) and water bodies (natural or artificial lakes, ponds etc.).

Settlements are areas matching the 'Artificial surfaces' category of the CORINE land-cover database, which comprises the urban and other residential areas, industrial, commercial and transport units, as well as mines, dump and construction sites and artificial non-agricultural vegetated areas.

Other Land includes areas matching the ‘Open spaces with little or no vegetation’ category of the CORINE land-cover database, which comprises all area that is not included in any of the above categories.

6.3 Land identification

This chapter describes data sources, the national adaptation of the IPCC land-use categories and the resulting land-use change matrices that are used to estimate emissions and removals from the LULUCF sector.

Note that the reported total area of all land-use categories is equal to the total official land area of Hungary as published by the annual HCSO’s land-use statistics (i.e., 9,303,400 ha) in each reporting year. (There are minor changes in the annually reported total land area in land-use statistics, which are due to movements of the borders of Hungary based on bilateral agreements with neighboring countries, and improvements of mapping techniques. To avoid inconsistency, the longer-term average of the annually published total areas is reported for each inventory year in this GHG inventory.)

6.3.1 Methodology of land identification

The development of the annual land-use and land-use change data in Hungary involves elements of Approach 1, 2 and (for the land-use change categories involving forests) 3. The system of identification of IPCC land-use categories, which is based on Hungarian statistical categories as well as the main data sources (together with a reference with respect to the Approach it allows for), is reported in Table 6.3.1.

Table 6.3.1. *The system of identification of IPCC land-use categories in Hungary based on national statistical categories and data sources to meet respective data requirements. Acronyms used: HCSO: Hungarian Central Statistical Office; NFD: National Forestry Database; CLC: Corine Land Cover; HLC85:* satellite-based land-use change database of FÖMI (Institute of Geodesy, Cartography and Remote Sensing; *see text for details*). CLC-change surveys were done for 1990-2000, 2000-2006, 2006-2012 and 2012-2018.

IPCC land-use categories	Category used in the respective database	Primary data sources (and associated Approach)
Forest Land	Land under Forest Management	NFD (maintained by the Forestry Department of the National Land Centre, NLC, Approach 3)
Cropland	Arable land	HCSO’s land-use statistics, and General Agricultural Censuses of 1991, 2000 and 2010, Vineyard and Orchard Censuses of 2001 and 2012 (Approach 1)
	Kitchen gardens	
	Orchards	
	Vineyards	
	Set-aside Cropland	HCSO’s land-use statistics, General Agricultural Censuses of 1991, 2000 and 2010, CLC-change (Approach 1)
Grassland	Grassland (meadows and pastures)	HCSO’s land-use statistics, General Agricultural Censuses of 1991,2000 and 2010, CLC-change (Approach 1)

IPCC land-use categories	Category used in the respective database	Primary data sources (and associated Approach)
	Set-aside Grassland (Unmanaged Grassland)	HCSO's land-use statistics, General Agricultural Censuses of 1991 and 2000, CLC-change (Approach 1)
Wetlands	Wetlands and water bodies	CLC2012, HLC-change1985-1990, CLC-change (Approach ½)
Settlements	Artificial surfaces	CLC2012, HLC-change1985-1990, CLC-change (Approach ½)
Other Land	all areas not included above	HLC85, CLC90, CLC-change (Approach ½)

Areas undergoing land-use change are identified using both national statistics and information on *changes* (between two consecutive surveys) from the Corine Land Cover (CLC) database. For *Forest Land*, the main source of national statistics is the National Forestry Database that includes information on conversions both from and to forests. Forestry statistics are in general available since 1985 and are detailed in Sections 6.5.1-6.5.2. However, for forest land converted to other land-uses, the rate of 1989 is the first data available, and it is used for all years 1985-1989. For mapping the main CLC land-cover categories to the IPCC categories, see Tables 6.3.2-6.3.5.

Table 6.3.2 *Classification of the* ***CLC 1990*** *land-cover categories into IPCC land-use categories*

CLC land-cover categories (Simplified nomenclatures)	IPCC category
311, 312, 313, 324 (310)	Forest land
211, 212, 213, 221, 222 (210, 220)	Cropland
231, 321 (230)	Grassland
111, 112, 121, 122, 123, 124, 131, 132, 133, 141, 142 (100)	Settlements
411, 412, 511, 512 (400, 500)	Wetlands
331, 332, 333 (330)	Other land

For other land-use change categories, it was necessary to use the statistics of the Hungarian Central Statistical Office (HCSO) and other datasets while ensuring consistency between them. The annual statistics on land-use by the HCSO is published (in Hungarian) at its website (https://www.ksh.hu/stadat_files/mez/hu/mez0008.html). The HCSO's land-use statistics record the whole official area of the country divided into the following nine land-use categories: Arable land, Kitchen gardens, Orchards, Vineyards, Grassland, Forest, Reed, Fishpond and Uncultivated land area. Lands not in use for agricultural purposes in the year of the statistic (including set-aside areas (SA), unmanaged grassland (UGL), Settlements and some parts of Wetlands) are reported aggregately as Uncultivated land area. The data acquisition is based on questionnaires, and some land-use data are available since 1853. There have been changes in the methodology since the beginning of the data collection (Kecskés, 1997), but the data set was adjusted considering these methodological changes to achieve consistency over time. The adjustment, which was implemented in consultation with the HCSO's expert, included the following steps and assumptions:

- Between 1985 and 1990 the system of landowners and data collection can be considered to be in steady state, therefore, the annual data was accepted without adjustment.
- Significant changes occurred in land ownership in the period 1990-2000 (i.e., after political changes in the country), making the HCSO statistics less accurate. Therefore, except for orchards and vineyards, the annual dataset for all categories was replaced with values that were interpolations between the statistics of two General Agricultural Censuses of 1991 and 2000. For the vineyards and orchard category, the results of the more detailed and reliable census on vineyards and orchards were accepted instead of the results of the general agricultural census.
- For the period 2000-2010, the annual Cropland and Grassland areas were interpolated between the areas reported for the years of General Agricultural Censuses conducted in 2000 and 2010. Vineyard and Orchard areas were interpolated between the years for which the most detailed survey data are available (2001 and 2012). For the period after 2012, an extrapolation is applied until new data is available.

Concerning the CLC data, the CLC-change 1990-2000 and CLC-change 2000-2006 databases (FÖMI, 2004; FÖMI, 2009a), as well as the CLC-change 2006-2012 (FÖMI, 2014) and CLC-change 2012-2018 databases were supplemented with the database (HCL85 and HLC-changes 1985-1990) on land-use changes of FÖMI (FÖMI, 2009b) that was developed for 1985-1990 using satellite images according to the requirements of the LULUCF GHG inventory, in order to get higher accuracy. Unlike the HCSO reports, the CLC data sets often include statistics on land cover change. It was assumed that, for any period between two CLC assessments (1990, 2000, 2006, 2012 and 2018) and where that was necessary, the difference between the area of the various land-*cover* categories corresponds to the change in the respective IPCC land-*use* change category. For the period after 2018, an extrapolation is applied until new data is available.

For *non-set-aside Cropland (non-SA CL), non-set-aside Grassland (non-SA GL), Settlements* (SE), *Wetlands* (WL) and *Other Land* (OL), the above databases directly include the statistics necessary for the land-use change matrix. Separating set-aside lands is necessary for the estimation of carbon stock changes in soils. For this separation, the differences between Category 330 of the CLC databases and the Uncultivated land area category of the HCSO statistics (which include SE and WL together with set-asides) were taken as the *total area* of set-aside agricultural areas. This area (available since 1984) was then split into *set-aside croplands* (SA CL) and *unmanaged grasslands* (i.e., set-aside grassland, SA GL, for both total areas and annual changes) using *expert judgment*.

For land-use changes that were estimated using the CLC database, it was necessary to map the CLC codes to the respective IPCC categories. The CLC code 411 represents inland marshes, which contains '*Low-lying land usually flooded in winter and more-or-less saturated by water all year round'* in accordance with the CLC's nomenclature (http://www.eea.europa.eu/publications/COR0-landcover). Therefore, conversions listed in Table 6.3.3 below can be the results of the change in total annual precipitation. The analysis of the total annual precipitation supports this assumption, because the total annual precipitation before the acquisition date of the satellite images, on which the CLC2000 data sets are based, highly exceeds the precipitation of the other years.

***Table 6.3.3** Areas classified as 'Grassland converted to Wetlands'*

Period	CLC code	Explanation
1990-2000		
	231-411	Pastures converted to inland marshes
	231-512	Pastures converted to water bodies
	321-411	Natural grasslands converted to inland marshes
	321-512	Natural grasslands converted to water bodies
2000-2006		
	231-512	Pastures converted to water bodies
	321-411	Natural grasslands converted to inland marshes
	321-512	Natural grasslands converted to water bodies
2006-2012, 2012-2018		
	231-512	Pastures converted to water bodies

The Settlements converted to Wetland category mainly contains the area of sandpits and gravel pits. The area of these conversions is small, and the emissions from these land-use change conversions are probably zero (Table 6.3.4).

***Table 6.3.4.** Areas classified as 'Settlements converted to Wetlands'*

Period	CLC code	Explanation
1990-2000		
	131-512	Mineral extraction sites converted to water bodies
	133-511	Construction sites converted to water courses
2000-2006		
	131-512	Mineral extraction sites converted to water bodies
	133-512	Construction sites converted to water bodies
2006-2012, 2012-2018		
	131-512	Mineral extraction sites converted to water bodies
	132-512	Dump sites converted to water bodies
	133-512	Construction sites converted to water bodies

Conversions in Table 6.3.5 below also include conversions of water courses and water bodies which are not covered by soil and biomass, therefore, they could not be source of anthropogenic CO_2 emissions.

Table 6.3.5. *Areas classified as 'Wetland converted to Settlements'*

Period	CLC code	Explanation
1990-2000	411-142	Inland marshes converted to sport and leisure facilities
	511-142	Water courses converted to sport and leisure facilities
	412-133	Peat bogs converted to construction sites
	511-133	Water courses converted to construction sites
2000-2006		
	411-122	Inland marshes converted to road and rail networks and associated land
	411-133	Inland marshes converted to construction sites
	411-142	Inland marshes converted to sport and leisure facilities
	512-122	Water bodies converted to road and rail networks and associated land
	512-131	Water bodies converted to mineral extraction sites
	512-133	Water bodies converted to construction sites
2006-2012, 2012-2018		
	411-122	Inland marshes converted to road and rail networks and associated land
	411-131	Inland marshes converted to Mineral extraction sites
	511-133	Water courses converted to construction sites

The classification of two CLC2018 categories, i.e., 2.4.2 Complex cultivation patterns and 2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation, represented a challenge as they involve rather small areas that could be classified, e.g., either as cropland or grassland. To estimate the share of these land-uses within the above two categories, data from the Lechner Knowledge Center (formerly FÖMI), obtained from high resolution studies, was used. For example, the shares of converting areas under code 2.4.3 to SE, CL, GL, FL, WL and OL in 2012-2018 were 0.299, 0.587, 0.009, 0.104, 0.000 and 0.000, respectively.

6.3.2 Land-use statistics and land-use change matrices

For the development of the area of the other land-use and land-use change categories, it was necessary to consider that the area of a category for a year may somewhat be different in the various statistical sources. Inconsistencies mainly occur because of differences in definition (including differences in the definition of land-use vs land cover) and data collection methodology. For example, the HCSO's and CLC forest land data only refer to areas that are covered by trees, whereas the forestry statistics also include areas that are managed in the forestry sector but are not covered by trees (see various sections on forests in Chapters 6.5.1-6.5.2 for more details).

Also, it was necessary to consider the possible uncertainty of the various data sources that is not only affected e.g. by the methodology used but also the size of the land pieces that are converted annually from one land-use category to another. This size shows significant differences, e.g., the total area of the FL-L category is the smallest, whereas that of CL-L is about ten times larger. Even this latter area is only a small portion of the total area. Also considering that the size of the converted units is small, it can generally be stated that the use of remote sensing currently involves rather large uncertainties.

Therefore, we mostly rely on data from administrative statistics where possible, which also involves uncertainties but probably less.

To develop the most accurate overall area estimates for the entire AFOLU sector based on all the above, the statistical sources on the various land-use and land-use change categories were treated hierarchically during the compilation of the annual land-use change matrices. This means that, if data from different sources were available, that from a data source deemed more accurate was used. For example, since the forestry statistics are regarded as the most accurate and forests are the most important for the overall accuracy in the LULUCF sector, the forestry statistics were used for all areas related to forests. The hierarchy of the available sources established is as follows:

- Forestry statistics
- CLC data
- HCSO land-use statistics.

In estimating the annual area of all non-forestry land-use *change* categories, first, periodic land-use changes (for the periods 1986-1992, 1992-2000, 2000-2006, 2006-2012 and 2012-2018) were estimated using the CLC database. Annual land-use change values were then calculated from periodic ones using interpolation (until 2018) and extrapolation (after 2018), using also expert judgment so that, for each land-use category, the net sum of the annual changes in the time period is equal to the difference between the *area* at the end and at the beginning of the given period in the CLC database. (For the forestry data where annual land-use change data is available, this data was used without any further adjustment.)

The arising net *changes* were in the second step compared with the net *changes* that could be calculated from the HCSO's land-use statistics calculated for the similar periods. The differences between the net change in the HCSO's land-use statistics and the land-cover change datasets were taken to happen due to conversions involving set-aside grassland and cropland areas.

The total area in each land-use change category was calculated applying the default assumption that transitions take place in a period of 20 years, and the areas in the conversion categories are not converted again to any other land-use category during this 20-year transition period. All land in each conversion category is moved to the respective 'remaining' category in the 21th year after the conversion.

Note that, as mentioned in Section 6.1.1 above, the reported area of the land-use conversion categories for 1985-2004, which should include areas under conversion for the (default) period of 20 years, assumes that the area of land that was converted before 1985 is zero as we have no accurate information on conversion areas before 1985. This is equivalent to reporting zero carbon stock changes for the years before 1985, and the trend of both the areas and the calculated emissions and removals before 2005 most probably involve artefacts. Thus, while we report on the entire time series of both areas and emissions and removals in the CRF tables, only data beginning 2005 are analyzed on the graphs with LUC information in this report.

The resulting time series of land-use data are shown in Figure 6.3.1, whereas areas in the 'land remaining' and 'land converted to' subcategories are reported in Figures 6.3.2 and 6.3.3.

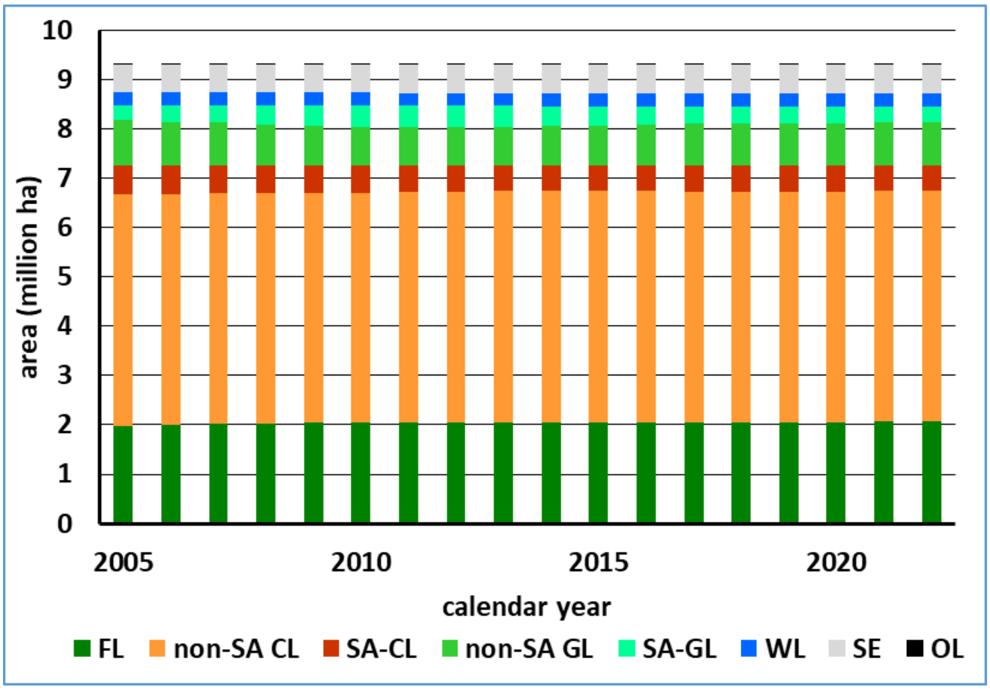

Figure 6.3.1. *The evolution of the area of the land-use categories since 2005. Note that CL and GL categories are split into non-SA and SA subcategories in order that carbon stock changes can include to and from non-SA – SA conversions, and N_2O emissions due to such conversions can also be estimated.*

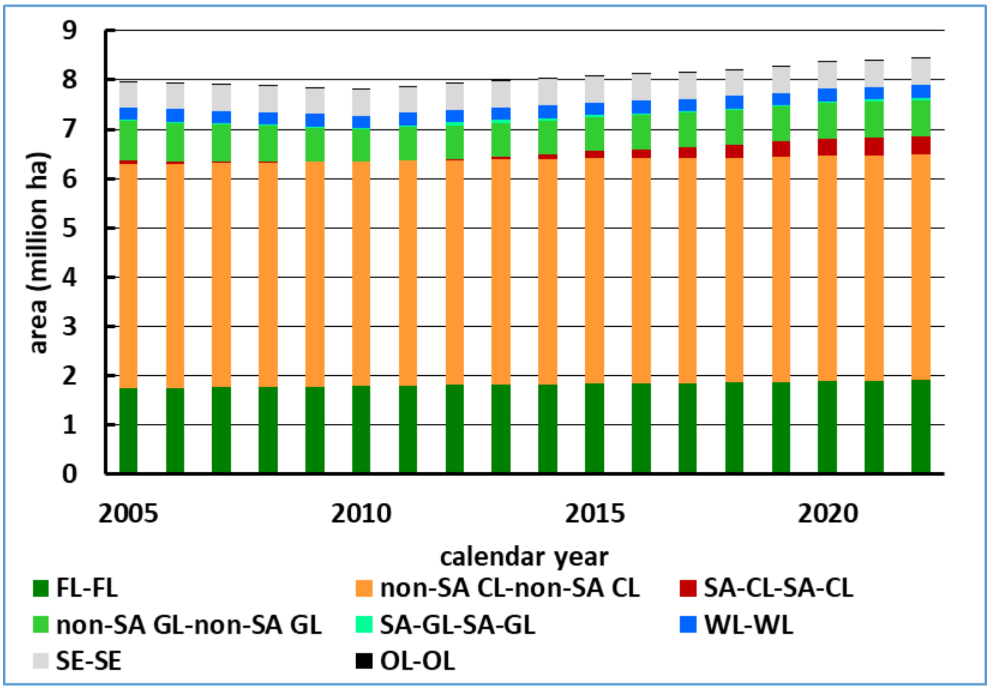

Figure 6.3.2. *The evolution of the area of the 'land remaining' categories since 2005. Note that the CL and GL categories are split into non-SA and SA sub-categories as on Figure 6.3.1.*

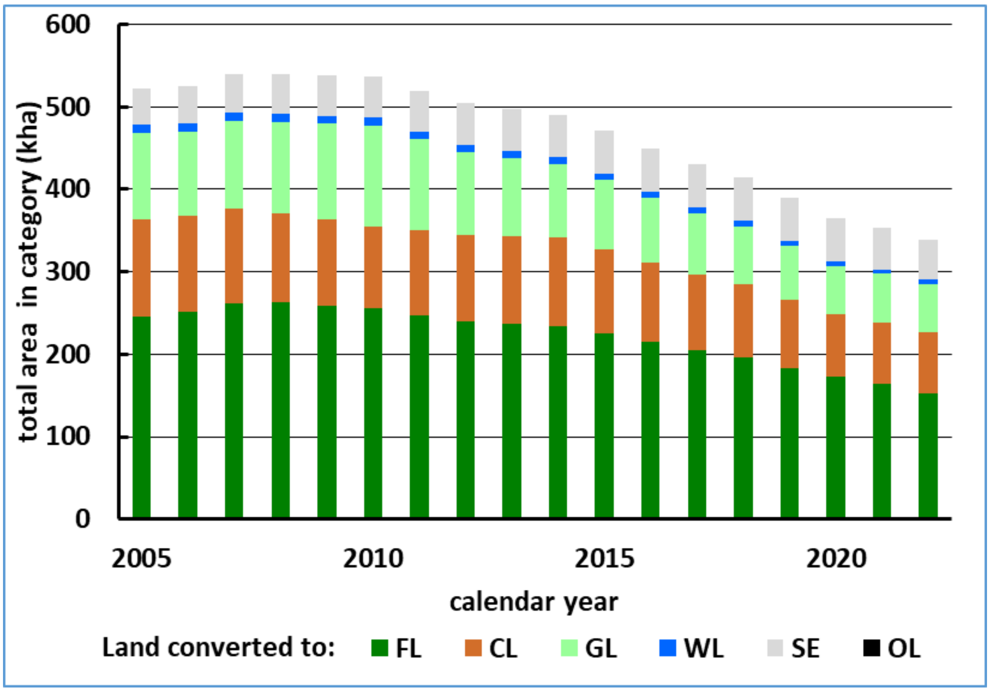

Figure 6.3.3. *The evolution of the area of the 'land converted to' categories since 2005.*

The above area estimates of the various land-use and land-use change categories include *all* areas in the land-use change categories for the default transition period of 20 years. For reasons of transparency, we include Figure 6.3.4 below that demonstrates *annual* conversion areas.

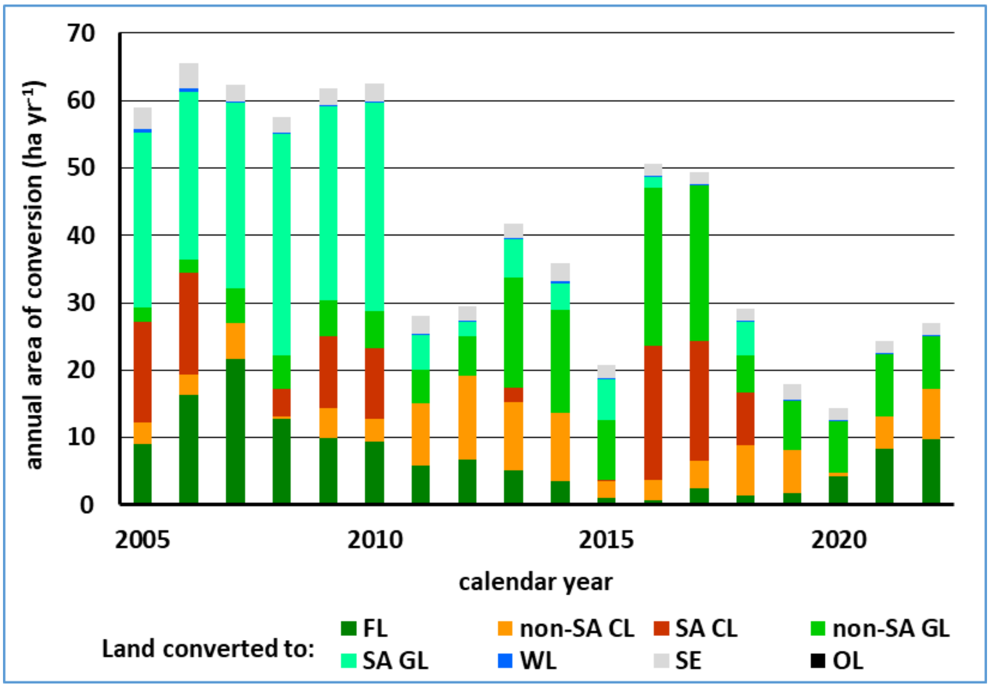

Figure 6.3.4. *Annual area of the 'land converted to' categories since 2005.*

Finally, we note also that land-use and land-use change categories are further subdivided by climate, soil, management and input for the estimation of soil carbon stock changes, see relevant sections, e.g., Section 6.4.1 for more details.

6.4 Generic methodological steps to estimate emissions and removals

In this section, general methodological description is provided for those methodological elements that are used for more than one land-use and/or land-use change sub-categories. Activity data and emission/removal factors are usually sub-category specific, and their description can be found in the respective sections below.

Concerning pools, the 2006 IPCC Guidelines (its Table 1.1. in Chapter 1 of Volume 4) define carbon pools in a generic manner. In Hungary, pools are defined in a bit different, and more specific way to match them with available data in order that the estimation is as accurate and precise as possible and practicable. These definitions are (see also section 6.5.3):

Above-ground biomass (AB): all above-ground biomass of living plants. The biomass of trees includes bark, branches, twigs and leaves that can be found above the height of potential cutting of the stem at its bottom by a chainsaw. This height is usually a few cm above ground; only 1-2 cm for small trees, 5-10 cm for trees at thinning age, and can be 10-30 cm for trees of the age of the final harvest. Note that, in the Hungarian forests, the understory and shrub layers usually have very little biomass.

Below-ground biomass (BB): all living parts of the living plants below ground or the above-mentioned potential cutting height. These parts thus include stumps (up to the heights defined above for AB), coarse roots (i.e., roots thicker than 2 cm) and fine roots.

Litter (LI): all dead plant mass, whether above-ground or below-ground, that is smaller than around 1 cm in diameter (in case of branches) and 2 cm (in case of dead roots). Note that the above diameter thresholds were chosen to match definitions in the quantitative assessment of the carbon content of the litter for the Hungarian forests (Heil et al., 2012).

Deadwood (DW): all dead plant mass, above-ground and below-ground, that is not litter (i.e., above the 1 cm threshold for standing and lying dead trees, including stumps, and 2 cm for dead roots).

Soil (SO): includes the organic carbon in the topsoil down to a depth of 30 cm that excludes deadwood and litter. Inorganic carbon, as well as organic carbon in the below-ground deadwood and litter pools are excluded, but organic carbon in the topsoil layer is included. (Carbon stocks below 30 cm usually do exist in the Hungarian soils, however, consistent with IPCC (2006), they are assumed to be in carbon equilibrium.)

In the below sections, those methodological details are reported that can be generalized for more than one land-use and land-use change categories and/or carbon pools or emission sources.

6.4.1 Soil carbon stock changes

Soil carbon stocks may change due to conversion of land to other land-use, conversion of land within a land-use sub-category to another sub-category (non-set-aside to set-aside or vice versa) or change of the management within a specific land-use sub-category over time. For the entire land-use sector (excluding FL-FL for which the Tier 1 assumption is applied, i.e., soil carbon stocks do not change), the sum of all soil carbon stock changes is estimated using the below formula:

$$\Delta C = \Sigma_i \Delta C_i$$

where

ΔC = total carbon stock changes in mineral soils due to land conversion or changes of soil management in the uppermost 30 cm topsoil, tC; and

i = any soil carbon stock change sub-category by land-use change, climate type, soil type, and/or management and input type as appropriate.

Except for those situations where it was necessary to use some Tier 1 data and that are explicitly mentioned, the estimation of ΔC_i follows the Tier 2 approach in which ΔC_i was estimated using the first formula in Equation 2.25 of the 2006 IPCC GL:

$$\Delta C_i = A_i * (SOC_{0–} - SOC_{0-T})_i / D$$

where

ΔC_i = annual soil organic carbon stock change in a soil carbon stock change sub-category, $tCha^{-1}yr^{-1}$;

A_i = area of sub-category *i* in the inventory year, ha (the relevant values are usually those in the land-use change matrix and include all area in the year in a 'remaining' category, or all areas for conversion category *i* that have been in the category for a maximum period of default length of 20 years, see section 6.2 for details);

$(SOC_0)_i$ = area-specific SOC soil organic carbon stock in sub-category *i* in the inventory year, tC;

$(SOC_{0-T})_i$ = area-specific SOC soil organic carbon stock in sub-category *i* T years prior to the inventory year, tC;

T = number of years over a single inventory time period, yr, T = 1 yr; and

D = default time period for transition between equilibrium SOC values, yr (the default value of 20 years is applied).

The above formula represents the essence of the IPCC methodology in that carbon stock changes in the soils due to changes in land-use or management result in the changes of stable mean levels of carbon stocks in D years. This is equivalent to saying that

$$\Delta C_i = A_i * \Delta SOC_i * 1 / D$$

where

ΔSOC_i = area-specific soil organic carbon stock change for the entire 20 years of the default period during which carbon stocks increase or decrease from the stable mean soil carbon stock of the pre-conversion category to the stable mean soil carbon stock of the post-conversion category.

As explained in Table 6.3.1, Section 6.3.1 of our NIR, our current land identification system directly allows for only the application of Approach 1 for the total area of CL and GL. However, CO_2 emissions and removals even in these categories arise predominantly from within-category conversions from non-set aside to set aside and back, the area of which is estimated using the CLC change database, which in turn allows for the application of Approach 3 (although we have not directly used the spatially explicit information in that database). For the estimation of the area of other conversion categories, Approach 2 or Approach 3 is applied. It is for this reason that we decided that, to estimate SOC, we apply Formulation B in Box 2.1 which is applicable to Approach 2 or Approach 3 applications.

For SOC for both the inventory year and T year before, and thus for ΔSOC, for all sub-categories and for any inventory year, country-specific estimates are used (see below). When such estimates are not available, the second formula in Equation 2.25 (i.e., Formulation B (in Box 2.1, p. 2.34) of Section 2, Volume 4) of the 2006 IPCC GL is applied together with Tier 1 data (possibly in combination with Tier 2 data):

$$SOC = SOC_{REF} * F_{LU} * F_{MG} * F_{I}$$

where

SOC_{REF} = area-specific reference soil organic carbon, $tCha^{-1}$, estimated from country-specific data; and

F_{LU}, F_{MG} and F_{I} = specific land-use, management and input stock change factors for which IPCC default values are used. (Note that F_{LU} changes from year to year due to land-use change, whereas F_{MG} and F_{I} change due to changes in management.)

Beginning 2023, all SOC values are thus entirely or partially country-specific ones, replacing earlier estimates by Zsembeli et. Al. (2013) and NIR (2015).

The estimation of the currently used SOC values is based on the Hungarian Soil Protection and Monitoring System (hereafter referred to as TIM). Considering physiographical and soil-ecological units that had been established by various former research programs, the TIM sample plots were established in 1991 in representative areas of these units based on expert judgment and considering available local research data. The number of sample plots by land-use category used in this study is as follows: FL: 186; CLa, i.e., annual cropland: 730; CLp, i.e., perennial cropland (orchards and vineyards): 57; and GL: 148 (Figure 6.4.1). All measurements were taken in lands of the "remaining" type (i.e., CL-CL, GL-GL, FL-FL etc.).

An important element of the current system is to only consider non-aquatic situations for conversions because the vast majority of conversions in Hungary typically occur on soils with no groundwater (at least not in the soil layers where roots and the carbon can be found whose change has to be accounted for). SOC stocks (tC/ha) for each sample point were estimated from measured soil organic matter (SOM, t/ha) values from the known depth of the respective layers, sample plot and layer-specific measured bulk density, and the so-called van Bemmelen SOM-to-SOC conversion factor of 0.58 (Pribyl, 2010). To reduce the uncertainty of sample plot-level SOC values arising from survey-specific errors, the average of all available SOC measurements was used for each sample plot where repeated measurements were available. Repeated measurements of carbon stocks on most sample points are available with a frequency of about once every 3-6 years. This study used altogether 5830 data from surveys between 1992 and 2016.

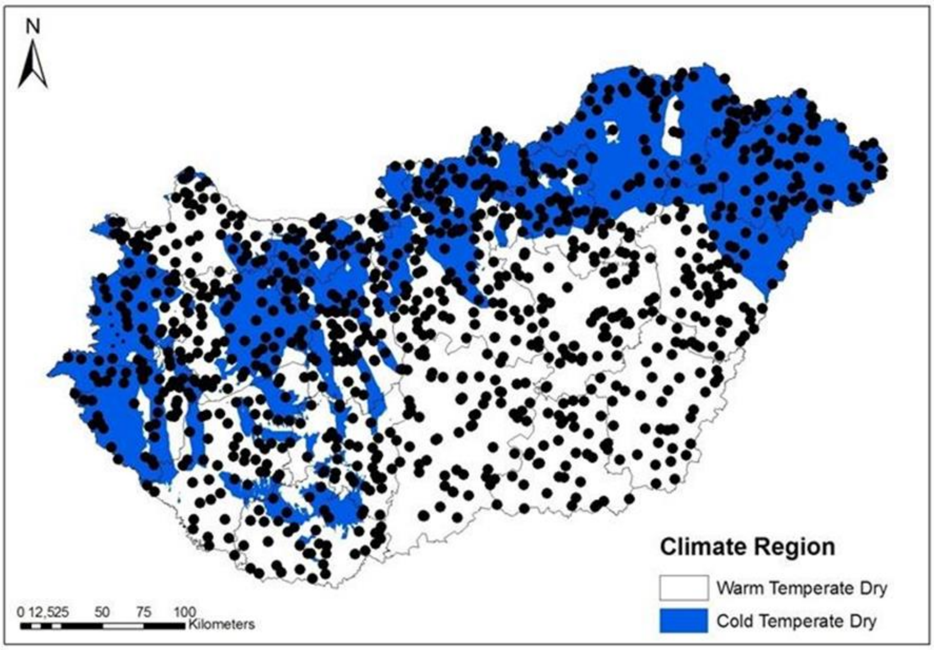

Figure 6.4.1. *The geographical distribution of the sample plots of the Soil Protection and Monitoring System (TIM) by IPCC climate region.*

For the scaling up of plot-level data to get mean ΔSOC values for a land-use change category (tC/ha for the entire default period during which soil carbon stock changes take place), the differences between mean equilibrium area-specific SOC stocks (tC/ha) of the relevant post-conversion and pre-conversion land-use categories *of otherwise similar conditions* were used as proxies:

$$\Delta SOC_{lu1-lu2} = SOC_{lu2} - SOC_{lu1}$$

where

$\Delta SOC_{lu1-lu2}$ = mean area-specific ΔSOC for LUC from pre-conversion land-use category *lu1* to post-conversion land-use category *lu2*;

SOC_{lu2} = equilibrium mean area-specific SOC stocks of the *lu2* post-conversion land-use category;

SOC_{lu1} = equilibrium mean area-specific SOC stocks of the *lu1* pre-conversion land-use category

so that the areas sampled for both *lu1* and *lu2* are have as similar soil characteristics as possible.

For *lu*, the following categories were used to develop country-specific values: FL, CLa, , CLp and GL. (For conversions involving the other categories, IPCC default F_{LU}, F_{MG} and F_I values had to be used, see below.)

SOC highly depends on site fertility. To ensure for each LUC (i.e., any *lu1-lu2* combination) that SOC estimates only sample areas of similar site fertility in both *lu1* and *lu2*, areas of both in both *lu1* and *lu2* were considered in proportion to the occurrence by soil type. Therefore, both SOC_{lu1} and SOC_{lu2} in the above equation are weighted means using the area of the various soil types, denoted by *j* below, of the pre-conversion land-use category:

$$SOC_{lu1} = sum(SOC_{j,lu1} * area_{j,lu1}) / sum(area_{j,lu1})$$

and

$$SOC_{lu2} = sum(SOC_{j,lu2} * area_{j,lu1}) / sum(area_{j,lu1})$$

where

$SOC_{j,lu}$ = arithmetic mean of relevant plot-level SOC stocks of TIM plots in soil type *j* and land-use category *lu*;

areas represent only those where annual conversions actually take place; and

summations are done over *j*.

Note that the values used for weighting, i.e., the area distribution and the total area, are both developed for *lu1* because it is the pre-conversion situation will determine the trajectory of the carbon stock change and final level of the post-conversion carbon stock. Note also that when developing the area distributions, only those areas were considered where conversions actually take place in practice.

For the soil types, the categories of Hungarian genetic soil classification system (Pásztor et al. 2018; Agrotopo, 2000) were used.

Calculating the area-specific ΔSOC values due to conversions using the above procedures thus assumes that conversions from one land-use category to another one happen over the same distribution in the respective land-use categories with respect to soil type. In contrast, whereas a different distribution may be applied to conversions in the opposite direction, which complies with practice in our case. In Hungary, for example, abandoned croplands of relatively poor soils are usually converted to forests to utilize these soils, whereas the conversion of forest land to cropland can mainly occur on forests of better soil, because these latter conversions are done to better exploit good soils.

An aggregated distribution of the area of the various sub-categories by climate and soil type using IPCC aggregate soil type and climate type categories is reported in Table 6.4.1. This distribution is not used for the revised calculations and is only reported for information, partly to support the above claim. The data shows that CL and GL have similar distributions, while the distribution of FL somewhat differs from that of the others. The data suggests, therefore, that forests occupy the poorer sites within the possible CL-FL and GL-FL conversion paths, whereas FL-CL and FL-GL conversions may also, or even predominantly, occur on better sites. For this and other reasons, SOC differences due to conversions should not be calculated along an *average* CL – *average* FL carbon stock change trajectory or other *average-to-average* trajectories.

Table 6.4.1. *The relative distribution of area and estimated SOC_{REF} by IPCC default soil and climate type for those areas that could be converted to and from other land-uses.*

soil type	climate type	Land use type		
		FL	CL	GL
HAC	CD	0,54	0,38	0,39
	WD	0,36	0,56	0,56
sandy	CD	0,10	0,03	0,02
	WD	0,01	0,03	0,03

For weighting SOCs for LUC involving forests, the frequency distribution of areas of conversions to forests (i.e., afforestations between 1990-2019) as well as that of FL (excluding afforestations) were queried from the National Forestry Database. For all conversions between non-forest categories, areas of CL and GL by soil types are available from a recent survey by the Plant, Soil and Agro-environment Directorate of the National Food Chain Safety Office.

The above method partially (but as much as possible) meets the requirements of the IPCC Guidelines (2006; 2019) in that, when applying paired-plots, „*it is good practice that the plots being compared have similar histories and management as well as similar topographic position, soil physical properties and be located in close proximity.*" In a similar fashion, FAO (2019) requires that "*Changes in SOC stocks estimated from paired-plot comparisons of new land use or management conditions against a business-as-usual baseline shall only be made when the starting point is consistent (i.e., same soil properties, climate, and prior land use and management).*" Pairing plots was not possible in this study but pairing mean land-use specific SOC values at the level of soil types was, and this can be considered analogous to pairing plots. The requirement for "close proximity" could not be met by the method applied here. This might increase uncertainty but might in general have been offset by the number of TIM plots that is probably much higher than in most, if not all, paired-plot experiments.

The distributions of converted areas by soil type change over time and so do the weighted averages in the L-FL category. However, such changes have been more like annual variation in Hungary rather than strong trends over time, and the use of longer-term averages of area distributions, which is the case in this study, mitigates this effect. In any event, the value of weights should be periodically checked and revised, if necessary. Weighting could be automated if Approach 3 land identification of the IPCC (2006) methodology were applied. In this methodology, planned to be introduced in Hungary later, spatially tracking land-use changes and the associated areas monitored this way are used in combination with appropriate maps of soil type to generate the appropriate distributions.

For the differences between set-aside and non-set-aside land, as noted above, appropriate ratios of the IPCC default $F_{LU} * F_{MG} * F_I$ values were used. For the SOC of land under Settlement, 80% of the SOC of the pre-conversion category was used, based on the Tier 1 approach by the 2006 IPCC GL. For Wetlands (which is only involved in small conversions in terms of area), no methodology is provided in the 2006 GL. For the sake of completeness only, the SOC of Wetland is set to equal to that of Grassland, and that of OL is set to equal to that of SE. For Wetlands, calculations will be revised later.

Based on the above considerations, we developed revised land-use specific SOC values (Table 6.4.2(a)) and conversion-specific SOC difference values (Table 6.4.2 (a, b)). Complying with theoretical considerations above, the results demonstrate that the difference between the *overall mean* mineral soil C stocks of FL and CL, or FL and GL, are *in general* different from the difference between mineral soil C stocks of areas that are *actually* converted from forest to another land-use and back. In other words, there are no "conversions from or to FL" *in general*, especially in Hungary, rather, lands that undergo conversions to forests may be typical to poor sites only. Therefore, it is possible e.g., that converting GL to FL increases SOC stocks in some regions, and if afforestations are only or mainly done in these regions, GL-FL conversions may yield carbon gains even in the entire country. It is for this reason that appropriate mean C stocks have to be matched. In the above methodology, this is achieved by matching mean C stocks of respective land-use categories by combining the same area distribution by soil type for the "from" and "to" land-use categories (i.e., that of the "from" category) with the mean C stocks by soil type. The same methodological principle has of course to be applied to all types of land-use conversions.

Table 6.4.2. (a) *Revised mean area-specific SOC (tC/ha) values by land-use category (in bold) and mean area-specific conversion-induced SOC change (ΔSOC, tC/ha) values for the main land-use and land-use change categories for the entire default 20 yr transition period as estimated from the TIM data.* ***(b)*** *The matrix of the calculated average area-specific ΔSOC values (for the default 20 yr transition period) for all land-use change categories using the above TIM estimates, soil type distributions as well as IPCC management factor values, where relevant.*

(a)

From	To				
	Afforestations	**FL (excl. afforestations)**	**CLa**	**CLp**	**GL**
Afforestations	***41.8 ± 0.1***	-	-	-	-
FL (excl. afforestations)		***45.1 ±0.1***	*-8.1 ±0.2*	*-10.2 ±0.2*	*-4.5 ±0.2*
CLa	*4.7 ± 0.1*	-	**50.9 ±0.1**	-7.0 ±0.2	9.5 ±0.2
CLp	*11.3 ± 0.2*	-	6.7 ±0.2	**35.9 ±0.1**	6.7 ±0.2
GL	*3.5 ± 0.2*	-	-7.6 ±0.2	-14.8 ±0.2	**54.6 ±0.2**

(b)

FROM	TO							
	FL	**non-SA CL**	**SA-CL**	**non-SA GL**	**SA-GL**	**WL**	**SE**	**OL**
FL	0,0	**-9,5**	**-1,3**	**-4,5**	**0,0**	0,0	-9,0	-9,0
non-SA CL	***10,0***	0,0	4,9	5,4	9,5	9,5	-6,4	-6,4
SA-CL	***4,7***	*-8,1*	0,0	0,4	4,6	4,6	-7,4	-7,4
non-SA GL	***3,5***	*-7,6*	*0,0*	0,0	4,3	4,3	-7,7	-7,7
SA-GL	***3,5***	*-7,6*	*1,0*	*-3,8*	0,0	0,0	-7,7	-7,7
WL	*3,5*	*-7,6*	*1,0*	*-3,8*	*0,0*	0,0	-7,7	-7,7
SE	*9,0*	*6,4*	*7,4*	*7,7*	*7,7*	*7,7*	0,0	0,0
OL	9,0	6,4	7,4	7,7	7,7	7,7	0,0	0,0

To see how SOC stocks within a land-use category may change over time and what effect these changes might have on the ΔSOC values developed, weighted mean annual carbon stock changes, or $dSOC_{lu}$ (tC/ha*yr), were calculated for each land-use category based on the plot-specific SOCs from different consecutive surveys and plot-specific time between the latest and earliest surveys as well as the areas by site type using the below formula:

$$\mathrm{dSOC_{lu}} = \mathrm{sum}(\mathrm{dSOC_{p,j,lu}} * \mathrm{area_{j,lu}} * \mathrm{pt_{p,j,lu}}) \;/\; \mathrm{sum}(\mathrm{area_{j,lu}} * \mathrm{pt_{p,j,lu}})$$

where

$dSOC_{p,j,lu}$ = mean annual SOC stock change for sample plot *p* in soil type category *j* and land-use category *lu* between the last re-measurement and the first measurement, tC/ha*yr;

$area_{j,lu}$ = area of soil type category *j* in land-use category *lu*;

$pt_{p,j,lu}$ = time between the last re-measurement and the first measurement on plot *p* in soil type category *j* and land-use category *lu*, yr; and

summation (*sum*) is simultaneously done for both *p* and *j*.

dSOC was defined as above to ensure that larger weight is attached to soil types with larger area and that, by always using the longest periods at the plot-level between consecutive measurements, sampling errors relative to the actual annual value of dSOC are minimized.

Concerning forests, dSOC was estimated using the distribution of area by soil types of both the FL category (i.e., all forests excluding afforestations) and the afforestation category. This was useful to see if there is any difference between the SOC accumulation rates in forests in general and in afforestations that usually occur on poorer or much poorer sites in Hungary than forests in general.

The uncertainty of the above SOC and dSOC values was estimated using the Monte Carlo method based on standard deviation (SD) of the plot-level SOC values and the SD values of the areas by soil type.

Results from the analysis of repeated measurements demonstrate that while the SOC stocks increased on FL, they decreased on both CLa and CLp, whereas those of GL did not change. dSOC values derived using the soil type distribution of areas within the afforestation category as weights were lower than those using the soil type distribution of areas within the FL category. Except for GL, the dSOC values obtained are statistically significantly different from zero (Table 6.4.3).

***Table 6.4.3**. Weighted mean annual $dSOC_{lu}$ values (kgC/ha*yr) from repeated measurements for each lu land-use category (using their respective area distribution by soil type for weighting) as well as the afforestation land-use change category together with their uncertainty (expressed as plus or minus half the confidence interval width) and related statistics.*

Statistics	**Land-use category**				
	FL		**GL**	**Cla**	**CLp**
	FL excluding afforestations	**L-FL**			
dSOC (kg C/ha*yr)	**384 ± 14**	**344 ± 6**	**6 ± 9**	**-149 ± 7**	**-46 ± 6**
number of points with repeated measurements	178		131	692	131
mean time between last and first measurement (yr)	19.0		19.8	18.6	19.5

Concerning forests, it must be added that forests on the sample points have not been subject to final cutting yet, which means that the development of the soil carbon stocks has been uninterrupted during the monitoring program so far. However, to estimate the net balance of all managed forests (i.e., both forests with no final cutting and regeneration and those with final cutting and regeneration which might reduce soil carbon), emissions from losses from harvests and regenerations should also be considered. The amount of these emissions depends on the type of regeneration (see NIR, 2022, section 11.3.1.2) but is quite uncertain. It is, however, unlikely, especially considering data in Table 6.4.3, that the overall net carbon balance of the FL-FL category is negative (the net carbon balance of the L-FL category is most probably positive). Nevertheless, since soil C stocks seem to change over time, the periodic revision of the soil carbon stocks and, thus, that of soil carbon stock change estimates seems warranted.

6.4.2 N_2O emissions from mineral soils

According to the IPCC 2006 Guidelines, N mineralizes in mineral soils when there is loss of soil organic C stocks through land-use change or management practices, and this loss also leads to N_2O emissions. For each land-use and land-use change sub-category and for each year when carbon is lost from mineral soils, these emissions were estimated, for each climate, soil, management, and input type as appropriate, using the following Equations of the 2006 IPCC GL:

Equation on page 11.10:

$$N_2O = N_2O\text{–}N * 44/28$$

where

N_2O = N_2O emissions, kg N_2O yr^{-1}

$N_2O\text{–}N$ = annual direct $N_2O\text{–}N$ emissions produced from managed soils, kg $N_2O\text{–}N$ yr^{-1};

Equation 11.1:

$$\text{Direct } N_2O\text{-}N = F_{SOM} * EF_1$$

where

F_{SOM} = annual amount of N in mineral soils that is mineralized, in association with loss of soil C from soil organic matter as a result of changes to land-use or management, kg N yr^{-1} (note that this value is also reported in the CRF table as AD);

EF_1 = emission factor for N_2O emissions from N inputs, kg $N_2O\text{–}N$ (kg N input)$^{-1}$ (the value 0.01 was taken from Table 11.1 of the 2006 IPCC GL); and

Equation 11.8:

$$F_{SOM} = \Delta C_{Mineral} / R * 1000$$

where

$\Delta C_{Mineral}$ = average annual loss of soil carbon for each land-use type (LU), tonnes C; and

R = C:N ratio of the soil organic matter. Due to lack of more specific data for the area, the default value of 15 is used for situations involving land-use change from Forest Land or Grassland to Cropland, and the default value of 10 is used for situations involving management changes on CL-CL (page 11.16 of the 2006 IPCC GL).

