Switzerland's
Greenhouse Gas Inventory
1990–2022

National Inventory Document

Submission of 2024
under the United Nations Framework Convention on Climate Change

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Bern, 2024

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Glossary

°C	degree Celsius
AD	Activity data
AFOLU	Agriculture, Forestry and Other Land Use
Agroscope	Swiss centre of excellence for agricultural research, affiliated with the Federal Office for Agriculture (FOAG)
AREA1	Swiss Land Use Statistics, first survey 1979/85
AREA2	Swiss Land Use Statistics, second survey 1992/97
AREA3	Swiss Land Use Statistics, third survey 2004/09
AREA4	Swiss Land Use Statistics, fourth survey 2013/18
AREA5	Swiss Land Use Statistics, fifth survey 2020/25
ART	Agroscope Reckenholz-Tänikon Research Station (formerly FAL) since 2014 Agroscope
Avenergy	Avenergy Suisse (Swiss Petroleum Association) formerly Erdöl-Vereinigung (EV)
Base year	1990
BCEF, BEF	Biomass conversion and expansion factor, biomass expansion factor
CAEP	Committee on Aviation Environmental Protection
Carbura	Swiss organisation for the compulsory stockpiling of oil products
CC	Combination category
CCGT	Combined cycle gas turbine
Cemsuisse	Association of the Swiss Cement Industry
CFC	Chlorofluorocarbon (organic compound: refrigerant, propellant)
CH_4	Methane, GWP: 28 (UNFCCC 2019; Myhre et al. 2013)
CHP	Combined heat and power
chp.	Chapter
CLRTAP	UNECE Convention on Long-Range Transboundary Air Pollution
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2, CO_2 eq	Carbon dioxide, carbon dioxide equivalent (GWP = 1 by definition)
COD	Chemical oxygen demand
COVID-19	Coronavirus disease 2019 is a contagious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2)
CORINAIR	CORe INventory of AIR emissions (under the European Topic Centre on Air Emissions and under the European Environment Agency)
CRF	Common Reporting Format
CRT	Common Reporting Tables (https://unfccc.int/documents/311076)
CSC	Carbon stock change
CSCF	Carbon stock change factor

DBH	Diameter (of trees) at breast height
DDPS	Federal Department of Defence, Civil Protection and Sport
DETEC	Dept. of the Environment, Transport, Energy and Communications
DOM	dead organic matter
dt	decitonne (100 kg)
EF	Emission factor
EMEP	European Monitoring and Evaluation Programme (under the Convention on Long-range Transboundary Air Pollution)
EMIS	Swiss Emission Information System (German: Emissions Informations System Schweiz)
Empa	Swiss Federal Laboratories for Materials Science and Technology
EnAW	Energy Agency of the Swiss Private Sector
ERT	Expert review team (under the UNFCCC)
ETS	Emission Trading System
EU	European Union
EV	Erdöl-Vereinigung (Swiss Petroleum Association), since 1. July 2019 Avenergy Suisse
FAL	Swiss Federal Research Station for Agroecology and Agriculture (since 2006: ART; since 2014 Agroscope)
FAO	Food and Agriculture Organization of the United Nations
FC	Fuel consumption
FCA	Federal Customs Administration, since 03.01.2022: Federal Office for Customs and Border Security (FOCBS)
FDFA	Federal Department of Foreign Affairs
FEDRO	Swiss Federal Roads Office
FOAG	Federal Office for Agriculture
FOCA	Federal Office of Civil Aviation
FOCBS	Federal Office for Customs and Border Security, formerly FCA
FOD	First order decay (model)
FOEN	Federal Office for the Environment (former name SAEFL until 2005)
FSO	Federal Statistical Office (formerly SFSO)
GHG	Greenhouse gas
GL	Guidelines
g	gram
GVS	Swiss Foundry Association
GWP	Global Warming Potential
ha	hectare
HFC	Hydrofluorocarbons (e.g. HFC-32 difluoromethane)
HAFL	School for Agricultural, Forest and Food Sciences
HWP	Harvested wood products