The method of estimating indirect N_2O emissions from N mineralization associated with loss of soil organic matter resulting from change of land-use or management on mineral soils due to leaching/runoff is also based on the methodology as suggested by the 2006 IPCC GL, and uses Equation 11.10 (only the part of the equation for leaching/runoff):

$$\text{Indirect } N_2O_{(L)}\text{-}N = F_{SOM} * Frac_{LEACH\text{-}(H)} * EF_5$$

where

F_{SOM} = as above;

$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralized in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kg N (kg of N additions)$^{-1}$ (the value 0,3 and 0 were taken from Table 11.3 of the 2006 IPCC GL for cold & dry and warm & dry, respectively);

EF_5 = emission factor for N_2O emissions from N leaching and runoff, kg N_2O–N (kg N leached and runoff)$^{-1}$ (the value of 0.0075 for EF_5 was taken from Table 11.1 of the 2006 IPCC GL).

6.4.3 Non-CO_2 emissions from wildfires

Except for slash burning in forests, and in accordance with Government Decrees No. 21/2001(II.14) and No. 306/2010. (XII.23.), the on-site burning of living biomass is prohibited in Hungary. Therefore, the controlled burning of biomass is reported as “not occurring” for Hungary for land-use categories other than Forest Land, and only emissions from wildfires in Forest Land, Cropland and Grassland are reported. Except for forests (where emissions from wildfires are separately reported for FL-FL and L-FL), all such emissions are reported in the “remaining land” categories that include any emissions in the conversion categories.

In estimating these emissions, the Tier 1 method and Equation 2.27 of the 2006 IPCC GL were used as follows:

$$L_{fire} = A * M_B * C_f * G_{ef} * 10^{-3}$$

where:

L_{fire} = amount of greenhouse gas emissions from fire, tonnes of each GHG

A = area burnt, ha

M_B = mass of fuel available for combustion, tonnes ha^{-1}

C_f = combustion factor, dimensionless

G_{ef} = greenhouse-gas specific emission factor g (kg.d.m.)$^{-1}$.

Data on the areas affected by wildfires (A) is derived from the statistics of the National Directorate General for Disaster Management. Data on the areas affected by wildfires has been collected since 1998, but in the system of data collection a methodological change has been introduced in 2007, therefore, more details and complete data are only available since then. To avoid inconsistency arising from the methodological changes, data for the period 1998-2007 had to be adjusted. For the period 1998-2007 the average of the areas affected by wildfires over the period 2007-2009 were applied to the trends. For the period 1985-1997 the average of the emissions since 1998 are reported, due to lack of data.

Note that the average for the period from 1998-2022 is not applied for AD. This is because one way to estimate gaps in a time series is to extrapolate activity data and then estimate emissions. However, if the emission factors do not change in time, this method would yield the same result as the one applied by Hungary, which is also in line with the 2006 IPCC GL (Section 5.3 of Volume 1). Hungary prefers the technique of directly extrapolating emissions rather than AD because, by reporting NE for the AD, it can be more transparent and indicate the fact that there is actually a gap in the activity data time series that causes a gap in the emissions time series that could only be filled using extrapolation.

The amount of M_B and C_f is sector-specific, see the relevant sections for details.

6.4.4 Conversion-related carbon stock changes of the biomass pools

Conversion-related biomass carbon stock changes occur due to land conversions (e.g., converting land to Forest land) but, in some cases, also on land remaining land (e.g., with converting perennial crops to annual ones and when wetland areas are opened for peat extraction). The estimation of carbon stock changes in these cases is done using Equation 2.16 of the 2006 IPCC GL:

$$\Delta C = A_{conv} * (B_{After} - B_{Before}) * CF$$

where

ΔC = carbon stock change, tonnes C yr^{-1}

A_{conv} = the area undergoing conversion, ha yr^{-1}

B_{After} = biomass after the conversion, t biomass d.m. ha^{-1}

B_{Before} = biomass before the conversion, t biomass d.m. ha^{-1}

CF = conversion factor, tonnes C tonnes $biomass^{-1}$.

Note that “biomass” here means the sum of above-ground and below-ground biomass except for annual croplands where, consistent with the 2006 IPCC GL, only the above-ground biomass is considered for the “from annual cropland” conversions. The method of the estimation of the above variables is described in the relevant sections.

6.4.5 Conversion-related carbon stock changes of the dead organic matter pools

The carbon stock of both litter and deadwood may change due to conversion of land to other land-use. For these pools, carbon stock changes are estimated as the sum of gains and losses using a modified form of Equation 2.23 of the 2006 IPCC GL:

$$\Delta C_{DOM} = A_{new} * (C_{new} - C_{old}) * T_{old\text{-}to\text{-}new}$$

where

ΔC_{DOM} = annual carbon stock changes in litter or deadwood, $tCha^{-1}yr^{-1}$;

A_{new} = area undergoing conversion from old to new land-use category, ha;

C_{new} = area-specific equilibrium carbon stocks in the new land-use category, tC ha^{-1};

C_{old} = area-specific equilibrium carbon stocks in the old land-use category, tC ha^{-1};

$T_{old\text{-}to\text{-}new}$ = time period of the transition from old to new land-use category, year. In case $C_{new} > C_{old}$, the default value of 20 years is applied, whereas a one-time loss is assumed in the year of the conversion in case $C_{new} < C_{old}$.

6.5 Forest Land (CRF sector 4.A)

This section describes forests and forestry in Hungary, as well as methodologies of estimating GHG emissions and removals in the forestry sector.

6.5.1 Category description

Forest land has been managed in Hungary in a sustainable manner for decades. Most forests of the country are more-or-less intensively managed. The area of forests that could be considered as "unmanaged" under the UNFCCC is negligible. There are some forests where no forestry operations have taken place for about two decades to a century. These are called forest reserves, however, the total area of their strictly protected so called "core zones" only amounts to a few hundred ha in the entire country and even these forests are managed in one way or another as we also consider forest monitoring, inspecting, forest protection, forest tourism and game management as forest management activities, and these may take place even in forest reserves. Therefore, all reported forests of Hungary are considered as managed under the UNFCCC.

The definition of "forest management" in Hungary is well described in the Forest Act. The relevant forest act that was mainly in effect for the period of 1990-2008 was passed by Parliament in 1996 (Act LIV of 1996 on Forests and the Protection of Forests, see at http://www.nfk.gov.hu/download.php?id_file=40588. Article 7 of this Act stated that "*For the purposes of this Act, forest management shall be qualified as the entire range of activities aimed at maintaining, guarding and protecting forests, ensuring their public function, increasing forest assets, and exercising the forest usufructs in accordance with the provisions of Article 2.*" The relevant section of Article 2, in turn, reads: "*Forests should be used and exploited in such a manner and at such a rate, which allows the prospects of management to endure also for future generations (hereinafter referred to as: sustainable forestry), so that the forests preserve their biological diversity, naturalness, fertility, ability to regenerate, viability, furthermore, that they satisfy the protective and economic needs in harmony with the requirements of society, and fill their role of serving the purposes of nature conservation and environmental protection, health and welfare, tourism, research and education.*"

The most recent forest act was passed in 2009 (Act XXXVII of 2009 on Forests, Protection of Forests and Forest Management), which further reinforced provisions to protect forests and avoid deforestations and initiated a transition to close-to-nature forestry at an increased rate. (The text of the Act, currently in Hungarian can be found at: http://net.jogtar.hu/jr/gen/hjegy_doc.cgi?docid=A0900037.TV.)

Forests in Hungary are predominantly managed in units of relatively homogenous tree cover, i.e., stands (or forest sub-compartments), with a mean area of about four ha. This means that the number of forest sub-compartments in the database is more than half a million, and the number of records with data for the main tree species is more than 1.2 million. The data collection practically covers all known sub-compartments in a well-developed and relatively stringent planning and inspecting system. A general description of this system together with a general description of the Hungarian forests can be found at http://www.nfk.gov.hu/download.php?id_file=40461. Additional information on the Forest Monitoring and Observation System can be found at https://nfk.gov.hu/download.php?id_file=40336.

The geographical location of all known sub-compartments can be identified (in Hungarian) at http://erdoterkep.nebih.gov.hu/. Further data and information, mainly in Hungarian, can also be found at www.nfk.gov.hu/erdeszeti_foosztaly. Finally, additional information concerning data, methods and demonstrating specific procedures can be found at http://www.nfk.gov.hu/Supplementary_Information_news_547.

Forest land is subdivided into sub-categories under the UNFCCC according to the 2006 IPCC GL. The definitions that are generally applied to identify the areas of these sub-categories, and to estimate emissions and removals in these sub-categories, are the following (see also section 6.2 above):

*"**Forest land**"* consists of forests as reported in section 6.2 above and other areas under forest management. It does not include land that is predominantly under agricultural or urban land-use. Both the *Forest Land remaining Forest Land, FL-FL* and the *Land converted to forest land (L-FL)* sub-categories include areas covered by trees and areas under regeneration (together accaled hereinafter 'forest' sub-compartments) as well as roads, areas serving game feeding, forest railways, glades, lanes, timber yards etc. and other areas that are under forest management but are not covered by trees (called hereinafter 'other' sub-compartments; see Table 6.5.1 below).

*"**Afforestation**"* is an activity that leads to the conversion of non-forest land to forest land. From a domestic administrative point of view, the afforestation process can take place in a period of 3-15 years, i.e., until the young stand is deemed established itself successfully, depending on tree species and site fertility. Notwithstanding this, the default transition period of 20 years is used in the GHG inventory to include areas in the L-FL category, consistent with the default IPCC methodology. In the area of the L-FL category, both forest sub-compartments and other sub-compartments are included.

*"**Deforestation**"* is an activity that leads to the conversion of forest land to non-forest land. In Hungary, such conversions take place within one year. Because of this reason, we account for all emissions due to deforestation (including emissions from soils) in each conversion sub-category in the year of the deforestation itself. Both the area covered by trees and all other land (i.e., other sub-compartments) that is moved from Forest land to another LU category are reported.

Using the above definitions, forest land covers a bit more than one fifth of the terrestrial area of the country. The *total area of managed forests*, which is considered in the land-use change matrix as forest land area, includes both forest sub-compartments that are at least potentially covered by trees and un-stocked areas, called other sub-compartments, that indirectly serve forest management purposes. The area of forest land using this definition was 2,072 thousand ha by the end of 2022. To be consistent with the land-use change matrix, forest land in the CRF tables also equals to this forest land area. However, due to historical reasons and because the area actually covered by trees is smaller than this, we also report other area statistics, too. The *total area of all forest sub-compartments*, which is the potentially stocked area, amounted to 1,956 thousand ha in 2022. (As the biomass carbon stock changes take place in the forest sub-compartments, the correct implied emission factors and m^3/ha data should reflect the area of forest sub-compartments.) The *area actually covered by trees*, which is the actually stocked area and which appears in several official Hungarian statistics, amounted to 1,876 thousand ha in 2022. This area is calculated from that of the forest sub-compartments by adjusting for gaps and overlaps in the canopy closure, which are measured during surveys as "canopy closure" (in percent; **Table 6.5.1**, **Figure 6.5.1**).

Table 6.5.1. *The area of forest land, forest compartments and land covered by trees (ha) for selected inventory years.*

Inventory year	Total forest area		
	under UNFCCC (forest and other subcompartments)	under UNFCCC (forest subcompartments)	under UNFCCC (area covered by trees)
	ha	ha	ha
1985	1 755 640	1 643 276	1 493 135
1990	1 813 902	1 681 467	1 551 375
1995	1 861 421	1 727 223	1 608 811
2000	1 921 170	1 787 372	1 657 827
2005	1 983 896	1 853 642	1 769 988
2010	2 046 394	1 922 108	1 862 002
2015	2 060 819	1 940 720	1 869 325
2020	2 057 004	1 941 579	1 872 778
2021	2 063 659	1 948 362	1 875 926
2022	2 072 186	1 956 487	1 875 935

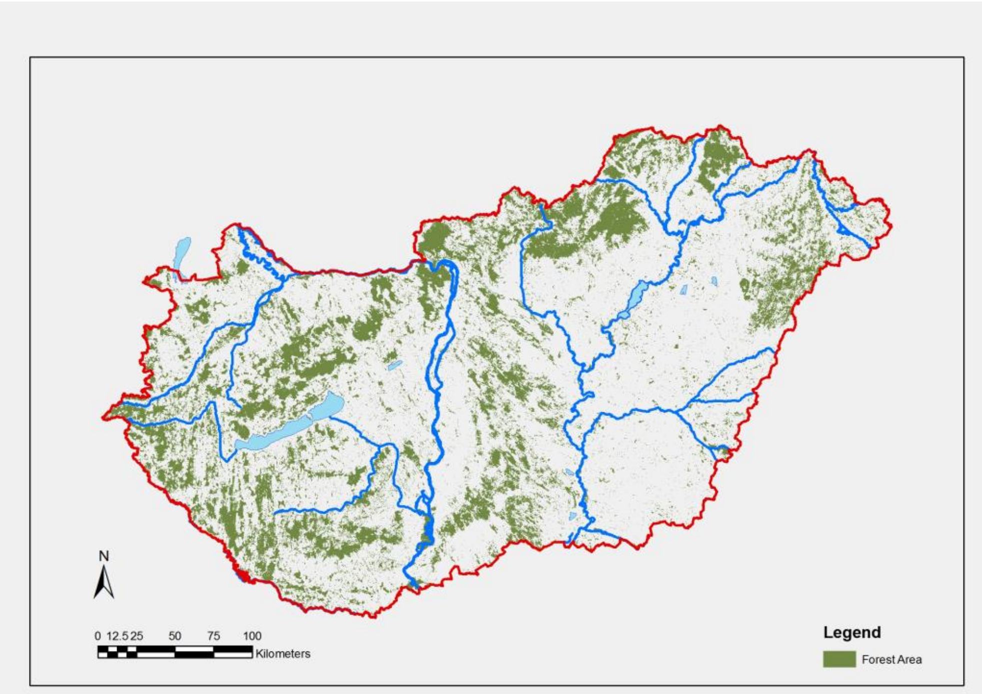

Figure 6.5.1. *The current distribution of forested areas in Hungary.*

The total area of forests has changed considerably since 1930, from about 11% to 21% today, because of systematic afforestations of well over 800 thousand ha and little deforestation. The reason for these area dynamics is mainly that the country is much less forested than other countries (or e.g., the European Union). Also, the Hungarian Forest Law is really rather rigorous, and it is also rather strictly implemented and inspected with respect to deforestations. Forest owners who make a deforestation are obliged to cover the costs of a new afforestation of the same area to offset that deforestation, and these costs are always used to make the afforestation elsewhere. The area of deforested forest sub-compartments (i.e., areas with tree cover before the conversion), which is the main source of emissions due to biomass loss, was under 1000 ha/year until 2015, which is only about 0.07% of the forest area and about 2.3% of the average rate of afforestation. After that year, a three-four times larger area, including area not covered by trees for which emissions from soils are also estimated, has been moved to the other land-use categories annually (**Table 6.5.2, Figure 6.5.2**). The annual area of both afforestations and deforestations has been slightly fluctuating, e.g., because of varying rate of resources in the case of afforestations, and varying rate of highway building in the case of deforestations.

Table 6.5.2. *The area of, and emissions from, conversion of forest land to other land-use categories for selected inventory years. (Emissions from biomass and soils are also reported here for information only. Emissions from other sources are also estimated and reported, see tables below.)* AC_t *= cumulative area at the end of the given inventory year;* AC_{t-1} *= cumulative area at the end of the previous inventory year;* AA_t *= annual area in the given inventory year;* AA_{t-20} *= annual area 20 years before the given year.*

Inventory year	Conversions from FL to other land use					
	Annual area (ha): AA_t		Cumulative area (ha) calculated as: $AC_t = AC_{t-1} + AA_t - AA_{t-20}$		CO_2 emissions ($ktCO_2$)	
	forest subcompartments	forest and other subcompartments	forest subcompartments	forest and other subcompartments	from biomass	from soils
1985	326	326	326	326	40	1
1990	613	613	2 243	2 243	67	4
1995	358	358	3 514	6 412	45	11
2000	719	1 187	5 898	10 586	72	16
2005	411	859	8 678	16 911	50	25
2010	208	2 351	8 467	22 667	28	31
2015	1 383	1 699	12 061	27 551	117	32
2020	1 191	1 503	19 220	37 593	134	37
2021	1 531	1 659	20 230	37 955	260	38
2022	1 225	1 225	20 817	37 323	127	38

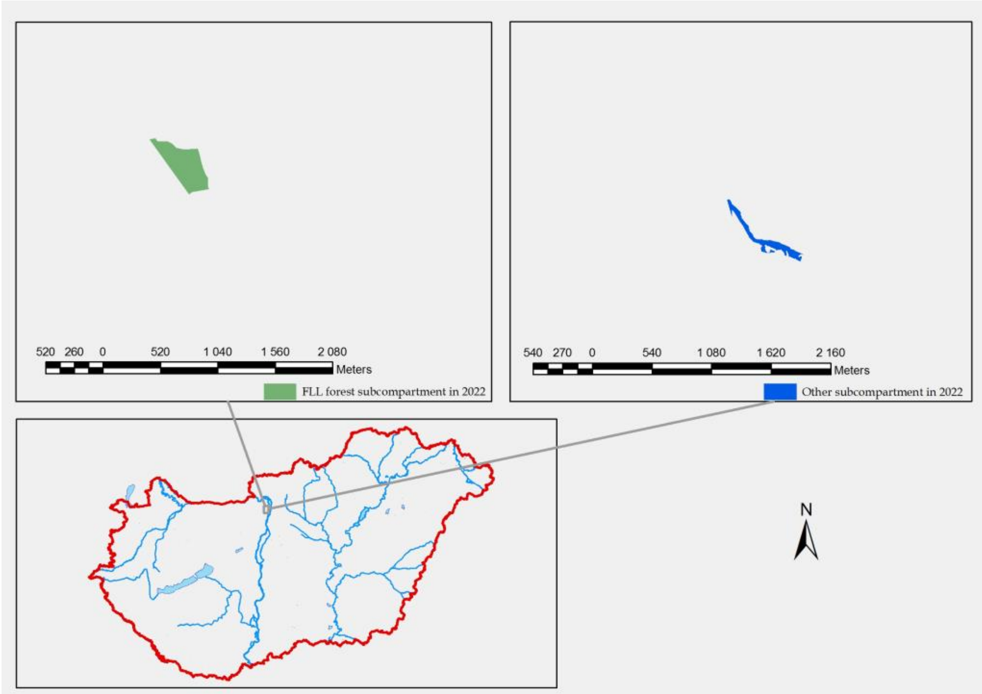

Figure 6.5.2. *Examples for polygons of deforestation areas (forest land converted to other categories, or FLL) in 2022. Note that converted forest sub-compartments and other sub-compartmens may not be close to each other, and that deforested areas are found scattered around the country.*

Some of the above net increase of the forest area is also due to the fact that surveys that are done for forest management planning purposes have identified new forests each year for most of the last three decades, and the area of these forests (called "**found forests**") was added to the managed forest land area.

The history of these found forests is usually unknown. The mean age of the found forests has been above 20 years (see below), but the age of the individual stands at the time of finding them varies. We decided not to estimate the carbon stock changes (typically sinks) of these predominantly young forests *before finding them*, rather, to treat them as an error (i.e., an underestimation) in our estimates for these historical years for the following reasons: (1) to be conservative; (2) because the total area of these forests is not small but not large, either; (3) to avoid estimations with rather high uncertainties (e.g., due to the unknown pre-conversion land-use, no biomass or soil carbon stock before conversion can be estimated); and (4) because it is not practicable to deal with rather small and uncertain amounts that had occurred in the past and the assumption about which does not really add to our understanding of the relevant trends of emissions and removals. (Note that, after finding forests, their carbon stock changes are estimated and reported.)

The trends of all forests have been rather steady for the Hungarian forestry since 1985, affecting both area and standing volume. **Figure 6.5.3** demonstrates these statistics for the FL-FL and L-FL categories.

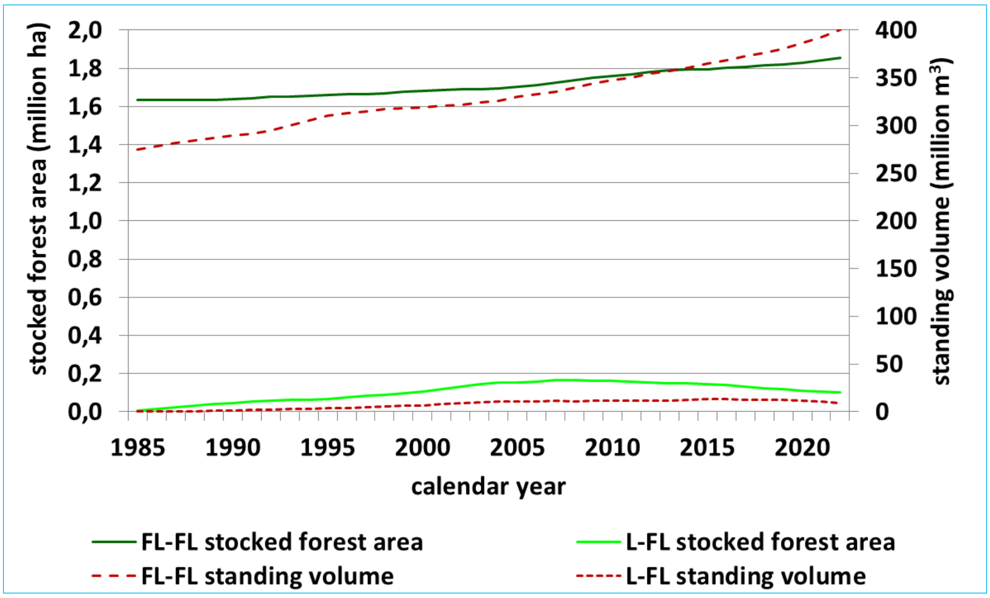

Figure 6.5.3. *The area and standing volume of stocked forest on forest land remaining forest land (FL-FL) and land converted to forest land (L-FL) since 2005. Note that the values of L-FL are rather small but not zero, and values between 1985 and 2004 exclude afforested areas before 1985 (see text below).*

The data demonstrate that the Hungarian forests have had a positive carbon stock change balance for the last almost four decades, mainly due to the above-mentioned large-scale afforestations, but also due to the distribution of the forest area by species as well as over age and site fertility classes, because much less wood has been removed from the forests than the woody increment, and because of the success to manage forests in a sustainable way in other respects, too.

6.5.1.1 Databases used for estimating activity data

Considering methodological issues in general, activity data (i.e. area and growing stock volume statistics) for estimating GHG emissions and removals were taken mainly from the *National Forestry Database* (NFD, see a detailed description about forestry-related databases at http://www.nfk.gov.hu/download.php?id_file=40461). NFD stores data on forest sub-compartments by species, age class and origin (seed or sprout) as well as on other sub-compartments. NFD data have two main sources: forest management planning (modelled growing stock volume and annual increment, see Chapter 6.5.2) and inspection (harvested volume, data related to forest land conversions).

Concerning forest management planning, it is done in 10-year cycles. Each year, the proportion of the forest area surveyed is 10% using field measurements by forest planners (i.e., fifteen forest districts per year out of 150 forest districts), while the characteristics of the remaining 90% of the stands is updated based on yield tables. Field measurements typically include basal area, crown closure and height measurements. With respect to standing volume, the updated value, separately for each species of each forest sub-compartment, is obtained by adding the 'modelled' increment to the standing volume of the previous year and subtracting the wood removed from forests, if any.

Concerning inspection, data is either communicated by forestry companies to authorities (for harvested volume) or directly collected by these authorities.

Besides NFD, Hungary has another database on forests containing data of the National Forest Inventory (NFI). Sampling methodology of the NFI was developed from a survey called Growth Monitoring System (described also in the document linked above) which means that the same grid of 2.8 x 2.8 km is applied in the NFI, as well. Each point of the grid serves as a southwest 'corner point' of a cluster (called 'tract'). Each tract consists of four corner points of a square being placed 200 m from each other. Sampling is carried out in concentric circular plots (of 3 m, 7 m and 12,6 m in radius) around the corner points. Corresponding to the size of the plot, diameter of all trees reaching 7, 12 and 20 cm diameter at breast height is measured. The height of individual trees is assessed from diameter-height curves created for each plot by species. The amount of deadwood is also assessed on the plots (see Chapter 6.5.5.2.2). NFI sampling is periodic, each tract is visited every 10 years. A detailed description of the NFI is available at https://nfi.nfk.gov.hu/.

Hungary chose to apply the NFI only for assessing the deadwood pool whereas living biomass and various area data necessary to estimate carbon stock changes of other pools are calculated from data of the NFD. The reasons for that are the following:

- consistent time series from 1985 is available only from the NFD;
- afforestation and deforestation are registered (in a spatially explicit way) only in the NFD;
- data on forest fire is available only in the NFD (in a spatially explicit way);
- the data updating system of the NFD provides annual data;
- NFD stores sub-compartment polygons 'wall-to-wall', thus not only changes of area but also those of the growing stock can be tracked in a spatially explicit way.

However, there are some disadvantages of NFD:

- data on afforestations is only available beginning 1985, which means that annual areas of the L-FL category in inventory years before 2004 only contain areas for 1-19 years instead of the default period of 20 years;
- the uncertainty of growing stock volume statistics cannot be calculated directly from field data due to two reasons:
    - forest planners apply 'preferential sampling' in most cases which means that sampling plots and trees are not chosen randomly or systematically;
    - sampling data are not stored in the NFD thus cannot be used for uncertainty assessment;
- all growing stock and increment statistics are modelled by yield tables and yield tables assume (refer to) specific harvesting regimes – if thinning intensity or frequency is different from that the statistics may be biased.

Thus, uncertainty of growing stock volumes of NFD must be analyzed indirectly (see https://nfk.gov.hu/download.php?id_file=40460).

Growing stock volume statistics of the NFI are not based on yield tables but rather on sampling, the data from which is stored in the database and can be used for uncertainty assessment. Land conversions may be detected but only with very high uncertainty. The NFI was started only in 2010 whereas the Growth Monitoring System was begun in 1993.

Most emission/removal factors, e.g., wood density, are available by species or species group as country specific data (arising from appropriate research projects). Some data are taken from literature, while only IPCC default values were available for other factors (see below). Expert judgment is rarely applied, and they are mentioned each time when such an expert judgment is used.

The following sections describe land identification and how carbon stock changes as well as non-CO_2 emissions are estimated.

6.5.2 Land identification

The basis of land identification is the field-based, GIS-supported, annual forest planning process whose main aims are:

- to sample the main stand attributes (such as height, diameter, basal area, age, canopy closure) by species and
- to map sub-compartment polygons and in this way
- to create forest management plans.

As mentioned above, each sub-compartment is surveyed every 10 years for the purposes of forest management planning. Forest mapping includes information of stands as small as 0.5 ha, i.e., even areas that are smaller than 1.0 ha. Individual stands that are larger than 0.5 ha are also mapped at a spatial assessment unit of minimum 0.5 ha. All information on sub-compartments (including not only area but growing stock, increment and others) together with sub-compartment polygons are stored in the NFD that is an Oracle database with spatial extension.

Besides storing the polygons of forest and other sub-compartments polygons of afforested and deforested compartments are saved in a separate database table that also contains the date of land conversion as well as the pre- or post-land-use category. However, such data on land-conversions related to forest land have been available only since 2008. The reason for that is that – just like in most other countries – the forest mapping system in Hungary had been designed and run in the last several decades to be predominantly be able to capture the (entire) *area* that is deemed to be forest according to laws and regulations in effect at any given point in time, and not to capture *changes* of this area. Therefore, any *changes* were only registered before 2008 as a result of different *mechanisms* that were *required by domestic law*, such as subsidizing afforestations, or inspecting the implementation of the Forest Act in effect, i.e., closely monitoring deforestations. The forest mapping system was thus not explicitly designed to capture forest area changes, although it especially aimed at identifying and minimizing deforestations, and in fact effectively resulted in a limited extent of forest area reductions that could not be captured. However, as mentioned above, to meet international reporting requirements, conversions involving forests have been registered at the stand level since 2008.

By using the so called *sdo_geom* package of Oracle it is possible to track temporal and spatial changes of all polygons. In this way, changes in forest land can be tracked in a spatially explicit way which can be regarded as 'wall-to-wall' since total forest land is covered by spatially-explicit polygons.

Concerning the difference between regenerations and deforestation, it must be highlighted that, in Hungary, all forests must be regenerated after clearing mature stands by law (as defined by all Forest Acts since 1879, the latest one passed in 2017). Regeneration usually means that a cut-and-regeneration sequence of operations is applied, which involves that most of the area that is cut in a year is void of mature trees for many years. Moreover, regeneration may start one or two years after the final cut is made. When the regeneration is established, it may take years, even a decade, for the seedlings to reach a height of one-two meters, and a full crown closure. In general, less time is needed to reach a crown closure of 30% (i.e., the minimum requirement to meet the definition of forests), but more time may be needed in parts of the regenerations where the first attempt is not successful (where seedlings cannot establish themselves due to, e.g., bad weather conditions, weed competition, browsing by game and others). In general, the rate of closure and whether an area is cleared (deforested) or is under regeneration can only be monitored in the field.

There are country specific professional standards (as defined in the Implementation Rules of the Forest Act, 2009, practically unchanged for years) that set the time limits when regenerations (and afforestations) are deemed as successful. According to these Rules, regeneration must be started not later than two years after clear-cutting. In case of shelterwood and selection cutting, the total cover of the upper canopy layer and that of seedlings and saplings must not be lower than 60 % during the regeneration. If necessary, seedlings must be planted until 15th April of the year after harvesting. “Success” of regeneration means that it is believed that, except for rare extreme events, trees will continue to normally develop after the regeneration has been deemed successful so it can already be regarded forest. This stage is defined by the following criteria:

- species composition is within the limits as requested by the forest management plan
- an even distribution of trees over the entire area
- healthy tree individuals overall
- the number of trees with main shoots is more than a species-specific minimum value, usually between four and eight thousand trees per hectare
- no invasive tree species is widespread in the stand
- minimum height of the main species (e.g., Quercus petraea and Quercus pubescens) reaches 1 m or 1.5 m (all other species).

This stage is to be reached by time limits that are also defined by the above Rules. The time limits depend on species and site conditions and can vary quite substantially (see Table 6.5.3 below). All areas that had to be regenerated have always been regenerated within these limits so far. In case the regeneration of an area is unsuccessful, it becomes part of the FL-L category.

Table 6.5.3. *Time limits of completing regenerations and afforestations (years after the area becomes subject to regeneration, e.g., after clear-cutting).*

Species and origin	Time limit (years) for regeneration type: shelterwood cutting or selection cutting
Quercus pubescens Quercus virgiliana	12
Quercus petraea Quercus robur Quercus cerris Quercus frainetto Fagus sylvatica	10
Other species	8
Species and origin	**Time limit (years) for other types of regeneration**
Quercus pubescens, seed origin Quercus virgiliana, seed origin	14
Quercus petraea, seed origin Quercus robur, seed origin Quercus frainetto, seed origin Fagus sylvatica, seed origin	12
Coniferous sp. Other hard broadleaves, seed origin	10
Other species, seed origin	8
Any species of shoot origin	5

As mentioned above, our system keeps finding new forests in some years. All FF, irrespective of the sub-category, are subject to land-use change, but since when they are found they are usually older than 20 years, all FF areas are included in the FL-FL category when they are found.

The identification of FF areas is based on the fact that we store spatially explicit polygons of all conversions (including found forests) in the NFD 2008 onward with respect to the forest sub-compartments. Thus, presently, we are able to assess the origin of the found forests only for this period. However, it is also possible the estimate the aggregated area of the found forests before 2008, as well. We do know for each inventory year before 2008: 1) the entire forest land area; 2) the area of land converted to forest land (L-FL); and 3) the area of forest land converted to other land-uses (FL-L). In this way we can calculate the annual area of found forest by the following equation:

$$FF = DTF - L\text{-}FL + FL\text{-}L$$

where

FF is the annual area of the found forests; and

DTF is the annual change of the total area.

The increase of the forest area in the FF sub-category over the past decades is due to the following processes and causes:

- natural expansion of the forest area, i.e., natural establishment of stands, sometimes resulting in an increase of the size of an area due to surpassing the thresholds of "forest" as detailed above,
- re-classification of land (i.e., areas of former "croplands," "grasslands" or "settlements" etc. that were found during a survey to be covered by trees, possibly due to unregistered earlier afforestation, or where the above thresholds of "forests" had been surpassed since the previous survey), and
- geodesic re-measurements of the area of previously existing stands at subsequent surveys.

The identified changes of the total forest area in any inventory year are thus only partly physical and actual increases of the "forest" area but are partly due to the continuous development of the ability of the forest mapping and the land-use inventory in general to identify forests with increasing accuracy.

Most stands in the FF category have been identifiable individually since 2008 (see Table 6.5.4 below and also Figure 6.5.2).

When they are found, the origin of found forests is unknown at the sub-compartment level, however, it can be assessed based from stand characteristics. In order to estimate the origin and attach it to each sub-compartment, we applied the following procedure:

1.) We investigated whether there were any planned forests in the 20-m-wide 'buffer zone' of the given found forest. If there weren't any we assumed that the given found forest had been planted. Otherwise (i.e., for all other found forests):
2.) We investigated whether there were any planned forests of the same age and stand type (see Table 6.5.4) like the given found forest in the 20-m-wide buffer zone. If there were any such stands and the area of the found forest was smaller than 0.5 ha, then we assumed that the found forest was a result of a geodesic remeasurement. Otherwise:
3.) All stands of hybrid poplars and willows were regarded as earlier human-induced conversions. Otherwise:
4.) Irrespective of their age all black locust stands were regarded as spontaneous forestation if there were any planned black locust stands in the nearby (in the 20-m-wide buffer zone). Note that very young black locust stands may expand by root sprouts. Otherwise:
5.) If there were any planned forests of the same type in the buffer zone which were older by at least a given 'threshold' number of years than the given found forest, we assumed spontaneous expansion of the stand. Otherwise:
6.) If there were any planned forests of the same type in the buffer zone which were younger than the given found forest, we assumed spontaneous expansion of the stand, too, because we assumed that the neighboring planned forest (from which the given found forest had spread) had been harvested earlier. Otherwise:
7.) We assumed that the given found forest was originated from human-induced afforestation activities. As it can be concluded from the previous steps no planned stands of the same type occurred nearby these found forests (again, in the 20-m-wide buffer zone) or the planned stand (of the same type) was older than the found forest but the difference between stand ages 'is not enough' for supposing spontaneous expansion.

Table 6.5.4. *Stand types and threshold ages (i.e., minimum age when spontaneous expansion may occur either from seeds or from sprouts) used for assessing the origin of found forests. For black locust, hybrid poplar and willow stands no such age was applied, see the assessment procedure described in the text.*

Stand type	Threshold age (year)
Sessile oak-hornbeam	40
Pedunculate oak-hornbeam	40
Sessile oak	40
Pedunculate oak	40
Pubescent oak	40
Turkey oak	40
Beech	40
Black locust	
Other hard broadleaves	30
Hornbeam	30
Maple	30
Ash	30
Hybrid poplar and willow	
Other soft broadleaves	30
Indigenous poplar	10
Willow	10
Alder	30
Lime	30
Birch	20
Scots pine	20
Black pine	20
Norway spruce	20
Other confireous	25

The result of the assessment procedure is summarized in Table 6.5.5 (see also Figure 6.5.4).

Table 6.5.5. *The proportion by type of origin and total annual area of found forests.*

Inventory year	Proportion (%)			Total area (ha)
	Spontaneous expansion	Human-induced conversion	Geodesic remeasurment	
2008	34	65	1	4 759
2009	46	51	3	4 255
2010	44	55	1	2 930
2011	35	63	2	3 183
2012	46	52	2	3 164
2013	50	48	3	2 607
2014	45	52	3	1 938
2015	42	56	2	1 669
2016	55	43	3	670
2017	44	55	1	394
2018	0	0	0	0
2019	0	0	0	0
2020	49	48	3	190
2021	34	62	4	120
2022	41	52	7	264

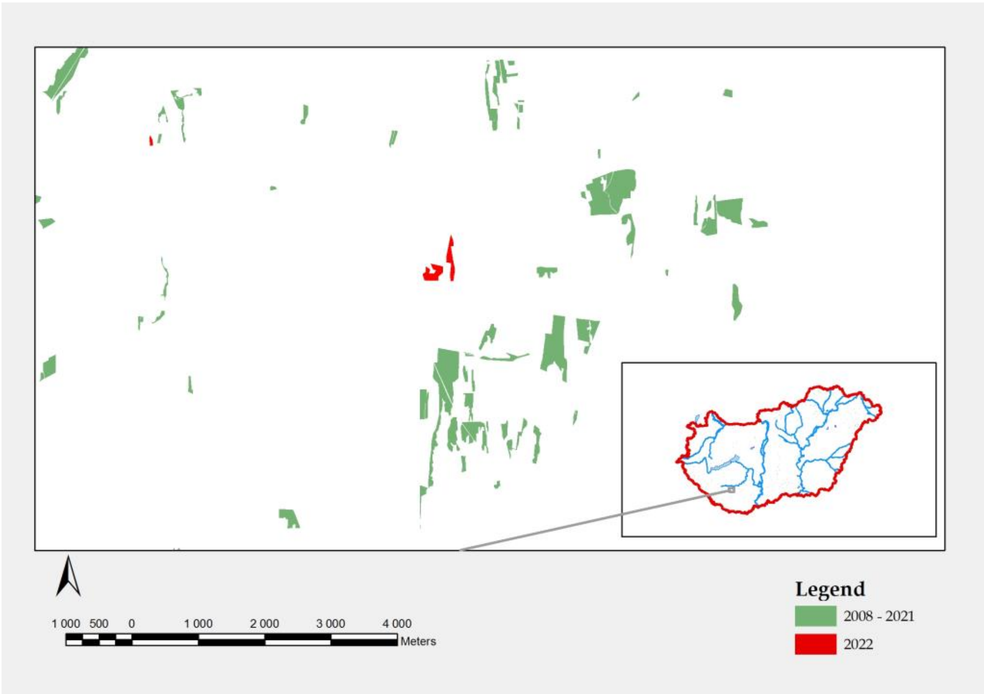

Figure 6.5.4. *Examples for the spatial distribution of found forests in a specific region of Hungary in 2008-2022.*

One important issue related to FF is the need to meet a specific requirement of the 2006 IPCC Guidelines (section 4.2.1.1) when using the stock difference method (Equation 2.5 of Chapter 2, Volume 4). According to this requirement, when estimating biomass carbon stock changes (and we apply this stock change method, see below), “subsequent inventories must also allow identical area coverage in order to get reliable results”. The area of the sub-category FF has been relatively large in some inventory years, i.e., on average about half of annual afforestations (see Figure), therefore, it must be, and is indeed kept, separate from the area of forests that were known at the beginning of the inventory year. (Note that, from a statistical and database management point of view, only those areas can be regarded as “forest” in any inventory year that the forest inventory system “knows” that they exist.) Under the UNFCCC these FF become parts of the forest land in the next inventory year because the definition of FL-FL starts over in each calendar year.

The algorithm of allocating area to the various above land-use and land-use change categories can be found in Table 6.5.6, whereas the evolution of the area of the land-use change categories involving forests is reported in Figure 6.5.5.

Table 6.5.6. *The algorithms of allocating the area of forest sub-compartments by inventory year for the last several years. In the formulas, t_1 means the beginning of the inventory year (i.e., the end of the preceding year), whereas t_2 means the end of the inventory year. The light-yellow color in some cells of the table (with “from DB”in the column title) shows that the data in those cells are taken from the database (i.e., they are the result of calculations elsewhere), whereas data in white cells are calculated in this table according to the formula below the variable name. FL = Forest Land; FL-FL = Forest land remaining forest land; L-FL = Land converted to forest land; FF = found forest; FL-L = deforestation. Δ is used to denote changes of the value of a land-use sub-category between two points of time, or changes estimated by using another methodology if the data is taken from the database. (The table is for demonstration only and may include rounding errors; for precise numbers, and for data by geographical locations, see the respective CRF tables.)*

Inventory year	AREA of forest sub-compartments, ha													
	FL FL = FL-FL + L-FL + new FF			new FL-L	new FF	L-FL (excludes FF)						FL-FL		
	t1	t2	Δ	Δ	Δ	t1	new	moved to FL-FL	FL-L on L-FL	Δ	t2	t1	t2, w/o FF	t2, w/ FF
	from DB; t2 of prev. year	from DB	t2-t1 = = nev L-FL + new FF - new FL-L	from DB	from DB	first: from DB; then: t2 of prev. year	from DB	from DB	from DB (excludes FL-L in age class 20)	new - moved to FL-FL - FL-L on L-FL	t1 + Δ	FL - L-FL	FL - L-FL - new FF	FL - L-FL
2008	1 890 866	1 903 360	12 494	294	5 567	167 556	7 221	8 484	0	-1 264	166 293	1 723 310	1 731 500	1 737 067
2009	1 903 360	1 912 917	9 557	450	6 487	166 293	3 520	7 285	0	-3 765	162 527	1 737 067	1 743 902	1 750 390
2010	1 912 917	1 922 108	9 191	208	3 132	162 527	6 267	6 494	0	-227	162 300	1 750 390	1 756 675	1 759 808
2011	1 922 108	1 927 702	5 594	276	4 229	162 300	1 641	6 334	0	-4 693	157 607	1 759 808	1 765 866	1 770 095
2012	1 927 702	1 933 604	5 902	782	5 522	157 607	1 162	6 739	0	-5 577	152 031	1 770 095	1 776 051	1 781 573
2013	1 933 604	1 938 139	4 535	532	4 370	152 031	697	3 045	0	-2 348	149 683	1 781 573	1 784 086	1 788 456
2014	1 938 139	1 941 016	2 878	1 891	3 348	149 683	1 422	2 713	0	-1 292	148 391	1 788 456	1 789 278	1 792 625
2015	1 941 016	1 940 720	-296	1 383	841	148 391	245	3 946	300	-4 001	144 390	1 792 625	1 795 488	1 796 330
2016	1 940 720	1 939 342	-1 378	2 116	496	144 390	242	6 240	384	-6 382	138 009	1 796 330	1 800 837	1 801 333
2017	1 939 342	1 940 052	710	1 711	1 664	138 009	756	7 854	152	-7 249	130 759	1 801 333	1 807 628	1 809 292
2018	1 940 052	1 939 175	-877	2 218	0	130 759	1 341	7 745	49	-6 453	124 307	1 809 292	1 814 868	1 814 868
2019	1 939 175	1 938 544	-631	2 307	0	124 307	1 676	8 219	53	-6 596	117 711	1 814 868	1 820 833	1 820 833
2020	1 938 544	1 941 579	3 035	1 191	1 795	117 711	2 431	9 242	85	-6 896	110 815	1 820 833	1 828 969	1 830 764
2021	1 941 579	1 948 362	6 782	1 531	879	110 815	7 434	12 402	140	-5 108	105 707	1 830 764	1 841 775	1 842 655
2022	1 948 362	1 956 487	8 125	1 225	259	105 707	9 091	14 001	168	-5 078	100 629	1 842 655	1 855 599	1 855 858

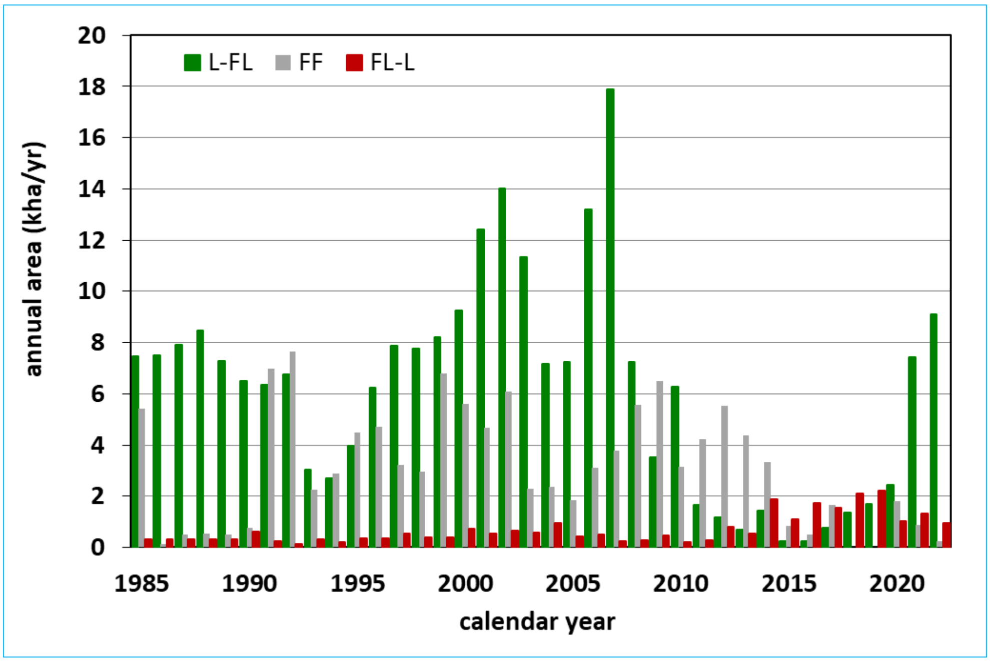

Figure 6.5.5. *The area of annual forest-related conversions over time.*

6.5.3 Methodology to estimate biomass carbon stock changes

For the estimation of carbon stock changes of the **biomass carbon pools**, we apply the **definitions** in Section 6.4. Additionally, we define ***"wood volume"***, or simply ***"volume"*** as the total above-ground overbark volume of trees, including small branches. Note that, in Hungary, the metric "merchantable volume" is not used, and the total above-ground volume is estimated from measured mean breast-height diameter or basal area, mean tree height and age using country-specific yield tables.

With respect to **carbon stock changes in the biomass pools**, only those of trees are estimated using different approaches for the various categories under the UNFCCC as the carbon stock and especially the carbon stock change of the understory vegetation is negligible. For FL-FL, the basis for all approaches is that, first, we calculate carbon *stocks* for *all* forests for year t and year t-1. From this, the *difference* of carbon stocks is calculated (i.e., we use the stock difference method, Equation 2.5 of Chapter 2, Volume 4 of the 2006 IPCC Guidelines). However, this must be corrected to obtain carbon stock change by excluding the stock of the *newly found* forests. For the formulas applied, see below; some of them are also highlighted in Table 6.5.10. Carbon stock *changes* are separately calculated for the other forest-related categories, i.e., L-FL and FL-L using category-specific methods (see sections 6.5.5 and 6.5.6).

In Hungary, the stock difference method is used for FL-FL because, due to the nature of the Hungarian forestry statistics, estimates of total above-ground volume of all forests in the country are available annually. The NFD contains aggregate annual statistics on total growing stocks by species and age classes. These statistics are produced by a bottom-up approach, i.e., growing stocks of stands are aggregated by species and age classes. The stock difference method is also used because, due to the relatively high uncertainties related to annual increment, harvest and mortality statistics, this method is deemed more accurate than the gain-loss method. Systematic errors, i.e., most types of bias, are considerably reduced when consecutive growing stock values are deducted to obtain stock changes. (Note, however, that since growing stocks and their changes incorporate the effects of all processes mentioned above, no particular inferences on emissions and removals can be made separately for any of these processes.)

To estimate carbon stock changes of *all forests*, the first part of Equation 2.8 of the 2006 IPCC Guidelines is used:

$$\Delta C_B = (C_{t2} - C_{t1}) / (t_2 - t_1)$$

where

ΔC_B = carbon stock changes of biomass (tonnes C)

C_t = carbon stock at time t (tonnes C)

t_1 and t_2 = (final day of) two consecutive years.

To estimate biomass carbon stocks, the second part of Equation 2.8 of the 2006 IPCC Guidelines has been *adapted* to the Hungarian conditions (by excluding BEF term from the equation, see below) in the following form:

$$C_t = [V_t * D] * (1 + R) * CF$$

where:

V_t = growing stock (i.e., above-ground volume of all trees) at time t (m^3)

D = basic wood density, tonnes m^{-3}

R = root-to-shoot ratio, dimensionless

CF = carbon fraction of biomass, tonnes C tonnes biomass^{-1}.

Growing stock in the NFD is calculated from measured mean basal area, height and age of sample trees using yield tables. Volume data of the yield tables are assessed by the volume functions by Király (1978) which are in turn based on the volume tables by Sopp et al. (1974). These functions were derived from field measurement of many felled trees, and directly provide total aboveground volume information which includes the volume of stem, all branches, twigs and bark, i.e., all above-ground parts of the trees. Thus, no (biomass or volume) expansion factors are included in the calculations (i.e., their value is taken to be equal to 1).

Growing stock is estimated during the continuous survey of the forest planning from various stand measures (such as height, diameter, basal area, and density) depending on species, age, site and stand quality. More accurate methods are usually used for stands of higher volume stocks. Given that, as mentioned above, growth and yield functions are used in years between surveys to update volume stocks of each stand, volume and carbon stocks are available for each stand and for each inventory year. (Note that, according to Somogyi (2008b), the growth of trees accelerated in Hungary recently. Yield tables cannot be regularly updated, however, this growth increase is equivalent to a small underestimation of the updated volume stock changes and net CO_2 removals, thus, the approach is conservative.)

For inventory years prior to 2008, we only identified the total area of FF, and conducted a sampling of management plans to establish their specific growing stock (m^3/ha). From these values, total growing stock of FF could be estimated for each inventory year by using the total FF area. The mean growing stock of all FF that were identified before 2007 is 129.6 m^3/ha. For years 2008 and later, we are able to directly estimate the volume stock of all FF land, and thus we are able to report that the average growing stock varies between 81.2 and 160 $m^3 ha^{-1}$ for the years of 2008-2020 and was 150 m3/ha in 2021. The mean age of FF varied between 22.0 and 27.8 years for the years of 2008-2020 (with no new forests in 2018 and 2019) and was 13.3 years in 2022.

Concerning wood density, the basic wood densities (Table 6.5.7), which is used across all reporting years, are based on a thorough revision of data reported in literature combined with re-measurements of wood densities for some species in a dedicated project (Somogyi, 2008a). Note that, to be consistent with the approach to use total aboveground volumes, the basic wood densities applied were measured from samples taken from all above-ground parts of the sample trees, including branches and bark.

Table 6.5.7. *Basic wood density values for the main tree species and species groups in Hungary (Somogyi, 2008a)*

Species or species group	Basic wood density (t/m^3)
Quercus robur	0.57
Quercus petraea	0.61
Other Quercus	0.55
Quercus cerris	0.64
Fagus sylvatica	0.59
Carpinus betulus	0.58
Robinia pseudoacacia	0.59
Acer sp.	0.52
Ulmus sp.	0.58
Fraxinus sp.	0.56
Other hard broadleaves	0.5
Hybrid poplars	0.34
Indigenous poplars	0.36
Salix sp.	0.36
Alnus sp.	0.43
Tilia sp.	0.48
Other soft broadleaves	0.48
Pinus sylvestris	0.42
Pinus nigra	0.47
Picea abies	0.39
Larix decidua	0.49
Other conifers	0.37

With respect to below-ground biomass, a general value for the root-to-shoot ratio (R) is applied. Due to lack of proper country-specific data, and in order to be consistent with previous estimates, IPCC default values (Table 4.4 of Chapter 4 of Volume 4 of the 2006 IPCC Guidelines) were considered by expert judgment). Considering that the majority of the forests in Hungary is young, and that the average volume stocks of FL-FL (calculated on the basis of volume and the area of forest sub-compartments) is 173 m^3 ha^{-1} (in 1990) and 209 m^3 ha^{-1} (in 2022), which demonstrates that stands predominantly grow on medium-quality sites, a conservative value of R of 0.25 is used for all species. The IPCC default values have relatively high uncertainty, but we believe that the probable value for the Hungarian forests is significantly higher then 0.25, which is thus a conservative value as long as forests are net sinks.

To ensure that the above R value is not too high, we checked values in the 2019 IPCC Refinement, too. Both the 2006 IPCC GL and its Refinement heavily rely on Mokany et al.[1] The IPCC GL do not of course contain data for all Hungarian forest types, however, on one hand, "Quercus spp." seems to be rather representative for our species, and on the other, the value of R tends to decrease over age (Figure 6a of Mokany et al.), thus, the value suggested for such forests of biomass larger than 70tC/ha, which is larger than the value of 0.25 that we selected, R for younger forests should be even larger. Also, R is larger for poorer sites than for better ones (Figure 5.b by Mokany et al.); and our sites are below average in terms of site fertility, which calls for the application of a larger-than-average R value.

We also note that the 2019 Refinement includes data for Temperate, Continental Europe (i.e., for this level) the value for which reported is much higher than 0.25 for both Quercus and Conifers.

Finally, the reported estimated values of a recent paper from Russia[2] (Table 4 & 5) are also consistent with our selection of the R value. It may happen that the value of 0.25 is an overestimation for some stands, but our aim with the GHG inventory is to come up with overall estimates, and considering all the above, we are confident that the R value that we apply leads to a net underestimation of the sink.

Concerning the carbon fraction of dry wood, the IPCC default values, i.e., 0.48 and 0.51 tonnes C tonnes biomass^{-1} (Table 4.3 of Chapter 4 of Volume 4 of the 2006 IPCC Guidelines) were used for broadleaves and coniferous species, respectively. (These values, just like wood density and R, were consistently applied for the entire time series.)

Note that losses of carbon in biomass on land converted to forests are also reported in section 6.5.5 below using the methodology described in section 6.4.4 above.

[1] Mokany, K., Raison, J.R. and Prokushkin, A.S. (2006). Critical analysis of root:shoot ratios in terrestrial biomes.

Global Change Biology 12: 84-96. URL: http://hdl.handle.net/102.100.100/176720?index=1

[2] Schepaschenko, Dmitry, Elena Moltchanova, Anatoly Shvidenko, Volodymyr Blyshchyk, Egor Dmitriev, Olga Martynenko, Linda See, and Florian Kraxner. 2018. "Improved Estimates of Biomass Expansion Factors for Russian Forests" Forests 9, no. 6: 312. URL: https://doi.org/10.3390/f9060312

6.5.4 Forest Land remaining Forest Land (CRF sector 4.A.1)

6.5.4.1 Category description

The main inventory estimates for the FL-FL category can be found in Table 6.5.8, whereas Table 6.5.9 summarizes methodological information for this category. (Note that, to be consistent with the CRF tables, only the area of forest and other sub-compartments is reported in this table.)

Table 6.5.8. *The area of forest and other sub-compartments as well as emissions (+) and removals (-) in the FL-FL sub-category by gas and inventory year for selected inventory years.*

Inventory year	Emissions (+) and removals (-) in the FL-FL sub-category by gas and inventory year					
	Area	CO_2	CH_4	CO	N_2O	NO_x
	(ha)	(kt)	(kt)	(kt)	(kt)	(kt)
1985	1 740 962	-337	0,52	10,65	0,029	0,299
1990	1 739 044	-2 918	0,49	9,42	0,027	0,264
1995	1 734 876	-5 384	0,40	6,92	0,022	0,194
2000	1 730 701	621	0,50	7,24	0,028	0,317
2005	1 738 729	-3 544	0,66	6,38	0,037	0,422
2010	1 791 235	-1 892	0,28	6,08	0,015	0,178
2015	1 833 870	-3 758	0,68	6,44	0,038	0,442
2020	1 883 577	-5 332	0,37	5,63	0,020	0,249
2021	1 898 990	-5 390	0,39	6,69	0,021	0,250
2022	1 917 857	-5 117	2,16	7,23	0,119	1,444

Table 6.5.9. *Methodological summary for the Forest Land remaining Forest Land category. (CS=country specific; D: default; EJ: expert judgment; IE: included elsewhere; AD: activity data; EF: emission/removal factor)*

<table>
<tr><th rowspan="2">Category</th><th rowspan="2">Type of information</th><th colspan="5">Carbon stock changes</th><th rowspan="2">Table(5) I, II, V</th></tr>
<tr><th>AGB</th><th>BGB</th><th>DW</th><th>LI</th><th>SOIL</th></tr>
<tr><td rowspan="4">FL-FL</td><td rowspan="3">E/R</td><td rowspan="3">CS</td><td rowspan="3">D/EJ</td><td rowspan="3">AD: CS; EF:CS</td><td rowspan="3">Not estimated (assumed to be in near equilibrirum)</td><td>Mineral: Not estimated (assumed to have positive C stock changes, see text)</td><td>Fertilization: IE</td></tr>
<tr><td>Organic: AD: CS</td><td>Drainage and re-wetting: NO</td></tr>
<tr><td>EF: D</td><td>Biomass burning (slash burning + wildfires): AD: CS; EF: D</td></tr>
<tr><td>Uncertainty</td><td colspan="3">Tier 2 (Monte Carlo) analysis</td><td colspan="2">N/A</td><td>Tier 2 (Monte Carlo) analysis</td></tr>
</table>

6.5.4.2 CO_2 emissions and removals

The methodology to estimate emissions and removals in the forestry sector is based on that of the 2006 IPCC Guidelines. Whenever it was possible, country specific data was used (Tier 2), and IPCC default values (Tier 1) and expert judgment were only used in a few cases. Emissions and removals from the biomass and soil carbon pools are quantified and reported, however, due to lack of data, only assumptions are applied with respect to the other carbon pools to comply with requirements for completeness.

6.5.4.2.1 Biomass

Carbon stock changes of the biomass pool in the FL-FL category are calculated from those of the entire Forest Land, FL-L and L-FL sub-categories. The methodology applied for the various sub-categories is as described in section 6.4 above. The input data from these categories, together with the formulas that are used to derive the FL-FL estimates are included in Table 6.5.10 below. The calculation method used ensures that the stocks of the new FF are excluded from calculating net removals. However, the net removals of all FF are included in the net removals of the FL-FL category. Removals for the areas that are found in the inventory year are not estimated based on a dedicated survey in the newly FF, rather, using an area specific mean net removal value (just like an "implied emission factor") of the entire FL-FL category (calculated as the ratio of the total net removals and total area of forest sub-compartments), multiplied by the total area of found forests. Note that C stock changes of all FF are accounted for under FL-FL, but those of FF with age under 21 are also separately estimated for reasons of transparency (see section 6.5.5.2.4).

To estimate total growing stock of forests found in a specific inventory year, average area-specific growing stock of FF was estimated from that of the 'identified' FF for which we had both area and growing stock data. Growing stock was calculated by multiplying the assessed total area by the calculated mean m^3/ha value. Carbon stock of FF was estimated in the same way as described in the relevant chapter (i.e., 6.5.3) of the NIR with the difference that for wood density, instead of species-specific values, we applied the generic average value of 0.5.

***Table 6.5.10** Algorithms and data sources of calculating carbon stock changes for FL-FL under the UNFCCC, together with sample data for the last several inventory years. For the calculation of emissions and removals from other categories in the table, see also the respective sections. The light yellow color in some cells of the table (with column title "from DB") shows that the data in those cells are taken from the database (i.e., they are the result of calculations elsewhere), whereas data in white cells are calculated in this table from the respective cells according to the formula below the variable name. NE means net emissions, and IEF means "implied emission factor". Symbol Δ is used to denote changes estimated as either differences between the value of a land-use category at two time points or using another methodology. All other notations are as in Table 6.5.3. (The table is for demonstration only and may include rounding errors; for precise numbers, see the respective CRF tables.)*

Inventory year	ΔC of BIOMASS under the UNFCCC													
	FL		new FF (identified in the inventory year)		FL-L, new (forest sub-compartments)		FL		L-FL				FL-FL	
	gross Δ	IEF	stock	IEF	Δ	IEF	net Δ = NR	IEF	gains	IEF	losses	Δ	NR	IEF
	from DB	NR/area (t CO_2/ha)	from DB	stock/area (t CO_2/ha)	from DB	Δ/area (t CO_2/ha)	gross ΔFL - new FF stock - FL-L	NR/area (kt CO_2/ha)	from DB	gains/area (t CO_2/ha)	from DB, only for information in this table (kt CO_2)	gains+ losses, only for information in this table (kt CO_2)	net ΔFL - L-FL gains (includes NR of all FF, kt CO_2)	NR/area (t CO_2/ha)
2008	-5 048	-2,67	876	157	27	92	**-4 199**	-2,22	**-1 260**	-7,5	120	**-1 140**	**-2 939**	-1,69
2009	-4 139	-2,17	980	151	58	129	**-3 217**	-1,69	**-1 202**	-7,2	59	**-1 143**	**-2 015**	-1,15
2010	-3 603	-1,88	478	153	28	134	**-3 153**	-1,65	**-1 216**	-7,5	98	**-1 118**	**-1 937**	-1,10
2011	-3 566	-1,86	644	152	46	166	**-2 967**	-1,54	**-1 144**	-7,1	27	**-1 117**	**-1 823**	-1,03
2012	-4 578	-2,37	872	158	132	168	**-3 838**	-1,99	**-1 098**	-7,0	20	**-1 078**	**-2 740**	-1,54
2013	-3 692	-1,91	630	144	62	116	**-3 124**	-1,62	**-1 086**	-7,1	12	**-1 075**	**-2 038**	-1,14
2014	-4 632	-2,39	555	166	85	45	**-4 161**	-2,15	**-1 097**	-7,3	20	**-1 077**	**-3 064**	-1,71
2015	-5 059	-2,61	156	186	117	108	**-5 020**	-2,59	**-1 075**	-7,2	4	**-1 071**	**-3 945**	-2,20
2016	-4 159	-2,14	87	175	151	88	**-4 224**	-2,18	**-1 041**	-7,2	4	**-1 036**	**-3 183**	-1,77
2017	-4 776	-2,46	329	197	168	109	**-4 615**	-2,38	**-1 003**	-7,3	12	**-991**	**-3 612**	-2,00
2018	-3 919	-2,02	0	0	217	103	**-4 135**	-2,13	**-973**	-7,4	22	**-952**	**-3 162**	-1,74
2019	-4 589	-2,37	0	0	228	103	**-4 817**	-2,48	**-942**	-7,6	27	**-916**	**-3 875**	-2,13
2020	-6 289	-3,24	180	100	134	130	**-6 243**	-3,22	**-911**	-7,7	39	**-871**	**-5 332**	-2,91
2021	-6 198	-3,19	163	185	260	199	**-6 296**	-3,24	**-906**	-8,2	123	**-783**	**-5 390**	-2,93
2022	-5 887	-3,02	27	103	127	132	**-5 987**	-3,07	**-870**	-8,2	149	**-722**	**-5 117**	-2,76

The resulting carbon stock changes in FL-FL, in combination with those in L-FL (see below) demonstrate that the biomass of the forests in Hungary has been a sink for the last almost four decades. This is consistent with the fact that the total current annual increment (CAI) for the country has been estimated to be much higher than the annual harvests for all historical years (Figure 6.5.6).

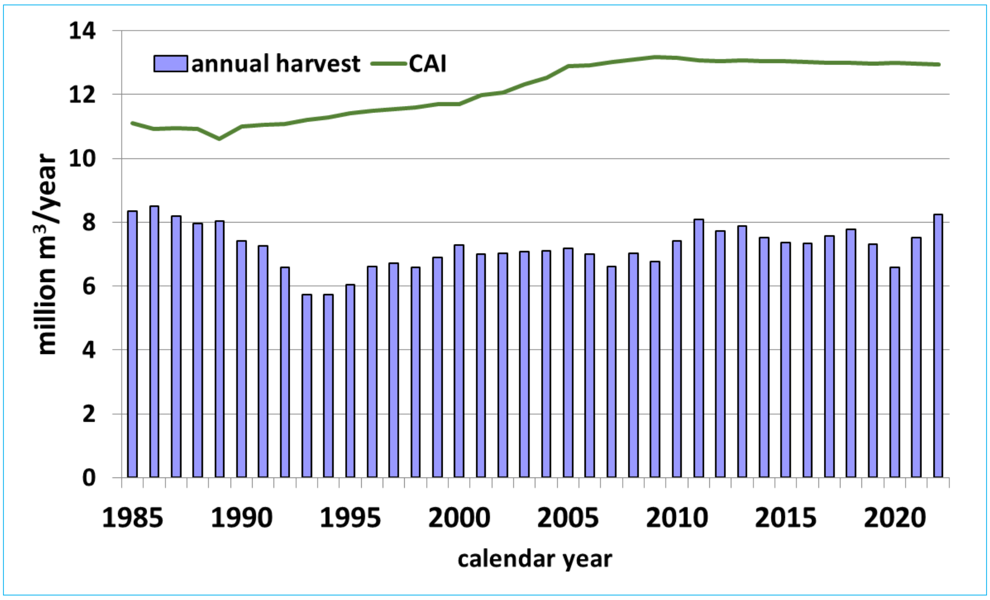

Figure 6.5.6 *Annual harvest and current annual increment (CAI) in Hungary for the entire time series. Data source: National Forestry Database.*

The net volume stock changes, and thus the net carbon stock changes display some variability which is a partly consequence of the stable CAI estimates and the rather variable harvest estimates, thus, the reported variability is considered to partly represent true variability. However, the applied survey method (i.e., continuous forest planning with a mean recycle length of about ten years, and the use of yield tables for updating between two consecutive surveys etc.) both reduces and removes and also adds some variability. If the real silvicultural practice differs from that assumed in the yield table used for updating, it can lead to bias in the modelled increment and consequently in the growing stock statistics at the level of the sub-compartment. These biases are, however, removed by field measurements every 10 years. The effects of weather conditions on increment and on mortality (varying over space and time) are also accounted for at the remeasurements, too. Thus, on one hand the data management system of the NFD leads to some kind of variability of growing stock statistics that results in much higher variability in stock changes (since the value of the annual stock-change is only approximately 1 % of the value of the total growing stock). On the other hand, the stock-change may be rather sensitive to harvesting rates which was demonstrated by model results cited in the Report of the technical assessment of the forest management reference level submission of Hungary submitted in 2011. In section 19 on page 7 of that report, it is stated: the change “estimate is highly sensitive to the assumed harvesting rate because an increase or a decrease of only 10 per cent in the assumed harvest value can result in significantly different results and even direction of the sign of the changes (i.e., from sink to source and vice versa)”.

Other components of the true variability, which are related to the annual variation of true increment of the stands due to weather may also be reflected in the data, but they cannot be separately captured by our estimation system. Finally, note that the reported inter-annual variability of the FL-FL carbon stock change estimates is not an artefact, and reflects relatively small changes in relatively large carbon stocks (these carbon stock changes being, in the last couple of years, less than one percent of the total biomass carbon stocks), mainly due to volume increment and harvest.

Forest-related land-use conversions, reforestations and harvesting operations are checked by forest inspectors who record various descriptive statistics in the NFD, as well.

As a consequence of the data management system of the NFD stock difference is highly variable over time which is a result not only of various effects in the given year but also those in the previous decade.

6.5.4.2.2 Dead organic matter

Of all dead organic matter (DOM), we report on the carbon stock changes of the deadwood (DW) pool based on regression models of area-specific deadwood volume that were developed from deadwood sampling data of the NFI. The regression models and calculation method of deadwood stock-change are described in Chapter 6.5.5.2 for land converted to forest land. By applying the same models for FL-FL and L-FL, the estimation for FL-FL was done as follows: first, appropriate areas for all forests by stand type were combined with the age-specific deadwood volume data to calculate deadwood stocks for all forests for each inventory year; then, annual carbon stock changes could be calculated for all forests; finally, the amount of annual deadwood C stock change for land converted to forest land was subtracted from that to obtain the annual deadwood C stock change for the FL-FL category.

The estimates show that the total amount of the above-ground and below-ground deadwood has been slowly but steadily increasing since 1985 (Figure 6.5.7).

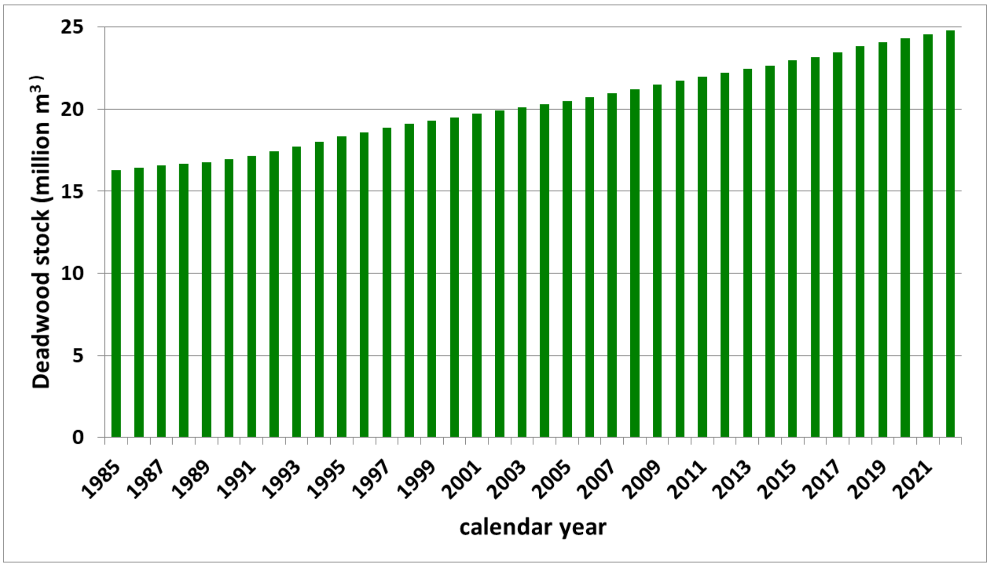

Figure 6.5.7. *The amount of the sum of the above-ground and below-ground deadwood stock for the FL-FL category for the entire time series. Data source: National Forest Inventory.*

This increase of the amount of DW stock, and also most probably that of LI, in the Hungarian forests is mainly due to two reasons. One is the prominent level of sustainability of the management of existing forests, which means that, for many years, less or much less wood has been harvested than what is grown (Figure 6.5.3). The difference between increment and harvests is large enough to claim not only sustained yield as detailed above, but also to assume that a lot of the uncut trees die due to the well-known process of self-thinning in stands where density has become high, or small-scale disturbances due to wind-break and snow-break which result in the increase of the amount of DW and LI. Also, for the last several decades, close-to-nature forest management has been promoted in Hungary, and clear-cuts have been restricted, especially after the adoption of the most recent Forest Act of 2009. This Act requests that semi-natural forests be managed in an increasingly natural way, which includes leaving more DW and LI in the forest after harvests than before, that gaps in the canopy be created and maintained, and that species mixture be enhanced. As a result of the implementation of these requirements, we can safely assume the accumulation of both DW and LI in the Hungarian forests for the last several decades.

Another reason of the increase of the amount of both DW and LI in all forests is that about one-third of all forests are afforestations since 1930 (i.e., before 1985), and much of these forests are still in their intensive growing phase, which means that carbon stocks of DOM pools have not saturated yet.

Finally, no major disturbances or other processes have occurred that could have resulted in substantial emissions from the DOM. Therefore, although no quantitative estimates can be made on the increase of the amount of DOM, the Tier 1 assumption can safely be made for LI, at least on average in the long run, that this pool is not a source.

The application of this assumption, as in most other countries, is due to the prohibitive costs and the very high variability which would require that measurements are taken on a very high number of plots, however, limits due to the practicability principle would not necessarily result in the reduction of the uncertainty to an acceptable level.

Our neighboring country, Austria e.g., demonstrated in its NIR of 2020[3] that the uncertainty of the LI and soil pools of forest land is very high (for LI, ±162% at the country level and ±144% at the foothills that are most similar to Hungary), and that Monte Carlo simulations showed that these two pools have by far the highest contributions (3/4 to 4/5) to the total uncertainties of the emissions/removals of the total forest land subcategory.

There are very few examples for a LI monitoring that could be used for the actual estimation of carbon stock changes in the LI pool. One example is the one of the Netherlands where five different datasets were combined for the purposes of the GHG inventory[4], yet, it was concluded that: "The results of the Monte Carlo analysis consistently showed a carbon sink in litter; however the magnitude was very uncertain (Figure 4.5). Therefore, the more conservative estimate was used to set the accumulation of carbon in litter in Forest Land remaining Forest Land to zero…."

Some countries apply modelling (e.g., the YASSO model) to estimate soil and LI carbon stock changes. However, to correctly apply such a model, proper parametrization or validation is required, and while we are also thinking about applying such a model, we are not yet ready to do it especially considering the still high associated uncertainty and resources required for parametrization and validation of applying such a model.

The above-mentioned monitoring in the Netherlands demonstrates that, in correlation with the increase of the biomass carbon stocks, the carbon stocks of both the DW and the LI pools are also increasing. Given the similarities between the forests of the two countries (not necessarily concerning forest types but other relevant characteristics such as age distribution which determine the trends over large, forested areas), the above correlation is also believed to apply to Hungary, and since our biomass carbon stocks have been increasing for several decades now, it follows that the litter carbon stocks have also been increasing.

As mentioned above, there is evidence from our NFI that the DW C stock is increasing in forest land remaining forest land. LI is a pool that contains dead mass of plants from two main sources: one is leaves and the other is dead woody parts such as twigs and cones that have currently not been accounted for in the deadwood pool. This means that when there is a carbon flow into the DW pool, then there must also be a carbon flow into the LI pool, i.e., the inflows are correlated, and an increasing deadwood C stock may lead to an increasing litter C stock. In the case of Hungary, LI is not removed from the forests, which means that even if emissions from decay are different from the DW and LI pools, the net carbon stock changes of these two pools should also correlate to a degree high enough to state that if the DW pool is a sink (and it is), then, as a minimum, the LI pool is not a source, either.

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[3] page 411 in: Austria's National Inventory Report 2020. Submission under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. URL: https://unfccc.int/sites/default/files/resource/aut-2020-nir-15apr20.zip

[4] pages 38-40 in: Greenhouse gas reporting for the LULUCF sector in the Netherlands. Methodological background, update 2019. E.J.M.M. Arets, J.W.H. van der Kolk, G.M. Hengeveld, J.P. Lesschen, H. Kramer, P.J. Kuikman & M.J. Schelhaas. Statutory Research Tasks Unit for Nature & the Environment, Wageningen, February 2019. URL: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwih77Gb7NnsAhXK_qQKHWkcBN8QFjAAegQIAhAC&url=https%3A%2F%2Fedepot.wur.nl%2F472433&usg=AOvVaw0FMmuFuzUNAMeVTRMNMZkk

In conclusions, we repeat that the main reason for the increase of the DW C stock in Hungary is the ageing of the forests (in general, there is less litter fall in young forests than in older ones) and the low intensity of harvest relative to the current annual increment. When harvests are less than current annual increment, self-thinning kicks in sooner or later, producing more and more of both DW and LI. On the other hand, there are no processes in the Hungarian forests that would lead to the loss of LI (or DW). The Hungarian forests have been sustainably managed (at least with respect to area and biomass) for decades, and transition to the forest land remaining forest land of formerly afforested areas, as well as that of FF, ensure that the increase of both the area and the carbon stock in the FL-FL category is larger than losses (note that losses due to deforestation are accounted for in the FL-L category). Therefore, by also considering the practicability principle, and applying the combination of literature review and sound scientific reasoning, we have demonstrated that the LI pool is not a source.

6.5.4.2.3 Soils

As noted above, the Tier 1 assumptions applied for mineral soils of FL-FL, i.e., that these mineral soils are in carbon equilibrium. However, because the amount of dead organic matter increases, the DOM input into the soils increases which ensures that, even if slowly, the carbon stocks of the soils increase in areas with no disturbance. Although there are some events in some forests that may lead to emissions (e.g., natural disturbances, harvests etc.), overall, there seems to be a net carbon sink on all areas. A recent evaluation of permanent soil sampling points in forests showed that carbon stocks of forests where final harvest and subsequent soil preparation has not been made, the mean annual rate of carbon stocks amounts to 0.357 tC/ha*yr with a half-width CI of 0.013 tC/ha*yr. Based on the combination of these quantitative estimates and reasoning (see details in Chapter 6.4.1) we conclude that, overall, mineral soils under the FL-FL category can be considered to be not a source.

With respect to organic soils, we conducted a dedicated project (Illés et al. 2013) to identify the forest area on organic soils. In this project, we measured the depth and carbon content of various layers in a sample of about 130 stands where it was suspected that we identify organic soils. The results of the project show that, in fact, the total area of forests on organic soils in the country amounts to 6.46 kha (the distribution of stands of organic soil is demonstrated on Figure 6.5.8). There is no rewetting of forest areas in Hungary. The emissions from the organic soils identified, which were typically drained several decades ago, are calculated by multiplying this area by the default emission factor given in Table 2.1 of the Wetlands Supplement for Drained Forest land, temperate zone, i.e., 2.6 tCO_2ha^{-1}. Direct N_2O emissions from organic soils were estimated by multiplying the area or organic soils by the default emission factor from Table 2.5 from the Wetlands Supplement for temperate forest land (2.8 kg N_2O-N ha^{-1} yr^{-1}).

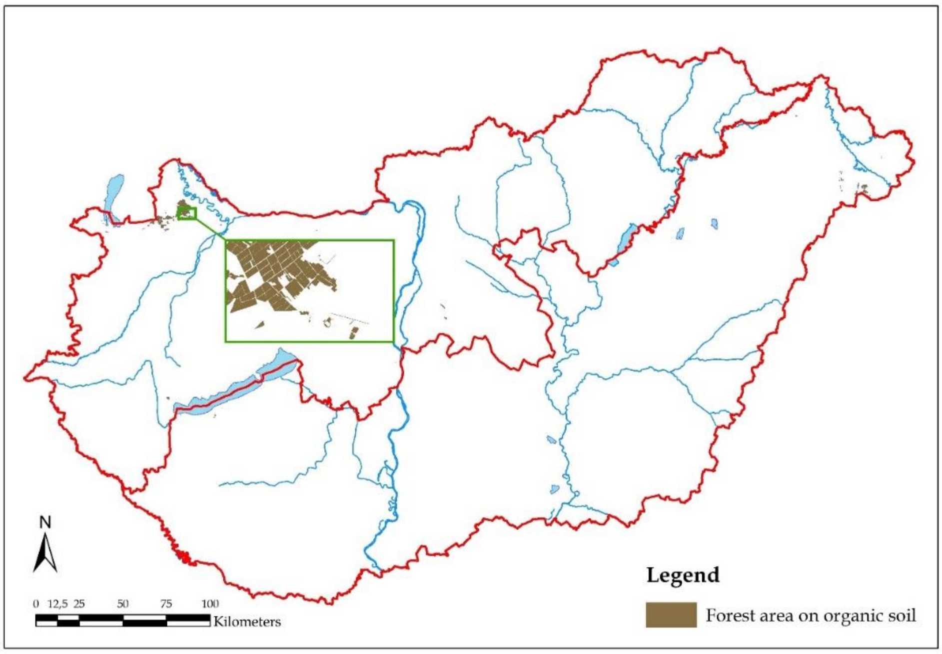

Figure 6.5.8. *The distribution of forest stands on organic soil in Hungary (brown-colored areas; based on Illés et al., 2013).*

6.5.4.2.4 Harvested Wood Products

Beginning 2023 we report emissions and removals form harvested wood products (HWP) pool based on the Tier 2 first order decay methodology given in the 2019 IPCC Refinement (i.e., equation 12.1, 12.2 and 12.4 of the Refinement). Country-specific HWP production and trade data and default emission factors are used. Only HWP from domestic harvest is taken into account, the estimates include export and exclude import (Equation 12.8 and 12.9). Conversions factors from Table 12.1 and half-life values from Table 12.3 of the Refinement (i.e., two years for paper, 25 years for wood panels and 35 years for sawn wood) are used. For wood in solid waste disposal sites instantaneous oxidation is assumed.

For the estimation of the carbon stock changes of the HWP pool, the following data sources were used.

International databases:

- UNECE/FAO TIMBER database, 1964-2010, as of January 2012;
- Joint Forest Sector Questionnaire (JFSQ) by ITTO, 2011-2014.

Domestic forestry databases:

- production data from the works of Aladár Halász (Halász, 1960; 1966; 1994);
- production and trade data from Statistical Yearbooks and Pocket Books published by the Hungarian Central Statistical Office (KSH, 1965-1988);
- production data from the National Statistical Data Collection Program (OSAP) by the National Land Centre;
- production and trade data of the Hungarian Central Statistical Office.

Data are available since 1900 for the production categories as well as by domestic removals, import and export, however, due to concerns of accuracy, only data since 1964 have been used. Some data as examples are shown in Table 6.5.11.

***Table 6.5.11**. Volume or mass of wood and HWPs in selected inventory years by product and production categories used in the calculation of the carbon stock changes of the HWP pool.*

Wood product category	Type of quantity	Unit	Calendar year					
			1990	2010	2015	2020	2021	2022
Industrial roundwood	Removals	1000 m^3	3 512	2 746	3 065	2 457	3 125	2 901
	Import	1000 m^3	958	262	284	260	258	290
	Export	1000 m^3	1 159	875	680	728	838	758
Wood pulp	Production	1000 m.t.	46	0	19	51	57	66
	Import	1000 m.t.	152	88	142	147	122	141
	Export	1000 m.t.	3	0	10	4	1	3
Coniferous sawnwood	Production	1000 m^3	331	139	168	120	141	85
Non-Coniferous sawnwood	Production	1000 m^3	767	274	319	280	302	414
Veneer sheets	Production	1000 m^3	14	12	14	35	36	13
Plywood	Production	1000 m^3	14	167	47	49	57	60
Particle board (including OSB)	Production	1000 m^3	317	728	418	693	815	826
Hardboard	Production	1000 m^3	0	275	168	398	477	457
MDF (medium density fibreboard)	Production	1000 m^3	0	47	1	0	0	0
Fibreboard, compressed	Production	1000 m^3	50	23	0	0	0	0
Other board	Production	1000 m^3	0	0	0	390	412	426
Paper and paperboard	Production	1000 m.t.	443	662	793	864	867	1 057

Data on recovered paper production, import and export was not available, thus in Equation 12.8 only industrial roundwood and wood pulp data was used.

Note that, this year, wood pulp and industrial roundwood production data was recalculated for some years between 1970 and 2014 due to the correction of copying errors. Particle board, hardboard, MDF, fiberboard, other board and paper and paperboard production data was also recalculated between the years 1996 and 2020. The previously used data of the National Statistical Data Collection Program of the National Land Centre was replaced as new, more accurate production data became available published by the Hungarian Central Statistical Office. The new data collection method was examined in detail and it was proven that the statistical sampling method used by the Hungarian Central Statistical Office is more accurate and the data series produced is unbiased and less uncertain.

6.5.4.3 Non-CO_2 emissions

Estimated non-CO_2 emissions include those from burning of slash on-site and those from wildfires. Non-CO_2 emissions from these sources are not significant and are only reported for the sake of completeness and that of time series consistency with previous years. CO_2 emissions from these sources are accounted for in the biomass pool because we apply the stock-change method. The carbon in the non-CO_2 emissions, i.e., the carbon of CO and CH_4, has also been accounted for in the carbon stock change of the biomass pool. These gases are nevertheless reported because of their high global warming potential, because the double counting of the carbon is negligible and also to comply with the 2006 IPCC GL.

6.5.4.3.1 Non-CO_2 emissions from burning of slash

The estimation of these emissions (see Table 6.5.12) is done according to section 6.4.3 with the following modification:

$$M_b = V_b * D$$

where

V_b = volume burnt, m^3 (only includes biomass, reported in Table 6.5.11);

D = wood density, kg biomass m^{-3} (values used here are the same as those used to estimate carbon stock changes in biomass, see Table 6.5.1 above); and

$$V_b = V_H * C_f$$

where

V_H = total harvest, m^3 of wood removed from forest (taken from harvest statistics), and

C_f = combustion factor, dimensionless, for which we use average country-specific values by species (Rumpf, 2013). These values are based on expert solicitation and are in line with the legislature on burning in forests.

Finally, when estimating non-CO_2 emissions from the above data, default IPCC G_{ef} values were used in Equation 2.27 (see Section 6.4.3).

Table 6.5.12. *The amount of harvested volume, slash burned and forest fires for selected inventory years based on all available data.*

Inventory year	Harvested volume (m3)	Slash burned on site (t)	Number of wildfires in forest	Area of forest subcompartments burnt in forest and agricultural fires (ha)	Area of forest subcompartments burnt in forest fires (ha)	Wood volume burnt in forest fires (m3)
1985	8 345 562	99 560	NE	NE	NE	NE
1990	7 415 162	88 002	NE	NE	NE	NE
1995	6 049 151	64 698	NE	NE	NE	NE
2000	7 287 456	67 632	811,00	1 595	1 595	80 000
2005	7 167 426	59 651	150,00	3 531	3 530	170 000
2010	7 424 046	56 780	7,00	878	239	5 324
2015	7 354 188	60 153	1 069,00	4 730	1 593	192 394
2020	6 580 366	52 646	1 239,00	2 895	629	61 530
2021	7 522 837	62 494	1 154,00	2 413	359	45 942
2022	8 242 151	67 524	2 733,00	20 977	5 082	784 817

6.5.4.3.2 Non-CO_2 emissions from wildfires

Wildfires are very erratic in nature and are not a significant phenomenon in Hungary. Beginning 1999, the Fire Department started to provide data on the number and area of forest wildfires, however, until 2006, these numbers are not deemed accurate, and the emissions based on these are only rough estimates.

In 2006, Hungary joined the European Forest Fire Information System (EFFIS, http://effis.jrc.ec.europa.eu/), and a new database was established. Thus, beginning 2007, the Fire Department locates the fires, surveys the affected area and, subsequently, the Forest Authority identifies the affected forest sub-compartments. This identification is done on site, during a survey after the fire. The Forest Authority also develops data, based on area estimates by the National Directorate for Disaster Management of the Ministry of the Interior, on the growing stock that was burnt in fires. This way, the activity data is double-checked, and the emissions can be accurately calculated based on the estimated amount of standing volume burnt.

The amount of wood volume burnt in wildfires between 1999-2006 are calculated by the ratio of fire-affected area for this period and the burned growing stock per unit area of wildfires of 2007-2008.

With the exclusion of some areas affected by forest fires that are subsequently considered and reported as Deforestation (D), the vast majority of burnt areas remain under forest management by law, and the Forest Authority prescribes the reforestation/regeneration of these areas and inspects their success.

The estimation of the amount of emissions is done according to section 6.4.3 with the modification that is also applied for slash burned, see above. The amount of V_b, i.e., the amount of volume burnt in the areas affected is reported in Table 6.5.12 above (i.e., $C_f = 1$). Finally, when estimating non-CO_2 emissions from the above data, default IPCC G_{ef} values were used in Equation 2.27 (see Section 6.4.3).

6.5.5 Land converted to Forest land (CRF sector 4.A.2)

6.5.5.1 Category description

In Hungary, mainly former croplands are afforested. Converting grasslands to forests occurs less frequently (in about 15% of all conversions), whereas converting other areas to forests is marginal, therefore, we report carbon stock changes from converting croplands and grasslands to forest land.

Land converted to forest land includes areas that, apart from soils, do not contain much carbon in either of the carbon pools before they are afforested. These areas are subject to the effect of intensive photosynthesis after the afforestation which, possibly after some pool-specific lag, usually results in the increase of carbon in all carbon pools. An exception to this is perennial cropland where perennial biomass may be present before the afforestation. Concerning soils, cropland usually stores less carbon than forest land. Thus, converting land to forest land increases the amount of carbon in all pools, although at different rates, due to tree growth after the afforestation.

Figure 6.5.9 reports estimated emissions and removals for the various pools, whereas Table 6.5.13 summarizes methodological information.

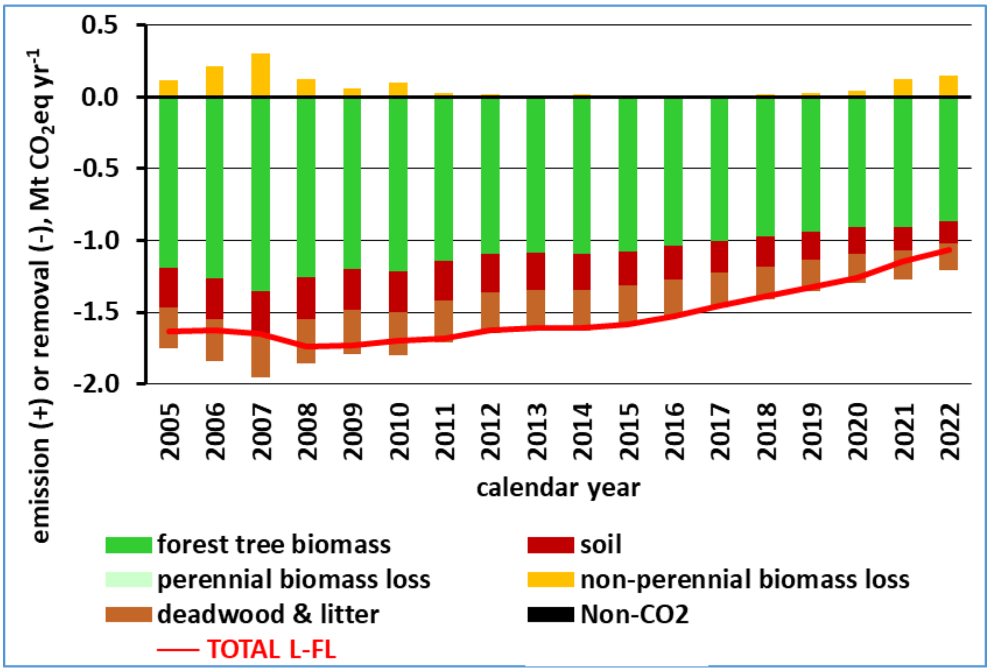

Figure 6.5.9. *The sources of emissions and removals in the various pools in the L-FL category since 2005.*

Table 6.5.13. *Methodological summary for Land converted to Forest Land. (CS=country specific; D: default; EJ: expert judgment; IE: included elsewhere; AD: activity data; EF: emission/removal factor)*

Category	Type of information	Carbon stock changes					Table(5) I, II, V
		AGB	BGB	DW	LI	SOIL	
L-FL	E/R	Post-conversion: CS	D/EJ	AD: CS; EF:CS	AD: CS; EF:CS	Mineral: AD: CS	Fertilization: IE
						EF: CS	Drainage and re-wetting: NO
						Organic: not occuring	Biomass burning: NO
	Uncertainty	Tier 2 (Monte Carlo) analysis					NE

6.5.5.2 CO_2 emissions and removals

6.5.5.2.1 Biomass

CO_2 emissions and removals from the biomass pool in the L-FL category are estimated from carbon stock changes due to gains in the trees appearing after the afforestations and losses of biomass before the conversion, if any. Whereas a country-specific method is applied for the estimation of gains, Equation 16 of the 2006 IPCC GL are used to estimate losses (see section 6.4.4). For both procedures, the estimation of the conversion area is necessary.

Area of conversion

The area is taken from the "initial planting of afforestations" statistics of the NLC Forestry Directorate by target stand-type (Quercus sp., Quercus cerris and other hard broadleaved, Fagus, Robinia, Hybrid Poplar and Salix sp., Indigenous poplars and other soft broadleaved, and Conifers). Data for 1990-2007 was taken from a historical dataset of the Forest Authority that is primarily used to have a subsidy-supporting roll. The area of L-FL cannot be identified on sub-compartment-level in this period. Therefore, for the entire period, modeling was used to develop the growing stock, increment and removal data based on total annual conversion area and age-mean volume function (see below).

Table 6.5.14 below demonstrates the evolution of total area of the category over time (similar tables are used for the estimation by the above species groups). The table shows the area *entering* the category as new afforestation in the second column (i.e., in year 1). The new area in a year is then rolled over to nineteen additional inventory years (in the subsequent columns and rows). The total area in the category in a year (in the last column) is thus the sum of all areas in all age classes. Each area is moved to the FL-FL category after the period of the default 20 years except for some L-FL areas that have been deforested and that are moved to the FL-L category.

Table 6.5.14. *The area of land that is successfully converted to forestland (for all species combined) by year of conversion for selected inventory years. Incoming areas are reported in the first year of conversion, and areas reported in the column "area of successfully converted land … in age class … 20" are transferred to the FL-FL category the next year. Note that, in rare cases, afforested areas are deforested and the values in the below matrix show the areas after the deforestation.*

Inventory year	area of successfully converted land (i.a. area actually covered by trees, ha) in age class (yr)																				Total in inventory year (ha)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1985	7 476	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7 476
1990	6 494	7 285	8 484	7 892	7 496	7 476	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45 127
1995	3 946	2 713	3 045	6 739	6 334	6 494	7 285	8 484	7 892	7 496	7 476	0	0	0	0	0	0	0	0	0	67 904
2000	9 242	8 219	7 745	7 854	6 240	3 946	2 713	3 045	6 739	6 334	6 494	7 285	8 484	7 892	7 496	7 476	0	0	0	0	107 203
2005	7 228	7 150	11 342	14 001	12 402	9 242	8 219	7 745	7 854	6 240	3 946	2 713	3 045	6 739	6 334	6 494	7 285	8 484	7 892	7 496	151 851
2010	6 267	3 520	7 221	17 888	13 206	7 228	7 150	11 342	14 001	12 402	9 242	8 219	7 745	7 854	6 240	3 946	2 713	3 045	6 739	6 334	162 300
2015	245	1 422	688	1 140	1 639	6 252	3 519	7 195	17 865	13 150	7 214	7 134	11 318	13 976	12 378	9 215	8 212	7 741	7 849	6 237	144 390
2020	2 431	1 662	1 321	747	237	222	1 403	669	1 095	1 619	6 200	3 479	7 132	17 798	13 085	7 170	7 060	11 251	13 914	12 320	110 815
2021	7 434	2 416	1 658	1 321	747	234	212	1 396	661	1 070	1 610	6 196	3 476	7 123	17 781	13 066	7 159	7 042	11 196	13 908	105 707
2022	9 086	7 369	2 384	1 658	1 320	747	234	212	1 396	581	1 021	1 608	6 196	3 476	7 123	17 780	13 046	7 158	7 037	11 196	100 629

A conversion of non-forest land to forest land, i.e., an afforestation activity, is deemed to have begun when soil preparation has been started. Typically, the first ("initial") planting of the propagation material on the area happens in a short time after soil preparation is done. Beating up may be carried out depending on the success rate of the initial planting.

Post-conversion biomass

Carbon stock changes in the biomass pool of the newly established trees are estimated using simplified regression-type models of growing stock over age on unit areas of afforestation. The models were developed by using a sample of young stands of varying age (which is known based on the year of the afforestation) for which volume was known. This volume was available from yield tables (height was measured and combined with known age for the correct application of the tables). The models are available separately for the seven stand-types (Figure 6.5.10 below is an example of data and the regression obtained for Quercus sp.). By broadly following the distribution of sample data, we used 3rd degree polynomial regressions for species of long rotation age (such as beech and oak), and linear regressions for species of short rotation age (such as Black locust). The regression curves were developed by also using stands somewhat older than 20 years to increase the robustness of the regression curve, but they are only used for stands between ages 1 and 20 years in the L-FL category. The curves were forced to start from the pole. All coefficients of determination are above 0.9, and the regression coefficients are significant for each species. (Note that these curves represent rather constant growing conditions, and it is only worth checking the validity of these curves, or revise them, rather rarely.)