ICAO	International Civil Aviation Organization
IDP	Inventory Development Plan
IEA	International Energy Agency
IFR	Instrument Flight Rules
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial processes and product use
IVZ	Information system for traffic admission (Informationssystem Verkehrszulassung IVZ) run by FEDRO, formerly MOFIS
KCA	Key category analysis
kha	kilo hectare
kt	kiloton (1’000 tons)
L1, L2	Key category according to level assessment with approach 1, approach 2
LiDAR	Light Detection And Ranging
LPG	Liquefied Petroleum Gas (Propane/Butane)
LTO	Landing/Take-Off cycle (Aviation)
LULUCF	Land Use, Land-Use Change and Forestry
MOFIS	Swiss federal vehicle registration database run by FEDRO (since 2022: IVZ)
MSW	Municipal solid waste
MSWIP	Municipal solid waste incineration plant
NABO	Swiss Soil Monitoring Network
NABODAT	National soil information system
NCV	Net calorific value
NCAC	(livestock) not covered by agricultural census
NF_3	Nitrogen trifluoride, GWP: 16'100 (UNFCCC 2019; Myhre et al. 2013)
NFI1, NFI2, NFI3,	First (1983–1985), Second (1993–1995), Third (2004–2006),
NFI4, NFI5	Fourth (2009–2017) and Fifth (ongoing) National Forest Inventory
NID	National Inventory Document (formerly known as NIR)
NIR	National Inventory Report (NIR = NID + CRT)
NIS	National Inventory System
NFR	Nomenclature for Reporting (under the UNECE)
NMVOC	Non-methane volatile organic compounds
N_2O	Nitrous oxide, GWP: 265 (UNFCCC 2019; Myhre et al. 2013)
NO_x	Nitrogen oxides
ODS	Ozone-depleting substances (CFCs, halons etc.)
PFC	Perfluorinated carbon compounds (e.g. Tetrafluoromethane)
PSD	Prosperity and Sustainability Division (of the FDFA)
QA/QC	Quality assurance/Quality control
QMS	Quality management system

Reporting year	2022 (i.e. the latest inventory year)
SAF	Sustainable aviation fuels
SAEFL	Swiss Agency for the Environment, Forests and Landscape (since 2006: Federal Office for the Environment FOEN)
SBV	Schweizerischer Bauernverband; Swiss Farmers Union
SCGT	Simple cycle gas turbine
SCR	Selective catalytic reduction
SD	Standard deviation
SDC	Swiss Agency for Development and Cooperation (of the FDFA), (German: DEZA)
SECO	State Secretariat for Economic Affairs
SFOE	Swiss Federal Office of Energy
SF_6	Sulphur hexafluoride, GWP:23'500 (UNFCCC 2019; Myhre et al. 2013)
SFSO	Swiss Federal Statistical Office, now: Federal Statistical Office (FSO)
SGWA	Swiss Gas and Water Industry Association (see SVGW/SSIGE)
SO_2	Sulphur dioxide
SO_x	Sulphur oxides (sum of SO_2 and SO_3, expressed as SO_2 equivalents)
SOC	Soil organic carbon
SOLV	Swiss Organisation for the Solvent Recovery of Industrial Enterprises in the Packaging Sector
SSIP	Sewage sludge incineration plant
SVGW/SSIGE	Schweizerischer Verein des Gas- und Wasserfaches / Société Suisse de l'Industrie du Gaz et des Eaux (Swiss Gas and Water Industry Association)
SWIP	Special waste incineration plant
Swissmem	Swiss Mechanical and Electrical Engineering Industries (Schweizer Maschinen-, Elektro- und Metallindustrie)
swisstopo	Federal Office of Topography
TOW	Total degradable organic material in wastewater
T1, T2	Key category according to trend assessment with approach 1, approach 2
UBA	Umweltbundesamt (Federal Environment Agency in Germany)
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
VFR	Visual Flight Rules
VOC	Volatile organic compounds
VSG	Verband der Schweizerischen Gasindustrie / Association Suisse de l'Industrie Gazière (ASIG) (Swiss Gas Industry Association)
VSLF	Swiss association for coating and paint applications
VSTB	Swiss Association of Grass Drying Plants
VSZ	Verband Schweizerische Ziegelindustrie (Swiss association of brick and tile industry)