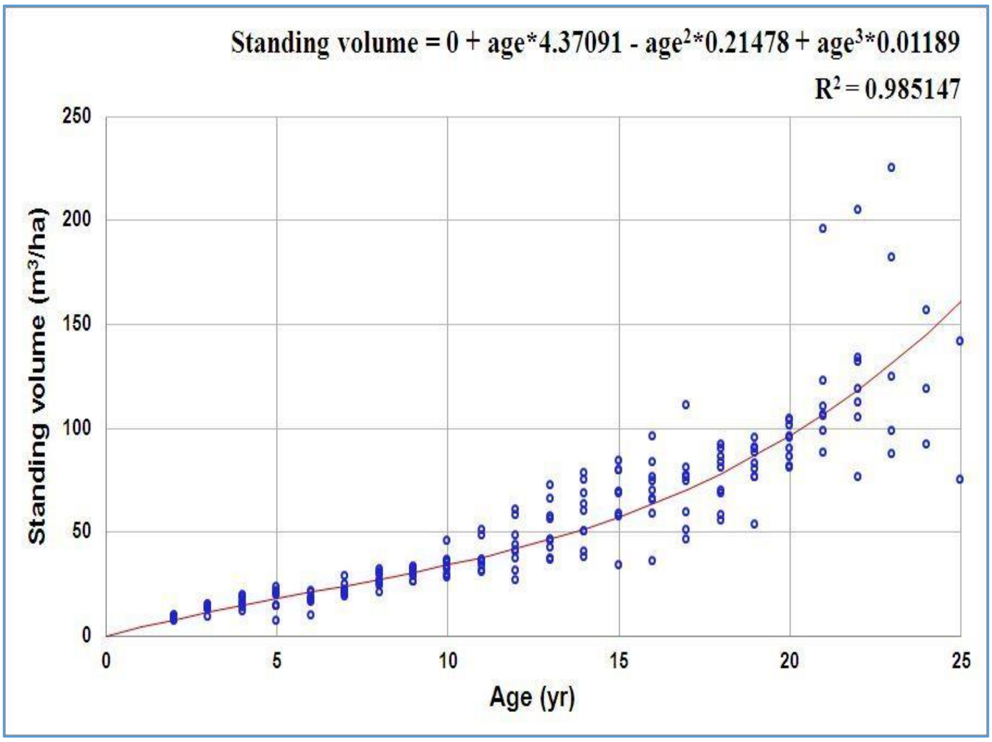

Figure 6.5.10. *An example of the regression curve of stand volume over age using data of Quercus sp.*

Volume stock *change* from a specific year of age to the next one is equal to the *difference* between the volume stocks of the respective consecutive ages as estimated from the regression curves. To get total carbon stock change, these differences for the various age classes and species were multiplied by the area of the same classes (whereas conversion factors by species were also used to develop amounts of carbon from amounts of volume). The estimated changes reflect the effects of tree growth, artificial thinning and self-thinning. The calculated changes are smoothed ones, i.e., they do not represent any inter-annual variation due to variation of growing conditions or other factors. More importantly, however, the above procedure ensures that the volume *stocks* of the respective classes are not directly applied in the calculations, and no transition of volumes are directly included (either for L-FL or FL-FL) in the calculation of carbon stock changes when stands are moved from the L-FL category to the FL-FL category.

In estimating *carbon* stock changes in these forests, the conversion of volume to carbon happens the same way as described above when discussing the second part of Equation 2.8 of the 2006 IPCC Guidelines.

Pre-conversion biomass

Emissions arising from removing perennial biomass carbon during conversions to forest are estimated using data from a study that estimated the amount of carbon lost by removing all above-ground biomass due to conversion *for a unit area*. This loss was measured to be 4.7 tC/ha in case of orchards and 9.39 tC/ha in case of vineyards. The average age of the converted areas is 15 and 15.9 years, respectively, which are half of the length of the rotation period of these perennials (Juhos and Tőkei, 2013). The respective amounts of carbon lost from annual biomass, which are IPCC defaults, are 4.7 and 2.94 tC ha^{-1} (see the respective sections on Cropland and Grassland for more details). The amount of *total loss* of carbon is estimated by multiplying the above values with the area actually converted. (In practice, carbon stock changes from biomass of perennials on CL-FL are estimated by first estimating all carbon stock changes from cropland with perennials to all other categories, the methodology of which is reported in section 6.6.2.1.1, and then multiplying it with the proportion of the area of perennial CL-FL to the total area of perennial CL converted to all other land-use category. For forest land, this proportion varies between 12 and 19%.)

Note that, according to the default method (Equation 2.12), the pre-conversion below-ground biomass is not considered a loss, and indeed it remains in the ground and adds to the carbon stocks of the deadwood, litter and soil pools.

6.5.5.2.2 Dead organic matter

Carbon stock changes in the DW pool are estimated the following way:

$$\Delta C_{DW} = \Sigma_{i,j}\, A_{i,j} * \Delta v_{i,j} * (1+R) * D * CF$$

where

$A_{i,j}$ = area of species group i (i = 1 … 7) in age class j (j = 1 … 20), ha;

$\Delta v_{i,j}$ = annual deadwood volume stock increase of species group i in age class j, tC * ha^{-1} * yr^{-1},

R = root-to-shoot ratio (same as for biomass, see above);

D = wood density as for woody biomass (same as for biomass, see above);

CF = carbon fraction as for woody biomass (same as for biomass, see above).

The area-specific $\Delta v_{i,j}$ values are based on data collected from 7629 sampling points of the NFI. The measurements were made in all forests (mostly in the FL-FL category) between 2010 and 2017. (The amount of data from plots in afforested areas was not enough to develop reliable regression fitting, see below.) Data were collected for standing dead trees with diameter breast height equal to or larger than 7cm, and for lying dead trees with a minimum length of 1m and a diameter of at least 10 cm. (This means that only above-ground values were measured with definitions that are a bit different from those for living trees, but the differences in the definitions render the carbon stock change estimates conservative.) Area-specific measurements were aggregated in seven tree stand types by age, and so seven lines were fitted to the data over age (Figure 6.5.11). The data show that the increase of DW carbon stock lasts until about 30 years (in case of fast-growing species like poplars) to well over 100 years (in case of slow-growing species like oaks); beyond available data, to be conservative, zero increase was assumed. However, as areas are in the L-FL category only for 20 years, we use data for only the 1-20 years of age part of the regression lines for each species. Note that most regression lines do not start at zero stocks because the analyses were done for regenerated stands in the FL-FL category where some stocks remain in the stands after a regeneration. For L-FL, however, we assumed that the initial stocks are zero and the increase (change over time) is the same as in the FL-FL category (i.e., it is a bit underestimated).

Figure 6.5.11. *Sample data of area-specific deadwood stock, fitted regression lines (straight lines) and their confidence bands (dashed lines) for the seven tree species groups over age. Beyond the oldest age categories with data, horizontal lines, i.e., Δv = 0, were used in the calculations.*

Concerning afforestations, it is a general experience that the DOM pools do not contain carbon on cropland and grassland before the conversion. This is corroborated by the fact that, for sanitary and other reasons, biomass (dead or alive) of all crops are removed during harvests, and there is usually not enough time on abandoned croplands for the woody biomass to develop substantial dead organic matter before the land is converted. Somogyi et al. (2013) also measured zero dead organic matter carbon stocks on pre-conversion land in their study.

Concerning the assumption that the rate of DW increase is the same on L-FL and FL-FL, our argumentation is based on the theory that if the initial stock is not zero, then the net change is the result of input to the pool and the loss from the decay of the initial stock. This means that the rate of increase on an afforested land, where the initial stock is zero, should be larger than on an FL-FL land. It follows that, while also limiting the accounting for the increase to the first 20 years of the afforestation, our approach is conservative.

For LI, the estimation is done by applying the methodology described in section 6.4.5 above. We assume that the carbon stock in the litter pool before the conversion is zero. For the equilibrium carbon stock in the forest land after the conversion, we apply the same value, 8.78 tC/ha (Heil et al., 2012), that is used for the estimation of emissions due to deforestation events (i.e., conversions of forest land to other land-uses), see section 6.5.6.1.2. We assume that the equilibrium litter carbon stock level is reached in 20 years. C_{old} in the equation in section 6.4.5 is thus zero and C_{new} is 8.78 tC/ha/20 years.

6.5.5.2.3 Soil

The estimation of carbon stock changes in soils is done according to section 6.4.1.

The results of the estimation are corroborated by recent estimates according to which converting land from cropland to forest does not entail any net emissions from soil, rather, net removals (see Somogyi, 2005, Somogyi-Horváth, 2006a, Somogyi-Horváth, 2006b, and Somogyi et al., 2013). Converting grassland to forest may lead to some emissions (see Horvath, 2006). However, because most of the huge amounts of marginal lands that are afforested are former croplands, and also because of biodiversity concerns, the overwhelming majority of conversions occur on abandoned croplands (see above) and only grasslands of poor quality, thus, overall, no major emissions from soils are expected due to conversion of land to forest land (Figure 6.5.12).

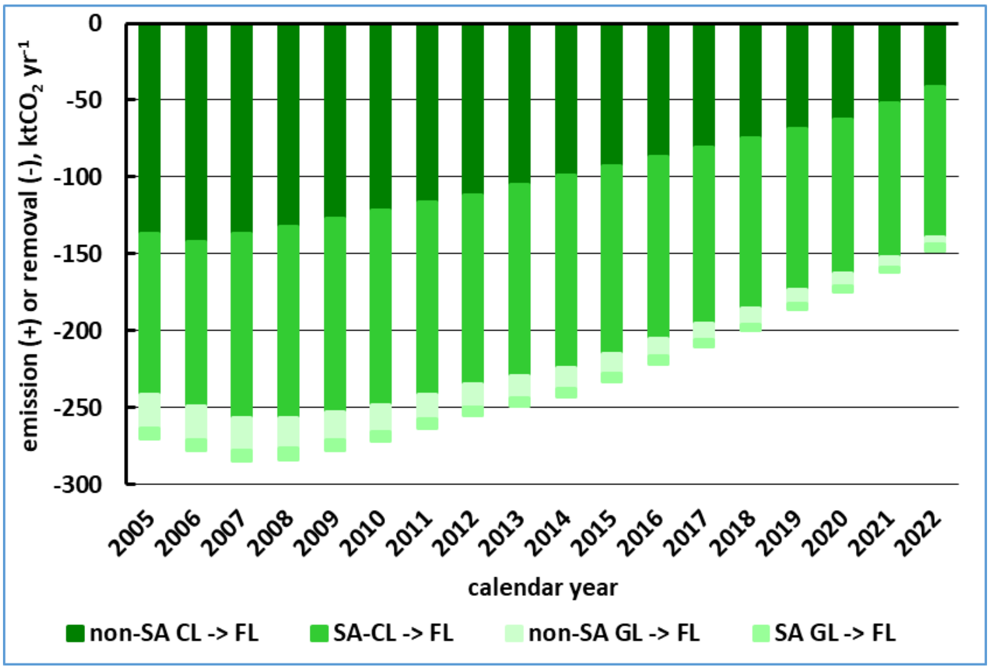

Figure 6.5.12. *Emissions and removals from converting land to forest land since 2005 (non-SA: non-set-aside; SA: set-aside).*

Concerning organic soils, there are no afforestations on such soils, therefore, no such emissions occur in the country.

6.5.5.2.4 Estimation of the carbon stock changes of found forests that are younger than 21 years

As mentioned above, because of their age distribution, all carbon stock changes of FF are reported under the FL-FL category. However, for reasons of transparency, we have attempted to estimate the emissions of those FF that, due to their age, could be classified as L-FL. The estimation procedure is the same as that for the L-FL category as described above. This procedure requires that one knows the area of FF by age (in this case, always less than 21 years) and species group. Since the estimation of age requires specific methods that are not practicable to apply to all stands, sampling and upscaling was necessary to develop the required area information. The results of the calculations are summarized in Tables 6.5.15-6.5.17. The data clearly show (when comparing e.g. with Figure 6.5.9) that the vast majority of the carbon stock changes in FF land occurs in areas with age>20 years, and that the net emission from FF in the year when they are found is rather small.

Table 6.5.15. Areas of FF land younger than 21 years of age

Inventory year	Total area of FF land with age<21 years (ha)				Cumulative area of annual FF areas (ha) if they were of L-FL type
	spontaneous expansion	human-induced	geodesic re-measurement	Total	
2008	935	355	1 221	2 511	78 463
2009	1 912	672	3 174	5 758	84 447
2010	2 273	794	3 846	6 914	86 808
2011	3 207	1 066	4 788	9 061	84 052
2012	3 889	1 383	5 955	11 227	81 930
2013	4 322	1 380	7 132	12 834	84 056
2014	4 377	1 385	7 440	13 202	84 516
2015	4 239	1 328	7 219	12 786	80 869
2016	4 089	1 304	7 050	12 444	76 664
2017	3 842	1 229	6 834	11 905	75 120
2018	3 457	1 042	6 189	10 687	72 176
2019	3 035	888	5 337	9 261	65 398
2020	2 708	1 195	5 031	8 934	61 591
2021	2 597	1 407	4 574	8 578	57 801

Table 6.5.16. Gains (i.e., negative emissions) and losses from the biomass pool of FF land younger than 21 years of age.

Inventory year	Gains in the biomass pool of FF land with age<21 years (ktCO2/year)				Losses in the biomass pool of FF land with age<21 years (ktCO2/year)			
	spontaneous expansion	human-induced	geodesic re-measurement	Total	spontaneous expansion	human-induced conversion	geodesic re-	Total
2008	-6	-3	-7	-16	1	0	1	1
2009	-13	-6	-20	-38	1	0	1	2
2010	-16	-7	-26	-49	1	1	2	4
2011	-24	-10	-35	-69	1	0	1	2
2012	-29	-12	-45	-87	1	0	1	2
2013	-33	-12	-54	-100	0	0	1	1
2014	-34	-12	-57	-102	1	0	1	2
2015	-35	-12	-58	-104	0	0	0	0
2016	-36	-12	-60	-108	0	0	0	0
2017	-35	-12	-61	-108	0	0	1	1
2018	-32	-10	-57	-99	1	0	1	2
2019	-28	-9	-50	-87	1	0	1	2
2020	-25	-9	-47	-81	1	0	2	3
2021	-25	-11	-44	-79	3	1	6	11

Table 6.5.17. Gains (i.e., negative emissions) from the DW and LI pools of FF land younger than 21 years of age.

Inventory year	Gains in the DW pool of FF land with age<21 years (ktCO2/year)				Gains in the LI pool of FF land with age<21 years (ktCO2/year)			
	spontaneous expansion	human-induced	geodesic re-measurement	Total	spontaneous	human-induced	geodesic re-measurement	Total
2008	0	0	0	-1	-2	-1	-2	-4
2009	0	0	-1	-1	-3	-1	-5	-9
2010	0	0	-1	-1	-4	-1	-6	-11
2011	-1	0	-1	-2	-5	-2	-8	-15
2012	-1	0	-1	-2	-6	-2	-10	-18
2013	-1	0	-1	-3	-7	-2	-11	-21
2014	-1	0	-2	-3	-7	-2	-12	-21
2015	-1	0	-2	-3	-7	-2	-12	-21
2016	-1	0	-1	-3	-7	-2	-11	-20
2017	-1	0	-1	-2	-6	-2	-11	-19
2018	-1	0	-1	-2	-6	-2	-10	-17
2019	-1	0	-1	-2	-5	-1	-9	-15
2020	-1	0	-1	-2	-4	-2	-8	-14
2021	-1	0	-1	-2	-4	-2	-7	-14

6.5.5.3 Non-CO_2 emissions

6.5.5.3.1 Emissions from wildfires

In Hungary, very few forest fires occur in the Land converted to Forest Land category. However, following the recommendation of a former inventory review, non-CO_2-emissions are separately reported for L-FL and FL-FL using the methodology summarized in section 6.5.4.3.

6.5.5.3.2 Direct and indirect N_2O emissions from mineral soils

The estimation of both direct emissions from mineral soils associated with loss of carbon resulting from change of land-use or management and indirect N_2O emissions from leaching/runoff is done according to section 6.4.2, using the appropriate carbon loss data for the sub-category. Note that, consistent with what is reported for soils above, emissions only occur when grasslands are converted to forests.

6.5.6 Forest Land converted to other land-uses (CRF sector 4.B.2.1, 4.C.2.1, 4.E.2.1)

FL-L areas are those that have been clear-cut and removed from areas under forest management in order that the area can be used for non-forestry purposes (i.e., for road building and other land-use).

An area enters the FL-L category right away, i.e., in the year, of the clear-cut which is made in order that the area can be used for non-forestry purposes. In Hungary, deforestations have not been done frequently since 1990 nor were they done before that.

The total area of deforestations (see Table 6.5.2 above) was established based on statistical data collection back to 1990 using the certificates of the deforestations as all conversions from forest area must be approved by forestry authorities. However, as mentioned above, geographical information on deforested areas has been collected since 2008, and areas for 1985-1989 were estimated using extrapolation backwards.

Beginning 2020, as a follow-up of the review in that year, we started to separately report on areas of the so called “forest compartments” (i.e., areas with forest stands) and “other compartments” that usually do not, but sometimes can, contain trees. To estimate emissions and removals, an important step was to categorize all types of the other sub-compartments into land-use categories by utilization type as if they belonged to one of the general land-use types (**Table 6.5.18**). This categorization makes it possible to estimate the amount of carbon in each pool before and after the conversion by the respective land-use types for the other sub-compartments.

Table 6.5.18. *Reclassification of the utilization type on deforested other sub-compartments.*

Utilization type on deforested "other sub-compartments"	LU category
Chrismas tree plantation	FL
Area for twig production for decoration	CL
Forest research area	FL
Plant nursery	CL
Lane	GL
Glade	GL
Area serving game feeding	CL
Area covered by scrubs	GL
Not managed forest	FL
Park	FL
Infertile area	OL
Arificial water body	WL
Forestry office building	SE
Private forest road	SE
Forest railway	SE
Timber yard	SE
Mine	SE
Lake or watercourse	WL
Other facilities under forest management	SE
Forest ski resort	GL
Unknown	FL

Table 6.5.19 below reports the proportion of the “other” sub-compartments by utilization type (under forest management) since 2008 for the FL-L category.

Table 6.5.19. *Share of area of other sub-compartments by utilization type since 2008 for **FL-L**.*

Utilization type	Share of area of "other" sub-compartments on FL-L														
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Chrismas tree plantation	0	0	0	0	0	0	1	1	0	8	0	0	0	0	0
Area for twig production for decorati	0	20	0	0	0	0	0	4	0	18	0	0	0	0	0
Forest research area	0	0	0	5	4	1	0	2	0	0	1	0	1	0	0
Plant nursery	2	15	0	1	1	2	2	0	7	41	0	0	0	0	0
Lane	7	4	4	2	4	5	8	3	2	1	0	1	2	1	0
Glade	65	10	12	19	37	23	27	38	8	4	11	22	25	13	0
Area serving game feeding	7	15	18	29	8	20	20	26	7	2	24	6	16	20	0
Area covered by scrubs	7	6	3	2	12	24	20	14	12	2	3	3	29	27	0
Not managed forest	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
Park	0	3	32	0	0	0	0	0	0	0	0	0	0	0	0
Infertile area	5	5	15	35	4	9	8	4	6	1	17	1	12	30	0
Arificial water body	0	0	1	0	0	2	0	0	0	0	0	0	1	0	0
Forestry office building	0	1	1	0	1	0	0	2	0	0	3	0	1	1	0
Private forest road	0	1	0	2	0	0	1	3	1	5	0	1	4	2	0
Forest railway	0	0	0	0	3	5	6	0	0	16	38	58	0	3	0
Timber yard	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Mine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lake or watercourse	0	0	0	1	2	1	0	0	38	0	0	1	2	2	0
Other facilities under forest manager	0	10	8	1	3	5	3	0	15	0	2	7	8	1	0
Forest ski resort	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unknown	7	9	5	2	21	2	4	1	2	0	0	0	0	0	0

With regard to the activity data for the calculation of the various emissions and removals from deforestation, it must be considered that, in addition to emissions from the biomass and DOM pools which are assumed to occur in the year of deforestation, emissions from soils also take place. These emissions are estimated using the default transition period of 20 years. Therefore, three types of areas within the FL-L category have to be used. The first is the total area which is now reported in the CRF tables using two sub-categories, i.e., the forest sub-compartments and all other sub-compartments. The second is the annual area of all sub-compartments. Finally, the third area statistics is the total area, which also includes forest and other sub-compartments, that is considered to be in transition (see Table 6.5.2 above).

The area of forest land converted to other land-uses has been small in Hungary for the last decades, and the conversions only include conversions to cropland, grassland and settlements. Conversions from forest land to any other land-use type are generally prohibited by the Forest Act and can take place only after the Forest Authorities grant the specific permission.

6.5.6.1 CO_2 emissions and removals

Table 6.5.20 reports CO_2 emissions and removals estimated for the biomass (above-ground plus below-ground), deadwood, litter and soil pools, whereas Table 6.5.21 reports methodological information for this sub-category.

Table 6.5.20. *Total emissions from biomass (above-ground plus below-ground), deadwood, litter and soils from the FL-L category. The light-yellow color in some cells of the table (with column title "from DB") shows that the data in those cells are taken from the database (i.e., they are the result of calculations elsewhere), whereas data in white cells are calculated in this table according to the formula below the variable. All notations are as for Tables 6.5.3 and 6.5.6. (The table is for demonstration only and may include rounding errors; for precise numbers, and for data by geographical locations, see the respective CRF tables.)*

Inventory year	All emissions and removals from FL-L, ktCO2 eq.				
	biomass	other pools			total
	NR	deadwood	litter	mineral soil	
	from DB	from DB	from DB	from DB	biomass + other
2008	27	15	11	21	75
2009	58	26	19	23	125
2010	28	44	33	24	129
2011	46	16	12	24	98
2012	132	45	33	24	233
2013	62	25	18	25	129
2014	85	86	63	28	260
2015	117	62	45	29	252
2016	151	94	68	31	346
2017	168	84	61	35	348
2018	217	99	72	37	425
2019	228	103	74	38	443
2020	134	53	38	38	264
2021	260	69	49	39	417
2022	127	55	39	38	260

Table 6.5.21. *Methodological summary. (CS=country specific; D=default; NO: Not occurring; NE: not estimated)*

Category	Type of information	Carbon stock changes					Table(5) I, II, V
		AGB	BGB	DW	LI	SOIL	
FL-L	E/R	Post-conversion: 0	0	CS	CS	D	Drainage: NO
		Pre-conversion: CS	CS				Biomass burning: NO
	Uncertainty	Tier 2 (Monte Carlo) analysis					

6.5.6.1.1 Biomass

For biomass in the forest sub-compartments, the methodology described in section 6.4.4 is applied. For all conversions of FL to other land-use categories, it is assumed that the forest biomass carbon stock after the conversion is zero, so all carbon in the biomass due to deforestation, estimated as described in section 6.5.3, is completely emitted as CO_2. (Note that, depending on the post-conversion land-use, there may be non-forest biomass after the conversion, which is estimated following the methodology described in the respective section on the post-conversion land-use.)

For the inventory years after 2007, the biomass cleared was recorded and could therefore be directly applied for the emission estimation. For the historical inventory years before 2008, for which only the area is known, this area information is combined with extrapolated area-specific emission using linear regressions (with area as independent variable) separately for the FL-CL, FL-GL etc. conversion types.

For the biomass pool in the other sub-compartments, the emission factors B_{Before} (in the equation in section 6.4.4. Conversion-related carbon stock changes of the biomass pools) are the following: for the utilization types that could be regarded as equivalent to forests, the annual B_{Before} emission factor is the same that is used for the "forest sub-compartments"; for the other types we assumed that the pre-conversion biomass is equal to the default biomass of the land-use category which the particular areas were classified to (see Table 6.5.15 above) before the conversion. The post-conversion value corresponds to the biomass on the "converted-to" land-use category.

6.5.6.1.2 Dead organic matter

Emissions from deadwood and litter are estimated by multiplying the area of annual deforestations by the average stock value of these pools. In these calculations, just like with biomass, we assume that all deadwood and litter are completely removed from the area, i.e., all carbon in these pools are emitted in the year of the deforestation.

In these calculations, the total deforested area is applied, i.e., in addition to the area of the forest sub-compartments, the area of the fraction of the other sub-compartments of the FL-L conversions that is re-classified as FL. However, due to the nature of the non-forest land-use categories, no litter or deadwood is assumed to be present in the other sub-compartments either before or after the conversion, therefore, emissions from the litter and deadwood pools in these areas is assumed to be zero and the activity data in the below calculations is the sum of the area of forest sub-compartments and those parts of the other sub-compartments that were classified as FL.

The area-specific value of the amount of deadwood comes from the National Forest Inventory as described in section 6.5.5.2.2. Since the amount of deadwood in the sampled years do not show a decreasing trend either overall (see Figure 6.5.4) or by species (see Figure 6.5.8), we believe that the average area-specific data calculated from these samples are suitable for estimating the emissions from deadwood for the entire time series.

In estimating total carbon stock changes from the estimated volume, we used the methodology of stock change as detailed above and applied the assumption that the average wood density of the deadwood is the same as for the woody biomass.

Considering litter, the dedicated case study by Heil, Kovács and Szabó (2012) provided an estimate of the mean litter content (excluding coarse litter between about 1 cm and 10 cm) of the Hungarian forests. In this study it was found that the average amount of carbon in litter is 8.78 tC/ha.

We note that, because of the small scale of deforestations each year, and because litter and especially DW are relatively small carbon pools, this simple but anyway Tier 2 approach can be regarded as an accurate methodology *as far as practicable*. We also note that the above value is considerably smaller than the IPCC default values reported in Table 2.2 of Chapter 2 of the 2006 IPCC Guidelines for mature forests (i.e., 27-28 tC/ha). This is partly because of the differences in the definition of litter in this NIR and the 2006 IPCC Guidelines (i.e., most fine woody debris is excluded from our definition of the litter), and partly because the IPCC default values are for mature forests whereas most of our forests are not mature, and possibly partly due to other methodological differences such as the carbon content of litter.

It is additionally assumed that neither deadwood nor litter are produced any more after Forest land to non-forest land conversions, thus, no removals are accounted for in these pools after the conversions.

6.5.6.1.3 Soil

The estimation of carbon stock changes in mineral soils was done according to section 6.4.1. No forest land on organic soils is converted to other land-uses.

For each piece of land converted to non-forest land-use categories (including both forest and other sub-compartments), the same amounts of annual carbon stock changes by conversion type are accounted for 20 consecutive years. Carbon stock changes for all conversion types are added up to get the aggregated emissions for the entire FL-L category.

For the forest sub-compartments, the post-conversion land-use type is known, therefore, values in Table 6.4.2 above can directly be used. Concerning the other sub-compartments, in addition to the assumption for the re-classification of the area to areas by land-use types, we had to make assumptions concerning the conversion type because it is not known for these other sub-compartments what pre-conversion land-use type is converted to what post-conversion land-use type. Because of these uncertainties, the assumption applied is that the difference between the amount of area-specific carbon before and after the conversion for a specific pre-conversion land-use type is the largest value of all the possible conversion types. For example, for an area within the other sub-compartments classified as Wetland (WL) before the conversion, we applied the emission factor for the WL – non-SA CL conversion in Table 6.4.2 because it involves the largest area-specific C loss.

The FL-L areas identified and the resulting total CO_2 emissions from all pools are included in Table 6.5.19.

Table 6.5.22. *The area, as well as CO_2 emissions from soils on land converted from forest to other land-uses for selected inventory years.*

Inventory year	FL converted to CL			FL converted to SE			FL converted to GL			All conversions from FL to other land use		
	Area (ha)		CO_2 emissions (ktCO_2)	Area (ha)		CO_2 emissions (ktCO_2)	Area (ha)		CO_2 emissions (ktCO_2)	Area (ha)		CO_2 emissions (ktCO_2)
	all	forest subcomp-artments		all	forest subcomp-artments		all	forest subcomp-artments		all	forest subcomp-artments	
1985	95	95	-0,03	210	210	-0,07	21	21	-0,003	326	326	-0,10
1990	180	180	-0,21	393	393	-0,45	40	40	-0,022	613	613	-0,68
1995	53	53	-0,56	244	244	-1,30	61	61	-0,081	358	358	-1,94
2000	112	68	-0,76	982	595	-2,18	93	56	0	1 187	719	-3
2005	149	71	-0,99	654	313	-3,68	56	27	0	859	411	-5
2010	670	59	-1,28	1 155	102	-4,84	526	47	0	2 351	208	-7
2015	521	424	-1,63	766	623	-5,48	413	336	-1	1 699	1 383	-8
2020	465	369	-3,34	546	433	-5,80	492	390	-1	1 503	1 191	-10
2021	500	462	-3,46	421	389	-5,66	737	680	-1	1 659	1 531	-11
2022	626	626	-3,63	430	430	-5,39	169	169	-1	1 225	1 225	-10

6.5.6.2 Non-CO_2 emissions

6.5.6.2.1 Emissions from fires

The estimation of non-CO_2 emissions from fires is based on the fact that deforestations in Hungary are done by clear-cutting the areas and removing most biomass from there.

As deforestations rarely occur in the country, the probability that wildfires affect these areas is negligible. In the last years, no wildfires occurred on land that later (in the same year) were converted to other land-use. Therefore, emissions from wildfires are reported as not occurring in this category.

On the other hand, controlled burning (burning of slash) occurs in this category. The methodology to estimate emissions from this source is the same as described in section 6.4.3. Activity data is available for both the area and the volume of forest land converted to other land-use.

6.5.6.2.2 Direct and indirect N_2O emissions from mineral soils

The estimation of both direct emissions from mineral soils associated with loss of carbon resulting from change of land-use or management and indirect N_2O emissions from mineral soils due to leaching/runoff is done according to section 6.4.2.

6.5.7 Category-specific uncertainties and time-series consistency

For this category, we updated the uncertainty analysis in 2023, see section 6.11.1.

6.5.8 Category-specific QA/QC and verification

The calculations to obtain emission and removal estimates are generally based on the activity data taken from the National Forest Database, and the databases of the Forest Authorities on afforestations and deforestations. These databases are the most accurate ones in the country on the forests. The first complete and country-wide inventory was accomplished in 1976. Forests have been continuously monitored since that year, and the responsible authorities have been applying computer-based information technology for data management since the early ’80-s. The database is updated annually, and the data is checked by many people at subsequent procedures from field assessment to data processing. The constant development of field methods and informatics, the improvement of checks, and the increasing requirements to ensure the quality of work resulted in the increasing accuracy of the Database in recent years.

The GHG inventory has currently been completed by the Forestry Department of the National Land Authority, i.e., the institute that runs the National Forest Database and other mentioned databases.

As a quality assurance, double-checking of the data processing of the calculations involved in the GHG inventory and the correct application of IPCC assumptions and methodologies have been performed at the national level by the Hungarian Forest Research Institute of Sopron University for years. The separation of the two roles (i.e., the preparation and the QA of the GHG inventory) improved the data quality. Final checks and integration of the data into the GHG inventory was performed by the Hungarian Meteorological Service, i.e., the institute responsible for the entire national GHG inventory.

Data verification was and is continuously conducted concerning activity data (see the comparison of volume stock changes with trends of wood volume increment and harvest in Section 6.5.4.2.1, and also previous NIRs of Hungary). All information used for the development of the GHG information is archived by the inventory agency. Thus, the correctness of the estimation methodology is in principle *verifiable*.

For other activities, see section 6.6.5 where activities are listed that have also been conducted in the forestry sector.

6.5.9 Category-specific recalculations

As noted in section 6.1.4, we have done a number of recalculations in the forestry sector to improve the accuracy of our estimates and to correct upload errors. However, most of these recalculations are only revisions of the areas reported in the sectoral tables that were different from that in CRF table 4.1, i.e., the land-use change matrix. Additionally, there were some minor revisions of some area data that resulted in very small revisions of the emission estimates, the difference between the new and previous estimates being hardly over 0.1% of the estimated total sectoral emission value of -7195 ktCO2eq in 2021.

6.5.10 Category-specific planned improvements

We will continue the revision of our databases that are the sources of activity data to ensure that estimates are better than previously estimated and as accurate as possible.

6.6 Cropland (CRF sector 4.B)

6.6.1 Description of category

Although the area of croplands decreased in the last three decades (roughly 800,000 hectares were abandoned or converted to another land-use category, after which only parts of this loss was regained), croplands with their approximately 56% proportion of the total area of the country still represent the main land-use category in Hungary (see Figure 6.3.1 above). All lands with annual crops, orchards, and vineyards (i.e., perennial woody crops) and kitchen gardens are classified as cropland. Set-aside croplands are also reported in this category (Figure 6.6.1.) The distribution of emissions and removals by sub-categories is reported in Figure 6.6.2.

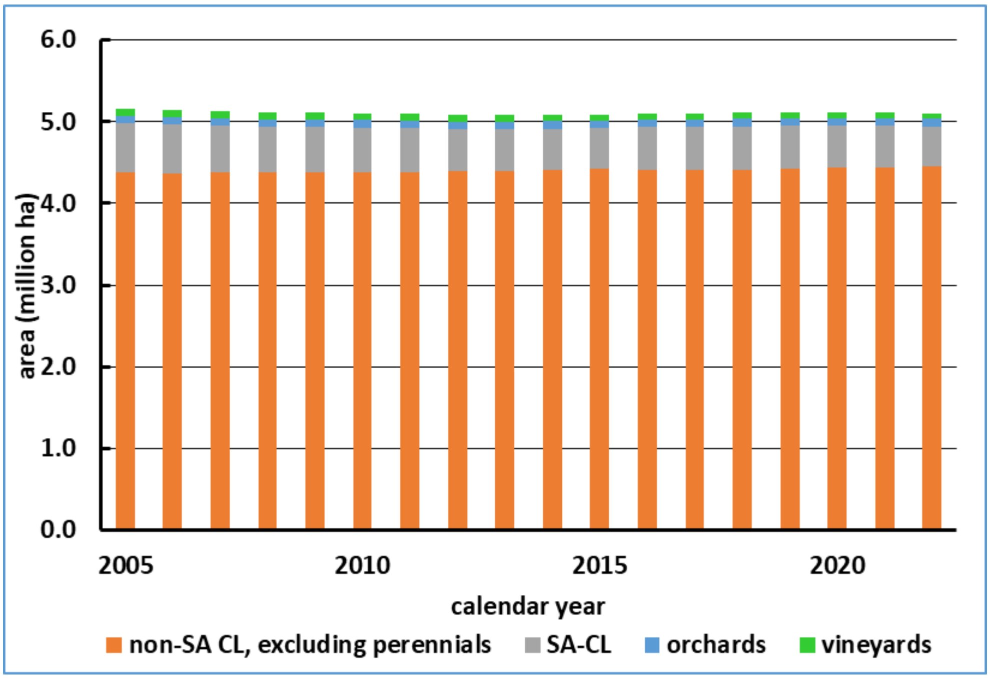

Figure 6.6.1. *The distribution of Cropland area since 2005.*

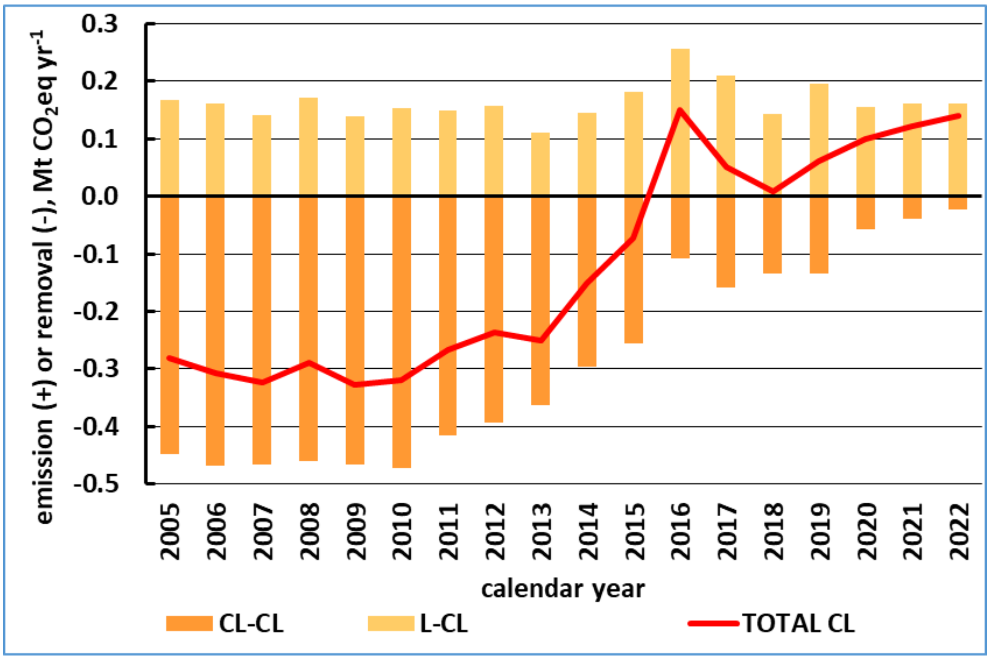

Figure 6.6.2. *Emissions and removals in Cropland since 2005.*

6.6.2 Cropland remaining Cropland

Figure 6.6.3 reports emissions and removals by pool and gas, whereas Table 6.6.1 reports methodological information for this sub-category. Figure 6.6.4 is reported to demonstrate that most removals in the Cropland category (including the CL-CL category) arise due to changes in land-use either between sub-categories or within a sub-category, i.e., from non-set-aside to set-aside land and back.

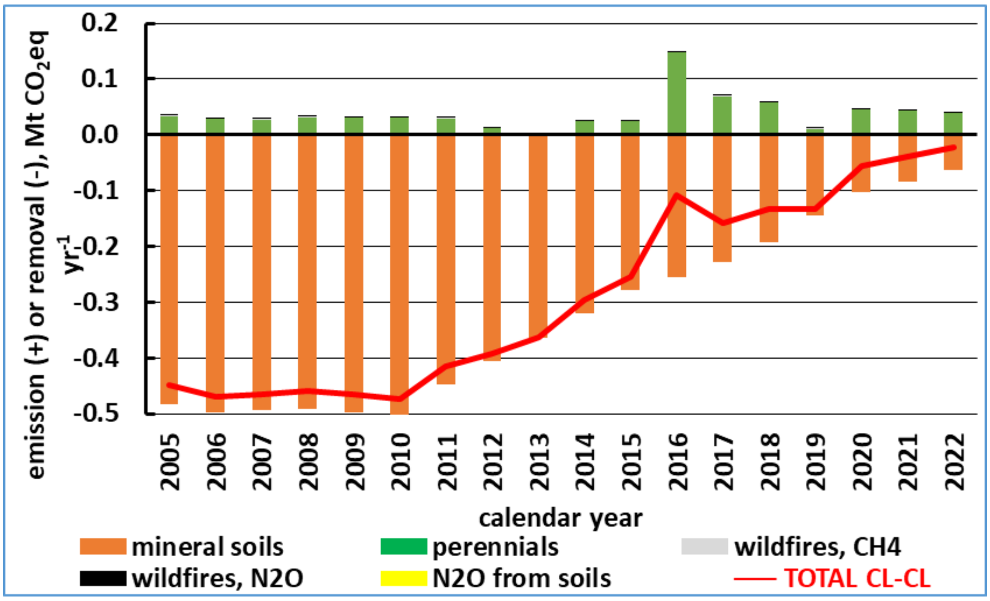

Figure 6.6.3. *Emissions and removals in CL-CL since 2005.*

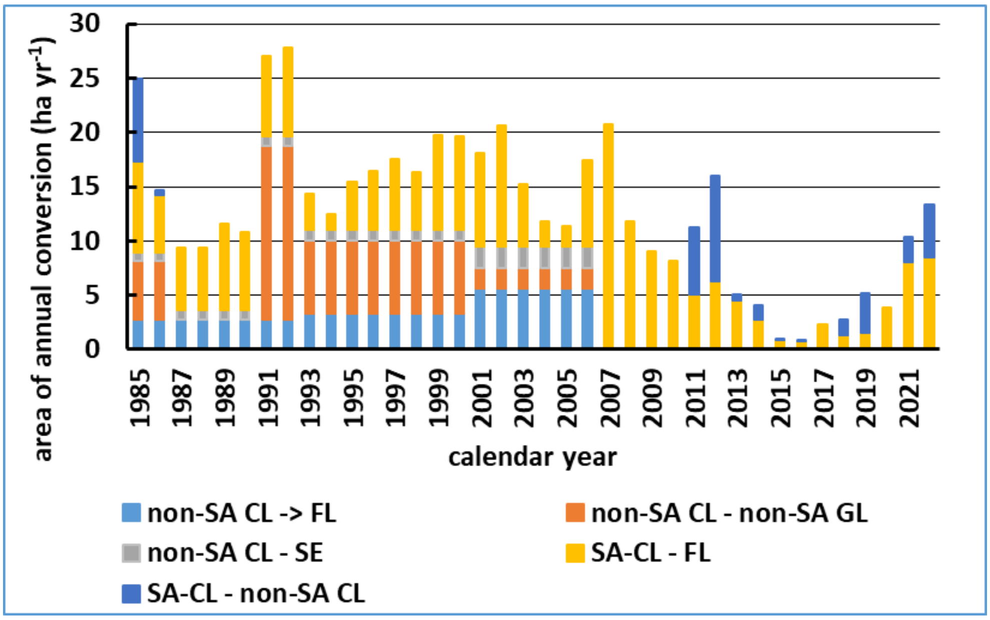

Figure 6.6.4. *The trend of annual area of the most important land-use change categories involving croplands for the entire time series.*

Table 6.6.1. *Methodological summary for CL-CL (CS=country specific; D: default; AD: activity data; EF: emission/removal factor; NO=not occurring).*

METHODOLOGY MATRICES TO BE INCLUDED IN NIR									
	Type of information	Carbon stock changes						Table (4)III, (4)IV	Table (4)V
		BIOMASS		DOM		SOIL			
		annual	perennial	DW	LI	mineral	organic		
CL-CL	E/R	Tier 1: 0	AD: CS; EF: CS and D	Tier 1: 0		AD: CS; EF: CS/D	NO	D	Wildfires: AD: CS; EF: D Biomass burning: NO
	Uncertainty	Tier 2		NE		Tier 2		Tier 2	

6.6.2.1 Biomass

Consistent with the 2006 IPCC GL, carbon stock changes of biomass are only estimated for perennial woody crops of orchards and vineyards (the biomass of annual crops is assumed to be in equilibrium). This chapter thus reports on emissions and removals from biomass in areas that remained orchards or vineyards in the inventory year. (Carbon stock changes from loss of perennial biomass due to land-use change are accounted for in the respective conversion sub-categories.)

Carbon stock change of biomass (ΔC_{Biom}) was estimated applying Equation 2.15 of the 2006 IPCC GL:

$$\Delta C_{Biom} = \Delta C_G + \Delta C_{Conversion} - \Delta C_{loss}$$

where

ΔC_{Biom} = annual change in carbon stocks of biomass, tonnes C yr^{-1}

ΔC_G = annual increase in carbon stocks due to biomass growth, tonnes C yr^{-1}

ΔC_L = annual decrease in carbon stocks due to biomass loss, tonnes C yr^{-1}

$\Delta C_{Conversion}$ = annual carbon loss due to converting perennials to other land-use, tones C yr^{-1}.

The estimation is done separately for orchards and vineyards and for growth and losses, and for losses due to conversions where perennials are converted to annual croplands or other land-use.

6.6.2.1.1 Growth and loss

Carbon stock changes due to growth and loss were estimated using Equation 2.7 of the 2006 IPCC GL:

$$\Delta C_{Biom} = \Delta C_G - \Delta C_L$$

Orchards and vineyards are assumed to be grown in rotations of 30 and 31.8 years, respectively. For the entire period, ΔC_G was estimated using Equation 2.9 of the 2006 IPCC GL:

$$\Delta C_G = A_{perennials} * G_{TOTAL} * CF$$

where

$A_{perennials}$ = area of orchards and vineyards at the beginning of the inventory year, ha (data is taken from the statistics of the HCSO),

G_{TOTAL} = county-specific net biomass accumulation rate (0.313 and 0.626 t biomass ha^{-1} yr^{-1} for orchards and vineyards, respectively), and

CF = carbon fraction (the default value of 0.5 tC t $biomass^{-1}$ is used).

G_{TOTAL} was estimated in the detailed study of Juhos and Tőkei (2013). Consistent with section 6.5.5.2.1, as it was not possible to measure below-ground biomass, G_{TOTAL} only includes above-ground biomass (which is the application of the default assumption, according to which there is no change in below-ground biomass of perennial trees in agricultural systems).

The annual decrease in carbon stocks from biomass loss due to regenerating perennials was estimated using Equation 2.16 of the 2006 IPCC GL:

$$\Delta C_L = A_{regenerated\_perennials} * B_{Before} * CF$$

where

$A_{regenerated\_perennials}$ = the area of regenerated orchard or vineyard in the inventory year =

= ($A_{perennials}$ – A_{conv}) / RPL, ha;

A_{conv} = area if orchards and vineyards that are converted to other land-use categories in the inventory year (see below), ha;

RPL = length of rotation period, 30 years (orchards) and 31.8 years (vineyards); and

B_{Before} = biomass of the regenerated orchard or vineyard at the end of the rotation period, t biomass, which is equal to G_{TOTAL} (tC ha^{-1} yr^{-1}) * RPL (years). (Since all biomass is considered lost during the regeneration, the “fraction of biomass lost in disturbance” term, or fd, in the original equation of the 2006 IPCC GL is taken to be equal to 1.)

Note that the above methodology implies that removals due to slight increases of the area of perennials (this has only happened in a few years and on small areas) are all accounted for in the CL-CL category (i.e., the assumption is applied that all increases of the area of perennials are due to conversions from annual cropland).

6.6.2.1.2 Conversions

Concerning conversions between perennial and annual crops, the total area of perennial croplands is rather low relative to annual croplands and there is little conversion from one to the other and vice versa. Nevertheless, the Corine Land Cover is used in the inventory (Table 6.3.1 to develop proportions of conversion of perennial CL to other land-uses.

Total emissions from biomass from converting orchards and vineyards are estimated by applying the methodology described in section 6.4.4 (i.e., Equation 2.16 of the 2006 IPCC GL) with

B_{After} = 0, and

B_{Before} and CF as above.

A_{conv} was estimated using an estimated proportion of converted perennials, P_P, which remained in the Cropland category:

$$A_{conv} = A_{perennials} * P_P.$$

P_P for Cropland was estimated from the land statistics database (see section 6.3.2 for details).

The areas removed are calculated from actual reduction, if any, of the total areas and thus the estimation of these areas is fully consistent with that of areas where growth occurs.

6.6.2.2 Dead organic matter

For DOM, the Tier 1 method is applied. This method assumes that the dead wood and litter stocks are not present in Cropland or are at equilibrium as in agroforestry systems and orchards. Thus, the carbon stock changes are not reported for these pools.

6.6.2.3 Mineral soils

The method and emission factors used are those described in section 6.4.1. For CL-CL, what may cause changes of the mineral soil carbon stocks are the following: changes in management, changes in input, and converting non-set aside to set-aside and back.

We highlight here that CL-CL is a category in Hungary that is split into non-set-aside and set-aside CL. There is difference in the assumed carbon stocks of these sub-categories (see Table 6.4.2 of the NIR) and when land is converted from one sub-category to the other, the soil SOC changes with a dynamics of over a 20-year period according to the IPCC default method. There were quite large areas converted to the set-aside sub-category even before 2011 (but in some years, later, too), and the overall effect of all these factors is reflected in the IEF values for the entire CL-CL category. In other words, even if the total area of the CL-CL category remains the same, there may be net emissions or removals from the soil if the distribution of the area of the SA and non-SA sub-categories changes over time, and thus the net of these changes may be different from zero.

Concerning the management of soils, the most recent data on the share of no-till and other reduced impact methodologies is available from 2016, which are incorporated in the GHG calculations.

6.6.2.4 Non-CO_2 emissions

The amount of non-CO_2 emissions is estimated according to section 6.4.2 (for N_2O emissions from soils) and 6.4.3 (for emissions from wildfires).

For the mass of available fuel (M_B) in the wildfire calculation, no proper country-specific values have been derived yet, therefore, a default value of 10 t d.m. ha^{-1} was assumed. This is a value taken from Table 2.4 of the 2006 IPCC GL for maize, which is quite a representative crop in Hungary, and can be considered as a conservative value as wheat and other crops of less biomass are also abundant. For the combustion factor Cf, and for the GHG-specific emission factors, default data (for maize residues in Table 2.6, and those in Table 2.5 of the 2006 IPCC GL, respectively) are used.

6.6.3 Land converted to Cropland

Figure 6.6.5 reports emissions and removals, whereas Table 6.6.2 reports methodological information for this sub-category. Note that non-CO_2 emissions from wildfires, if any, are reported as IE and accounted for in the CL-CL category. Emissions from burning is NO.

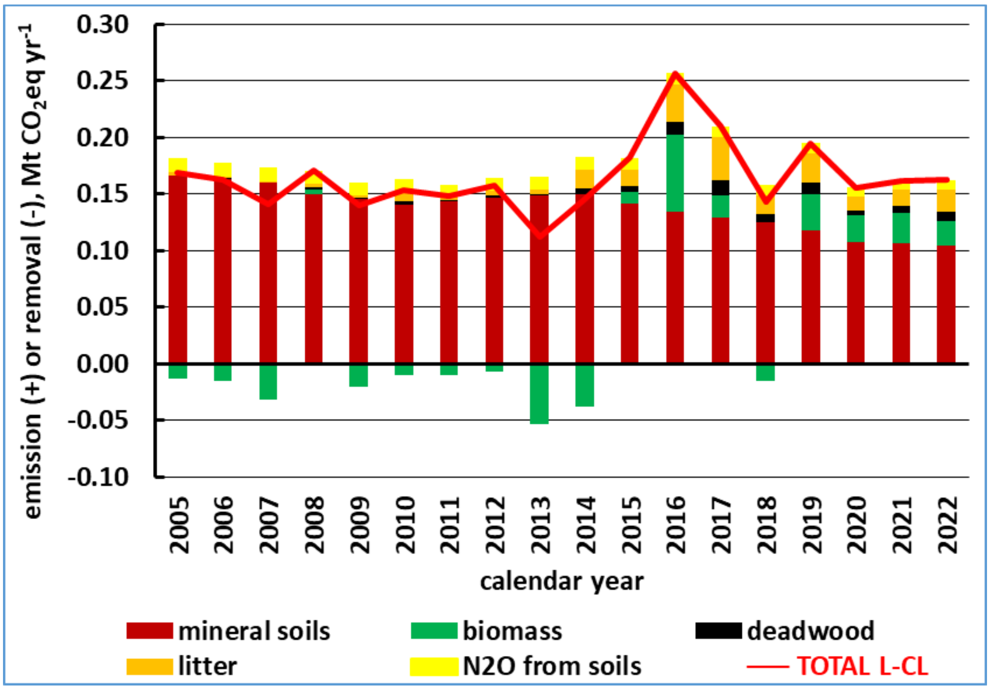

Figure 6.6.5. *Emissions and removals in L-CL since 2005.*

Table 6.6.2. *Methodological summary for L-CL. (CS=country specific; D: default; IE: included elsewhere; AD: activity data; EF: emission/removal factor)*

	Type of information	"FROM" category	BIOMASS	DOM		SOIL		Table (4)III, (4)IV	Table (4)V
				DW	LI	mineral	organic		
L-CL	E/R	FL	AD: CS; EF: CS	AD: CS; EF: CS		AD: CS; EF: CS/D	NO	D	slash burning: IE (FL-FL)
		GL	AD: CS; EF: D	Tier 1: 0		AD: CS; EF: CS/D	NO		IE (CL-CL)
		WL	NO	NO		NO	NO		IE (CL-CL)
		SE	Tier 1: 0	Tier 1: 0		AD: CS; EF: CS/D	NO		IE (CL-CL)
		OL	NO	NO		NO	NO		IE (CL-CL)
	Uncertainty	Tier 2		NE		Tier 2		Tier 2	

6.6.3.1 Forest Land converted to Cropland

For the methodology to estimate carbon stock changes in the biomass, DOM, and soil pools, see Sections 6.5.6.1.1, 6.5.6.1.2 and 6.5.6.1.3, respectively. Note that the total emissions from these pools were split between FL-CL and other conversions by the area of these conversions. The long-term average share of FL-CL to all FL-L is 27% and was 51% in 2022.

6.6.3.2 Grassland converted to Cropland

6.6.3.2.1 Biomass

Equations 2.15 of the 2006 IPCC GL were applied as follows:

$$\Delta C_B = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

where:

ΔC_B = biomass carbon stock change due to land-use conversion, tC year^{-1},

ΔC_G = annual increase in carbon stocks in biomass due to growth on the 'converted to' land, tonnes C yr^{-1},

ΔC_L = annual decrease in biomass carbon stocks due to losses, tonnes C yr^{-1},

$\Delta C_{CONVERSION}$ = initial change in carbon stocks in biomass on the 'converted to' land, tonnes C yr^{-1}, estimated using Equation 2.16 of the 2006 IPCC GL as described in section 6.4.4.

For A_{Conv}, data from the annual land-use change matrix was used. B_{before} was estimated from the proportion of Grassland area of cold dry and warm dry climate types (P_{CD} = 0.41, P_{WD} = 0.59) and respective specific default Grassland biomass (in order that all biomass is accounted for, the following total above- and below-ground biomass values were taken from Table 6.4 of the 2006 IPCC GL: B_{CD} = 6.5 t biomass ha^{-1} and B_{WD} = 6.1 t biomass ha^{-1}, respectively). The resulting weighted biomass is: $B_{before} = P_{CD} * B_{CD} + P_{WD} * B_{WD}$ = 6.26 t biomass ha^{-1} (see section 6.7.2.1 for more details). In accordance with the Tier1 assumption, B_{after} in the equation is 0, and the carbon fraction is the default value of 0.47 tC t biomass^{-1} (page 6.29 of the 2006 IPCC GL). For ΔC_G, the value of 4.7 tC ha^{-1} was used, whereas ΔC_L was assumed to be equal to 0.

6.6.3.2.2 Mineral soils

The method and emission factors used are those described in section 6.4.1.

6.6.3.3 Wetlands converted to Cropland

This land-use change is not occurring in Hungary.

6.6.3.4 Settlements converted to Cropland

For the small conversion areas in this category, only carbon stock changes in mineral soils are estimated. The method and emission factors used are those described in section 6.4.1.

6.6.3.5 Other Land converted to Cropland

This land-use change is not occurring in Hungary.

6.6.4 Uncertainties and time-series consistency

See section 6.11.

6.6.5 Category-specific QA/QC and verification

Emissions/removals were estimated by the National Food Chain Safety Office, whereas the QA/QC was done by an external expert. This division of tasks made it possible to separate the work related to emission estimation and the QA/QC procedures.

The LULUCF QC measures are based on the QC procedures as described by Chapter 5 of the 2006 IPCC Guidelines.

The main checks carried out are related to the following issues:

Activity data:

- Methodological issues of the collection of the land-use / land-cover data.
- The differences between the different land-use datasets.
- Consistency of the activity data. In the case of inconsistency (methodological change in the data collection) the dataset is adjusted in consultation with the data provider.
- Data inputs for transcription errors.
- The units of activity data in the calculation sheets throughout the emission calculation.
- Consistency of the total area of Hungary in the land-use change matrices and the CRF tables.
- The comparison of activity data with data from other sources, if possible.

Methodology:

- The applied methodologies and emission factors against the 2006 IPCC GL.
- The correctness of the equations and factors in the calculation sheets.
- The consistency of the applied methodology throughout the entire time series.

Emissions and removals:

- Reported emissions for transcription errors between the calculation sheets and the CRF tables.
- Recalculation differences and reasons for recalculations.

6.6.6 Category-specific recalculations

As noted in section 6.1.4, we have done a number of recalculations this year to improve the accuracy of our estimates and to correct upload errors. Most of these recalculations are only revisions of the area data reported in the sectoral tables that was different from that in CRF table 4.1, i.e., the land-use change matrix and that was actually used for the emission calculations. Additionally, there were some minor revisions of some area data that resulted in very small revisions of the emission estimates, the difference between the new and previous estimates being hardly over 0.1% of the estimated total sectoral emission value of -7195 ktCO2eq in 2021.

6.6.7 Category-specific planned improvements

No improvements are currently planned.

6.7 Grassland (CRF sector 4.C)

6.7.1 Description of category

In 1985, the livestock of grazing animals included 2 million cattle, 1 million geese and 3 million sheep. The decade beginning 1980 both saw the highest number of grazing livestock in the country and was the period of the most intensive management of the Hungarian grasslands with respect to fertilizer doses and irrigation. The number of grazing animals and the intensity of grassland management started to decrease after about the mid-1980's and reached its bottom in the middle of the 1990's. All this also affected the area of managed grassland which considerably decreased after 1985 but started to increase again beginning 2011 (Figure 6.7.1). Of the emissions and removals due to changes to and from grasslands, those that are accounted for in the Grassland category are reported in Figure 6.7.2.

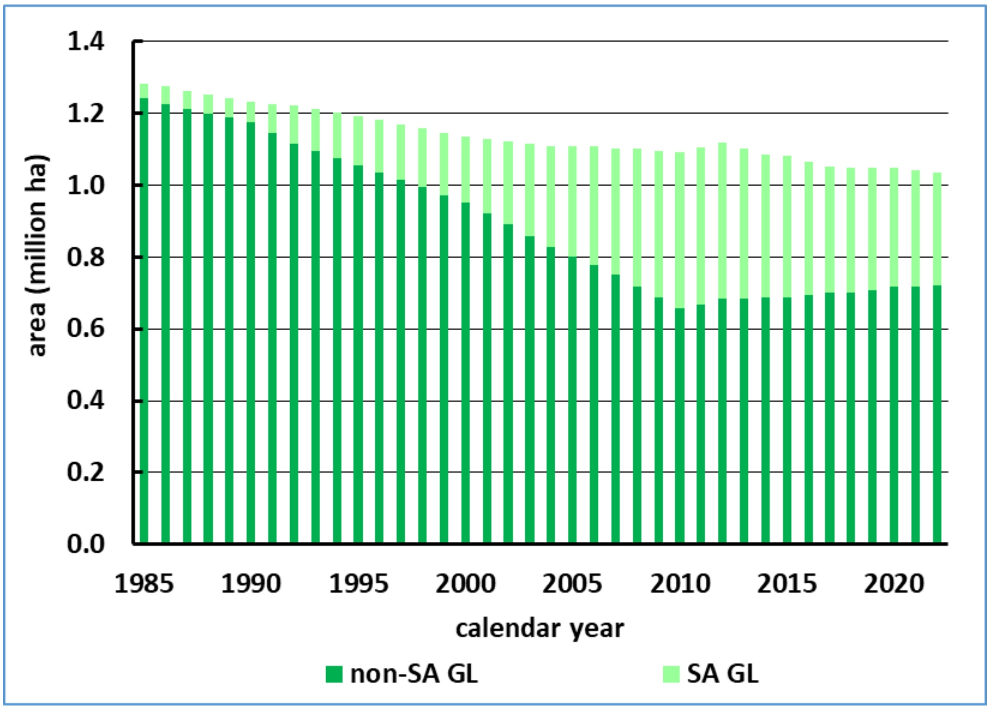

Figure 6.7.1. *The area of the Grassland category since 1985.*

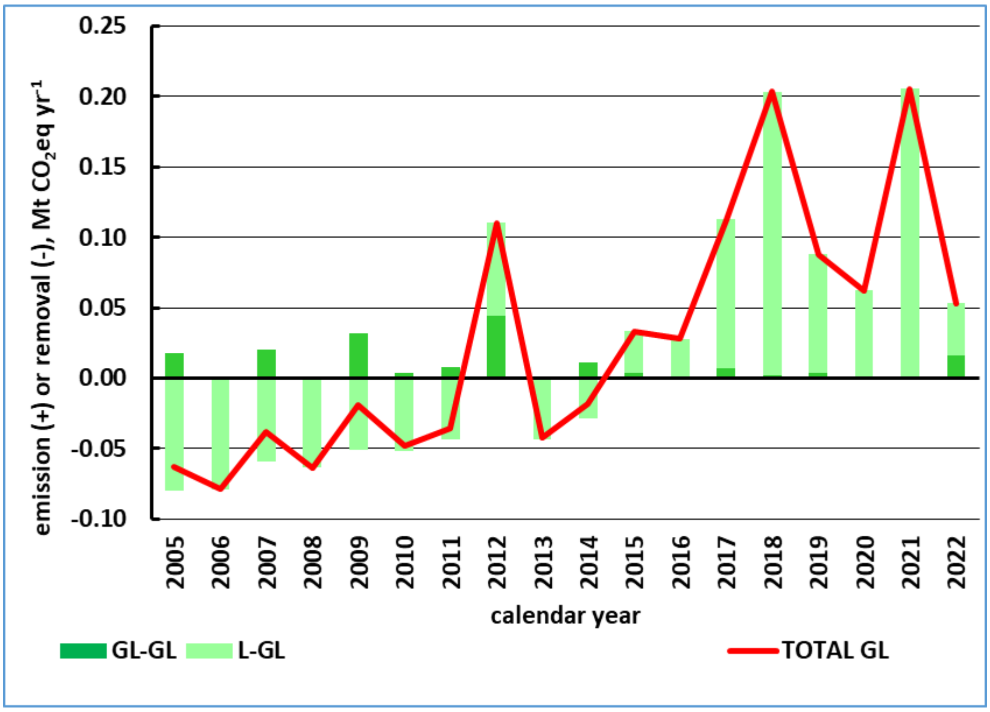

Figure 6.7.2. *Emissions and removals in the Grassland category since 2005.*

6.7.2 Grassland remaining Grassland

Figure 6.7.3 reports emissions and removals, whereas Table 6.7.1 reports methodological information for this sub-category.

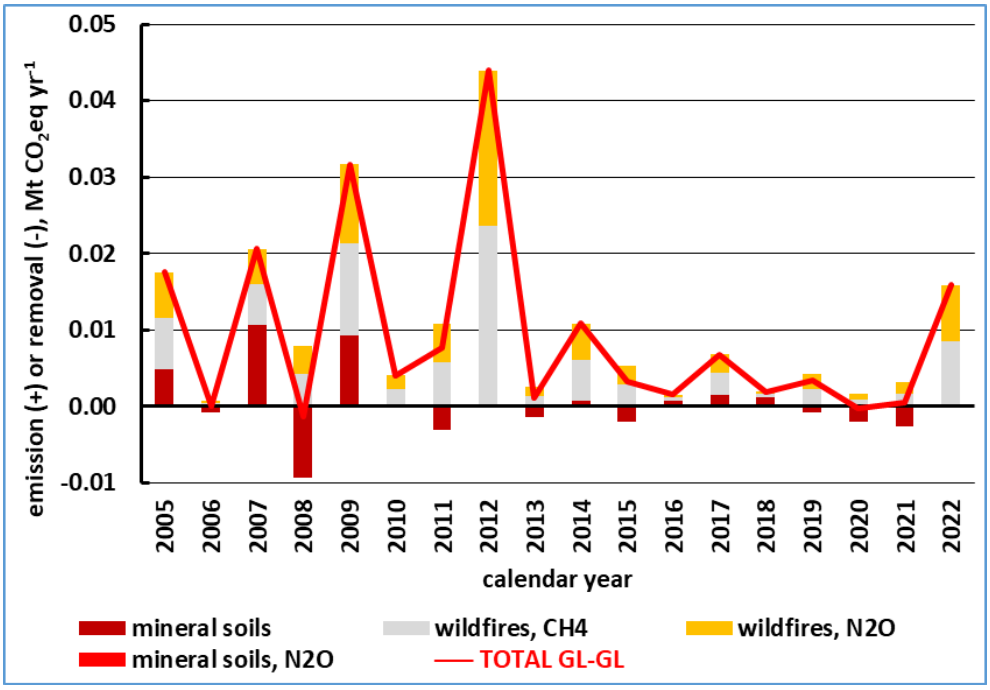

Figure 6.7.3. *Emissions and removals in the GL-GL category since 2005.*

Table 6.7.1. *Methodological summary for GL-GL (CS=country specific; D: default; AD: activity data; EF: emission/removal factor).*

	Type of information	Carbon stock changes						Table (4)III, (4)IV	Table (4)V
		BIOMASS		DOM		SOIL			
		annual	perennial	DW	LI	mineral	organic		
GL-GL	E/R	Tier 1: 0	Tier 1: 0	Tier 1: 0	Tier 1: 0	**AD: CS; EF: CS/D**	NO	D	**Wildfires: AD: CS; EF: D** Biomass burning: NO
	Uncertainty	Tier 2		NE		Tier 2		Tier 2	

6.7.2.1 Biomass

Grasslands are meadows and pastures some of which are grazed or harvested annually, while others are unmanaged, and where tree cover is non-existent or very low. Due also to its small area and dynamics, the biomass of GL-GL is not a key category. Therefore, we adapt the Tier 1 method of the 2006 IPCC GL which assumes no change in the biomass carbon stocks. In line with this, 'NO' is reported for the biomass of this category. Note that, due to the increase of set-aside grassland earlier, a rather slow increase in woody biomass might have been occurring, thus, applying the Tier 1 method might slightly underestimate carbon removals.

Note that a domestic study (Tasi et al. 2016) reports highly variable above-ground biomass on grasslands, but no estimates for the below-ground biomass. The change of grassland management, such as from non-set-aside grassland to set-aside grassland and vice versa, does not lead to a change in grassland productivity in biomass. This information together with expert judgment suggests that the total biomass is around the default IPCC value. Therefore, we apply the IPCC default value for the biomass of grasslands.

6.7.2.2 Dead organic matter

As the dead organic matter pool and its carbon stock changes are small, the Tier 1 method is applied which assumes that the dead wood and litter stocks are at equilibrium, and the carbon stock changes for these pools are thus not estimated.

6.7.2.3 Soils

As of now, only some direct local results have already been published concerning CO_2-emission from grasslands (Nagy et al. 2007, Zsembeli et al. 2006). Therefore, the Tier 2 monitoring results as described in section 6.4.1 are applied.

Concerning management, sufficient statistics are lacking for the period 1985-2002. As an approximation, the management, hence the quality of grasslands is determined for this period using expert judgment based on the number of grazing animals and the level of management costs for each soil type and climate region, taking into consideration the spatial distribution of the number of livestock by species. The spatial distribution of quality, utilization and load of grasslands were estimated and overlaid on the genetic soil maps and climatic zone maps mentioned in section 6.4.1. Based on this, the following two broad categories are used to characterize the management of the Hungarian grasslands: nominally managed (non-degraded) grasslands (with no input), which includes pastures, rangelands and other unmanaged grasslands, and improved grasslands with medium input. The area of the latter can be calculated from HCSO data based on the area of grasslands treated with chemical fertilizers (Table 6.7.2) and that of irrigated grasslands which are available for some inventory years since 2003. The proportion of irrigated grasslands is less than 0.1 per cent, therefore, the area of grasslands treated with chemical fertilizers is considered to represent improved grasslands in Hungary, and the rest is taken as nominally managed.

Table 6.7.2. *The area of grasslands treated with chemical fertilizer as well as the amount of active ingredient applied to grasslands for recent years (data source: HCSO: https://www.ksh.hu/stadat_files/mez/hu/mez0042.html, with the exception of 2020 for which interpolation is applied).*

Year	Grasslands treated with chemical fertilizer [ha]	Amount of active ingredient used (kg/ha)		
		N	P	K
2003	22361			
2004	21290			
2005	no data			
2006	no data			
2007	10114			
2008	16412			
2009	8962			
2010	8774			
2011	11441			
2012	11494	50.3	1.2	1.4
2013	12387	51.9	2.7	3.3
2014	11675	68.3	2	2
2015	13233	50.5	2	3.9
2016	NA	57.8	4.2	5.5
2017	NA	52.6	5.9	5.1
2018	NA	49.4	5.6	6.2
2019	NA	49.1	6.8	6.1
2020	NA	58.0	9.3	8.1
2021	NA	66.9	11.8	10.1
2022	NA	62.7	14.0	14.7

The management of grasslands was considerably reduced due to the introduction of Agro-environmental Management Program in 2002-2003 and was limited to slightly intensive planted grasslands. This program resulted in the natural succession of pastures that is characterized by the propagation of weeds and soil degradation. Since the above years, the management of grasslands has been mainly limited to their grazing and cutting.

For the years after 2003, the above information formed the basis for the expert judgment that was necessary to develop the required proportions. For years for which area data is available, the proportion that can be calculated from the area treated with fertilizers and the total grassland area. For later years, the time series was extrapolated using overlapping period of area treated with fertilizer and the amount of N applied. For earlier years, we had to rely on the personal communication of a grassland expert a number of years earlier. The proportion of nominally managed grasslands is estimated to have been 0.98 for 2022.

Note that carbon stock changes for mineral soils (for both grasslands and elsewhere) depend on both the area (activity data) and the appropriate emission factor that in turn depends on the management practice. Since the distribution shows a change over time, and the factor F_{MG} is different for the non-degraded and the improved grasslands, it follows that carbon stock changes are not zero (but rather small anyways).

For the above climate, soil, management and input categories, the applied reference soil organic carbon stocks were the same as those reported in Table 6.4.2 above. The land-use factor (F_{LU}) is 1.0 for all grasslands, whereas the selected management factors (F_{MG}) are reported in Table 6.7.3 and the level of input (F_I) was assumed to be 1.0 for both the nominally managed grasslands and the improved grassland (IPCC 2006).

Note also that the above methodology may result in zero carbon stock change estimate in some years. To demonstrate that it is the result of a calculation, it is reported as zero and not as "NO".

Table 6.7.3. *Management factors (F_{MG}) applied for Grassland*

Management regime	F_{MG}
Nominally managed (non-degraded)	1.00
Improved	1.14

6.7.2.4 Non-CO_2 emissions

The amount of non-CO_2 emissions is estimated according to section 6.4.2 (for N_2O emissions from soils) and 6.4.3 (for emissions from wildfires).

For the mass of available fuel (M_B) in the wildfire calculation, no proper country-specific values have been derived yet, therefore, the value of 6.26 t d.m. ha^{-1} was assumed, which is the same that we use in the GL-CL conversions (see section 6.6.3.2.1 above). For the combustion factor Cf, the conservative value of 1 is used (Table 2.6 of the 2006 IPCC GL fails to report appropriate values), whereas for the Gef emission factors default values in Table 2.5 of the 2006 IPCC GL are used.

6.7.3 Land converted to Grassland

Figure 6.7.4 reports emissions and removals, whereas Table 6.7.4 reports methodological information for this sub-category.

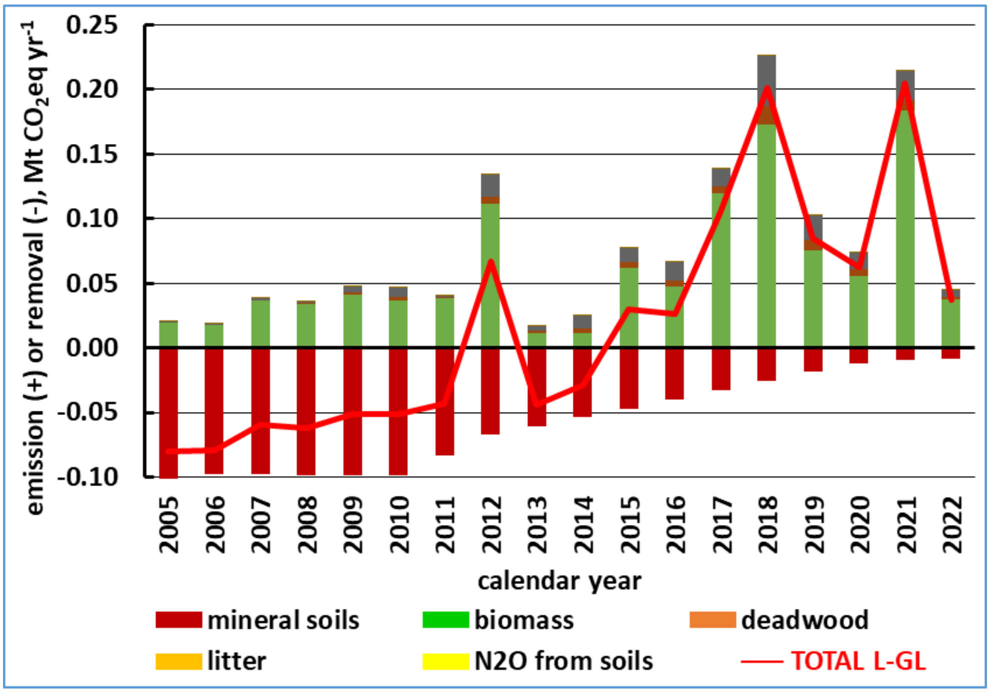

Figure 6.7.4. *Emissions and removals in the L-GL category since 2005.*

Table 6.7.4*. Methodological summary for L-GL. (CS=country specific; D: default; IE: included elsewhere; AD: activity data; EF: emission/removal factor)*

	Type of information	"FROM" category	BIOMASS	DOM		SOIL		Table (4)III, (4)IV	Table (4)V
				DW	LI	mineral	organic		
L-GL	E/R	FL	AD: CS; EF: CS	AD: CS; EF: CS		AD: CS; EF: CS/D	NO	D	Wildfires: IE (GL-GL)
		CL	AD: CS; EF: D	Tier 1: 0		AD: CS; EF: CS/D	NO		
		WL	NO	NO		NO	NO		
		SE	Tier 1: 0	Tier 1: 0		AD: CS; EF: CS/D	NO		
		OL	NO	NO		NO	NO		
	Uncertainty	Tier 2		NE		Tier 2		Tier 2	

6.7.3.1 Forest Land converted to Grassland

For the methodology to estimate carbon stock changes in the biomass, DOM and soil pools, see Sections 6.5.6.1.1 and 6.4.4, 6.5.6.1.2 and 6.5.6.1.3, respectively. The total emissions from these pools estimated using this methodology was split between FL-GL and other conversions by the area of these conversions. The share of FL-GL to all FL-L varies between about 4 and 50% and was 14% in 2022.

6.7.3.2 Cropland converted to Grassland

6.7.3.3 Biomass

Carbon stock changes in biomass in this category are the sum of those from converting Cropland with annual crops to Grassland and those from converting Cropland with perennials to Grassland.

For annual crops, the methodology of estimating carbon stock changes is the same as reported in sections 6.4.4 and 6.6.3.2.1, and symbols applied there are used here, too.

For A_{Conv}, data from the annual land-use change matrix was used.

The value of B_{before} for annual croplands, the default 10 t biomass/ha, was taken from text to Table 5.9 of the 2006 IPCC GL, whereas B_{after} was estimated from the proportion of Cropland area of cold dry and warm dry climate types (P_{CD} = 0.41, P_{wD} = 0.59) and respective specific default Grassland biomass (total above- and below-ground biomass, Table 6.4 of the 2006 IPCC GL: B_{CD} = 6.5 t biomass ha^{-1} and B_{wD} = 6.1 t biomass ha^{-1}, respectively): $B_{after} = P_{CD} * B_{CD} + P_{wD} * B_{wD}$ (see section 6.7.2.1 for more details). In accordance with the Tier 1 assumption, B_{after} in the equation is 0, and the carbon fraction is the default value of 0.47 tC t $biomass^{-1}$.

For ΔC_G, the same biomass value of 6.26 tC ha^{-1}, together with the default carbon fraction of 0.47 tC t $biomass^{-1}$ was used as for the pre-conversion biomass of B_{before} in the CL-GL category, whereas ΔC_L was assumed to be equal to 0.

When converting perennial Cropland to Grassland, the methodology of estimating carbon stock changes is consistent with the one reported in section 6.6.2.1.1. P_P for Grassland was also estimated from the CORINE land cover change database (see section 6.2 for details).

6.7.3.3.1 Mineral soils

The method and emission factors used are those described in section 6.4.1.

6.7.3.4 Wetlands converted to Grassland

This land-use change is not occurring in Hungary.

6.7.3.5 Settlements converted to Grassland

The land cover change databases indicate small areas of Settlement converted to Grassland (ranging between 119 and 222 ha/yr). These areas are predominantly biological re-cultivation of abandoned surface mines. In general, the biological re-cultivation results in an increase in the carbon stocks. For the sake of consistency and completeness, carbon stock changes in mineral soils are estimated using the method and emission factors that are reported in section 6.4.1.

6.7.3.6 Other Land converted to Grassland

This land-use change is not occurring in Hungary.

6.7.4 Uncertainties and time-series consistency

See section 6.11.

6.7.5 Category-specific QA/QC and verification

See section 6.6.5.

6.7.6 Category-specific recalculations

As noted in section 6.1.4, we have done a number of recalculations this year to improve the accuracy of our estimates and to correct upload errors. Most of these recalculations are only revisions of the area data reported in the sectoral tables that was different from that in CRF table 4.1, i.e., the land-use change matrix and that was actually used for the emission calculations. Additionally, there were some minor revisions of some area data that resulted in very small revisions of the emission estimates, the difference between the new and previous estimates being hardly over 0.1% of the estimated total sectoral emission value of -7195 ktCO2eq in 2021.

6.7.7 Category-specific planned improvements

No improvements are currently planned.

6.8 Wetland (CRF sector 4.D)

6.8.1 Description of category

Wetlands account for only about 2.8 per cent of the total area of Hungary (Figure 6.3.1) and include inland marshes, peat bogs, and natural and artificial water courses and open water bodies. Wetlands are *ex lege* protected in Hungary that is among the signatories of the Ramsar Convention. The preservation and the sustainable use of Wetlands became standard practice decades ago. In 2017, altogether 29 Hungarian wetland areas (with a total area of 256,948 ha) were included the Ramsar List of Wetlands of International Importance and managed accordingly (http://www.ramsar.org/sites/default/files/documents/library/sitelist.pdf).

The current methodology of identifying Wetlands (see section 6.3) does not allow for the separation of managed and unmanaged Wetlands (the latter having a small share), but the area of Wetlands could be split into remaining and 'converted to' sub-categories. As wetlands are sensitive to the annual amount of precipitation, their extent varies. This variability could not be entirely reflected in the annual land-use change matrices.

Anthropogenic emissions from wetlands are not significant in Hungary because both the managed and total Wetland area have been small and quite constant at the decadal timescale, therefore, the Tier 1 method is applied for the estimation of the emissions. To ensure completeness, emissions from both land conversions to wetlands (as conversions to 'flooded land') and peat extraction are reported. The Supervisory Authority of Controlled Activities (abbreviated in Hungarian as SZTFH, URL: https://sztfh.hu/) provides data on the establishment of new peat extraction sites and on the amount of peat extracted annually. The effect of converting peat bogs to peat extraction sites seems to be small, because peat mining is an exceedingly rare activity due to the strict natural protection law. No new extraction sites have been established since 2006.

6.8.2 Wetland remaining Wetland

Table 6.8.1 reports methodological information for this sub-category.

*Table **6.8.1**. Methodology summary for WL-WL (CS=country specific; D: default; AD: activity data; EF: emission/removal factor; NO: not occurring).*

	Type of information	Carbon stock changes		CO_2 emissions, on-site	N_2O emissions, on-site	CO_2 emissions, off-site	Table (4)I, II, III, IV	Table (4)V
		BIOMASS	DOM	SOIL				
WL-WL	E/R	AD: CS; EF: D	Tier 1: 0	AD: CS; EF: D	AD: CS; EF: CS/D	AD: CS; EF: D	Direct N_2O emissions from N inputs to managed soils: NO; Emissions from peat extraction: D; Direct and indirect N_2O emissions from N mineralization: D	**Wildfires: NO** Biomass burning: NO
	Uncertainty	NE		NE			NE	

Wetlands in Hungary are currently not separated to flooded land remaining flooded land and other wetlands, therefore, except for peat extraction sites, all wetland areas are reported under "Other wetlands".

In WL-WL, the main sources of emissions are related to peat extraction. Biomass carbon stock changes unrelated to peat extraction, which are negligible, are not estimated. For the sake of completeness, soil carbon stock changes in "other wetlands" (i.e., wetlands with predominantly grassy vegetation) are estimated using the methodology described in section 6.4.1. Note that this methodology may result in a zero carbon stock change estimate in some inventory years.

6.8.2.1 Carbon stock changes as well as CO_2 emissions (on-site and off-site)

According to Equations 7.3. and 7.4 of the 2006 IPCC GL, one source of CO_2 emissions (for all production phases) from peatlands is emissions from peatland extraction (both on-site and off-site) and from biomass clearing:

$$CO_2\text{-}C_{WW\ peat\ on\text{-}site} = [(A_{peatRich} * EF_{CO2\ peatRich}) + (A_{peatPoor} * EF_{CO2\ peatPoor})] / 1000 + \Delta C_{WW\ peat\ B}$$

where

$CO_2\text{-}C_{WW\ peat\ on\text{-}site}$ = on-site CO_2-C emissions from peat deposits, kt C yr^{-1}
$A_{peatRich}$ = area of nutrient-rich peat soils managed for peat extraction, ha
$A_{peatPoor}$ = area of nutrient-poor peat soils managed for peat extraction, ha
$EF_{CO2\ peatRich}$ = CO_2 emission factors for nutrient-rich peat soils managed for peat extraction or abandoned after peat extraction, tonnes C ha^{-1} yr^{-1}
$EF_{CO2\ peatPoor}$ = CO_2 emission factors for nutrient-poor peat soils managed for peat extraction or abandoned after peat extraction, tonnes C ha^{-1} yr^{-1}
$\Delta C_{WW\ peat\ B}$ = CO_2–C emissions from change in carbon stocks in biomass due to vegetation clearing, kt C yr^{-1}.

Data for $A_{peatRich}$ and $A_{peatPoor}$ was obtained from the SZTFH for the period 1995-2021 (Table 6.8.2). The total area of both $A_{peatRich}$ and $A_{peatPoor}$ is small: 1185 and 575 ha in 2022, respectively. For the years 1985 to 1994 data on area conversions are not available, therefore, proxy data, i.e., data of 1995 was used for the estimation. For the emission factors, IPCC default values, i.e., 1.1 and 0.2 tonnes C ha^{-1} yr^{-1}, from Table 7.4 of Volume 4 of the 2006 IPCC GL, were used for nutrient-rich and nutrient-poor peats, respectively, irrespective of the current status (in operation vs abandonment) of the various peat extraction sites.

Table 6.8.2. *Area of land converted annually to peat extraction for selected years (ha).*

Inventory year	Area of land converted annually to peat extraction (ha)	
	Mire	Peat
1995	33.21	24.42
2000	60.7	NO
2005	NO	NO
2010	NO	NO
2015	NO	NO
2020	11.5	NO
2021	NO	NO
2022	NO	NO

Various situations that occur after extraction has ceased on a site, such as abandonment, restoration or land conversion, may result in different levels of emissions according to the 2006 IPCC Guidelines and the Wetlands Supplement. The impact of these emissions is small on the national level of emissions because of the very small areas involved, therefore, no emission estimates have been developed.

Concerning the methodology to differentiate between nutrient rich and nutrient poor sub-categories, the basis for the classification is the type of organic material in the soil. The database we have allows us to apply two classes here: "mire" that we regard as being poor in nutrients, and "peat" that we regard as being rich in nutrients.

Carbon stock change in biomass due to vegetation clearing was estimated using Equation 2.16 (see Section 6.4.4). In Hungary, the typical biomass of peat bogs, i.e., B_{before} in this equation, is grass as demonstrated in different studies (e.g., Hubayné, 2005 and Dömsödy, 2006). Therefore, B_{before} was estimated from the proportion and average specific biomass for cold dry and warm dry climate types: $B_{before} = P_{CD} * B_{CD} + P_{WD} * B_{WD}$ ($P_{CD} = 0.41$, $P_{WD} = 0.59$, $B_{CD} = 6.5$ t biomass ha^{-1} and $B_{WD} = 6.1$ t biomass ha^{-1}, respectively; see more details in Section 6.7.3.3). B_{after} in the equation is 0, and the carbon fraction is the IPCC default value of 0.47 tC t biomass^{-1}.

Off-site emissions from managed peatlands were estimated using Equation 7.5 (by modifying it, i.e., deleting the division by 1000, to correct for appropriate dimensions):

$$CO_2\text{-}C_{WW\ peat\ off\text{-}site} = Wt_{dry\_peat} * Cfraction_{wt\_peat}$$

where

$CO_2\text{-}C_{WW\ peat\ off\text{-}site}$ = off-site CO_2-C emissions from peat removed for horticultural use, tC yr^{-1}
Wt_{dry_peat} = air-dry weight of extracted peat, tonnes yr^{-1}
$Cfraction_{wt\_peat}$ = carbon fraction of air-dry peat by weight, tonnes C (tonnes of air-dry peat)$^{-1}$.

Wt_{dry_peat} was estimated from the annual statistics (based on measured values) of the amount of peat extracted (provided by the SZTFH, Table 6.8.3) and the density of the peat (i.e., 0.2 tonnes biomass m^{-3}) to convert volume extracted to biomass extracted (Hahn, 1984). For $Cfraction_{wt\_peat}$, the area-weighted value of 0.42 tonnes C (tonnes of air-dry peat)$^{-1}$ is used, which was calculated based on the area of nutrient rich and nutrient poor sites and respective data from Table 7.5 of the 2006 IPCC GL. Note that while the conversion factors are constant, the amount of peat extracted varies from year to year due to the high variation of demand for peat.

Table 6.8.3. *Annual amount of peat extracted for selected years.*

Inventory year	Amount of peat extracted	
	Estimated by SZTFH, 1000 m^3	Converted to mass, tonnes
1995	321	64 200
2000	330	66 000
2005	294	58 800
2010	169.5	33 900
2015	286	57 200
2020	214.0	42 796
2021	206.0	41 199
2022	247.6	49 512

6.8.2.2 N_2O emissions

The 2006 IPCC GL provides a Tier 1 methodology to estimate N_2O emissions due to peat extraction. These emissions were only estimated for nutrient rich sites using Equation 7.7:

$$N_2O_{\ WW\ peatExtraction} = (A_{\ peatRich} * EF_{\ N2O\ peatRich}) * 44/28 * 10^{-6}$$

where

$N_2O_{\ WW\ peatExtraction}$ = N_2O emissions due to peat extraction, Gg N_2O yr^{-1}
$A_{\ peatRich}$ = area of nutrient rich peat extraction sites, ha (see above)
$EF_{\ N2O\text{-}N\ peatRich}$ = emission factor for drained nutrient-rich wetlands, kg N_2O–N $ha^{-1}yr^{-1}$ for which the IPCC default value of 1.8 kg N_2O–N $ha^{-1}yr^{-1}$ from Table 7.6 was used (the multiplier 10^{-6} is necessary in the equation to obtain the result in units of Gg N_2O yr^{-1}).

6.8.3 Land converted to Wetland

Table 6.8.4 reports methodological information for this sub-category.

Table 6.8.4. *Methodology summary for Land converted to Wetland (CS=country specific; D: default; AD: activity data; EF: emission/removal factor; NO: not occurring).*

	Subcategory	"FROM" category	BIOMASS	DOM		SOIL		Table (4)I, III, IV	Table (4)V
				DW	LI	mineral	organic		
L-WL	E/R, land converted to peatland	not estimated (insignificant amounts; if any, included in E/R in land converted to flooded land)							
	E/R, land converted to flooded land	FL	NO	NO	NO	NO	NO	Direct and indirect N2O emissions from N inputs to managed soils: NO; Direct and indirect N2O emissions from N mineralization/ immobilization: NO	Wildfires: NO; Biomass burning: NO
		CL	NO	NO	NO	NO	NO		
		GL	AD: CS; EF: D	Tier 1: 0		AD: CS; EF: CS/D	NO		
		SE	Tier 1: 0	Tier 1: 0		AD: CS; EF: CS/D	NO		
		OL	NO	NO		NO	NO		
	Uncertainty	Tier 2		NE		Tier 2		Tier 2	

6.8.3.1 Grassland converted to Wetland

The general methodology of identifying the area of Land converted to Wetland is described in section 6.3.1.

6.8.3.1.1 Biomass

Equation 7.10 of the 2006 IPCC GL was applied as follows:

$$\Delta C_{LWfloodLB} = A_{Conversion} * (B_{after} - B_{before}) * CF$$

where:

$\Delta C_{LWfloodLB}$= biomass carbon stock change due to land-use conversion to Wetland, tC year^{-1};
$A_{Conversion}$ = annual area of land converted to Wetland, ha year^{-1};
B_{after} = carbon stocks of biomass after the conversion to Wetland, tonnes C ha^{-1};
B_{before} = carbon stocks in biomass before the conversion to Wetland, tonnes C ha^{-1};
CF = carbon fraction, tC (t biomass)$^{-1}$.

To estimate the amount of biomass cleared in the year of conversion, the annual areas of Cropland or Grassland converted to Wetland need to be used because these are the types of conversions that have so far occurred in the time series since 1985.

It is assumed that B_{after} is zero, and B_{before} was estimated the same way as described for wetland prepared for peat extraction above. For more details see “Grassland converted to Cropland” in Chapter 6.6.3.2.

6.8.3.2 Settlements converted to Wetland

There area of Settlements converted to Wetland is exceedingly small. The CLC codes which were classified into this category are reported in Table 6.3.2. This land-use change category mainly contains the area of sandpits, gravel pits, and extraction and construction area which are not covered by soil and do not contain biomass. Therefore, emissions from these land-use change conversions are most probably, and taken to be, zero.

6.8.4 Uncertainties and time-series consistency

See section 6.11.

6.8.5 Category-specific QA/QC and verification

See section 6.6.5.

6.8.6 Category-specific recalculations

As noted in section 6.1.4, we have done a number of recalculations this year to improve the accuracy of our estimates and to correct upload errors. Most of these recalculations are only revisions of the area data reported in the sectoral tables that was different from that in CRF table 4.1, i.e., the land-use change matrix and that was actually used for the emission calculations. Additionally, there were some minor revisions of some area data that resulted in very small revisions of the emission estimates, the difference between the new and previous estimates being hardly over 0.1% of the estimated total sectoral emission value of -7195 ktCO2eq in 2021.

6.8.7 Category-specific planned improvements

Currently, there are no planned improvements for this sector.

6.9 Settlements (CRF sector 4.E)

6.9.1 Description of category

Settlements account for 6.3 per cent of the area of Hungary, and they are the sources of only a tiny fraction of all domestic emissions.

6.9.2 Settlements remaining Settlements

As this category is not a key category, the Tier 1 assumption of no change in carbon stocks in all pools is applied.

6.9.3 Land converted to Settlements

Table 6.9.1 reports methodological information for this sub-category.

Table 6.9.1. *Methodology summary for Land converted to Settlements (CS=country specific; D: default; AD: activity data; EF: emission/removal factor; NO: not occurring).*

<table>
<tr><th rowspan="2"></th><th rowspan="2">Type of information</th><th rowspan="2">"FROM" category</th><th rowspan="2">BIOMASS</th><th colspan="2">DOM</th><th colspan="2">SOIL</th><th rowspan="2">Table (4)I, III, IV</th><th rowspan="2">Table (4)V</th></tr>
<tr><th>DW</th><th>LI</th><th>mineral</th><th>organic</th></tr>
<tr><td rowspan="6">L-SE</td><td rowspan="5">E/R</td><td>FL</td><td>AD: CS; EF: CS</td><td colspan="2">AD: CS; EF: CS</td><td>AD: CS; EF: CS/D</td><td>NO</td><td rowspan="5">Direct and indirect N2O emissions from N inputs to managed soils: NO;
Direct and indirect N2O emissions from N mineralization: D</td><td rowspan="5">Wildfires: NO; Biomass burning: NO</td></tr>
<tr><td>CL</td><td>AD: CS; EF: D</td><td colspan="2">Tier 1: 0</td><td>AD: CS; EF: CS/D</td><td>NO</td></tr>
<tr><td>GL</td><td>AD: CS; EF: D</td><td colspan="2">Tier 1: 0</td><td>AD: CS; EF: CS/D</td><td>NO</td></tr>
<tr><td>WL</td><td>Tier 1: 0</td><td colspan="2">Tier 1: 0</td><td>AD: CS; EF: CS/D</td><td>NO</td></tr>
<tr><td>OL</td><td>NO</td><td colspan="2">NO</td><td>NO</td><td>NO</td></tr>
<tr><td>Uncertainty</td><td colspan="2">Tier 2</td><td colspan="2">NE</td><td colspan="2">Tier 2</td><td colspan="2">Tier 2</td></tr>
</table>

6.9.3.1 Forest land converted to Settlements

The share of emissions from FL-SE to all FL-L varies between about 16 and 88%, and it was 35% in 2021. For the methodology to estimate carbon stock changes in the biomass, DOM and soil pools, see Sections 6.5.6.1.1, 6.5.6.1.2 and 6.5.6.1.3, respectively.

6.9.3.2 Cropland converted to Settlements

6.9.3.2.1 Biomass

Carbon stock changes in biomass in this category are the sum of those from converting Cropland with annual crops to Settlement and those from converting Cropland with perennials to Settlement.

For annual crops, the methodology of estimating carbon stock changes is the same as reported in Sections 6.4.4 and 6.6.3.2.1, and symbols applied there are used here, too.

For A_{Conv}, data from the annual land-use change matrix was used.

For B_{before} for annual croplands, the default 10 t biomass/ha, was taken from text to Table 5.9 of the 2006 IPCC GL. In accordance with the Tier 1 assumption, B_{after} in the equation is 0, and the carbon fraction is the default value of 0.47 tC t biomass^{-1}. ΔC_L was assumed to be equal to 0.

When converting Cropland with perennials to Settlements, the methodology of estimating carbon stock changes is the same as reported in section 6.6.2.1.1. P_P for Settlements was also estimated from the CORINE land cover change database (see Table 6.9.2 and section 6.2 for details).

Table 6.9.2. *The distribution of the area of cropland annually converted to Settlements for selected years (ha).*

Inventory year	Annual area of conversions (ha)			
	Cropland converted to Settlements	Vineyard converted to Settlements	Orchard converted to Settlements	Total CL-SE
1995	920	18	0	938
2000	892	46	0	938
2005	1 862	75	28	1 965
2010	1 184	45	17	1 246
2015	821	20	14	854
2020	927	36	0	962
2021	927	35	0	962
2022	925	37	0	962

6.9.3.2.2 Mineral soils

The method and emission factors used are those described in section 6.4.1.

6.9.3.3 Grassland converted to Settlements

6.9.3.3.1 Biomass

The methodology of estimating carbon stock changes applied for Grassland converted to Settlement is the same as reported in section 6.6.3.2.1. B_{before} was estimated from the proportion of Grassland area of cold dry and warm dry climate types (P_{CD} = 0.41, P_{wD} = 0.59) and respective specific default Grassland biomass (total above- and below-ground biomass, Table 6.4 of the 2006 IPCC GL: B_{CD} = 6.5 t biomass ha^{-1} and B_{wD} = 6.1 t biomass ha^{-1}, respectively). The weighted value of $B_{before} = P_{CD} * B_{CD} + P_{wD} * B_{wD}$, whereas, in accordance with the Tier 1 assumption, B_{after} is 0.

6.9.3.3.2 Mineral soils

The method and emission factors used are those described in section 6.4.1.