VTG	Swiss Armed Forces – Defense
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research
WWT(P)	Wastewater treatment (plant)
ZPK	Verband der Schweizerischen Zellstoff-, Papier- und Kartonindustrie

Executive summary

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

Long-term measurements indicate a marked shift towards a warmer climate in Switzerland. Between 1864 and 2020, the average temperature in Switzerland has increased by more than +2.0°C, about twice as much as observed on global average (FOEN 2022j). In the course of the 21st century, Switzerland's climate is projected to further depart from present and past conditions. Mean temperature will very likely increase in all regions and seasons (CH2018 2018). Summer mean precipitation will likely decrease by the end of the century all over Switzerland by up to 40 %, while winter precipitation will likely increase, particularly in Southern Switzerland. This will have consequences for all regions and sectors (FOEN et al. 2020n). Based on a decision of the Federal Council, Switzerland has established its National Centre for Climate Services, which coordinates the development and dissemination of climate services (https://www.nccs.admin.ch/nccs/en/home.html).

The Federal Office for the Environment (FOEN) is the designated national authority for climate policy and environmental monitoring. The FOEN bears overall responsibility for Switzerland's national greenhouse gas inventory and the national registry and is in charge of compiling the emission data. In addition to the FOEN, the Swiss Federal Office of Energy (SFOE), Agroscope (i.e. the Swiss centre of excellence for agricultural research, affiliated with the Federal Office for Agriculture (FOAG)) and the Federal Office of Civil Aviation (FOCA) participate directly in the compilation of the inventory. Several other administrative offices and research institutions are involved in the preparation of the inventory. In preparing the national greenhouse gas inventory, Switzerland takes recommendations and encouragements of the review process under the UNFCCC into account. The improvements made in response to the review process are documented in chp. 10.1.1.

ES.2 Summary of trends related to national emissions and removals

In 2022, Switzerland's total GHG emissions were 41'630 kt CO_2 eq (kilo tonnes of CO_2 equivalent), corresponding to 4.7 t CO_2 eq per capita. This includes indirect CO_2 emissions (94 kt CO_2 eq), but emissions from international aviation and marine bunkers (4'232 kt CO_2 eq), and net emissions and removals from land use, land-use change, and forestry (LULUCF, +433 kt CO_2 eq) are excluded. Mean uncertainty of the emission level in 2022 is 3.1 % (excl. LULUCF) and 4.3 % (incl. LULUCF), the uncertainty of the emission trend between 1990 and 2022 is 3.5 % (excl. LULUCF) and 4.8 % (incl. LULUCF) (based on approach 2, see chp. 1.6 for details).

Figure E-1 shows Switzerland's annual GHG emissions by individual gases from 1990 to 2022. With 24.4 % below the value in 1990, total emissions excluding LULUCF were lowest in 2022.

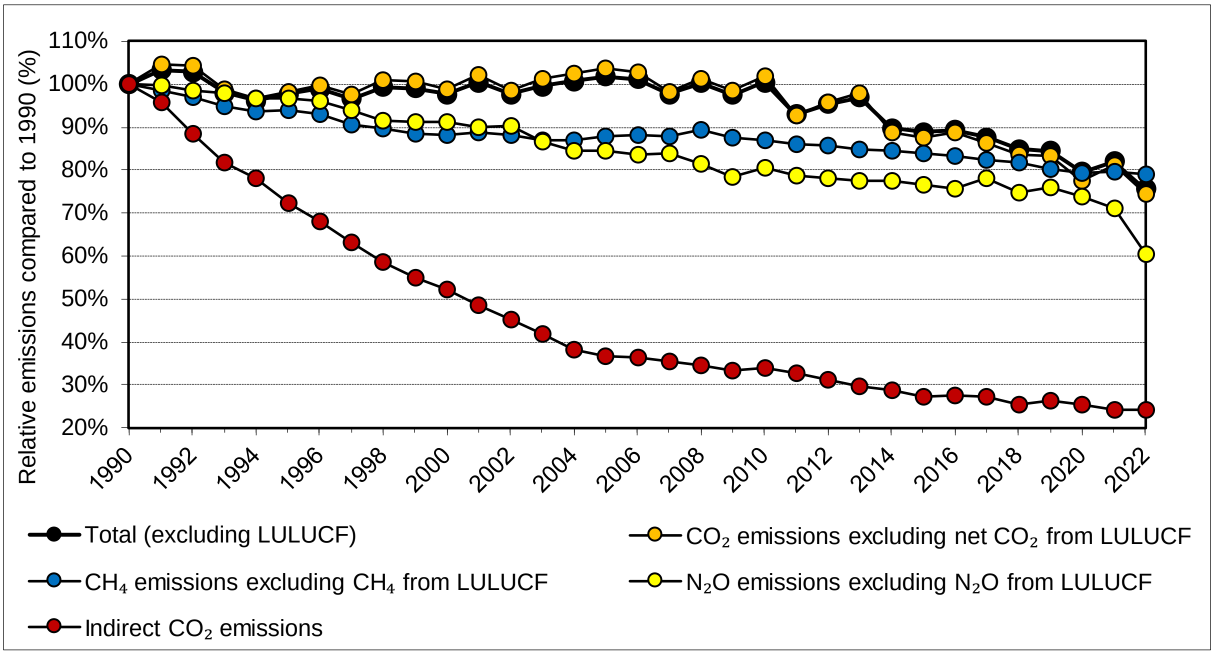

Figure E-1 Relative trends of Switzerland's greenhouse gas emissions (excluding LULUCF). The base year 1990 represents 100 %. F-gases are not illustrated here, but included in the total.

ES.3 Overview of source and sink category emission estimates and trends

Figure E-2 shows the GHG emissions and removals by the main source and sink categories. Sector 1 Energy clearly dominates national emissions, accounting for three quarters of the total GHG emissions (excluding LULUCF). Sectors 2 Industrial processes and product use (IPPU) and 3 Agriculture contribute a considerable share of GHG emissions as well, while sectors 5 Waste and 6 Other are of minor importance. The total includes indirect CO_2 emissions; however, those too are of minor importance. Sector 4 LULUCF is a net GHG sink over the inventory period except for the years 2000, 2018 and 2022.

Overall, Switzerland's GHG emissions in 2022 are lower than in 1990. This is mainly due to the decrease in the energy sector, but all other sectors have also contributed to the decreasing trend. The decrease in the energy sector is dominated by a substantial decrease in 1A4 Other sectors and 1A2 Manufacturing industries and construction (see Figure 2-6 and Table 2-4).

As shown in Figure E-2 GHG emissions in the period 1990–2022 are subject to fluctuations with a decreasing trend starting after 2005. The fluctuations derive from the year-to-year variability of emissions in the energy sector caused by changes in winter temperatures and hence in the use of heating fuels. Since around 2006, there has been a growing decoupling of winter temperatures and emissions from fuel combustion, reflecting the impact of emission reduction measures in the building sector.