6.9.3.4 Wetland converted to Settlements

6.9.3.4.1 Biomass

Wetland converted to Settlements typically includes inland marshes (rarely peat bogs) the biomass of which is typically grass (Dömsödi, 2006) and water bodies with no biomass. Therefore, the emissions from biomass were estimated using the methodology that is applied for the Grassland converted to Settlement, see Section 6.9.3.3.1 which, for water bodies, may somewhat overestimate the amount of biomass lost and is thus conservative.

6.9.3.4.2 Organic soils

For these conversions, Equation 2.26 was used to estimate the annual carbon loss:

$$L_{organic\ from\ water\text{-}bodies} = A_{entire\ category} * P_{water\text{-}bodies} * EF_{water\text{-}bodies}$$

and

$$L_{organic\ from\ marshes\text{-}bogs} = A_{entire\ category} * P_{marshes\text{-}bogs} * EF_{marshes\text{-}bogs}$$

where

$L_{organic}$ = annual carbon loss from organic soils of water bodies and marshes-bogs, respectively, from converting Wetland to Settlements, $tCyr^{-1}$
$A_{entire\ category}$ = area of the entire category of Wetland converted to Settlements, ha
$P_{water\text{-}bodies}$ = proportion of the area of water bodies relative to $A_{entire\ category}$, %
$P_{marshes\text{-}bogs}$ = proportion of the area of marshes-bogs, relative to $A_{entire\ category}$, %
$EF_{water\text{-}bodies}$ = emission factor for water bodies, $tCha^{-1}yr^{-1}$
$EF_{water\text{-}bodies}$ = emission factor for marshes and bogs, $tCha^{-1}yr^{-1}$.

The P values were identified according to section 6.3.1, whereas for the emission factors the default IPCC (2006) values of 0.25 $tCha^{-1}yr^{-1}$ (cold temperate), 2.5 $tCha^{-1}yr^{-1}$ (warm temperate, Table 6.3) and 10.0 $tCha^{-1}yr^{-1}$ (Table 5.6) were used, respectively.

6.9.4 Uncertainties and time-series consistency

See section 6.11.

6.9.5 Category-specific QA/QC and verification

See section 6.6.5.

6.9.6 Category-specific recalculations

As noted in section 6.1.4, we have done a number of recalculations this year to improve the accuracy of our estimates and to correct upload errors. Most of these recalculations are only revisions of the area data reported in the sectoral tables that was different from that in CRF table 4.1, i.e., the land-use change matrix and that was actually used for the emission calculations. Additionally, there were some minor revisions of some area data that resulted in very small revisions of the emission estimates, the difference between the new and previous estimates being hardly over 0.2% of the estimated total sectoral emission value of -7195 ktCO2eq in 2021.

6.9.7 Category-specific planned improvements

No improvements are currently planned in this category.

6.10 Other Land (CRF sector 4.F)

The Other Land category includes the sparsely vegetated areas, which account for only 0.03 percent of the total area of the country (see Figure 6.3.1). The area in the Other Land category is unmanaged (excludes unmanaged grasslands) with very little conversions from and to Other Land.

6.10.1 Uncertainty and time-series consistency

See section 6.11.

6.10.2 Sector specific QA/QC and verification

See section 6.6.5.

6.10.3 Sector specific recalculation

This year, no recalculations were made in the OL category.

6.10.4 Sector specific planned improvements

One of the main plans is to conduct an uncertainty analysis sometimes in the future.

6.11 Uncertainty analysis of the LULUCF sector. Time series consistency

In general, information on uncertainties includes, among others, information on completeness, accuracy, and non-quantifiable elements. Concerning completeness, some minor emissions and removals could not be estimated because of the reasons provided in the respective sections above (and/or these emissions and removals were approximated by assumptions), however, it is highly probable that their exclusion only results in conservative estimation, i.e., overestimation of net emissions, and underestimation of net removals.

The reported estimated emissions and removals are generally considered accurate and precise as far as practicable and are based on the currently available best data and methods. Where uncertainty seems to be high, and for non-quantifiable factors, the principle of conservativeness is always applied. Conservative estimates are used for volume stock change, the root-to-shoot ratio, and carbon stock changes in the soil, litter and deadwood pools. Where no country-specific values are available, IPCC default values are used. Whenever more accurate methods could be identified, these were applied.

It is probable that total forest area is somewhat underestimated, which is shown by the fact that the forest inventory has identified new forest areas (“found forests”) most years for the last four decades or so. As long as forests in Hungary are a sink, this underestimation of the forest area can only lead to the underestimation of net removals, especially because found forests are predominantly relatively young and have a positive carbon balance. Nevertheless, the detection and monitoring or forest area has been continuously improving and will continue to improve.

It is also probable that, due to conservativeness built into the methods of the national forest inventory to comply with traditional requirements for sustained yield, both volume stocks and volume stock changes are underestimated due to the fact that the current forestry database does not “see” some forests in the country. This assessment is also supported by preliminary statistical results of a sample-based inventory (i.e., the National Forest Inventory) which indicate higher area, volume stocks and annual volume increment than the continuous forest inventory that is currently used for the purposes of the GHG inventory. Finally, wood harvests also seem to be underestimated a bit due to illegal cuttings which, according to some expert judgments, may annually account for up to 250,000 m^3/yr. This amount is additional to, but small relative to, the annual official figure of annual harvests of around 7-8 million m^3/yr. Although this means that actual wood harvests are somewhat underestimated, so is volume stock increment but to a larger extent, thus, net volume stock changes, and therefore net removals, are most probably underestimated.

We have continuously been improving not only our stand statistics, but also our country-specific emission factors. As reported in the previous NIRs, the accuracy was improved over the years, among others, by introducing new, more realistic, country-specific basic wood density values, slash fraction estimates, soil C/N values and the biomass of orchards and vineyards that have been removed during conversions of cropland to forest land and grassland.

Uncertainty cannot always be quantified partly because the error distributions are unknown due to lack of measured data, and partly because calculation errors or assumptions cannot be quantified. However, calculation errors during the development of the GHG inventory are becoming less and less unlikely due to the double-checking of the data processing.

For carbon stock changes in biomass, the system of calculations allows for the use of a simple sensitivity analysis. This is especially true if only the major sources of CO_2 emissions and removals are considered, which represent the bulk of all emissions and removals. The reason for this is that the equation used for the calculation is simple: only volume stock changes, wood density, root-to-shoot ratio, and carbon fraction factors are involved.

With respect to net annual CO_2 emissions (i.e., net removals) of forests, actual values may deviate from estimated values as the stock volume inventory for the whole country is not able to capture all inter-annual variability of timber growth and harvests, which can be high due to the variability of meteorological conditions. As mentioned above, the inter-annual variability of the estimated net removals in the Forest Land sector is due to a number of reasons, including the continuously, although slowly, changing structure of the forests by species, site fertility and age, and the annual variability of weather, harvests, and mortality. All of these effects have rather different delayed effects on the inventory estimates, and these effects may be rather small relative to the total volume stocks. These effects can reinforce or naturalize each other when combined.

It can be concluded that in general, with regard to carbon stock change estimation in the forestry sector, errors are rather limited, and it is expected that current estimates rather well reflect actual emissions and removals associated with forest land over longer periods.

With regard to non-CO_2 emissions, the estimation is accurate and precise as far as practicable for the years for which we have data on wildfires and controlled burning, as well as for forests on organic soils. Data collection considerably improved in the last several years.

Finally, both methods and data are applied consistently throughout the entire reporting period. This results in a consistent time series of both the area and the GHG information.

This year, we conducted an uncertainty analysis for the entire LULUCF section. The analysis was done in two separate modules: one for the forestry sector and one for the non-forestry sector, and these were then combined to produce results for the entire LULUCF sector.

Important to note is that the analysis was done for the inventory years 2005 and 2021. The latter year was selected in reporting year 2023. Since objective of the uncertainty analysis is not to annually estimate and report data, but rather to help inventory development, we don't plan to repeat the exercise until a new land-use change matrix is not developed and made available for the GHG inventory.

The selection of the year 2005 as the starting point of the analysis is due to the fact that, as mentioned above, no AD is available before 1985, therefore, neither the time series is consistent before 2005, nor bias due to artifacts cannot be ruled out. (Time series consistency after 2004 is ensured, see section 6.3.) Because of the years that could thus be selected, the analysis of the trends is based on a period of 17 years.

Due to its larger importance, first, details of the uncertainty analysis for the forestry sector are reported.

6.11.1 Uncertainty analysis for the forestry sector

If not mentioned otherwise, uncertainty means the 95 % percentage confidence interval half-width (i.e., half of the 95 % confidence interval divided by the absolute value of the given statistics and expressed as percentage). However, for some constants and emission factors that are used in the Hungarian GHG inventory, confidence interval values are not available. If only range values were available they were treated as confidence intervals (following the instructions of IPCC 2006 GL on page 3.21 and those of Box 3.0A of 2019 IPCC Refinement). If only standard deviation values were published for default emission factors, they were used for confidence interval construction following the equation for 'Case 2' of Box. 3.0A of the 2019 IPCC Refinement.

The forest land-related activity data include both volume (growing stock, burnt or deadwood volume as well as volume of various harvested wood products) and area data. The calculation of most activity data follows a 'bottom-up' approach which means that the data recorded on the sub-compartment level are aggregated to the level of a given UNFCCC category and multiplied by the emission factors to assess GHG emissions and removals. Therefore, uncertainties of activity data are also aggregated from sub-compartment level to UNFCCC category levels (Table 6.11.1). Bottom-up uncertainty aggregations, and the combinations of activity data and emission factor uncertainties (Table 6.11.2) were carried out by both error propagation and Monte Carlo simulation.

The uncertainty analysis was programed in R (v.4.0.4). Both for error propagation and Monte Carlo simulation, proprietary functions were developed ensuring the reliability of the algorithms. These functions automatically calculate the required uncertainty on the required level (e.g., species group level, UNFCCC category level etc.) based on input parameters such as:

- the type of the mathematical operation (e.g., addition, subtraction, multiplication, division, aggregation to a given level by addition etc.);

- the types of distributions (if applying Monte Carlo simulation) by variables (it can be normal or triangular);
- the uncertainty of the input variables (in the case of Monte Carlo simulation it can be asymmetrical);
- the mean of the input variables; and
- the level of aggregation.

Normal distributions were simulated by the *rnorm* function, triangular distributions were generated by the *rtriangle* function (of the *triangle* package) of R. Equations 3.1 and 3.2 of the 2019 IPCC Refinement were applied for combining and aggregating errors by the error propagation equations. The functions developed in R calculated the given statistics and its uncertainty simultaneously (both for error propagation and Monte Carlo simulation). In this way, the results could be crosschecked with each other (error propagation with Monte Carlo simulation) and with our GHG inventory statistics that are developed in MS Excel.

The ‘steps’ of uncertainty calculation follow the methods used in the GHG inventory.

Table 6.11.1. *Forest-related activity data types and uncertainties of various sink/source categories.*

Pool or sink/source category	Aggregated data type	Data source	Data types	Source of uncertainty components	Uncertainty value of the uncertainty components
Living biomass	Growing stock changes (m3)	NFD	Area-specific volume (m3/ha) and forest sub-compartment area (ha)	Modelled confidence interval of the area-specific volume by species groups and calculated confidence interval of forest sub-compartment areas supposing +/- 6 m error in position of sub-compartment borders	For area-specific volume: modelled, therefore varying between 5 % and 80 % depending on the mean m3/ha value and on the species groups. For sub-compartment area: calculated from the area and perimeter of forest sub-compartment, varying between 3 % and 4 000 % (note that the absolute value of the extremely high uncertainty is low because the +/- 6 m error of borders influences uncertainty of areas of small sub-compartments relatively more; for example, the maximum uncertainty value of approximately 4 000 % refers to a sub-compartment of 0.01 hectare.).
Living biomass of L-FL	Growing stock changes (m3)	Modelled from NFD data	Age~area-specific growing stock regression models by stand types	Confidence band of the applied regression models	Modelled, therefore varying between 0.6 % and 482 % (note that the extremely high uncertainty value is assessed for young – 2-years-old – stands thus, in absolute value the uncertainty is low).
Deadwood	Stock changes (m3)	Modelled from NFI data	Age~area-specific deadwood stock regression models by stand types	Confidence band of the applied regression models	Modelled, therefore varying between 10 % and 134 %.
Litter	Area (of the given UNFCCC category – ha)	NFD	Forest sub-compartment areas.	See the biomass pool.	

Pool or sink/source category	Aggregated data type	Data source	Data types	Source of uncertainty components	Uncertainty value of the uncertainty components
Controlled burning	Harvested volume (m3)	NFD	Harvested volume by forest sub-compartments.	Expert judgement by Nagy-Bozsoky (2022)	+/- 10 %
Wildfires	Burnt ("disappeared in fire") volume (m3)	NFD	Burnt area (ha) and area-specific growing stock (m3/ha)	Regarding burnt area, the same uncertainty was assumed as for sub-compartment areas; area-specific growing stock uncertainty was modelled in the same way as at the biomass pool	See at the biomass pool (both for area-specific volume and for area).
Annual and perennial losses	LFL area (ha)	NFD	Forest sub-compartment areas.	See at the biomass pool.	
Harvested Wood Products	Production and trade statistics (m3 and tonnes)	Hungarian Central Statistical Office	Country-level production and trade data by HWP categories.	Production and trade statistics are based on census. Uncertainty values were taken from GL for LULUCF 2006 Volume 4 Table 12.6	+/- 15 %
Organic soils	Area of organic soils in forests (ha)	Expert judgement by Illés (2013)	Total area of organic soils in forests.	Expert judgement by Illés (2013)	+/- 11.6 %

Table 6.11.2. *Forest-related emission factors and their uncertainties by various sink/source categories.*

Pool or sink/source category	Name	Uncertainty	Type of uncertainty	Source of uncertainty value	Type of distribution used for Monte Carlo simulation
Living biomass	Root-to-shoot ratio (dimensionless)	-50 / +100 %	Range	GPG for LULUCF 2003 Annex 3A.1 Table 3A.1.8	Triangular
	Carbon fraction (tonnes C / tonnes biomass)	+/- 4.17 % (deciduous species), +/- 7.84 % (conifers)	Range	GL for LULUCF 2006 Table 4.3	Normal
	Wood density (tonnes / m3)	+/- 10 %	Confidence interval	Expert judgement based on Somogyi (2008)	Normal
Deadwood	Root-to-shoot ratio(dimensionless)	See the biomass pool.			
	Carbon fraction (tonnes C / tonnes biomass)				
	Wood density (tonnes / m3)				
Litter	Area-specific carbon stock (tonnes C / ha)	-94/+308 %	Range	Expert judgement of Heil et al. (2012)	Triangular
Controlled burning	Wood density (tonnes biomass / m3)	See the biomass pool.			
	Burned slash fraction of harvested volume (dimensionless)	-100 % / +98-269 % (depending on the tree species; in the case of beech +2608 %, however, it means little absolute volume value)	Range	expert judgement (Rumpf 2012)	Triangular

Pool or sink/source category	Name	Uncertainty	Type of uncertainty	Source of uncertainty value	Type of distribution used for Monte Carlo simulation
	Emitted CH4 from burnt biomass (g / kg)	+/- 79.2 %	1.96x standard deviation	GL for LULUCF 2006 Volume 4 Table 2.5	Normal
	Emitted N2O from burnt biomass (g / kg)	+/- 52.8 %	1.96x standard deviation	GL for LULUCF 2006 Volume 4 Table 2.5	Normal
Wildfires	Wood density (tonnes / m3)	See the biomass pool.			
	Emitted CH4 from burnt biomass (g / kg)	See at slash burning.			
	Emitted N2O from burnt biomass (g / kg)				
Annual and perennial losses	Carbon content of orchards and vineyards (tonnes C / ha)	+/- 40 %	Range	Expert judgement (Juhos and Tőkei 2012)	Normal
Harvested Wood Products	Half-life (year)	+/- 50 %	Range	GL for LULUCF 2006 Volume 4 Table 12.6	Normal
	Carbon conversion factor (tonnes C / m3)	+/- 27%	Range	GL for LULUCF 2006 Volume 4 Table 12.6 (combined uncertainty of oven dry product weight to carbon weight (+/- 10 %) and product volume to product weight (+/- 25 %))	Normal
Organic soils	Emission factor (t CO2-C / ha / year)	-23/+27 % (+/- 27 % was applied)	Confidence interval	IPCCC WL Suppl., Table 2.1	Normal
	Emission factor of 2 for temperate and boreal organic	-80/+ 200 %	Range	GL for LULUCF 2006 Volume 4 Table 11.1	Triangular

Pool or sink/source category	Name	Uncertainty	Type of uncertainty	Source of uncertainty value	Type of distribution used for Monte Carlo simulation
	nutrient poor forest soils (kg N2O–N / ha)				

Forest area

Forest area uncertainties for all UNFCCC categories were assessed from those of forest sub-compartments:

1.) range of forest sub-compartment areas was calculated supposing +/- 6 m error in border line positions;

2.) the obtained uncertainties were aggregated to the required category level.

A more detailed description of forest area uncertainty estimation is available here.

Living biomass pools

The NFD contains area-specific growing stock (m3/ha) data for each species of each of the circa five hundred thousand forest sub-compartments by origin (i.e., seed or sprout) and age. For each species group, total volume stock on sub-compartment level is obtained by multiplying the area-specific growing stock by the area of the forest sub-compartment.

As a consequence of volume estimation procedure applied in the NFD, the uncertainty of emissions and removals of biomass pools originates from two main sources:

1.) the uncertainty of forest sub-compartment areas (see above);

2.) the uncertainty of area-specific growing stock volumes (by species groups) which in turn arises from sampling and modelling errors and is assessed in a detailed study that is available here.

The aggregated uncertainty by UNFCCC category was calculated in the following steps:

1.) the uncertainty of forest sub-compartment areas and that of area-specific growing stock values were combined on forest sub-compartment level by species groups for the inventory year;

2.) the combined uncertainties were aggregated to species group level;

3.) the species group level uncertainties of volume stocks were combined by those of the previous inventory year in order to obtain uncertainties of stock changes on a species group level (in this step, Equation 3.2 of the 2019 IPCC Refinement was applied for the subtractions where values of the previous years were subtracted from those of the given inventory year in the denominator);

4.) stock change uncertainties were combined with those of the relevant emission factors on species group level in order to convert volume stock changes to carbon stock changes;

5.) carbon stock change uncertainties of species groups were aggregated to the category level.

For L-FL, as mentioned above, the area-specific stock and stock-change were modelled as a function of age by tree stand type. The aggregated uncertainties were calculated from the confidence bands of the regression models:

1.) the uncertainty of forest sub-compartment areas was aggregated by tree stand type and age group;

2.) confidence bands of the age ~ area-specific growing stock regression models were created;

3.) the uncertainty of stock-changes was assessed from the confidence intervals of the area-specific growing stock by age groups and stand types;

4.) the uncertainty of total stock-change was estimated by combining area (step 1) and area-specific stock-change uncertainties (step 3) and then aggregated to stand type-level;

5.) finally, the obtained uncertainties were combined with those of the emission factors on stand type-level and aggregated to the L-FL category-level.

Following our methods in the GHG inventory, the uncertainties of the FL-FL sector were estimated from those of FL, L-FL and FL-L using the equation:

FLFL gains = FL gains – LFL gains + FLL losses.

Deadwood and litter pools

The amount of deadwood and its uncertainty was estimated for L-FL and FL-FL from the models described in Chapter 6.5.5.2.2 of the NIR and their confidence bands (see Figure 6.5.11) the following way:

1.) the uncertainty of the predicted area-specific deadwood volume stock was calculated by age using the confidence bands of the model;

2.) the uncertainty of stock changes was assessed by age and stand type;

3.) the uncertainty of age group areas was estimated by stand type;

4.) the uncertainties calculated in the 2nd and 3rd steps were combined;

5.) the resulted uncertainties were aggregated to stand type level;

6.) the aggregated uncertainties were combined by those of the relevant constants and emission factors;

7.) finally, the stand type level uncertainties were aggregated to the deadwood pool level.

For FL-L, the calculation method was different: total deadwood stock is regarded lost due to the conversion and calculated from the mean area-specific deadwood of forest land. The related uncertainties were estimated in the following way:

1.) total deadwood volume stock uncertainty of the entire forest land was calculated by stand type as described above in steps 1-5;

2.) area uncertainties of FL-L and FL were calculated as described in Chapter 2;

3.) deadwood stock and area uncertainties of FL were combined to obtain the uncertainty of the mean area-specific deadwood stock by stand type;

4.) area uncertainties of FL-L were combined with that of mean area-specific deadwood stock by stand type;

5.) the obtained uncertainties were combined with those of the relevant constants and emission factors by stand type;

6.) the stand type level uncertainties were aggregated to the deadwood pool level.

As in the case of the biomass pool, carbon stock change uncertainty of the deadwood pool of FL-FL was calculated from that of FL, L-FL and FL-L on category level.

Uncertainties of carbon stock changes of the litter pool were calculated for FL-L and L-FL. Regarding FL-L, the total carbon stock of the litter pool is regarded lost and taken equivalent to stock changes (supposing instantaneous emission), therefore, the uncertainty estimation was carried out in the following steps:

1.) first, area uncertainties of forest sub-compartments were calculated;

2.) then, forest sub-compartment uncertainties were aggregated to the category level;

3.) finally, area uncertainties were combined with that of area-specific litter carbon stock.

The procedure is the same for L-FL since the only difference is the application of the 20-year-long transition period that does not cause further uncertainties.

Controlled burning and wildfires

The basis of the uncertainty estimation of controlled burning is the uncertainty of the estimated harvested volume on forest sub-compartment level. As required in the Hungarian forest law, forest managers have to report harvested volume by species after each harvesting occasion. If a harvesting operation is started in a given year and is ended in the next year, the gross amount harvested before 31st December must be reported separately and the remaining amount must be reported after ending the operation. In this way, harvested volume statistics of the NFD refer exactly to the proper calendar years.

As harvested volume is assessed by forest managers its uncertainty depends on the accuracy of this estimation and not on the error of the growing stock estimates. Thus, the uncertainty of the emitted GHG from controlled burning was calculated according to the following steps:

1.) the uncertainty of the sub-compartment level harvested volume was aggregated to the category level by species groups;

2.) the aggregated harvested volume uncertainties were combined with those of the relevant constants and emission factors by species groups;

3.) the obtained uncertainties of emissions from controlled burning) were aggregated to category level.

The uncertainties related to wildfires were estimated similar to those of the biomass pools since the emitted greenhouse gases are assessed from:

1.) area-specific growing stock volume and

2.) the relevant area, which is the area burnt in wildfires (these are not necessarily fully overlap with the area of the affected forest sub-compartments).

The uncertainties of these input variables were combined and aggregated to category level and then combined with uncertainties of the emission factors in the same way as it was done for the living biomass (note that total burnt volume is equal to stock changes since it is assumed that the total volume is lost in the wildfire).

Organic soils

In his detailed study, Illés (2013) assessed the uncertainty of activity data (i.e., the area of organic soils), which was combined with that of the applied emission factors to obtain the uncertainty of the emissions from organic soils.

Harvested Wood Products

Uncertainties related to the HWP pool were combined only by Monte Carlo simulation because the applied formulas involve not only addition/subtraction and multiplication/division but also exponentiation for which neither the 2006 IPCC GL, nor the 2019 IPCC Refinement offer an error propagation equation.

The calculation steps carried out in the Monte Carlo simulation were exactly the same as those described in Chapter 6.5.4.2.4 of the NIR since input statistics necessary for the assessment were identical.

The results of the uncertainty estimation for the inventory year 2021 are reported in Table 6.11.3.

Note that there are two reasons why the results of error propagation and Monte Carlo simulation may be different (apart from the stochastic differences):

1.) if a confidence interval was asymmetric, the larger half-width was applied in the case of error propagation following the instructions of IPCC 2006 GL, page 3.29; whereas triangular distribution was simulated when combining uncertainties by Monte Carlo simulation – in this way the error propagation overestimated the combined uncertainty;

2.) sometimes a range was regarded as confidence interval (as mentioned above) in the case of error propagation; however, when simulating triangular distributions, the endpoints of the distributions (i.e., the maximum and minimum values) served as input parameters, so the input of triangular distribution simulation was really the range and not the confidence interval that is narrower than the range, which again led to an overestimation of the combined uncertainty in the case of error propagation.

It can be concluded that differences between results of error propagation and Monte Carlo simulation is the highest if one or more of the input uncertainties are highly asymmetrical, such as in the case of burned slash fraction, area-specific litter carbon stock or the emission factor applied for organic soils (see Tables 6.11.1 and 6.11.2 above).

Table 6.11.3. *Results of the uncertainty analysis for the main forestry categories by using both Approach 1 (i.e., based on error propagation) and Approach 2 (i.e., Monte Carlo simulation).*

Category	Sink/source	Gas	Percentage uncertainty			
			Error propagation	Monte Carlo simulation		
				CI_lower	CI_upper	SE
FL-FL	Living biomass	CO2	11.2	8.1	8.3	4.3
FL-FL	Controlled burning	CH4	176.5	70.6	99.1	43.7
FL-FL	Controlled burning	N2O	173.9	62.8	85.6	38.8
FL-FL	Deadwood	CO2	213.2	126.3	217.4	96.7
FL-FL	HWP	CO2	NA	1 493.3	1 582.0	786.4
FL-FL	Organic soils	CO2	29.4	26.9	30.1	15.1
FL-FL	Organic soils	N2O	200.3	76.9	118.2	56.1
FL-FL	Wildfires	CH4	36.8	35.2	36.2	18.4
FL-FL	Wildfires	N2O	25.0	25.8	24.0	12.8
FL-L	Living biomass	CO2	6.3	5.1	4.8	2.6
FL-L	Deadwood	CO2	23.2	21.5	21.6	10.9
FL-L	Litter	CO2	308.0	89.2	142.7	64.8
L-FL	Living biomass	CO2	17.0	7.8	8.0	4.0
L-FL	Deadwood	CO2	161.1	178.2	174.8	90.7
L-FL	Litter	CO2	308.0	89.9	137.6	66.9
L-FL	Losses	CO2	66.7	61.0	66.0	32.9
L-FL	Wildfires	CH4	53.1	49.4	58.5	26.2
L-FL	Wildfires	N2O	37.6	35.8	39.7	19.3

Trend uncertainty

Trend analysis was carried out by Approach 1 using formulas given in Table 3.2 of the 2019 IPCC Refinement (Table 6.11.4).

Table 6.11.4. *Results of the uncertainty analysis for the main forestry categories by using both Approach 1 (i.e., based on error propagation) and Approach 2 (i.e., Monte Carlo simulation).*

Category	Source/pool	Gas	2005 emissions, CO_2 eq	2021 emissions, CO_2 eq	AD uncertainty, %	AD correlated across years?	EF Uncertainty, %	EF correlated across years?	Combined uncertainty, %	Contribution to variance, %	Type A sensitivity, %	Type B sensitivity, %	Uncertainty in trend introduced by EF, %	Uncertainty in trend introduced by AD, %	Uncertainty introduced into trend, %
FL-FL	Biomass	CO2	-3 544,0	-5 389,8	7,9	No	7,9	No	11,2	0,2	0,1	1,0	11,3	11,4	256
FL-FL	Controlled burning	CH4	7,9	8,2	0,1	No	176,5	No	176,5	0,0	0,0	0,0	0,4	0,0	0,1
FL-FL	Controlled burning	N2O	4,1	4,3	0,1	No	173,9	No	173,9	0,0	0,0	0,0	0,2	0,0	0,0
FL-FL	Deadwood	CO2	-184,9	-198,2	213,2	No	0,0	No	213,2	0,1	0,0	0,0	0,0	11,2	126
FL-FL	HWP	CO2	-398,7	-933,4	15,0	No	1 572,8	No	1 572,8	99,6	0,1	0,2	390,2	3,7	152 301
FL-FL	Organic soils	CO2	61,6	61,6	11,6	No	27,0	No	29,4	0,0	0,0	0,0	0,4	0,2	0,2
FL-FL	Organic soils	N2O	7,5	7,5	11,6	No	200,0	No	200,3	0,0	0,0	0,0	0,4	0,0	0,2
FL-FL	Wildfires	CH4	10,7	2,6	3,9	No	36,6	No	36,8	0,0	0,0	0,0	0,0	0,0	0,0
FL-FL	Wildfires	N2O	5,6	1,4	3,9	No	24,7	No	25,0	0,0	0,0	0,0	0,0	0,0	0,0
FL-L	Biomass	CO2	49,9	260,5	2,2	No	5,9	No	6,3	0,0	0,0	0,0	0,4	0,2	0,2
FL-L	Deadwood	CO2	5,0	19,4	1,7	No	23,1	No	23,2	0,0	0,0	0,0	0,1	0,0	0,0
FL-L	Litter	CO2	14,2	49,3	1,1	No	308,0	No	308,0	0,0	0,0	0,0	4,0	0,0	16,3
L-FL	Biomass	CO2	-1 193,6	-906,4	13,7	No	10,1	No	17,0	0,0	0,1	0,2	2,4	3,3	16,9
L-FL	Deadwood	CO2	-37,2	-26,3	152,2	No	52,8	No	161,1	0,0	0,0	0,0	0,4	1,1	1,3
L-FL	Litter	CO2	-244,4	-170,1	0,1	No	308,0	No	308,0	0,1	0,0	0,0	13,9	0,0	194
L-FL	Losses	CO2	116,5	123,3	0,4	No	66,7	No	66,7	0,0	0,0	0,0	2,2	0,0	4,8
L-FL	Wildfires	CH4		0,1	15,1	No	50,9	No	53,1	0,0	0,0	0,0	0,0	0,0	0,0
L-FL	Wildfires	N2O		0,1	15,1	No	34,4	No	37,6	0,0	0,0	0,0	0,0	0,0	0,0

Analysis of results

The results show that the uncertainty of the emissions and removals in the forestry sector are affected mostly (more than 99 %) by the HWP pool. Although the removals of the FL-FL biomass pool is by far the highest (76 % of total removal in the forestry sector), the uncertainty contribution of the HWP pool is much higher due to the high uncertainty of its emission factors (partly caused by the effect of the exponential function applied in the estimation formulas). The results indicate that the uncertainty of removals could be decreased by more precise country-specific emission factor values for the HWP pool as well as by improving the accuracy of the AD and EF estimation of the biomass pool.

6.11.2 Uncertainty analysis for the non-forestry sectors and the entire LULUCF sector

The uncertainty analysis of the emission and removal estimates for the non-forest land-use and land-use change categories was done using a standard Tier 2 Monte Carlo (MC) approach according to Chapter 3 of Volume 1 of the 2006 IPCC GL.

Concerning the error distributions of the various EFs (the values of which is always assumed to be constant), some uncertainty information was taken from the 2006 IPCC GL when no respective country-specific data was available. When this uncertainty information was used, which is usually provided by the IPCC GL in the form of plus and minus percent uncertainty (U+% and U-%, respectively), we used triangular probability density functions, or PDFs, with parameters

$$a = EF - EF*U\text{-}\%/100$$

and

$$c = EF + EF*U\text{+}\%/100$$

for lower and upper limits of the variables, respectively, and the EF value itself for the preferred value. We also applied expert judgment in some cases due to lack of appropriate data. Otherwise, which was the majority of the cases, we collected country-specific data. Concerning carbon stock change in mineral soils, which are the most important sources of emissions and removals, we could develop estimates based on measurements in the TIM database referred to above (see section 6.4.1). These estimates are under publication now. The relevant data of all PDFs is reported in **Table 6.11.5**.

Table 6.11.5. Data related to emission factor uncertainty assumed in the uncertainty estimation for the non-forest categories.

Variable name	Unit	Mean value	SD	a	c	Source of uncertainty information
SOCref, cold dry, HAC	tC/ha	48		43,2	52,8	exp. judg.
SOCref, warm dry, HAC	tC/ha	58,0		52,2	63,8	exp. judg.
SOCref, cold dry, sandy	tC/ha	15,0		13,5	16,5	exp. judg.
SOCref, warm dry, sandy	tC/ha	21,0		18,9	23,1	exp. judg.
SOCref, cold dry, aquic	tC/ha	116,0		104,4	127,6	exp. judg.
SOCref, warm dry, aquic	tC/ha	132,0		118,8	145,2	exp. judg.
SOC reduction factor (relative to respective categories) for SE	dimensionless	0,80		0,640	0,960	exp. judg.
ΔSOC, FL to non-SA CL	tC/ha	-11,1	0,38			Somogyi, 2021; exp. judg.
ΔSOC, FL to SA CL	tC/ha	-1,5	0,38			Somogyi, 2021; exp. judg.
ΔSOC, FL to non-SA GL	tC/ha	2,6	2,00			Somogyi, 2021; exp. judg.
ΔSOC, FL to SA GL	tC/ha	2,6	2,00			Somogyi, 2021; exp. judg.
ΔSOC, FL to SE	tC/ha	-9,6	0,50			Somogyi, 2021; exp. judg.
ΔSOC, FL to WL	tC/ha	20,3	2,50			Somogyi, 2021; exp. judg.
ΔSOC, non-SA CL to SA CL	tC/ha	11,8	0,50			Somogyi, 2021; exp. judg.
ΔSOC, non-SA CL to non-SA GL	tC/ha	18,7	0,52			Somogyi, 2021; exp. judg.
ΔSOC, non-SA CL to SA GL	tC/ha	18,7	2,50			Somogyi, 2021; exp. judg.
ΔSOC, non-SA CL to SE	tC/ha	-9,9	0,50			Somogyi, 2021; exp. judg.
ΔSOC, non-SA CL to WL	tC/ha	18,7	2,50			Somogyi, 2021; exp. judg.
ΔSOC, SA CL to non-SA GL	tC/ha	7,0	2,50			Somogyi, 2021; exp. judg.
ΔSOC, SA CL to SA GL	tC/ha	7,0	2,50			Somogyi, 2021; exp. judg.
ΔSOC, SA CL to SE	tC/ha	-12,3	0,50			Somogyi, 2021; exp. judg.
ΔSOC, SA CL to WL	tC/ha	7,0	2,50			Somogyi, 2021; exp. judg.
ΔSOC, non-SA GL to SA GL	tC/ha	0,0	0,50			Somogyi, 2021; exp. judg.
ΔSOC, non-SA GL to SE	tC/ha	-13,7	2,00			exp. judg.
ΔSOC, non-SA GL to WL	tC/ha	0,0	0,52			Somogyi, 2021; exp. judg.
ΔSOC, SA GL to SE	tC/ha	-13,7	2,00			exp. judg.
ΔSOC, SA GL to WL	tC/ha	0,00	0,50			Somogyi, 2021; exp. judg.
ΔSOC, SE to WL	tC/ha	13,67	2,00			Somogyi, 2021; exp. judg.
FLU, non-SA CL, temperate, dry, CL-CL	dimensionless	0,8	0,072			IPCC GL Vol. 4. Ch. 4. Table 5.5
FLU, SA CL, temperate, dry, CL-CL	dimensionless	0,93	0,102			IPCC GL Vol. 4. Ch. 4. Table 5.5
FMG, full till, temperate, dry, CL-CL	dimensionless	1		0,8	1,2	exp. judg.
FMG, reduced till, temperate, dry, CL-CL	dimensionless	1,02	0,061			IPCC GL Vol. 4. Ch. 4. Table 5.5
FMG, no till, temperate, dry, CL-CL	dimensionless	1,1	0,055			IPCC GL Vol. 4. Ch. 4. Table 5.5
FI, low, temperate, dry, CL-CL	dimensionless	0,95	0,124			IPCC GL Vol. 4. Ch. 4. Table 5.5
FI, medium, temperate, dry, CL-CL	dimensionless	1		0,8	1,2	IPCC GL Vol. 4. Ch. 4. Table 5.5
FI, high without manure, temperate, dry, CL-CL	dimensionless	1,04	0,135			IPCC GL Vol. 4. Ch. 4. Table 5.5
FLU, GL-GL	dimensionless	1		0,5	1,5	Table 6.2 of Chapter 6
FMG, nominally managed, GL-GL	dimensionless	1		0,8	1,2	exp. judg.
FMG, improved, GL-GL	dimensionless	1,14		1,0	1,3	Table 6.2 of Chapter 6
FI, improved, GL-GL	dimensionless	1		0,9	1,1	as per Table 6.2 of Chapter 6
R = C/N ratio	tN / tC	15		10,5	19,5	page 11.16 of IPCC 2006 GL
R = C/N ratio, for CL-CL only	tN / tC	10		7,0	13,0	CL-CL only, p. 11.16 of 2006IPCCGL
EF1 of Equation 11.1	tN2O-N / tN	0,01		0,0	0,0	Table 11.1 of IPCC 2006 GL
FracLEACH-(H)	t N / t N additions	0,3		0,1	0,8	Table 11.3 of IPCC 2006 GL
FracLEACH-(H), for Warm & Dry	t N / t N additions	0,3		0,1	0,8	Table 11.3 of IPCC 2006 GL
EF5 of Equation 11.10	tN2O-N / tN leaching/runoff	0,0075		0,0	0,0	Table 11.1 of IPCC 2006 GL

Table 6.11.5 (ctd.). Data related to emission factor uncertainty assumed in the uncertainty estimationfor the non-forest categories.

Variable name	Unit	Mean value	SD	a	c	Source of uncertainty information
length of rotation period, orchards	years	30		21,0	39,0	exp. judg.
length of rotation period, vineyards	years	31,8		22,3	41,3	exp. judg.
carbon fraction, orchards	tC/t biomass	0,5		0,5	0,5	as per Table 4.3 of the GL
carbon fraction, vineyards	tC/t biomass	0,5		0,5	0,5	as per Table 4.3 of the GL
average biomass carbon (measured, i.e., average carbon before conversion, AB + BB) and the age for which it refers to, orchards	tC/ha	2,35		1,6	3,1	exp. judg.
average biomass carbon (measured, i.e., average carbon before conversion, AB + BB) and the age for which it refers to, vineyards	tC/ha	4,43		3,1	5,8	exp. judg.
the age for which the average biomass carbon refers to, orchards	years	15		10,5	19,5	exp. judg.
the age for which the average biomass carbon refers to, vineyards	years	15		10,5	19,5	exp. judg.
combastion factor	dimensionless	0,8		0,0	1,6	exp. judg.
emission factor, CH4	g/kg dm burnt	2,7		1,8	3,6	exp. judg. based on Table 2.5
emission factor, N2O	g/kg dm burnt	0,07		0,0	0,1	exp. judg. based on Table 2.5
GWP, CH4	tCO2eq / t CH4	25	4,2	16,8	33,3	exp. judg. based on several literature sources
GWP, N2O	tCO2eq / t N2O	298	50,2	199,7	396,3	exp. judg. based on several literature sources
Biomass removed when preparing sites, cold dry, L-CL	t/ha	6,5	2,4			Table 6.4 (total AG+BG: BG also due to tillage)
Biomass removed when preparing sites, warm dry, L-CL	t/ha	6,1	2,288			Table 6.4 (total AG+BG: BG also due to tillage)
C conversion factor, L-CL	tC/t biomass	0,47		0,5	0,5	as per Table 4.3 of the GL
Cropland (annual): Biomass carbon present after conversion, L-CL	t biomass/ha	10	3,750			as per Table 6.4 of the GL
emission factor, CH4	g/kg dm burnt	2,3		1,4	3,2	Table 2.5
emission factor, N2O	g/kg dm burnt	0,21		0,1	0,3	Table 2.5
emission factor, poor sites, WL-WL	tC/ha*yr	0,2		0,0	0,4	exp. judg. based on Table 7.4
emission factor, rich sites, WL-WL	tC/ha*yr	1,1		0,0	2,2	exp. judg. based on Table 7.4
carbon fraction, poor sites, WL-WL	tC/t biomass	0,45		0,4	0,5	exp. judgment based on other Cf U%s
carbon fraction, rich sites, WL-WL	tC/t biomass	0,4		0,4	0,4	exp. judgment based on other Cf U%s
emission factor, rich sites, WL-WL	kgN2O-Nha-1yr-1	1,8		0,6	3,0	exp. judg. based on Table 7.6
emission factor from water bodies, cold dry, WL-WL	tC/ha*yr	0,25		0,0	0,5	Table 6.3
emission factor from water bodies, warm dry, WL-WL	tC/ha*yr	2,5		0,3	4,8	Table 6.3
Emission factor: from inland marshes and peat bogs, WL-WL	tC/ha*yr	10		1,0	19,0	Table 5.6
basic density of peat, WL-WL	t dry peat/m3	0,2	0,100			exp. judg.
Proportions of FL, CL and GL by climate and soil types	dimensionless	0,536	0,055	0,4	0,6	exp. judg.
Proportions of FL, CL and GL by climate and soil types	dimensionless	0,357	0,036	0,3	0,4	exp. judg.
Proportions of FL, CL and GL by climate and soil types	dimensionless	0,098	0,010	0,1	0,1	exp. judg.
Proportions of FL, CL and GL by climate and soil types	dimensionless	0,009	0,001	0,0	0,0	exp. judg.

Concerning AD (i.e., area data), expert judgment had to be used because the current complicated land identification system that produces them, especially the land-use change data, does not really allow one to mathematically or numerically derive uncertainty-related information. The basis for the expert judgment was area data for the forest-related conversions and their uncertainties that were estimated in a dedicated project as reported in section 6.11.1 above. This area data is collected in the forestry surveys, and since it is deemed rather accurate, an uncertainty of 5% is used in this analysis. In contrast, the accuracy of the non-forest related conversions is assumed to be lower primarily due to two main factors. One is the uncertainty of identifying land-use changes by the CLC system, assumed to be 20%, and the uncertainty due to the fact that this system provides land-use change information for six-year periods (section 6.3), and the annual data during such periods is assumed to have an *uncertainty* of plus and minus 30 percent for all non-forest related LUC categories.

Note that we assumed different percentage *errors* for both the different land-use change classes and each year. However, for each year, we calculated the area of the land remaining land categories from the area in the previous year and the area of all land-use changes affecting these categories in that year, the sum of which thus always adds up to the total area of the country. We also note that the land-use change matrix of the totals of the land-use change sub-categories is also recalculated for each inventory year using the perturbed annual areas of the land-use change categories for the default transition periods of 20 years. (Since some annual land-use change areas in a sub-category can be larger than the median value, and some can be smaller than that, the area of the 20-year land-use change sub-categories changes much less over time in relative terms than that of the annual changes.)

Based on all measured and assumed data, and assuming normal error distributions for variables for which this PDF type is known and triangular distributions for variables with uncertainty information (including the land-use change areas) and other variables, we run the MC analysis using the same software in which the inventory calculations are done, thus ensuring that all calculations in the MC analysis are consistent with the inventory calculations. The MC simulations were repeated 10,000 times. For the uncertainty estimates, the 2.5 and 97.5 percentiles of the simulated sub-category or category-level distributions were used as the lower and upper limits of the confidence intervals, respectively. The contribution of the subcategory and pool/gas levels to the total variance and the uncertainty of trends were also calculated, again according to the 2006 IPCC GL.

The results of the analysis, which includes relevant results from the analysis for the forestry sector and where categories of relatively high uncertainty are highlighted, are reported in **Table 6.11.6**.

Table 6.11.6. Summary results of the LULUCF-level uncertainty analysis. (N/A means that the emissions in the given sub-category were not occurring. Important sub-categories are highlighted using yellow background and bold-face fonts.

Category	Sub-category	Gas	sub-category	2005				2021				Trend uncertainty	
				E/R	Uncertainty, %		Contribution to variance, %	E/R	Uncertainty, %		Contribution to variance, %	Mean value, %	Contribution to variance, %
					(-)	(+)			(-)	(+)			
FL-FL	Biomass	CO2	N/A	-3 543 962	-14	14	**36**	-5 389 781	-8	8	**43**	256	**23**
FL-FL	Controlled burning	CH4	N/A	7 850	-61	88	<0.1	8 224	-71	99	<0.1	0	0
FL-FL	Controlled burning	N2O	N/A	4 110	-60	80	<0.1	4 306	-63	86	<0.1	0	<0.1
FL-FL	Deadwood	CO2	N/A	-184 912	-157	268	**37**	-198 203	-126	217	**40**	126	**60**
FL-FL	Organic soils	CO2	N/A	61 623	-26	30	<0.1	61 623	-27	30	<0.1	0	<0.1
FL-FL	Organic soils	N2O	N/A	7 537	-76	133	<0.1	7 537	-77	118	<0.1	0	<0.1
FL-FL	Wildfires	CH4	N/A	10 678	-73	79	<0.1	2 623	-35	36	<0.1	0	0
FL-FL	Wildfires	N2O	N/A	5 591	-53	56	<0.1	1 374	-26	24	<0.1	0	0
L-FL	Living biomass	CO2	N/A	-1 193 608	-8	8	**1**	-906 354	-8	8	**1**	17	0
L-FL	Deadwood	CO2	N/A	-37 162	-112	105	0	-26 274	-178	175	0	1	0
L-FL	Litter	CO2	N/A	-244 399	-90	149	**20**	-170 132	-90	138	**12**	194	**8**
L-FL	Losses	CO2	N/A	116 464	-63	64	1	123 326	-61	66	1	5	0
L-FL	Wildfires	CH4	N/A				<0.1	107	-49	58	<0.1		<0.1
CL-CL	All, biomass	CO2	perennials	30 747	-32	47	<0.1	46 215	-34	52	0	50	0
CL-CL	Soil	CO2	mineral soil	264 874	-36	39	**2**	263 723	-13	15	0	0	**8**
CL-CL	NA	CH4	wildfires	1 153	-87	166	<0.1	680	-87	168	<0.1	41	<0.1
CL-CL	NA	N2O	wildfirest	284	-87	167	<0.1	166	-87	173	<0.1	41	<0.1
L-CL	FL-CL	CO2	Biomass	8 849	-15	15	<0.1	24 079	-15	16	<0.1	172	0
L-CL	GL-CL	CO2	NA	-18 463	-238	223	0	-11 482	-237	220	0	38	0
L-CL	All	CO2	mineral soil	163 127	-6	6	<0.1	104 929	-6	6	<0.1	36	0,0
L-CL	Soil	non-CO2	N/A	16 253	-74	111	<0.1	10 513	-74	113	<0.1	35	<0.1
GL-GL	Soil	CO2	mineral	-3 270	-120	144	<0.1	9 894	-144	120	<0.1	403	<0.1
GL-GL	NA	CH4	wildfires	6 660	-57	76	<0.1	982	-56	75	<0.1	85	<0.1
GL-GL	NA	N2O	wildfires	5 693	-57	85	<0.1	841	-58	85	<0.1	85	<0.1
L-GL	CL-GL	CO2	Biomass	17 320	-148	157	0	8 669	-155	166	<0.1	51	0
L-GL	WL, SE, OL - GL	CO2	Biomass	-1 269	-65	55	<0.1	-2 376	-64	55	<0.1	88	0
L-GL	All	CO2	mineral soil	-97 565	-8	8	<0.1	-9 817	-36	34	<0.1	90	<0.1
L-GL	NA	non-CO2	N/A	169	-74	111	<0.1	739	-74	111	<0.1	337	<0.1
WL-WL	NA	CO2	soil	6 224	-74	76	<0.1	3 197	-59	60	<0.1	49	0
WL-WL	NA	N20	N2O from soils	1 106	-51	54	<0.1	428	-51	54	<0.1	61	<0.1
WL-WL	NA	CO2	off-site burning, peatlands	90 891	-97	104	**1,3**	63 876	-97	103	0,9	30	0,1
L-SE	FL-SE	CO2	biomass	73 940	-34	40	0	78 711	-20	21	<0.1	7	0
L-SE	CL-SE, GL-SE, WL-SE	CO2	biomass	40 821	-60	71	0	21 653	-56	65	<0.1	47	0
L-SE	All	CO2	mineral soils	61 133	-64	62	0	68 461	-64	63	0	12	0
L-SE	All	CO2	organic soils	2 072	-65	66	<0.1	1 936	-65	67	<0.1	7	0
L-SE	NA	N2O	soils	5 680	-79	175	<0.1	6 359	-79	175	<0.1	12	<0.1
TOTAL			***non-forest only***	***676 428***	***45***		***14***	***692 375***	***32***		***7***	***42***	***<0.1***
			LULUCF	**-4 313 762**	**22**		**100**	**-5 789 249**	**12**		**100**	**49**	**100**

Concerning the uncertainty ranges in the above table, one often finds that they are large, e.g., >100% in absolute values. This is only partly because of the high uncertainties, however, also (and often mainly) partly because of the nature of the percentage calculations, i.e., if a central net emission estimate, C, is close to zero, then the U- and U+ absolute uncertainty values, when converted to percentages by dividing them with C and multiplying by 100, become large or very large. This is an inherent difficulty of the uncertainty analysis for the LULUCF sector where net emissions (i.e., the net of emissions and removals, often not insignificant in themselves) and certain emissions can be rather small.