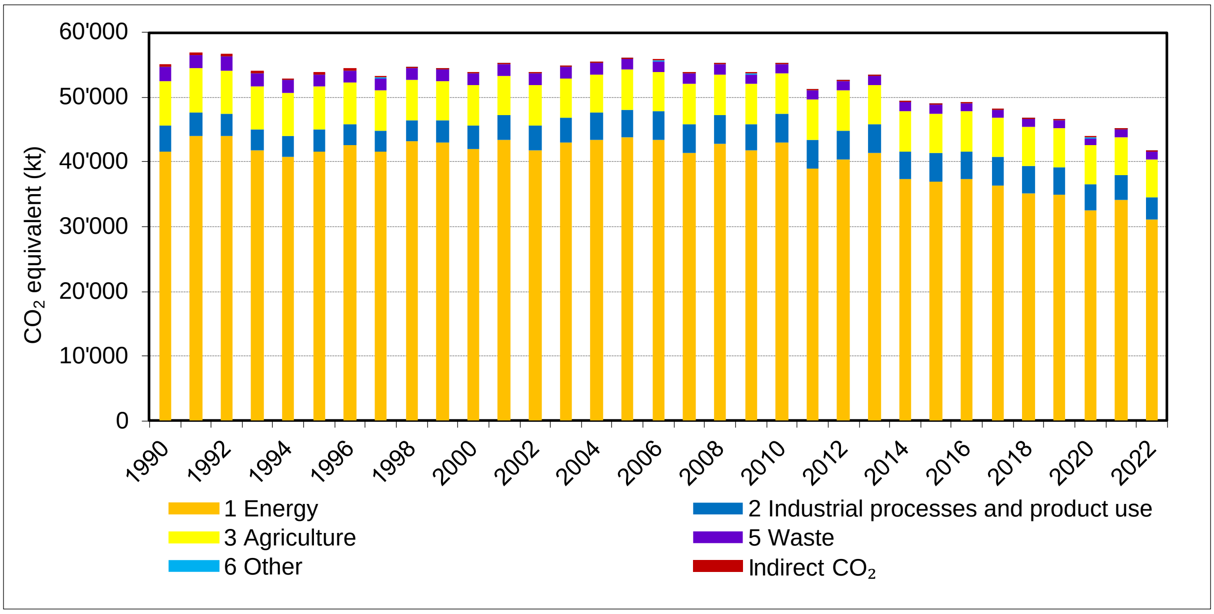

Figure E-2 Greenhouse gas emissions in CO_2 equivalent (kt) by sectors (excluding LULUCF).

ES.4 Other information

Emissions from precursor gases show a very pronounced decline (see Table 2-6 and Figure 2-10). A strict air pollution control policy led to strong decreases in emissions of precursor gases over the period 1990–2022. An overview concerning precursors is given in chp. 2.2.3 and details are provided in Switzerland's Informative Inventory Report (FOEN 2024b).

ES.5 Key category analysis (KCA)

Key category analyses were conducted according to approaches 1 and 2 (see details in chp. 1.4.2 and IPCC (2006)). For both approaches, level assessments were conducted for the years 2022 and 1990 and a trend assessment for 1990–2022, including LULUCF categories and indirect CO_2 emissions. A total of 45 key categories were identified out of the 192 categories considered:

- Approach 1: For the year 2022, 31 out of 192 categories were identified as level key categories. About half of these categories are part of sector 1 Energy, accounting for the largest share of total emissions.
- Approach 2: For the year 2022, 28 out of 192 categories were identified as level key categories. Under approach 2, the most important categories originate from the sectors 3 Agriculture and 4 LULUCF.

Key category analyses were also performed excluding LULUCF categories. They are not represented in the NID but are available on request.

ES.6 Improvements introduced

Only major improvements are mentioned here. A quantitative description of large recalculations is provided in chapter 10.1.2. Further, smaller recalculations are described in the sector chapters.

General

- This NID is consistent with the reporting tables expected to be produced by the CRT Reporter when it becomes available in summer 2024. Please see further remarks in Annex 7 and Annex 8.

Energy

- Fugitive emissions from 1B2b – Natural gas were reassessed, resulting in lower losses of natural gas. As a consequence, more natural gas is available in source category 1A, in particular in the source categories 1A2 Manufacturing industries and construction and 1A4 Other sectors.
- A new model for stationary engines and gas turbines was introduced, leading to major reallocations within the source categories in 1A Fuel combustion activities, however, with no overall effect on total CO_2 emissions (and only small effects on CH_4 and N_2O emissions).

Industrial processes and product use (IPPU)

- 2A1: The geogenic CO_2 emission factor for 2A1 Cement production was revised for all years from 1990–2021 based on plant-specific measurements of the CaO and MgO content of clinker.

Agriculture

- 3D: N_2O emissions from cultivated organic soils were recalculated for 1990–2021. New disaggregated emission factors for grassland and cropland were adopted from the IPCC Wetland Supplement (IPCC 2014a).

LULUCF

- 4 Activity data: The dataset defining the geographical distribution of organic soil was updated.
- 4A1: The first robust estimates for carbon gains and losses between the fourth and the fifth National Forest Inventories were produced. Consistent data for the entire time series since 1990 were derived.
- 4A1: The soil carbon model Yasso20 replaced the previous version Yasso07.
- 4B1 and 4C1: New soil information was available for soil carbon modelling of Cropland and Grassland: Both the initial carbon stocks and clay content classes were calculated using a digital soil mapping approach.

Waste

- 5D: New emission estimates for CH_4 from effluents of wastewater treatment plants are included (see chp. 7.5.2).

1. National circumstances, institutional arrangements and cross-cutting information

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On 10 December 1993, Switzerland ratified the United Nations Framework Convention on Climate Change (UNFCCC) (UNFCCC 1992). Since 1996, the submission of its national greenhouse gas inventory has been based on IPCC Guidelines. In 2004, Switzerland started submitting annually its National Inventory Report (NIR) under the UNFCCC.

After ratifying the Kyoto Protocol under the UNFCCC (UNFCCC 1998) in July 2003, Switzerland submitted its Initial Report under Article 7, paragraph 4 of the Kyoto Protocol in 2006 (FOEN 2006h), including the description of the Swiss National Inventory System (NIS) according to Article 5.1 of the Kyoto Protocol. On 6 December 2007, the NIS quality management system (QMS) was certified to comply with ISO 9001. The QMS has been audited annually and recertified according to the ISO 9001 requirements ever since.

1.2. National circumstances and institutional arrangements

1.2.1. National entity

Based on the Organisation Ordinance for the Federal Department of the Environment, Transport, Energy and Communications (DETEC), the Federal Office for the Environment (FOEN) is the designated national authority for climate policy and environmental monitoring. According to the decree of the Federal Council of 8 November 2006, the FOEN is in charge of the National Inventory System (NIS) (Figure 1-1). The Swiss National Inventory System was formally set up in 2006 in compliance with the requirements of the UNFCCC and the Kyoto Protocol (FOEN 2006h). The FOEN established a process led by the Climate division, which covers maintaining the National Inventory System and fulfilling all reporting obligations under the UNFCCC.