According to the results, and also considering the above, both the ratio of the net emissions and the uncertainty values considerably depend on the inventory year and the land-use category. In both inventory years analyzed, FL-FL and L-FL are by far the most important categories. Whereas biomass estimates are important because of the absolute level of the net sink, deadwood (for FL-FL) and litter (for L-FL) are important because of the very high uncertainty associated with them. The largest non-forest contribution in 2005 is due to the (then large) carbon stock changes from mineral soils from CL-CL. In 2021, since the sink in CL-CL dropped considerably, its contribution dropped, too. In contrast, as the sink from FL increased, its relative importance increased, too.

Considering trends, the same categories seem important. When analyzing trends, one must also take into consideration the relatively high inter-annual variability. In other words, changing either the start year or the end year of the analysis might have impact the results of the analysis.

One overall conclusion of the key category analysis, the uncertainty analysis and the expert knowledge of the LULUCF sector is that, among others, it is the area of the various land-use and land-use change categories that may considerably contribute to the uncertainty of the emission estimates. A follow-up project to improve these area estimates was indeed started in 2023 to reduce this uncertainty.

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7 Waste (CRF sector 5)

Recent key developments:

- In contrast with other sectors, emissions from the waste sector are by 5% higher now than in the base year.
- However, the growth in emissions had stopped in the last decade, and a reduction of 21% could be observed between 2005 and 2022.
- Amount of disposed municipal waste decreased by more than 50% between 2005 and 2022.
- Emissions from wastewater handling have a pronounced decreasing trend due to a growing number of dwellings connected to the public sewerage network.

Major changes from previous submission:

We employed the latest IPCC waste model to ensure a comprehensive and up-to-date assessment of greenhouse gas emissions from waste sources. The utilization of this model aligns with current international standards and best practices in emission inventory management.

7.1 Overview of sector

This section discusses the emissions from solid waste disposal (CH_4), biological treatment of solid waste including composting and anaerobic digestion at biogas facilities (CH_4, N_2O), waste incineration (CO_2, CH_4, and N_2O), and domestic and industrial wastewater treatment (CH_4 and N_2O). One peculiarity of the sector is that most part of the carbon-dioxide emissions is generated from biological (biogenic) sources and this CO_2 emissions are either reported as carbon stock change in the LULUCF sector or do not need to be accounted for (e.g. annual crops).

The waste sector with 3833.21 Gg CO_2 equivalent represented % of total national GHG emissions in 2022. In the base year, total GHG emissions from the waste sector amounted to 3,666.21 Gg CO_2 equivalent which accounted for 3% of total national GHG emissions. In 2022 largest category was solid waste disposal on land, representing 87%, followed by wastewater treatment and discharge (9%), biological treatment of solid waste (4%), and incineration of waste without energy recovery (less than 1%). In contrast with other sectors, emissions from the waste sector are slightly higher now than in the base year. However, the growth in emissions stopped in the last decade, and a reduction of 21% could be observed between 2005 and 2022. The degradation process in solid waste disposal sites is quite slow which means that waste that were disposed many years earlier have still an influence on current emission levels. However, the amount of disposed waste had dropped significantly since 2005 (e.g. landfilled municipal waste decreased by more than 50%) consequently methane emissions started to decrease as well. GHG emissions from wastewater handling have a pronounced decreasing trend due to a growing number of dwellings connected to the public sewerage network. All these developments are summarized in Figure 7.1.1.

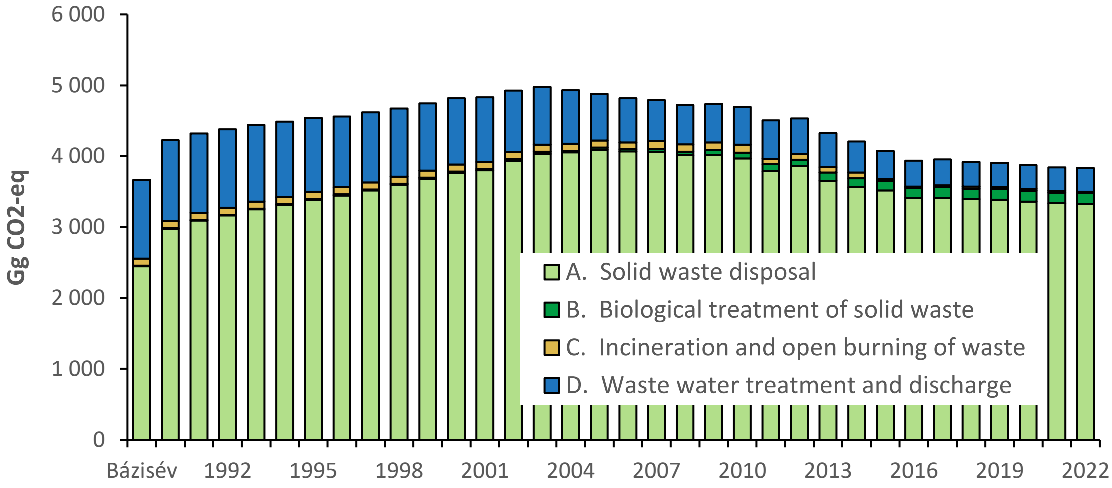


Figure 7.1.1 *Trend of emissions of the different categories in waste sector*

A major but decreasing part of ***municipal solid wastes (MSW)*** is treated by managed disposal and a smaller part by reuse, incineration or other means. The average specific municipal household waste generation rate decreased from 1.3 to 1.0 kg/capita/day in the last few years. The total amount of MSW was 3,290 Gg in 2022. In 2021, 1,411 Gg (35%) was recovered by recycling and composting, 500 Gg (12%) was incinerated for energy purposes, and 2,061Gg (51%) went to landfills and 3 Gg (0.1%) waste was treated in other ways. Data for 2022 is expected to be published in May 2024 by the Statistical Office. (In previous years, before 2010, 30-228 Gg waste was treated in other ways which meant mostly mechanical biological treatment (MBT) that produced refuse-derived fuel that could be used in power plants and cement factories.)

Figure 7.1.2 summarizes recent changes in generation and treatment of municipal waste for the period 2004-2021. The following beneficial trends could be observed:

- The increase of waste generation stopped around 2006, and started to decrease quite significantly afterwards (-14% between 2006 and 2021);
- Share of landfilling decreased from 84% to 47% between 2004 and 2021. However, in comparison with the Western-European situation, the share of waste disposal is still relatively high;
- Importance of both recycling (including export) and composting increased significantly; currently they represent 25% and 9%, respectively.

Please note that the above general information relates only to municipal solid waste whereas in the calculations also other waste types (e.g. industrial, construction) are included.

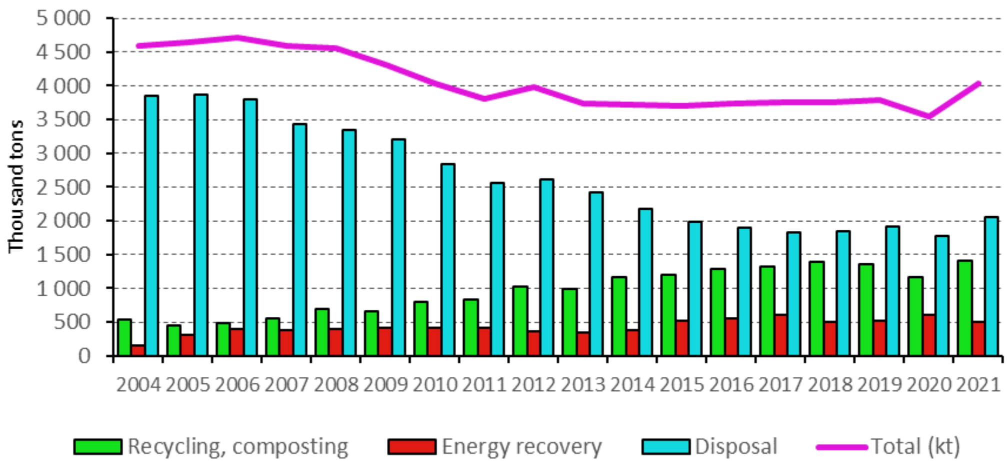


Figure 7.1.2 *Main trends in municipal waste handling*

7.2 Solid waste disposal in landfills (CRF sector 5A)

Emitted gas: CH_4
Key source category: Level, Trend

7.2.1 Source category description

In case of managed disposal, the waste is disposed in landfills where it is compacted and covered. Under these circumstances, anaerobic degradation occurs, during which methane and carbon dioxide is emitted. In advanced disposal sites, the generated methane is recovered by incineration or flaring. Degradation requires several decades and occurs at varying rates. Since waste disposal is continuous, gas generation can also be considered continuous on a country scale.

The CO_2 generated in landfills is of biogenic origin and is thus excluded from the inventory. Under the conditions prevailing in landfills, CO_2 generated from wastes containing carbon of fossil origin is insignificant and direct incineration does not occur in landfills. Illegally disposed wastes are not considered here, partly as they are disposed in batches, in thin layers without compaction, in a fashion well-penetrable for oxygen. Therefore, degradation is aerobic and only carbon dioxide is produced. In accordance with the IPCC Guidelines, no CO_2 emission has to be included in this category.

7.2.2 Methodological issues

Emissions were calculated using the default first order decay methodology. For the calculations, the IPCC Waste Model from the 2019 Refinement to the IPCC Guidelines was used with the “waste by composition” option. The FOD method produces a time-dependent emission profile which reflects the true pattern of the degradation process.

Activity data

The FOD method requires a quite long time series. The default first year in the IPCC Waste Model is 1950. As the eldest data which could be found in statistical publications were for 1975, extrapolation had to be made. For this purpose, a similar pattern as in Figure 7.2.1 had been used. This figure was taken from a university textbook sponsored by the Ministry of Education and Culture.

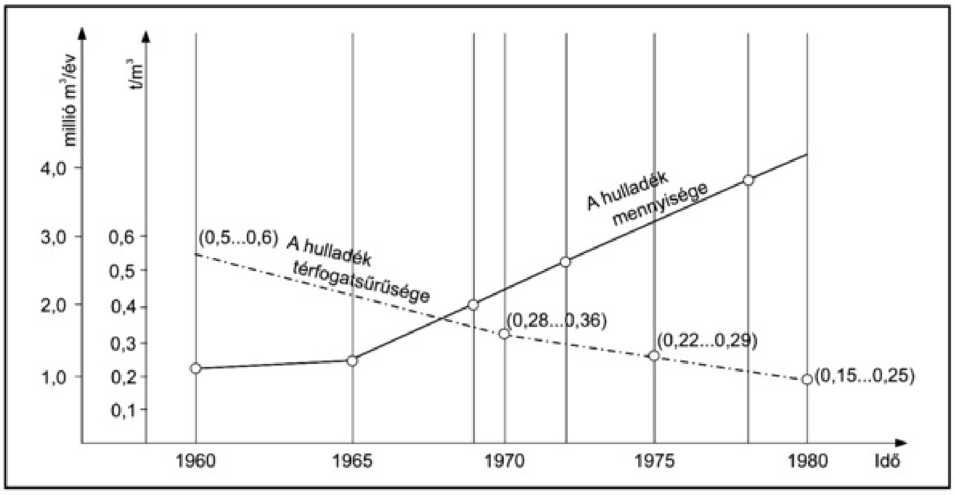


Figure 7.2.1 *The loosening trend of municipal solid waste in Budapest. The solid line denotes the amount of waste while the dotted line shows the decrease of volume-density. Source: (http://www.hik.hu/tankonyvtar/site/books/b108/).*

Before 2001, the amount of removed solid waste was reported in volume units (m^3), therefore these data had to be converted to mass unit using the gravimetric density (t/m3) as an important physical characteristic of the waste. Between 1975 and 2000, the value of this parameter decreased from 0.3 t/m^3 to 0.2 t/m^3 based on the data of the Statistical Office. Both international and national studies suggested that the mass of municipal solid waste increased hardly while waste volumes increased drastically all over the world, which is reflected in decrease of the gravimetric density. These changes are attributable to the increasing amounts of paper and plastic in the packaging sector. In other words, this is the so-called loosening trend in MSW which can be seen clearly in Fig. 7.2.1. To summarize the above, the following densities can be used for conversion from volume to waste units:

Table 7.2.1 *Waste densities suitable for conversion*

	1975-1985	From 1990	2000
Density (t/m^3)	0.3	0.22	0.2

(As the statistical office publishes data in mass units from 1990, practically there was no need for the compiler institute to do this conversion for the recent years.)

For the period 1950-1975, the following assumptions were made. The first data found in statistical publication was from 1975, i.e. 6,241 thousand m^3. This value was converted using a density of 0.3 t/m^3 which resulted in a mass value of 1,872 kilotonnes. The IPCC Guidelines suggest using surrogates, e.g. population in cases where domestic data do not cover the last 50 years. In this submission amount of disposed waste between 1950 and 1975 is assumed to be proportional to urban population. Urban population increased by more than 50 per cent between 1950 and 1975 based on information from the statistical office. GDP might have been an alternative but then the increase would have been steeper. (GDP grew by 128 per cent, whereas urban population changed by 31 per cent between 1960 and 1975. A little experiment carried out a few years ago showed, however, that the model is not that sensitive for early years. Even when halving the landfilled amount in 1950, the resulting change in emissions was minus 2% to 3% between 2000 and 2011.)

The next published data for landfilled waste we found was 9,952 thousand m^3 for 1980. Using the same conversion, this amount is equivalent to 2,986 kilotonnes. For the years between 1975 and 1980, simple interpolation was carried out. The next data was from 1985, i.e. 13,791 thousand m^3. Using the same density, it equaled to 4,137 kt from which the incinerated amount (244 kt) was subtracted. Again, an interpolation was made between 1980 and 1985. Then, from 1986, the now yearly published statistical data were converted from volume to mass with a diminishing waste density (from 0.29 t/m^3 in 1986 to 0.24 t/m^3 in 1989).

From 1990, yearly data in mass units published by the central statistical office was used.

From 2005, data from the Waste Management Information System maintained by the Ministry of Environment and Water were analyzed and used for calculations. This database contains very detailed information on waste management practices in Hungary. The Waste Management Information System (EHIR) can be accessed via internet as well (http://web.okir.hu/en/ehir). Data availability has been improved significantly, at least for recent years.

For activity data collection, the main data sources were the following:

- From 1975: Statistical Yearbooks
- 1990-2004: Statistical Yearbooks, Environmental Statistical Yearbooks, Eurostat;
- 2005- Waste Management Information System, Statistical Yearbooks, Eurostat

Beside municipal waste, also industrial waste disposal is taken into account in emission estimations. In the waste information system, disposed waste is categorized by waste types in line with European legislation. The waste types in the database are defined both on the basis of the six-digits European Waste Catalogue (EWC) codes and on the basis of the statistical waste nomenclature European Waste Classification (EWC-Stat), which is a substance-oriented nomenclature and which has been specially created for EU waste statistics (See Eurostat Manual on Waste statistics).

For this submission, we used mainly the latter categorization with only a few exceptions. Especially the following waste categories were included in the calculations:

- Health care and biological wastes (W05)
- Paper and cardboard wastes (W072)
- Wood wastes (W075)
- Textile wastes (W076)
- Animal and vegetal wastes (W091 Animal and mixed food waste +W092 Vegetal wastes +W093 Animal faeces, urine and manure);
- Mixed ordinary wastes (W101 Household and similar wastes + W102 Mixed and undifferentiated materials + W103 Sorting residues)
- Mineral waste from construction & demolition (W121).

As exceptions from the above, EWC codes are applied for the following categories:

- EWC 200307 (bulky waste): it is assumed that half of it is wood waste;

- EWC 200201 (biodegradable waste from garden and park wastes): this made possible to include garden / park waste as a separate category into the IPCC Waste model.

Sludges: Here we take also into account data reported by wastewater treatment plants (and collected by the General Directorate of Water Management). In contrast to the “normal” waste management data, sludges are reported not in fresh amount but in tonnes of dry matter.

The categories above are considered as degradable, all other categories are considered as inert.

Currently, about half of the disposed waste can be considered as degradable (i.e. falls into the above waste categories) within which mixed ordinary (mostly municipal) waste is the dominant category representing 59% of all disposed waste in 2022. The other half was inert waste where combustion wastes dominated with a share of 32% in 2022. The amount of all disposed waste decreased quite significantly after 2005 as demonstrated with the following figure.

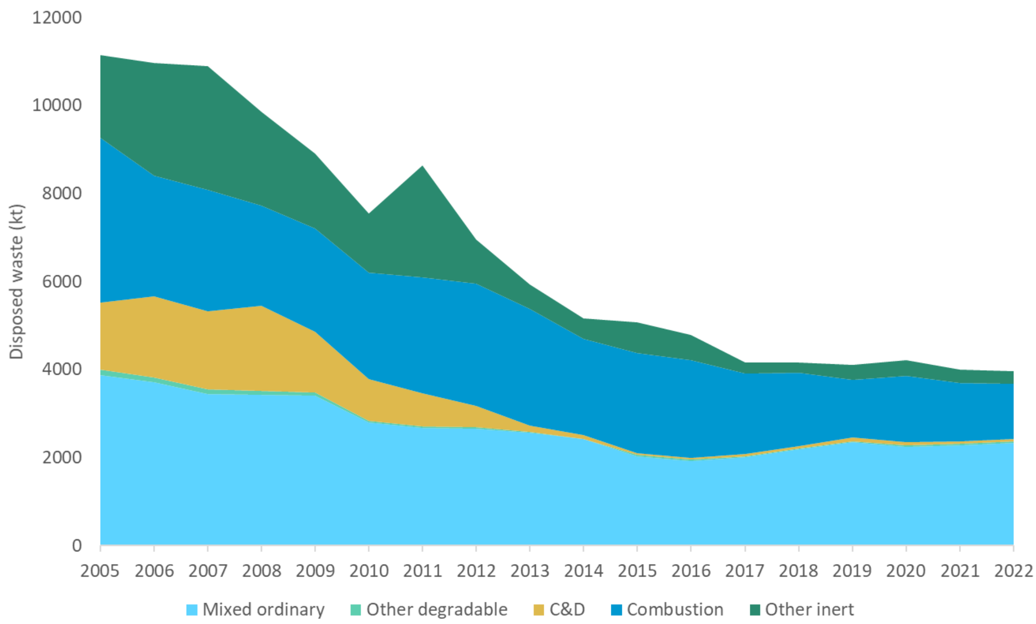


***Figure 7.2.2** Decreasing trend in waste disposal based on data from the EHIR database (2005-2022)*

As reliable information on waste treatment in the EHIR database is only available from 2005, data on disposed waste needed to be extrapolated back to 1950. The following proxy data were used for this extrapolation.

- For paper, wood, textile, animal and vegetal (and other industrial wastes):
  - 1990-2004: primer energy use with the assumption that energy efficiency measures might go hand in hand with improved material usage in industry (i.e., who is wasting energy might be wasting materials too).
  - 1960-1990: volume index of GDP was used as proxy. For the preceding 10 years (1950-1959) the amount was kept constant.
- For clinical waste:
  - 1960-2004: Number of active hospital beds. Similarly, as above, the amount was kept constant for the preceding 10 years.
- For construction and demolition waste:

- 1989-2004: volume indices of value added in the construction sector were used as proxy;
- 1960-1989: similar to industrial waste, the volume indices of GDP were used as proxy. For the preceding 10 years (1950-1959) the amount was kept constant.

Other parameters used in the calculations:

As regards ***waste composition*** of mixed (municipal) waste, up to the inventory year 2014, statistics only existed for the waste collected in Budapest and in good quality only from 1990. Having no other choice, these yearly data were used for the entire country. Again, as the FOD method requires data starting in 1950, further assumptions had to be made. For 1950, the regional default values representative for Eastern Europe were taken from Table 2.3 of the 2006 IPCC Guidelines (i.e. food 30.1%, paper 21.8%, wood 7.5%, textiles 4.7% etc.), and interpolation was carried out between these and the measured values for 1980.

In the Hungarian statistics, the following waste composition categories have been used for a longer period of time: paper, plastic, textile, glass, metal, degradable organic, hazardous waste, other non-organic. Recently, hygienic waste (e.g. nappies) has been added to the categories. These categories are mainly in line with the requirements of the models. We have added wood to MSW composition categories with a share of 2.5% for the period 1990-2004, and data from the waste statistics were used directly from 2005. Emissions from garden/park waste were calculated separately.

As detailed information on waste composition became available from about 70 waste disposal sites from the 2014 inventory year onwards, it was decided to use the weighted average of the reported waste composition data as country-wide average in this submission. Comparing the estimated DOC values calculated from the different waste composition data, we can see a quite good agreement for 2014 and 2022. However, in recent years, DOC seems to be higher in the capital than in other parts of the country mainly due to higher share of disposed degradable organic waste (food and green waste) in Budapest. The result of this comparison is shown in the figure below.

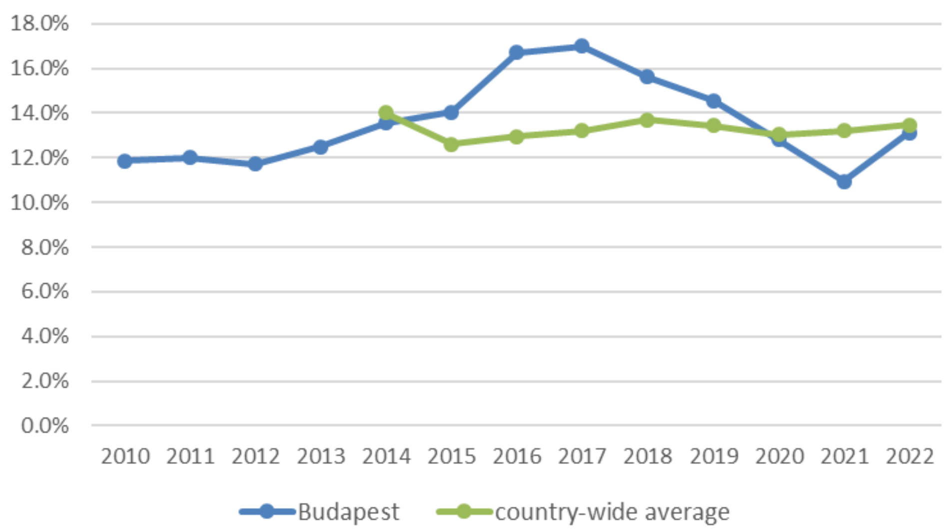
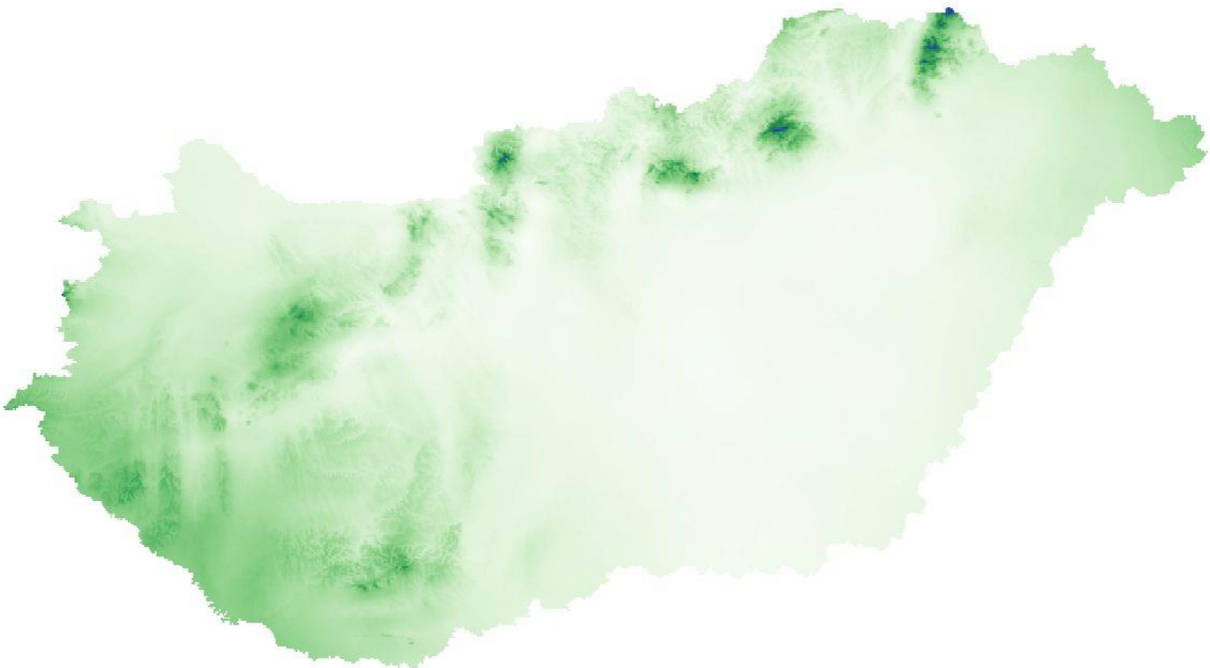


Figure 7.2.3 *Comparison of DOC estimated from waste composition in Budapest vs country-wide average*

In the IPCC waste model, the following waste categories were used:

- Food = degradable organic waste in mixed ordinary waste + separately collected animal and vegetal wastes (i.e., W091, W092, W093);
- Garden/park waste = biodegradable waste from garden and park wastes (EWC 200201);
- Paper = paper, cardboard and composite part of mixed ordinary waste + separately collected paper and cardboard wastes (W072);
- Wood = wood in mixed ordinary waste + separately collected wood wastes (W075) + half of bulky waste (EWC 200307);
- Textiles = textiles in mixed ordinary waste + separately collected textile wastes (W076);
- Nappies = share of hygienic waste in mixed ordinary waste + separately collected health care and biological wastes (W05);
- Sludge = mainly sludges from domestic wastewater plants.
- Construction and demolition waste = mineral waste from construction & demolition (W121).

Default parameters of the IPCC waste model typical of ***dry temperate climate*** were used. In accordance with Table 3.4 in the 2006 IPCC Guideline, a climate zone can be defined as dry when the mean annual precipitation (MAP) is lower than the potential evapotranspiration (PET). Now, the climatological average of MAP/PET is between 0.48 and 1.11 with a mean of 0.6. Values higher than 1 occur only on 0.04% of our territory (see the map below with greenish and blue colors representing P/PET<1 and P/PET>1, respectively.)



The methane generation rate constants (k) were between 0.04 and 0.06 depending on waste type with an average value of 0.05. The default 50% fraction of methane in developed gas was kept, and so was the 6 month of delay time. Basically, the default values given in the IPCC 2006 Guidelines were chosen for DOC, too. (In previous submissions we used one category ("degradable organic waste") for food and non-food (e.g. garden waste) fraction of the municipal solid waste, therefore a value (0.16) between the default values representative for food (0.15) and garden (0.2) was chosen for degradable organic carbon (DOC) content. As garden waste is reported now separately, there is no need any more for changing the default DOCs.)

Table 7.2.2 *Used DOC content and methane generation rate constant of different waste categories*

	DOC IPCC 2006	DOC Used values	Methane generation rate constant (k)
Paper	0.4	0.4	0.04
Textiles	0.24	0.24	0.04
Food	0.15	0.15	0.06
Garden	0.2	0.2	0.05
Wood	0.43	0.43	0.02
Sewage sludge	0.05	0.5*	0.06
Hygienic waste	0.24	0.24	0.05
Construction and demolition	0.04	0.04	0.05
DOCF	0.5	0.5	

**Calculated on dry matter basis*

In earlier submissions, constant methane correction factor of 1.0 valid for well managed landfills was used for the entire time series. This approach could be regarded as overly conservative as it did not take into account the modernization process in solid waste disposal practices and available information on landfill sites. Let us quote a study "Landfills in Hungary" under a research framework "Organising for EU Enlargement: A Challenge for the Member States and the Candidate States"

> **State-of-the-art: the Hungarian landfills**
>
> In Hungary the typical form of managing waste is disposal: 85 per cent of collected waste is disposed of into landfills. According to a PHARE project designed to assess all landfills in the country, there were 2700 operational landfills, out of these only 728 were registered landfills serving all the municipalities in Hungary in 2002 (European Commission, 2001). Only 6 are so far in line with the *acquis* and a further 67 seem to be aligned to a large extent. In particular, a great number of low capacity local landfills do not conform to the *acquis* and there are a large number of illegal ones. Measures are being implemented to close down all the illegal or non-EU compliant landfills. The objective laid down in the National Waste Management Plan is to establish regional collection and management systems with a maximum of 100-120 landfills. At the end of 2004, the regional collection and management systems planned in the framework of ISPA programme cover one-third of the country. A further objective is that the abovementioned cover-rate should reach 100 per cent by 2009.

In 2002, a comprehensive survey of landfill sites was carried out with the support of PHARE. During this project, stock was taken of no less than 2,667 landfill sites of which 1,300 were already closed. Out of the operating 1,367 sites, only 42 met current environmental requirements. It was suggested, though, that further 216 sites could operate temporarily till 2009, and the rest should be closed. One of the outcomes of the project was a database of landfills with several attributes such as depth, volume, insulation, cover etc. The database contained information among others on controlling, lining, compacting, leachate drainage, biogas collection. Summarizing the data based on total volume of disposed waste (and not on number of landfills), 15% of the disposal could be classified as managed (controlled), 16% as unmanaged shallow, and the remaining 69% as unmanaged deep.

Based on the above information, it didn't seem to be appropriate anymore to allocate all waste disposals to the managed category for the entire time series. Instead, all disposed waste is allocated now to the uncategorized category between 1950 and 1974. For the next period, between 1975 and 2000, the outcome of the above mentioned PHARE project is used, i.e. 85% of the disposed waste is considered as unmanaged (mostly deep), and the remaining 15% as managed. From 2001 on, all disposals are regarded as managed reflecting also the fact that a domestic act on waste management came into force in 2000 (Act No. XLIII of 2000 on waste management).

Naturally, changes did not occur from one day to another. Still, the development was quite rapid. Hungary started a modernization program relating disposal sites: the number of SWDSs decreased from about 2700 to 701 in 2000, then to 340 in 2005, to 213 in 2008, and to 69 in 2011. Currently (2022), 68 disposal sites are in operation.

Parallel to the closure of obsolete sites, the general level of management of the remaining disposal sites must have been improved.

Some domestic statistics indicate that only about 4% of municipal waste was still disposed uncontrolled in the early 2000's, therefore we decided to use MCF=1 for all years after 2000 which might be a little conservative estimate for the transition years.

As a consequence of this new approach, the formerly used parameters, especially the constant MCF value of 1.0 had to be replaced as follows:

- 1950-1974: MCF=0.6 for uncategorized SWDS, OX=0.
- 1975-1985: MCF=0.77 representing 15% managed, 16% unmanaged shallow and 69% unmanaged deep disposal. OX=0. (This means MCF=0.72 in the unmanaged category, and MCF=1.0 in the managed category.)
- 1986-2000: MCF=0.77-0.81 keeping the same share of managed/unmanaged sites but gradually decreasing shallow disposal. (This means MCF=0.72-0.78 in the unmanaged, and MCF=1.0 in the managed category.) OX=0
- 2001-2003 MCF=1.0 OX=0
- 2004-2009 MCF=1.0, OX=0.05-0.1.
- 2009- MCF=1.0, OX=0.1.

As for the oxidation factor, previously the default zero value was applied for the entire time series. However, based on the IPCC Guidelines, the use of the oxidation value of 0.1 is justified for covered, well managed SWDS to estimate both diffusion through the cap and escape by cracks/fissures.

The Hungarian Waste Information System that serves as our main source of information for activity data from 2004 contains two categories for disposals:

D1 Deposit into or onto land, e.g. landfill

D5 Specially engineered landfill, e.g. placement into lined discrete cells which are capped and isolated from one another and the environment

Landfills categorized as D5 can be regarded as well-managed modern landfills that comply with the EU Landfill Directive and where daily and temporary soil covers are applied therefore an oxidation value of 0.1 is justified. The following table shows, how the share of disposal into well-managed landfills increased in the last years.

Table 7.2.3 *The ratio of managed vs. well-managed landfills*

	D1	D5
2004	50%	50%
2005	48%	52%
2006	34%	66%
2007	36%	64%
2008	44%	56%
2009	29%	71%
2010	17%	83%
2011	35%	65%
2012	12%	88%
2013	2%	98%
2014	1%	99%
2015	1%	99%
2016	1%	99%
2017	0%	100%
2018	0%	100%
2019	0%	100%

Also managed landfills (D1) are covered in Hungary but not necessarily immediately after waste was deposited. In some instances the application of a soil cover oxidation might be delayed owing to modernization efforts or post-closure management. In 2017, for example, all managed (D1 and D5) landfills in Hungary were covered. For the period before 2003 Hungary does not have information on covering of managed landfills and therefore 0 per cent oxidation is assumed.

A 2009-report on the implementation of the EU Landfill Directive indicates that in the period 2007-2009 all managed landfills already met the requirements from the EU Landfill Directive and are therefore covered. Based on the conclusion of the above mentioned report from 2009 onwards OX=0.1 is assumed.

The amount of recovered CH_4 was calculated on the basis of energy production data obtained from the Energy Centre Hungary. These data in energy unit (TJ) were converted to mass unit as the amount of recovered methane by using the net calorific value from Table 1.2 in the 2006 IPCC Guidelines (Volume 2, Chapter 1), which is 50.4 TJ/Gg. Data collection has also been started on flaring. Disposal sites were contacted and asked for amount of flared landfill gas and methane content when available. In case site-specific methane content was not available, it was assumed that the share of methane in biogas was 50%. The collected data are summarized in the table below.

Table 7.2.4 *Data on flaring and biogas utilization (2001-2022)*

	2001	2002	2003	2004	2005	2006	2007	2008	2009
Flaring Mm^3	3.060	3.115	2.868	2.893	3.230	7.753	7.353	9.500	4.357
CH_4 kt	1.0970	1.1167	1.0282	1.0371	1.1580	2.7794	2.6362	3.4058	1.5620
Biogas TJ	-	-	-	-	2	46	85	86	119
CH_4 kt					0.04	0.91	1.69	1.71	2.36
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Flaring Mm^3	4.050	4.271	6.283	7.929	7.438	2.107	0.692	0.958	0.750
CH_4 kt	1.4519	1.5310	2.2525	2.8994	2.7642	0.8566	0.2045	0.225	0.269
Biogas TJ	199	462	190	471	576	674	771	631	530
CH_4 kt	3.95	9.17	3.77	9.35	11.43	13.37	15.30	12.52	10.52

	2019	2020	2021	2022
Flaring Mm^3	1.821	1.714	4.318	2.363
CH_4 kt	0.653	0.615	1.548	0.847
Biogas TJ	438	410	323	289
CH_4 kt	8.7	8.1	6.4	5.7

Recovered methane has been subtracted from the calculated emissions.

Please note that the earliest available data on the amount of CH_4 flared are from 2001 therefore NE was reported previously for earlier years. It is most possible that flaring activity did not occur before 2001 as landfill gas production also started only in 2005. Therefore, we have changed the notation key to “NO”.

The following figure summarizes the used activity data and the results of our calculations.

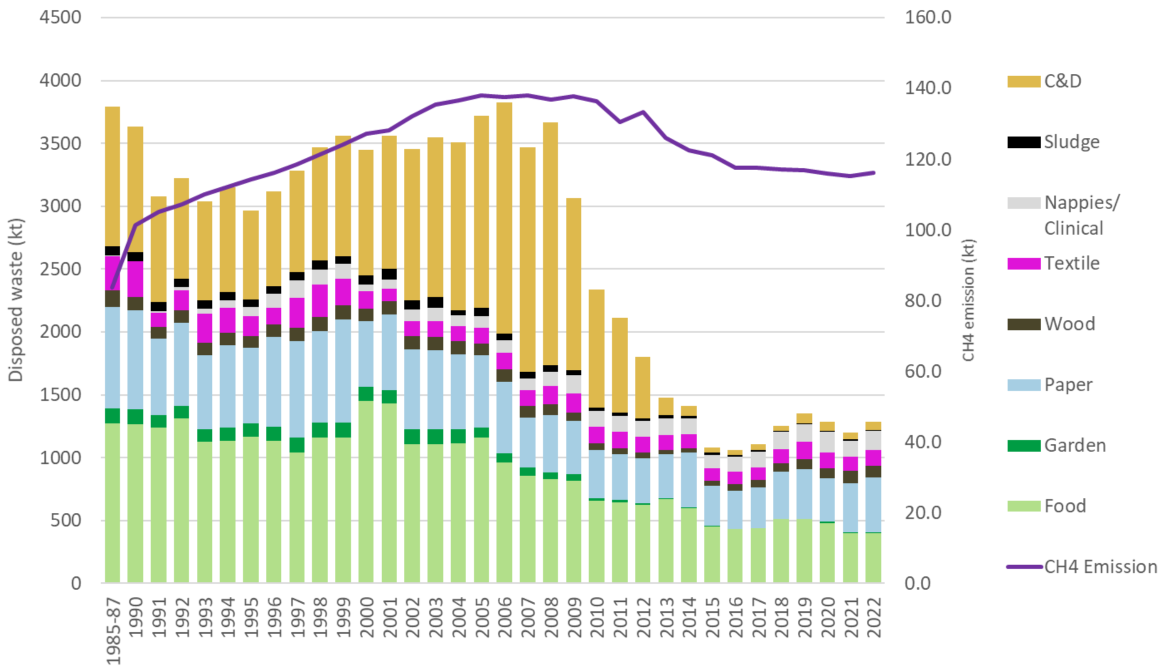


Figure 7.2.4 *Summary of activity data and the resulting emissions*

7.2.3 Uncertainties and time-series consistency

Uncertainty can be estimated using Table 3.5 of the 2006 Guidelines. Accordingly, the following values were obtained:

Quantity of disposed municipal solid wastes	>±10%
Degradable organic carbon	±20%
Fraction of Degradable Organic Carbon Decomposed	±20%
CH_4 correction factor (=1)	-10 %,+0 %
CH_4 content of landfill gases (0.5)	±5%
CH_4 recovery	one order of magnitude
Half-life	±25%

The time series can be regarded as consistent.

(In the past, complete and obligatory data reporting on the collection of municipal solid waste did not exist in Hungary and the published data were estimations partly based on representative surveys. During the initial part of the calculation period, the authority procedures for waste recording were not uniform. In this system, which was based on self-reporting (self-registering), data were processed at varying detail and quality levels due to the lack of legal and technical regulations related to individual waste types. In addition, an overall central registry of industrial waste was missing and the rules related to such wastes were not laid down in any legal instruments).

7.2.4 QA/QC information

The compiler institute has now direct access to the Waste Management Information System maintained by the ministry responsible for environment. Data from different sources are compared. Our most detailed data source is the Waste Management Information System (EHIR) maintained now by the Ministry of Agriculture. This contains among others data on amount, type, consistency, management practices, mode of treatment. Converting these data to an Excel file, we get about 16,000 rows for one year. After analyzing these data, comparisons are made with the aggregated data published by the Hungarian Statistical Office, and also by EUROSTAT. Should we detect any problem, both the statistical office and the ministry can be contacted. The calculations with the IPCC Waste Spreadsheet Model have been saved and archived for future reviews.

7.2.5 Recalculation

Across the entire waste sector, the recalculations resulted in a 2.9% increase in 2021. For 2005, this resulted in a 4.8% increase; for 1990, a 3.4% increase; and for the base year, a 2.8% increase.

5.A.1.

During the development of the new emission inventory, we applied the latest IPCC waste model based on the IPCC’s 2019 refinement to ensure a comprehensive and up-to-date assessment of greenhouse gas emissions from waste sources. The utilization of this model aligns with current international standards and best practices in emission inventory management. As a result, we retroactively updated the data from 2022 back to the base year.

As a consequence of modifying the IPCC waste model, the emission values exhibited a positive shift in the whole time series.

5.A.

In the base year, emissions increased by 4% in the source category 5.A. In 2021, our new estimates are 3.4% higher (+109.6 kt CO_2-eq) compared to the previous submission.

7.2.6 Planned improvements

It is planned to analyze the latest most detailed waste composition analysis available.

7.3 Biological treatment of solid waste (CRF sector 5B)

Emitted gases: CH_4, N_2O
Key source: none

As composting is showing a growing tendency recently, GHG emissions were calculated and reported for this category also in the submissions in the first commitment period using the IPCC 2006 methodology.

7.3.1 Methodological issues

The Tier 1 method from 2006 Guidelines was used with default emission factors.

Table 7.3.1 *Activity data and emissions from biological treatment of solid waste*

	Composting					Biogas facilities	
	MSW (kt) wet weight	dry weight	Sludge (kt)	CH_4 (kt)	N_2O (kt)	Biogas (TJ)	CH_4 (kt)
1985			20	0.20	0.01		
1986			20	0.20	0.01		
1987			20	0.20	0.01		
1988			20	0.20	0.01		
1989			20	0.20	0.01		
1990			20	0.20	0.01		
1991			20	0.20	0.01		
1992			20	0.20	0.01		
1993			20	0.20	0.01		
1994			20	0.20	0.01		
1995			28	0.28	0.02		
1996	18	7	29	0.36	0.02		
1997	19	8	26	0.34	0.02		
1998	18	7	23	0.30	0.02		
1999	18	7	32	0.39	0.02		
2000	17	7	30	0.37	0.02	6	0.01
2001	17	7	27	0.34	0.02	4	0.00
2002	47	19	37	0.56	0.03	4	0.00
2003	47	19	56	0.75	0.04	62	0.06
2004	39	16	24	0.40	0.02	107	0.11
2005	41	16	53	0.69	0.04	102	0.11
2006	58	23	43	0.66	0.04	129	0.13
2007	64	26	51	0.77	0.05	250	0.26
2008	85	34	62	0.96	0.06	490	0.51
2009	90	36	90	1.26	0.08	734	0.77
2010	148	59	82	1.41	0.08	898	0.94
2011	183	73	81	1.55	0.09	1336	0.40
2012	183	73	90	1.63	0.10	1105	1.15
2013	187	75	93	1.68	0.10	2042	2.13
2014	236	94	97	1.92	0.12	2018	2.11
2015	231	92	99	1.92	0.11	1954	1.53
2016	294	118	102	2.19	0.13	1965	1.54
2017	309	124	103	2.26	0.14	2297	1.80
2018	310	124	99	2.23	0.13	2127	1.67

	Composting					Biogas facilities	
	MSW (kt) wet weight	dry weight	Sludge (kt)	CH_4 (kt)	N_2O (kt)	Biogas (TJ)	CH_4 (kt)
2019	353	141	92	2.33	0.14	2142	1.68
2020	375	150	93	2.43	0.15	2108	1.65
2021	382	153	93	2.46	0.15	1932	1.51
2022	414	166	88	2.54	0.15	2389	1.87

The amount of composted municipal waste was received from the Hungarian Central Statistical Office. In 2022, 414.317 Gg waste was composted which represented 14% of all generated MSW.

As regards the amount of composted sludge, the time series was constructed using the following data sources:

- Data published by the statistical office;
- Composting related information from the Waste Management Information System (the same database that is used for SWDS);
- Data from the Wastewater Information System or for recent years from the Urban Wastewater Information System (the same databases that are used for emission calculations for wastewater treatment);
- For the period 1985-1993 we used a constant value corresponding to the amount reported for 1994.

In 2022 88.15 kt (dm) sludge was composted.

As generally the calculations were carried out on ***dry weight basis***, and the corresponding emission factors from Table 4.1 in the 2006 IPCC Guidelines were applied (i.e., 10 g CH_4/kg dry waste and 0.6 g N_2O/kg dry waste), some of the original data had to be converted to dry weight. Sludge data in the Waste Management Information System are categorized on the basis of their dry matter content which allowed this conversion. For composted municipal waste, 60% moisture content was assumed (see Remarks in Table 4.1 in the IPCC Guidelines).

Our starting point for estimating methane emission from anaerobic digestion at biogas facilities was produced biogas from the energy statistics. The energy values (TJ) were then converted to mass of methane (kt) using the default calorific value of biogas, i.e., 50.4 TJ/Gg. Emissions of CH_4 due to unintentional leakages at biogas facilities were then assumed to be 5% as suggested by the 2006 IPPC Guidelines.

Biogas from manure management has been subtracted from biogas accounted for under 5.B.2.b as it is accounted for under the Agriculture sector. In agreement with the agriculture expert, and on the basis of feedstock data from the period 2017-2020, it is assumed that 25% of all biogas is produced from manure. (The average share of manure was 26.4% in the analyzed period, so 25% seemed to be a safe estimate.)

Although not used in the calculation, activity data are reported as annual waste amount treated in kt dm. For the period 2017-2021, a very detailed database on various feedstock used for anaerobic digestion was analyzed. This database contains information on more than 40 types of feedstocks including fresh weight and dry matter content which was used for this period directly. For the remaining part of the time series, data on produced biogas (TJ) taken from the IEA/Eurostat Annual

Questionnaire was used with a conversion factor of 7.8 TJ/kt dm (which was derived from the average values from the period 2017-2021).

Please note that there is no information on flaring activity for 5.B.1 Composting therefore NE was reported previously for flaring. As we believe, flaring is not occurring in composting plants, we have replaced the notation key with NO. Furthermore we reported NE for the amount of CH4 flared because there is no information on flaring activity for subcategory 5.B.2.b.

7.3.2 Uncertainties and time-series consistency

No category specific information is available.

7.3.3 Source-specific QA/QC and verification

The used data from Eurostat was compared with data from the Hungarian Central Statistical Office.

7.3.4 Recalculations

No recalculation has been made for this submission.

7.3.5 Planned improvements

None.

7.4 Incineration of waste (CRF sector 5C)

Emitted gases: CO2, CH4, N2O

Key source: none

7.4.1 Source category description

This subsector covers only emissions from thermal waste treatment without energy recovery (D10). Emissions from waste incineration for energy purposes (R1) are allocated to the energy sector.

During waste incineration, mainly CO_2 is emitted out of which only the fossil part contributes to the total emissions. (Biogenic CO_2 emissions were calculated as well but these were included only as memo items). Methane emissions are insignificant and N_2O generation is also minimal.

In 1986 a decree on the protection of air quality came into force, under which waste incineration (of any kind) required authorization. In 2001, decree 21/2001 (II.14) came into force explicitly prohibiting the open burning of waste, including in household furnaces. The same prohibition was included in the current Government Decree on air protection (306/2010 (XII. 23.). Based on a Government Decree on air protection (306/2010 (XII. 23.), open burning of waste (or incineration of waste in an installation that does not comply with the legislation setting the conditions for incineration of waste), with the exception of household waste paper and incineration of untreated non-hazardous wood waste is prohibited.