National entity with overall responsibility for the inventory

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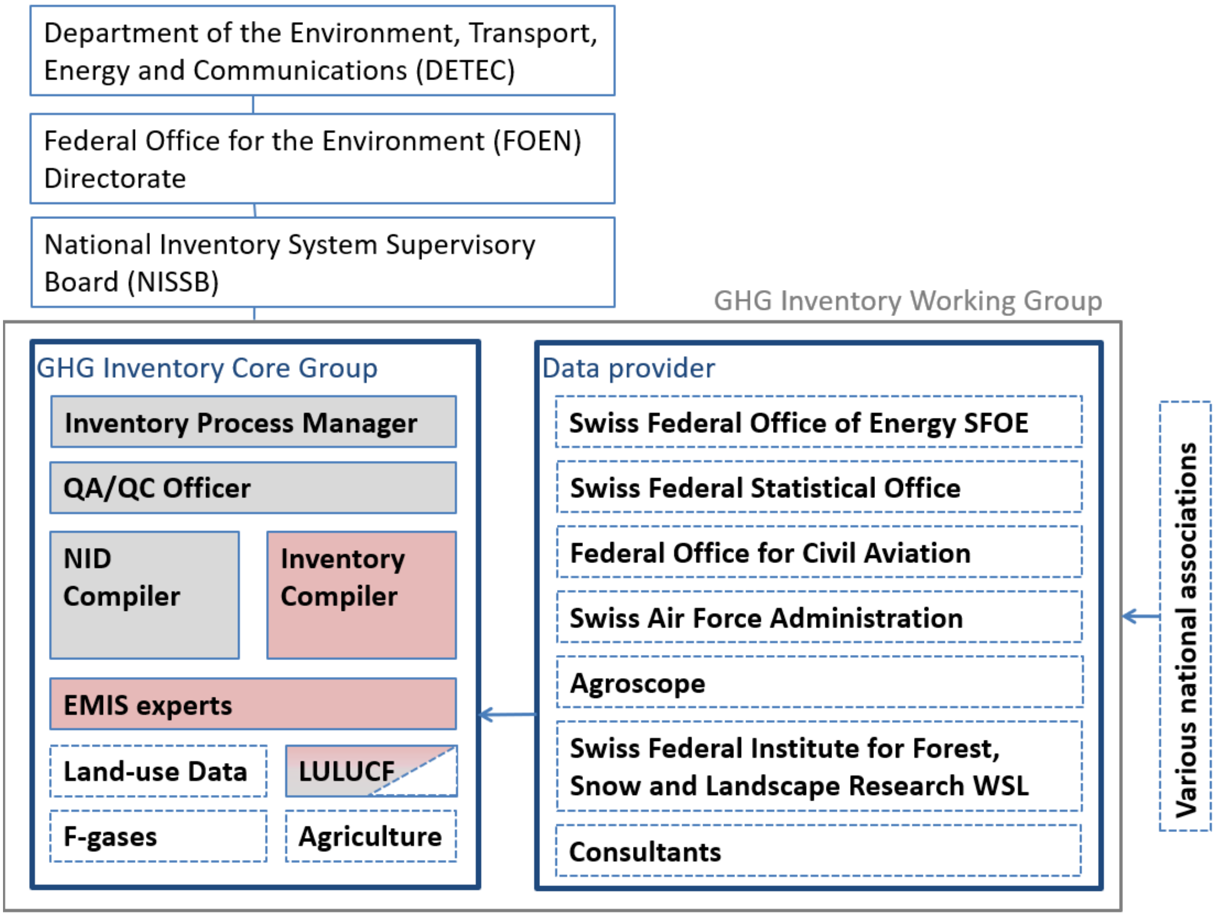

Figure 1-1 The National Inventory System. Colours refer to divisions at FOEN. Grey: Climate division, red: Air Pollution Control and Chemicals division, Forest division. Boxes with dashed lines refer to external mandates.

1.2.2. Inventory preparation process

The process of inventory planning, preparation and management in Switzerland is well-established. Responsibilities and decision-making power are assigned to specific people or groups of people (Figure 1-1). The management responsibility for the NIS lies with the

National Inventory System Supervisory Board (NISSB). The board consists of a member of the FOEN directorate and FOEN division heads of the relevant divisions (Climate, Forest, Air Pollution Control and Chemicals, International Affairs).

At the operational level, the process of planning, preparation and management of the greenhouse gas inventory is led by the process manager. The QA/QC officer oversees design, development, and operation of the quality management system and is the primary contact point during the UN review process. The greenhouse gas (GHG) inventory core group is the committee that combines all technical expertise required for greenhouse gas inventory planning, preparation and management. It consists of the process manager, the QA/QC officer, the inventory compiler, sectoral experts, as well as the NID compiler. Additional experts join the core group as required. The GHG inventory core group ensures conformity of the inventory with the relevant UNFCCC reporting guidelines (UNFCCC 2019, 2022a), timely inventory preparation, and consideration and approval of methodological changes, choice of data and recalculations. The GHG inventory working group encompasses all technical personnel involved in the inventory preparation process or representing institutions that play a significant role as suppliers of data.