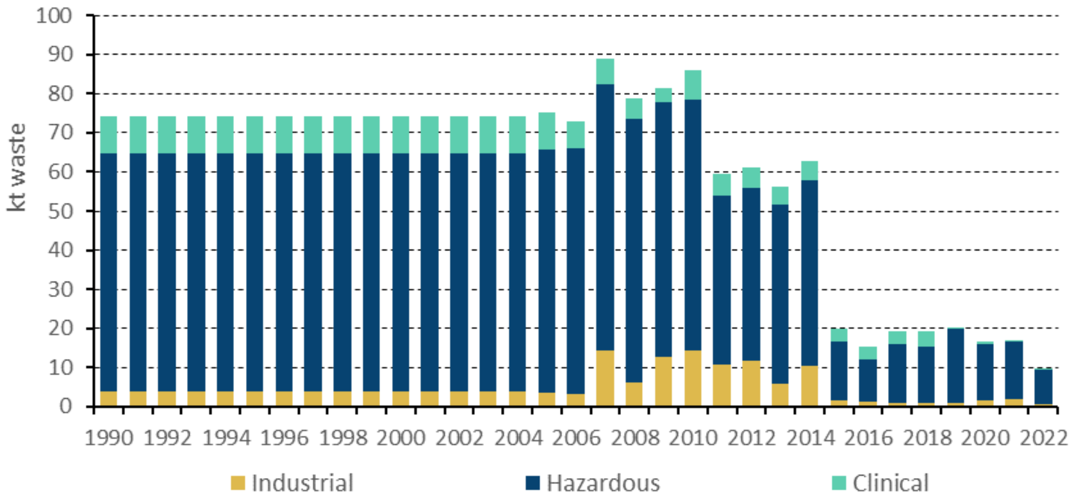


Figure 7.4.1 *Activity data in waste incineration*

7.4.2 Methodological issues

For estimating CO2 emissions, the Tier 2 method was applied as country-specific data on waste amount, composition and management practices was used. The very detailed Hungarian Waste Management Information System made it possible to disaggregate the activity data (amount of incinerated waste) into different waste types according to the European Waste Catalogue (EWC codes) and European Waste Classification (EWC-Stat). It might be an interesting fact that 82 to 97 per cent of all incinerated waste in this source category was hazardous waste of which most part was liquid. Therefore, it was decided that all incineration would be reported in the “Hazardous Waste” category in the CRF. However, different emission factors were applied in the emission calculations for the following waste types:

- clinical waste: defined as EWC-Stat code W05 (Health care and biological wastes)
- fossil liquid waste: defined as liquid wastes with EWC-Stat codes W011 (spent solvents) and W013 (used oils);
- hazardous (non-liquid, non-clinical) waste: defined as all other hazardous waste;
- other waste: all other incinerated waste

Having these country-specific waste amount and composition data, the carbon content of the incinerated waste and the fossil fraction thereof could be determined by using default values from Table 2.5 and Table 2.6 in the 2006 Guidelines (Volume 5. Ch. 2). For liquid waste, the default carbon content of 80% was applied from Table 5.2 of the 2006 IPCC Guidelines. For hazardous waste, the average of 5-50 per cent was used, i.e. 0.275. The same value was applied for all other wastes.

The CH4 emission factor of 300 kg/kt was derived from the default emission factor of 30 kg/TJ for industrial wastes (Table 2.3 in Chapter 2) with an assumed calorific value of 10 TJ/kt.

The following table summarizes the used emission factors for the different waste types.

Table 7.4.1 *The used GHG emission factors*

Waste type	Carbon EF	Ref.	CH4	Ref.	N2O	Ref.
Fossil liquid	0.8	Table 5.2	0.56	Page 5.20	9.8	Table 5.5 (waste oil)
Clinical	0.25	Table 2.6	300	Chapter 2	100	Table 5.6 (industrial waste)
Hazardous (non-liquid, non-clinical)	0.275	Table 2.6	300	Chapter 2	100	Table 5.6 (industrial waste)
Other waste	0.275		300	Chapter 2	100	Table 5.6 (industrial waste)

The CH4 emission factor of 300 kg/kt was derived from the default emission factor of 30 kg/TJ for industrial wastes (Table 2.3 in Chapter 2) with an assumed calorific value of 10 TJ/kt.

7.4.3 Uncertainties and time-series consistency

Consistency of the time series needs to be investigated, as constant values are used for the years before 2004.

7.4.4 QA/QC information

Data taken from the Hungarian Waste Management Information System for the calculations are compared with the relevant data published by the domestic statistical office and by Eurostat. As most part of waste incineration occurs with energy recovery, even if the resulting emissions are accounted for in the energy sector it is worth mentioning here that the IEA and ETS data were cross-checked, and also the biggest incinerator plant is contacted once in a while for verification purposes.

7.4.5 Recalculations

No recalculation has been made for this submission.

7.4.6 Source-specific planned improvements

None.

7.5 Wastewater treatment and discharge (CRF sector 5D)

Emitted gas: CH4, N2O

Key source: CH4: Level, Trend

7.5.1 Source category description

This sector covers emissions generated during municipal and industrial wastewater treatment. When the wastewater is treated anaerobically, methane is produced. Wastewater handling can also be a source of nitrous oxide, therefore N_2O emissions from human sewage are also part of the inventory.

7.5.2 Methodological issues

While estimating the methane emissions of wastewater handling, the key parameter is the fraction of wastewater treated anaerobically. Methane emissions from wastewater treatment were calculated using partly basic statistical data, partly very detailed facility level information on wastewater discharge together with the specific emission factors recommended by the 2006 IPCC Guidelines. For recent years, wastewater data (COD values for the industrial sector, proportion of different treatment methods) based on measurements conducted by the authorities and emitters were obtained from the regional inspectorates for environment, nature and water. Besides, the inventory compilers consulted with experts, visited a few wastewater plants and checked the calculations of the neighboring countries as well.

General background information

Based on data of the Wastewater Information System that contains about 1500 emission reports per year, from an analysis of the period 2005-2013 the following conclusions could be drawn:

- 140 to 240 million cubic meter wastewater from industrial facilities was discharged into rivers and seas. On average, 60% of this amount had either no treatment or only mechanical treatment beforehand (trend decreasing);
- The average COD content of the above, only partially treated wastewater was as low as 0.05 kg/m3.
- On average, about 30 million m3 industrial wastewater was collected via the public sewerage system, and treated in centralized plants, consequently domestic and industrial wastewater treatment could not be separated entirely. Around 80% of this amount went into the public sewerage system after at least biological treatment.
- The average COD content of the above, mostly treated industrial wastewater was definitely higher with 0.6 to 0.8 kg/m3 in 2008-2012.
- Domestic and commercial wastewater treatment plants, (that also treat industrial wastewater), discharge yearly 440 to 580 million m3 into open water.
- The share of the collected wastewater treated at least biologically or at more advanced treatment plants increased from 35% in 1990 to 65% in 2005, and to 96-98% in 2010-2017;
- In line with the above development, the average BOD5 content of the discharged wastewater decreased from 0.15 kg/m3 in 2005 to 0.02 kg/m3 in 2013.

Activity data

For domestic wastewater, the activity data - the quantity of total organic waste (TOW) - was calculated by multiplying the population of the country by the IPCC default value of Biochemical Oxygen Demand that is BOD5 = 60 g/person/day (Table 6.4 in Volume 5 Chapter 6 of the 2006 IPCC Guidelines). This default BOD value was confirmed by Hungarian experts of the Ministry of Environment and Water as well and was used uniformly for the entire times series and for the whole country.

Total organics produced by industrial facilities is partly taken into account with the default correction factor I (=1.25) corresponding to additional industrial BOD discharged into sewers thus accounted for in the domestic category. From 2015 on, total organic load as reported by wastewater treatment plants to the statistical office are also taken into consideration. The average difference between the calculated and the reported total BOD values was 3% with a growing tendency.

As described above, the degree of utilization of modern, centralized WWT plants increased, and tertiary treatment became the dominant technology.

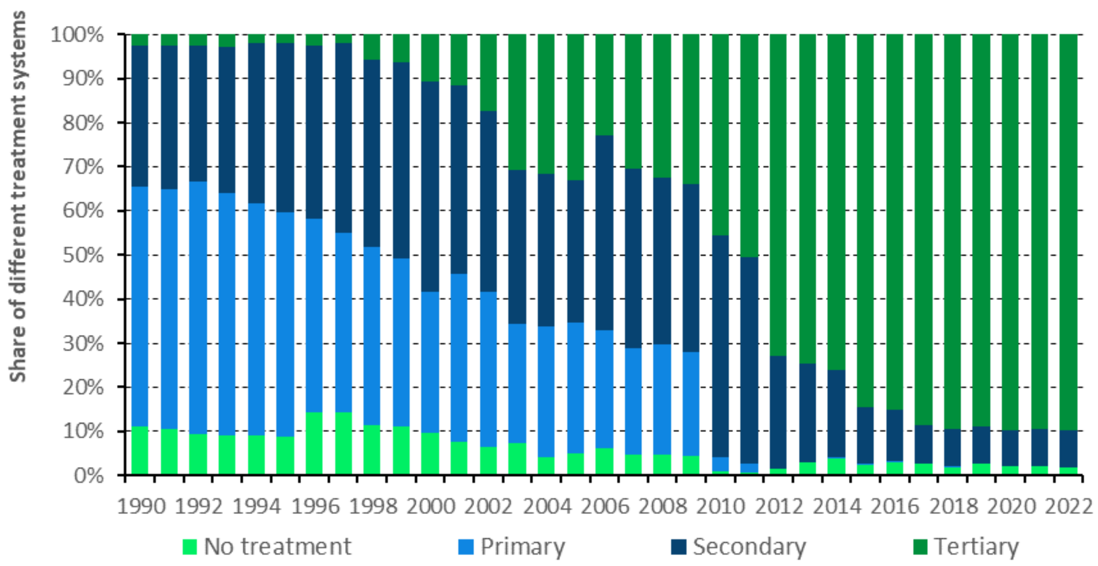


Figure 7.5.1 *The evolution of the different treatment systems (1990–)*

Source of data: Hungarian Central Statistical Office:
https://www.ksh.hu/stadat_files/kor/en/kor0026.html
https://www.ksh.hu/stadat_files/kor/en/kor0027.html

The activity data in the industrial wastewater category were the total output of wastewater [1000m3/year], the emitted total organic wastewater [kg COD/year] and in some cases the organic load (kg BOD/day) which were collected by the regional inspectorates and further processed by the (former) Research Institute for Environmental and Water Management (VITUKI). However, limited data were available on the industrial wastewater generation in individual sectors, especially for the initial years of the calculation period.

Activity data for the industrial wastewater category were partly taken from the Wastewater Information System database. For earlier years, before 2008, activity data were extrapolated using proxy data, i.e. volume of water supplied to other than household consumers published by the statistical office. (see http://www.ksh.hu/docs/eng/xstadat/xstadat_annual/i_uw004.html) For the period 1985-1990, constant values are used.

For a few years now, we have received a very detailed database containing all domestic wastewater treatment plants (around 800) collected by General Directorate of Water Management, an independently operating institute and a central government body under the direction and supervision of the Minister of Interior.

This database contains among others information on the amount of treated wastewater by treatment type, but also other inventory relevant parameters such as BOD, COD, and Nitrogen content of both the influent and the effluent, and information on sludge treatment.

Few years ago, we had also the possibility to look also into detailed reports of wastewater facilities of different industrial plants. Special emphasis was given to industries with high COD output, e.g. food and beverage, paper and pulp, chemical industry etc. By analyzing organic load data before treatment, we were able to introduce the following country-specific data on industrial wastewater as summarized in Table 7.5.1 below:

Table 7.5.1 *The used data for industrial wastewater*

	BOD
	[kg/m3]
Pulp and paper	2
Starch	1.14
Sugar	3.4
Pharmaceutical	1.5
Beer	1.5
Meat	1
Dairy products	1.5
Vegetable oils	0.85
Wine	5.27
Fruits	2.9
Chemical industry	0.25
Coke production*	5
Oil refinery*	1

**refers to COD*

As for industrial wastewater, generally COD values are used, the above BOD values were converted using a conversion factor of 2.4. Please note, as we expect more data from individual facilities, the above data might be subject of changes.

Emission factors

For the calculation of the emission factor (EF), default maximum CH4 producing capacities of 0.25 kg CH4/kg COD and 0.6 kg CH4/kg BOD were used for industrial and domestic wastewater, respectively.

The choice of a proper methane conversion factor (MCF) was somewhat more difficult. To calculate the weighted average of MCF, additional information was collected on the share of population with no connection to the public sewerage system. Using these additional activity data, the following assumptions were made:

- In accordance with the 2006 IPCC Guidelines, for people using septic systems or any other domestic means (no connection to public sewerage network), it can be assumed that half of the BOD settles, therefore MCF=0.5 was chosen. (Table 6.3 in the 2006 Guidelines). In the base year, the portion of population (or dwellings) connected to public sewerage system was 38%, now it's around 87.2% (2017). It must be noted, however, that the percentage of dwellings connected to public sewerage network is still below the Central-European average.

- As a refinement of the above, for those dwellings where neither public nor domestic sewerage exists and probably latrines are used, MCF=0.1 was used in accordance with the above referenced table from the 2006 Guidelines.
- Annual data on the number of dwellings connected to public sewerage systems are provided by the Hungarian Central Statistical Office for 1990–2022. Data on the proportion of the population connected thereto are available for 2011 onward. Prior to 2011 the share of population connected or not connected to a sewerage system was estimated based on the number of all dwellings using a correction factor of 5%.
- Usually, collected wastewater undergoes aerobic treatment in treatment plants. Default MCF for centralized, aerobic treatment plant is zero. (Table 6.3 in the 2006 Guidelines) Still, an MCF value of 0.05 was applied to secondary treatment up to 2004, thus to allow some emissions in case of incidental overload, and more importantly, to reflect modernization in the sector. (In a previous submission, the default MCF value of 0.1 was applied for direct discharge into rivers and lakes. This was abolished following a recommendation of a European review team, since it can be assumed that flowing rivers (such as the Danube) are not oxygen-deficient.)
- For industrial wastewater, MCF of 0.05 (i.e. the middle of the range for aerobic treatment from Table 6.8 in the Guidelines) is used from 2000, and the highest value of the range (MCF=0.1) for the beginning of the time series (until 1995), and interpolated values between 1995 and 2000. We applied the general assumptions that industrial wastewater is treated aerobically and that, in the case of anaerobic sludge treatment, CH4 generated is recovered as sewage sludge gas with an assumed leakage of 5 per cent.

Methane recovery

Based on the energy statistics, sewage sludge gas utilization started in 2001 in Hungary. As unintentional leakage might occur during anaerobic digestion of sewage sludge, some CH4 emission are added to this category. The same methodology was used as for the category 5B Biological treatment of solid waste, i.e., 5% leakage was assumed. (Please note that the total amount of CH4 for energy recovery is reported under category 5.D.1 domestic wastewater as this value is calculated on the basis of energy statistics and the data available include sewage sludge gas from both municipal and industrial wastewater plants. For this reason notation key IE is reported for 5.D.2 Industrial wastewater.)

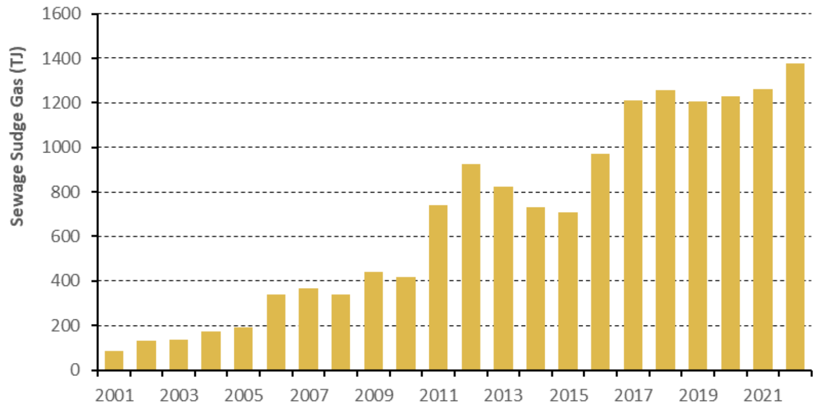


Figure 7.5.2 *Sewage gas production (TJ)*

As regards flaring, we were not aware of any official database therefore individual wastewater treatment plants were contacted. About 10 WWTPs reported flaring activity. The aggregate amount of flared methane expressed both in Nm3 and kt is included in Figure 7.5.3. Methane density was assumed as 0.717 kg/m3. As it can be seen, the amount of flared methane is far below 1 kt. (Please note that flared methane is not part of the emission estimates.)

Please note that flaring did not occur on domestic wastewater treatment plants in years 1990-2000 therefore notation key NO is reported. As there is no information on flaring activity for subcategory 5.D.1 for years 2001-2003 the notation key NE is reported.

Please note that there is no information on flaring activity for subcategory 5.D.2 Industrial wastewater therefore NE is reported from 2001 on (previously no sewage gas production occurred).

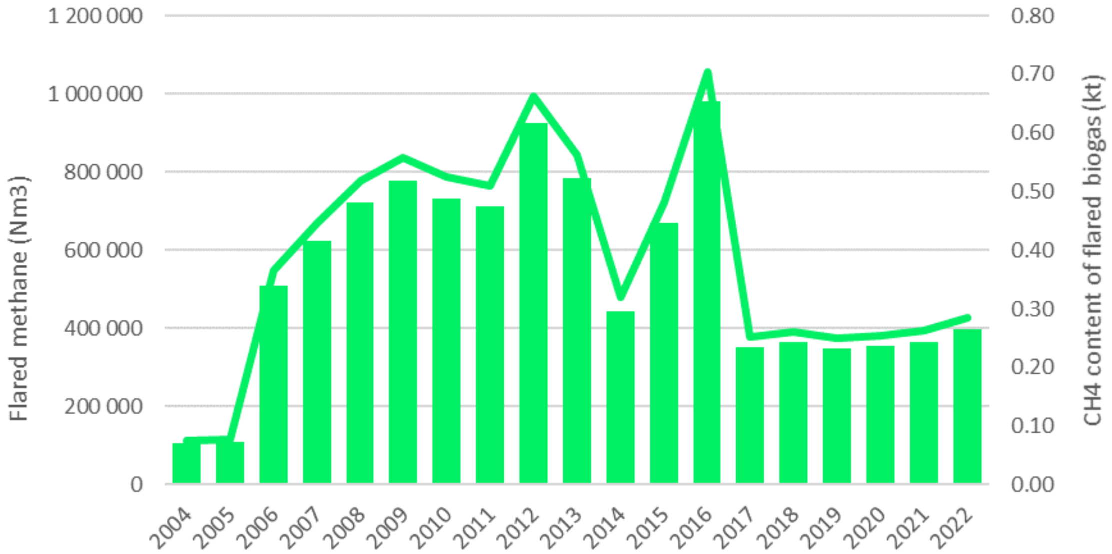


Figure 7.5.3 *Flared methane in WWTPs (2004-2022)*

The above considerations, used parameters and the resulting emissions are summarized in the Figure below. It seems obvious that the decrease in emission is mostly due to the growing share of households connected to the public sewerage system that increased from 43.7% in 1990 to 86.9% in 2020.

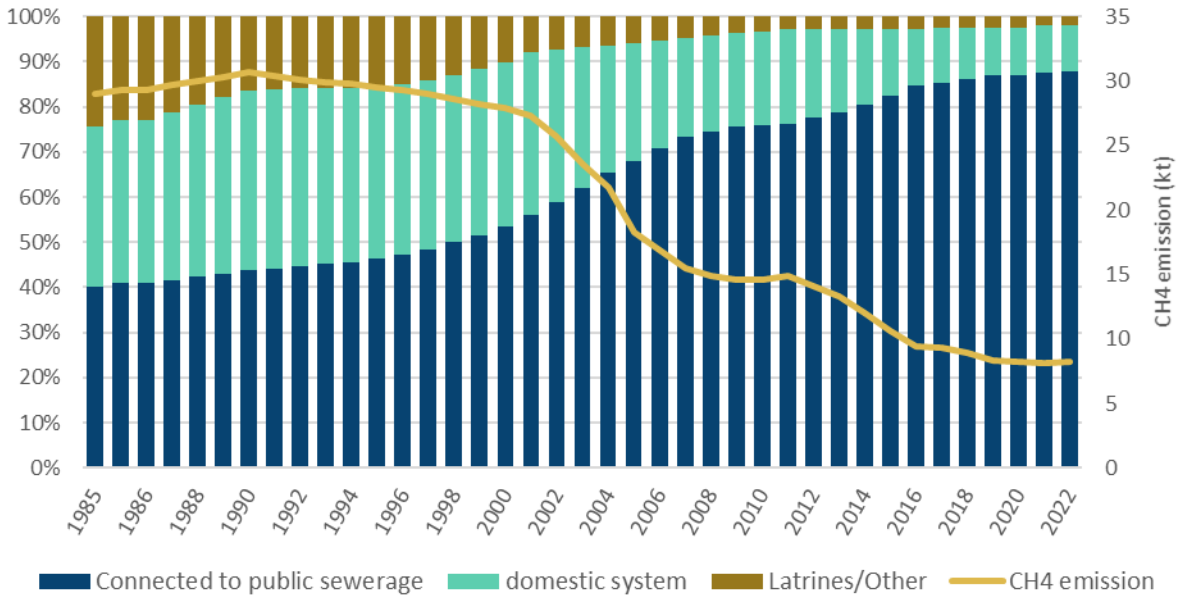


Figure 7.5.4 *Domestic wastewater treatment (1985-2022)*

As regards emissions from sludge treatment, our approach is as follows. It is assumed that whenever anaerobic digestion of sludge takes place, the generated methane (reported as sludge gas in the energy statistics) is recovered and used for energy purposes. The amount of methane recovered for energy is reported in CRF Table 5D but this amount was not subtracted from the total emissions as no additional methane emission from sludge digestion was taken into account in the above calculations.

It has to be emphasized that emissions from sludge treatment (besides leakage at biogas facilities) are taken into account in other emission categories:

- Landfilled sewage sludge is accounted for in the 5A Solid waste disposal in landfills category;
- Composted sewage sludge is taken into account in the 5B Biological treatment of solid waste category;

Considering direct emissions, the calculation method for nitrous oxide emissions from advanced centralized wastewater treatment plants remained the same, i.e., the method described in Box 6.1 in the 2006 IPCC Guidelines was used. We have, however, changed our approach for indirect N_2O emissions on the basis of newly collected data. Based on measurements of the total nitrogen content of incoming wastewater, we have re-evaluated the total N content in wastewater. It turned out that there is no need to apply the parameters for non-consumed protein and for industrial a commercial co-discharged protein.

For example, modern (third category) domestic wastewater plants measured 30.9 kt nitrogen in the influent in 2015 based on information collected by General Directorate of Water Management and further processed by the compiler institute. We know that 85% of all wastewater went in such advanced WWTPs. We also know that 83% of the population is connected. Based on protein consumption (100.1 g/cap/day), the estimated N in the effluent would be 58 kt (without applying the parameters Fnon-con and Find-com). Using this figure with the degree of utilization of modern centralized WWT plants (85%) and the connection rate of the population (83%), we would get 55 x 85% x 83% = 40.2 kt that is higher by more than 20% than the measured value, therefore it seems that there is no need for these two additional F parameters. (We got similar results for the period 2011-2018 where measured data were available.)

Consequently, we have recalculated the basic activity data (i.e., available nitrogen in the effluent) by using the same protein consumption data but not taking into account the default parameters for non-consumed protein and for industrial a commercial co-discharged protein. And we went one step further. As we have measured data for the nitrogen content in both the influent and the effluent (see Table 7.5.2), their difference was considered as removed nitrogen in the treatment process that won't be discharged to aquatic environments anymore, therefore it was subtracted from the calculated value of N in effluent.

Table 7.5.2 *Measured N content in wastewater in advanced WWT plants (tertiary treatment)*

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total N in influent (kt)	18.36	23.59	24.68	28.58	30.86	33.82	34.13	39.01	36.11	36.67	36.44	36.67
Total N in effluent (kt)	4.28	4.75	4.63	4.85	5.34	5.45	5.62	6.57	6.10	6.53	6.33	6.37

For a comparison, the table below summarizes the overall performance of all domestic wastewater treatment plants in Hungary on the basis of data collected by the statistical office. As it can be seen, BOD removal efficiency is 97%, N-removal efficiency is around 82%. (These data are not yet used in the calculations.)

Table 7.5.2a *Summary table of the overall performance of domestic WWTPs in Hungary*

	2015	2016	2017	2018	2019	2020	2021	2022
BOD_in_kt	213.7	233.0	244.6	245.2	247.9	247.3	239.3	252.1
COD_in_kt	404.9	419.3	441.2	444.9	447.3	452.0	433.1	460.2
COD/BOD	1.89	1.80	1.80	1.81	1.80	1.83	1.8	1.8
BOD_effl_kt	6.3	6.8	7.2	7.6	8.0	7.8	7.8	7.1
BOD_removal	0.97	0.97	0.97	0.97	0.97	0.97	1.0	1.0
N_influent_kt	39.2	43.2	42.9	43.6	44.4	42.1	41.7	42.9
N_effluent_kt	7.4	7.4	7.4	7.9	8.0	7.8	7.8	7.1
Removal (%)	81%	83%	83%	82%	82%	81%	81%	83%

Our results are summarized in Table 7.5.3 and Figure 7.5.5. Total N was estimated from the statistics "per capita amount of available proteins" with the parameter "fraction of nitrogen in protein, default = 0.16 kg N/kg protein". The used emission factor for N2O effluent was also a default one from Table 6.11 of the 2006 IPCC Guidelines (i.e., 0.005 kg N2O-N/kg-N). In the reported N2O emissions in the CRF Table 5.D, however, also emissions from advanced treatment plants are included (see “N2O plants” in Table 7.5.3) which was calculated applying Equation 6.9 from the Guidelines with country-specific and yearly changing values for P (human population) and Tplant (degree of utilization of modern, centralized WWT plants), and defaults for $F_{ind\text{-}com}$ and EF_{plant}. This is why the IEF is somewhat higher than 0.005.

Table 7.5.3 *Protein consumption and all the resulting N_2O emissions*

Year	Protein [g/day]	Total N [kt]	N_removed [kt]	N_effluent [kt]	N2O plants [kt]	N2O effluent [kt]	N2O Total [kt]
BY	107.3	66.1	0.0	66.1	0.00	0.52	0.52
1990	104.7	63.4	0.5	62.9	0.00	0.49	0.49
1991	100.5	60.9	0.5	60.4	0.00	0.47	0.48
1992	101.1	61.2	0.4	60.8	0.00	0.48	0.48
1993	94.8	57.4	0.5	56.9	0.00	0.45	0.45
1994	91.3	55.2	0.3	54.8	0.00	0.43	0.43
1995	87.0	52.5	0.3	52.2	0.00	0.41	0.41
1996	84.4	50.9	0.4	50.5	0.00	0.40	0.40
1997	87.7	52.8	0.3	52.4	0.00	0.41	0.41
1998	87.2	52.4	1.0	51.4	0.00	0.40	0.40
1999	89.5	53.6	1.1	52.4	0.00	0.41	0.41
2000	96.6	57.7	2.2	55.5	0.00	0.44	0.44
2001	93.9	55.9	2.4	53.5	0.00	0.42	0.42
2002	93.5	55.6	3.7	51.8	0.00	0.41	0.41
2003	103.0	61.0	7.7	53.3	0.01	0.42	0.43
2004	101.0	59.7	8.1	51.6	0.01	0.41	0.41
2005	105.4	62.2	9.3	52.9	0.01	0.42	0.42
2006	104.6	61.6	6.7	54.9	0.01	0.43	0.44
2007	101.3	59.5	8.8	50.7	0.01	0.40	0.41
2008	100.6	59.0	9.5	49.5	0.01	0.39	0.40
2009	99.5	58.3	9.9	48.4	0.01	0.38	0.39
2010	95.8	56.0	12.7	43.3	0.01	0.34	0.35
2011	93.6	54.6	14.1	40.5	0.02	0.32	0.33
2012	93.4	54.2	18.8	35.3	0.02	0.28	0.30
2013	92.1	53.3	20.1	33.2	0.02	0.26	0.28
2014	95.7	55.2	23.7	31.5	0.02	0.25	0.27
2015	100.1	57.6	25.5	32.1	0.03	0.25	0.28
2016	103.2	59.2	28.4	30.9	0.03	0.24	0.27
2017	106.5	60.9	28.5	32.4	0.03	0.25	0.28
2018	109.8	62.7	32.4	30.3	0.03	0.24	0.27
2019	110.9	63.3	30.0	33.3	0.03	0.26	0.29
2020	109.6	62.5	30.1	32.4	0.03	0.25	0.29

2021	109.6	62.3	30.1	32.2	0.03	0.25	0.28
2022	110.0	62.2	30.3	31.9	0.03	0.25	0.28

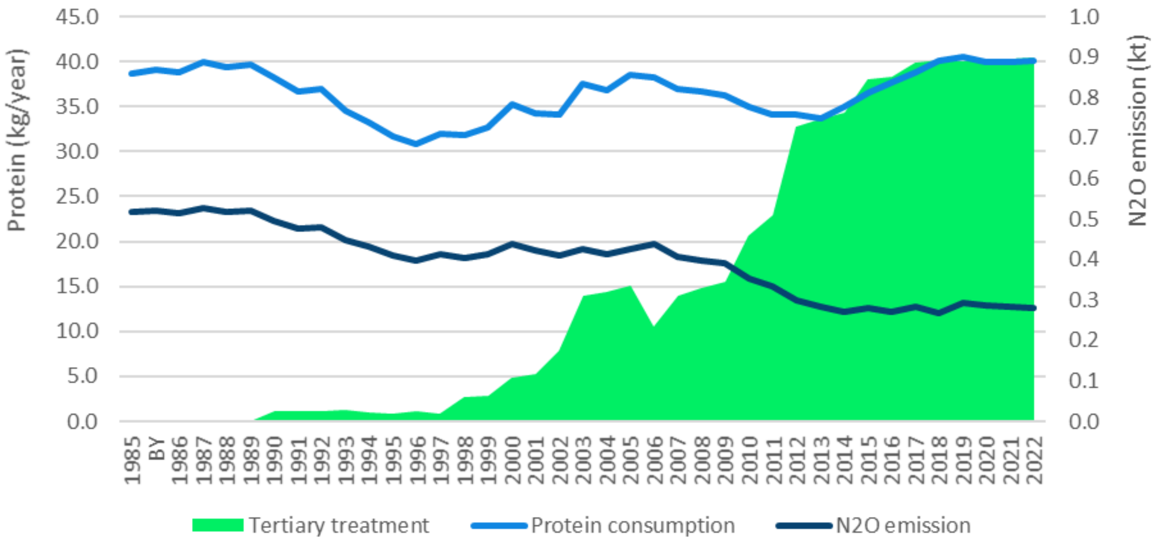


***Figure 7.5.5** Increasing share of tertiary treatment leads to decreasing N2O emissions*

7.5.3 Uncertainties and time-series consistency

Based on the above considerations, the uncertainty of the calculation of the emissions from household wastewater is relatively high. In the industrial sector, data became more reliable in the recent years as a result of the new reporting requirements. However, they do not cover all the emitters, although the most important wastewater emitting sectors are included.

Uncertainty of the emissions from household wastewater treatment:

Per human populations	-5 % to +5 %
BOD/capita	-30 % to +30 %,
Maximum methane production capacity B0	-30 % to +30 %
Uncertainty of the emissions from industrial wastewater treatment:	
Quantity of industrial wastewater:	-25 % to +25 %
Wastewater /unit of production COD/ unit of wastewater:	-50 % to +100 %
Maximum CH4 production capacity Bo :	-30 % to + 30 %
Uncertainty of N2O emissions	
Emission factor	order of 2
Per capita protein consumption	±10%
Used factors	±20%

Source: according to the recommendations of the Revised Guidelines and 2006 Guidelines, on the basis of expert estimates

The time series of emissions are most probably consistent.

7.5.4 QA/QC information

The data collected by the environmental authorities were checked by an independent institution (VITUKI) that further processed the data. Data from the database of facility level wastewater information that are used ultimately by the inventory compiler institute undergoes basic checks, e.g. duplications are removed, outliers are analyzed and corrected whenever necessary.

7.5.5 Recalculation

No recalculation has been made for this submission.

7.5.6 Planned improvements

More analyses of the industrial wastewater treatment facilities are planned to confirm or modify data in Table 7.5.2 above. More importantly, should the Refinement of the 2006 IPCC Guidelines be accepted, we plan to implement the revised methodology in a future submission.

8 OTHER (CRF SECTOR 6)

CRF Table 6 comprises NOx emissions from 3B Manure management and total NH3 emissions from 3. Agriculture to ensure the consistency with the reporting to the UNECE under the Convention on Long Range Transboundary Air Pollution (CLRTAP) and the EU Directive on the reduction of national emissions of certain atmospheric pollutants.

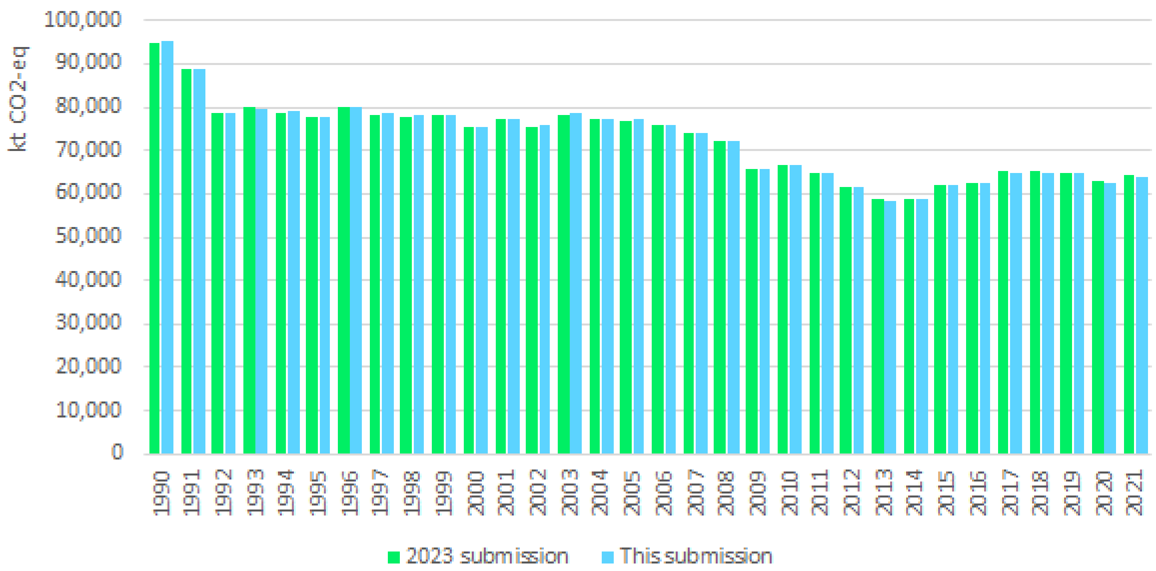
9 INDIRECT CO2 AND NITROUS OXIDE EMISSIONS

Not applicable in this submission.

10 RECALCULATIONS

Recalculations of some data-series of the inventory occur and can be justified by several reasons. Just to name a few, QA/QC procedures, ERT recommendations, changing for higher Tier methodologies can lead to a recalculation. As a basic rule, whenever new information emerges that improves the quality or accuracy of the emission data, the emissions are recalculated.

The overall effect of all recalculations described below was +461.0 kt CO2-eq or +0.4%, +76.8 kt CO_2-eq or +0.1%, and -473.1 kt CO2-eq or -0.7% of the total emissions in the base year, 1990, and 2021, respectively. The figure below shows the total emissions from the base year until the last year assessed in the last two submissions (without LULUCF).



ENERGY

General: The latest versions of the Annual IEA/Eurostat Questionnaires submitted end of October 2023 and slightly updated in March 2024 were used as activity data. All the changes in the energy statistics are reflected in the current inventory. In addition, activity data have been rounded to TJ values with zero decimals in several source categories.

1.A.3.b: CO2 emission factor for gasoline has been changed again for the following reasons: (1) It was noted that our previous approach (i.e. using the measured carbon content of the E5 blend and applying the ratio of default CO2 EFs for fossil petrol and E5 (3.169/3.063=1.035) from Table 3-12 in the 2019 EMEP/EEA Guidebook) led to one of the highest EF among reporting Parties. (2) This approach was introduced earlier on the basis of a former version (2013) of the EMEP/EEA Guidebook with a lower ratio of CO2 EF of fossil and E5 fuel (3.18/3.125=1.0176). (3) It was also noted that the bio component was lower than 5% in one of the samples for which the default CO2 fossil/CO2 E5 ratio might not be suitable. Therefore, for this submission, we applied the “French method” from the EU methodology paper “Country-specific CO2 emission factors from road transport” although based on much less samples. Our new EF is 71.63 t CO2/TJ, higher than the IPCC default (69.3), also a bit higher than the used value in the 2022 (and earlier) submissions (71.28) but lower than what was used in the 2023 submission (72.47).

1.A.3.b: We have also switched to the latest version of the COPERT model (version 5.7.2 – Nov 2023) for the whole time series.

1.A.3.a: Activity data (aviation gasoline and kerosene used for national aviation) have been revised based on latest Eurocontrol data (2005-2022).

“Autoproducers”: Following the ERTs repeated recommendation, we did some further re-allocations of fuel consumption in the early period of the time series to include the emissions of autoproducers in their relevant industrial end-use categories. It must be noted that there are still some autoproducers that are included in the source category 1A2gviii. In the early 1990s, some energy consumption is reported as "industrial boilers" in the energy statistical yearbooks without further specification, therefore it seems impossible to allocate the corresponding emissions to a specific industrial branch.

1.A.2: NCV of (mostly imported) lignite used in industry have been revised for the period 1985-1998 based on traditional printed energy statistical publications that seemed more appropriate than the quite low (and constant) NCV values included in the IEA/Eurostat Coal Questionnaire.

1.A.4.a/1.A.4.b: Natural gas consumption is reported as included in the IEA/Eurostat Gas Questionnaire (except for some addition of autoproducers in 1.A.4.a). This means that no natural gas is re-allocated from 1.A.4.a to 1.A.1.c and no “theft” is taken into account in 1.A.1.b as in previous submissions. With this, we are more in line with the official energy statistics. Also, the amount of stolen natural gas is a highly uncertain figure, and currently not as significant as around 2010. (Based on newspaper articles from that time, theft increased drastically from 2008 and reached an estimated amount of 80-90 million cubic meters in 2010-2011 but it was reduced to a third by 2015, and most probably it decreased further since then.) Also, we would like to note that in the energy statistics we see negative statistical differences of 5-17 PJ in recent years, which means higher observed than calculated inland consumption, so further additions to the sectoral fuel consumption seem unnecessary.

1.A.2.f: CO2 emissions from coal and petroleum coke was revised for 2020-2021 based on ETS data

1.B.2: Natural gas, transmission: CH4 emissions have been revised for 2020-2021 based on information received from the owner and operator of the whole domestic natural gas transportation system (FGSZ Ltd.)

1.B.2: Natural gas, distribution: amended activity data in 2005-2008 affected also interpolated data between 1994 and 2004.

The overall effect of the above recalculations are as follows:

- Emissions from combustion activities increased by 424.7 kt CO2-eq (0.4% of total emissions), 31.4 kt (0.0% of total emissions) in the base year and 1990 respectively, and decreased by 250.7 kt CO2-eq (0.4% of total emissions) in 2021.
- Fugitive emissions did not change in the base year or in 1990 but decreased by 240.2 kt CO2-eq (0.4% of national total) in 2021.

INDUSTRIAL PROCESSES AND PRODUCT USE

2.A.4.a – Ceramics and bricks. Activity data and CO_2 emissions were recalculated for the year 2021 caused by a minor calculation error.

2.A.4.d – Waste gas scrubbing. Activity data and CO_2 emissions were recalculated causing minor changes in the period 2019-2021 because of a calculation error.

2.B.8.d – VCM production. Instead of reporting as confidential, vinyl-chloride monomer activity data are reported from the year 2016, based on the producer's permission for reporting.

2.C.1 – Iron and steel. Coke consumption for sinter production for the year 2022 has been changed compared to the 2024 January submission causing -5.41 kt change in the CO2 emissions of the whole sector.

2.D.3 – Indirect CO2 emissions. Because of various recalculations in the different sources, the amount indirect emissions (NMVOC emissions) have been changed for the whole time series.

2.F.1. Refrigeration and air conditioning – Revision of activity data for category of MAC. In the case of the output of trains, the entire time series has been recalculated for this submission, as more detailed data have been received from the largest Hungarian railway company. For buses, trams and cars emission values only for recent years have been corrected.

2.F.2. Foam blowing agents – Production data of activity data (PRODCOM - Cellular plates, sheet, film, foil and strip of polymers of styrene and of polyurethanes) have been updated for the year 2021.

2.G.2. SF6 and PFCs from other product use – Emission from subapplication particle accelerators are reported. In response to a recommendation from review conducted in 2023 Hungary should report emission from particle accelerators. A first estimate is included in this submission.

The overall effect of the above recalculations is not significant: -5.4 kt CO_2-eq (0.01% of total emissions) in 2021, caused mainly by recalculations of F-gases and indirect emissions from the non-energy products from solvent use.

AGRICULTURE

The main reasons for changes in GHG emissions from Agriculture (CRF sector 3) are as follows:

Updating the climate data from 1981-2010 to 1991-2020 provided by the Hungarian Meteorological Service (HMS),

Upgrading VS calculation for swine,

Revision of the nitrogen content of biogas feedstocks, especially in case of poultry manure and processing industrial by-products.

The overall effect of the recalculations in sector 3. Agriculture resulted in emissions changes ranging from -122.35 kt CO2-eq to -71.1 kt CO2-eq for the period 1985-2021, representing a percentage change ranging from -1.81% to -0.71%.

Reasons for recalculations by CRF categories are as follows:

3.B Manure Management

3.B.1 CH4 emissions and 3.B.2 N2O emissions from Manure Management

The update of climate data has an impact on the entire time series The annual average temperature was higher between 1991 and 2020 than between 1981 and 2010, resulting in a higher methane conversion factor for liquid/slurry. In addition to updating the climate data, the livestock distribution by county also has been revised based on HCSO's censuses for the year 2020.

The revision of N content of biogas feedstocks resulted in minor changes in N2O emissions form manure management, primarily due to the revised distribution of manure management technologies.

3.B.1.3 CH4 Emissions from Manure Management – Swine, whole time series

The VS calculation method was extended to Tier 2 method in case of swine, resulting in significant reduction in CH4 emission.

3.B.1.1 (CH4), 3.B.1.2 (CH4), 3.B.1.4 (CH4), 3.B.2.1 (N2O), 3.B.2.2 (N2O) and 3.B.2.4 (N2O) CH4 and N2O Emissions from Manure Management – Non-dairy Cattle, Sheep and Poultry in 2021

Correction of calculation errors regarding the manure management system of non-dairy cattle (<1 year), sheep, and geese in 2021 resulted in only minor changes in CH4 and N2O emissions.

3.B.1.1 CH4 and 3.B.2.1 N2O Emissions from Manure Management – Dairy Cattle in 2020

A correction of a calculation error resulted in minor changes in the feeding of dairy cattle, slightly reducing gross energy intake, nitrogen excretion etc. for the year 2020, which led to slight decrease in CH4 and N2O emissions.

The overall changes in CH4 emissions from 3.B.1 Manure management ranged from a -94.52 kt CO2-eq to -52.31 kt CO2-eq for the period 1985-2021. The percentage changes varied between 12.00% and -4.18%. This decrease is primarily attributed to the extended calculation of VS for swine. The overall changes in the N2O emissions from 3.B.2 Manure management are negligible between 2004 and 2021 (below 0.1%), except for the year 2020, when the change was -0.52% due to the recalculation of feeding of dairy cattle.

3.D Agricultural Soils

3.D.1 Direct N2O Emissions from Managed Soils

3.D.1.1 Inorganic N Fertilizers for the period 2013-2021

The amount of N fertilizers has been revised for the period 2013-2021, resulting in an insignificant increase in the N-inputs from N fertilizers.

3.D.1.2.c Other Organic Fertilizers Applied to Soils for the period 2004-2021

The emission slightly increased for the period 2004-2021 due to the revision of N content of biogas feedstock by expert and minor data revision for year 2017 provided by the Hungarian Energy and Public Utility Regulatory Authority (MEKH).

3.D.1.4 Crop Residues for the period 2016-2021

The grass yields have been revised between 2016 and 2021 based on data from Hungarian Central Statistical Office (HCSO), resulting in a negligible change in N2O emission from crop residues.

The overall change in 3.D.1 Direct N2O Emissions from Managed Soils due to recalculations varied between -1.14 kt CO2-eq and 0.71 kt CO2-eq for the period 2004-2021. These changes are below 0.05%.

3.D.2 Indirect N2O Emissions from Managed Soils

3.D.2.1 Atmospheric Deposition, whole time series

The 3.D.AI.1 Fraction of synthetic fertilizer N applied to soils that volatilises as NH3 and NOx has increased significantly due to the change of NH3 emission factors of fertilizers, following the 2023 EMEP/EEA Guidebook.

The 3.D.AI.2 Fraction of livestock N excretion that volatilises as NH3 and NOx slightly increased due to the changes in the 2023 EMEP/EEA Guidebook. Additionally, NH3 emissions from crop residues have been included as a new emission category. Although the name of the indicator '3.D.AI.2 Fraction of livestock…', may be misleading, it encompasses indirect emissions from crop residues, leading to a slight increase in emissions in this category.

The correction of the NH3 emissions from sewage sludge and other organic fertilizers in the national air pollutant emission inventory for the year 2021 resulted in only minor changes. However, the decrease in Nex of dairy cattle in 2020 has also influenced the changes.

3.D.2.2 Nitrogen Leaching and Run-off, whole time series

The update of climate data and the change in methodology have impacted the entire time series. The definition of wet climate used in the latest inventory aligns with the 2019 Refinement, requiring less detailed data (no need for monthly data) compared to the method in IPCC 2006 Guidebook. Additionally, the ratio of annual precipitation to reference evapotranspiration between 1991 and 2020 is significantly lower compared to the period 1981-2010.

The proportion of irrigated area on agricultural lands has been revised for the year 2020 based on HCSO data. Additionally, changes in the NH3 emissions from sewage sludge and other organic fertilizers in 2021, as well as changes in the Nex of the dairy cattle in 2020, have also contributed in a minor way to the overall change.

The overall change in emissions in the 3.D.2 Indirect N2O Emissions from Managed Soils is quite large, ranging from -31.72 kt CO2-eq to -11.96 kt CO2-eq for the period 1985-2021. The percentage change varied between -14.42% and -4.00%. This remarkable change arises from the update of climate data.

3.I Other Carbon-containing Fertilizers, for the period 2013-2021

The revision of N fertilizers for the period 2013-2021 resulted in a negligible change (<0.00%) in CO2 emissions from CAN fertilizers.

LULUCF

Relative to the previous inventory year, recalculations in the LULUCF sector were done due to the revision of wildfire activity data as well as the revision of some data in the land-use change matrix. The reason for the latter is that the matrix was not fully coherent yet. In terms of percentage, the effects of the recalculations can be large, but in terms of absolute quantities, they are small.

WASTE

5.A.1 Solid Waste Disposal

During the development of the new emission inventory, we applied the latest IPCC waste model based on the IPCC's 2019 refinement to ensure a comprehensive and up-to-date assessment of greenhouse gas emissions from waste sources. The utilization of this model aligns with current international standards and best practices in emission inventory management. As a result, we retroactively updated the data from 2022 back to the base year.

As a consequence of modifying the IPCC waste model, the emission values exhibited a positive shift in the whole time series.

5.A

In the base year, emissions increased by 4% in the source category 5.A. In 2021, our new estimates are 3% higher (+109.6 kt CO_2-eq) compared to the previous submission.

5.F

Additionally, long-term storage of C in waste disposal sites changed also as a result of adopting the IPCC's 2019 refinement, with a decrease of less than 0.1% in 2021. The change was more pronounced in the base year, with an increase of 4%.

5.

Across the entire waste sector, the recalculations resulted in a 2.9% increase in 2021. For 2005, this resulted in a 4.8% increase; for 1990, a 3.4% increase; and for the base year, a 2.8% increase.