The overall responsibility for the greenhouse gas inventory lies with the Climate division of the FOEN. The Air Pollution Control and Chemicals division of the FOEN maintains and updates the emissions database (greenhouse gases and air pollutants), named EMIS, in close collaboration with the Climate division. The national energy statistics from the Federal Office of Energy (SFOE) provides the basis for the energy sector. The Federal Office for Civil Aviation (FOCA) delivers the domestic and international aviation emissions. A consultancy (Carbotech) is mandated to survey and model fluorinated gases use and emissions and to provide an annual update thereof. Agriculture emissions are compiled by Agroscope. For LULUCF, detailed land use survey data are provided by the Federal Statistical Office (FSO). The Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) is in charge of the National Forest Inventory and forestry-related modelling. The WSL provides the input for the FOEN Forest division, which compiles emissions and removals data for Forest land. Soil carbon modelling for Cropland and Grassland is carried out at Agroscope. Two consultancies (Sigmaplan, Meteotest) are mandated to process the land use survey and carbon stock change data to derive land-use change matrices and associated emissions and removals. The LULUCF sector is coordinated by a member of the Climate division of the FOEN. A collaboration between two consultancies (Meteotest, Infras) is mandated to support data handling in the Swiss Emission Information System (EMIS), the reporting tables (CRF/CRT) and updating the National Inventory Document (NID).

1.2.3. Archiving of information

Archiving of inventory material is performed during preparation and after submission by the EMIS and sectoral experts, by the contributing authors and by the QA/QC officer.

The EMIS database as well as background information on activity data and emission factors are archived by the national inventory compiler for each submission. In the sectors where data collection is made by EMIS experts (e.g. Energy, IPPU, Waste), additional background information is compiled as appropriate (e.g. interim worksheets; references; rationale for choice of methods, data sources, activity data, emission factors). Whenever such documents are cited, they are labelled as “EMIS 2024/NFR-Code” in this report.

Nearly all of the data necessary to compile the Swiss GHG inventory are publicly available. There are exceptions for emission data that refer to a single enterprise, for the most disaggregated level of F-gases, and for land use statistics raw data as long as they have not yet been published the Federal Statistical Office (FSO). However, confidential data will be made available by the FOEN in line with the procedures agreed under the UNFCCC for the technical review of GHG inventories (UNFCCC 2019).

FOEN operates a website (www.climatereporting.ch) where the Swiss GHG inventories (NID, reporting tables, UNFCCC review reports), the Swiss National Communications and other reports submitted to the UNFCCC may be downloaded. On this website, most papers, reports, domestic reviews, and other difficult-to-access materials (‘grey literature’) quoted in the Swiss GHG inventory are provided online. The climate reporting homepage thus provides the option for public review.

1.2.4. Processes for official consideration and approval of inventory

The NIS supervisory board (NISSB) normally meets twice a year. At its spring meeting, the inventory is presented for official consideration. Based on that, the NISSB submits the inventory to the FOEN directorate for official approval. Submission is coordinated by the process manager and carried out by the national inventory compiler and the QA/QC officer.

1.2.5. Changes in the national inventory arrangements since previous submission

No changes.

1.3. General description of methodologies and data sources used

According to the revised reporting guidelines under the UNFCCC and the Paris Agreement (UNFCCC 2019), emissions are calculated based on standard methods and procedures provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) its 2019 Refinement (IPCC 2019), the 2013 KP Supplement (IPCC 2014), and the 2013 Wetlands supplement (IPCC 2014a). All key categories are estimated using approach 2 or higher or country-specific methods. The methodological tier used is described in detail in the sectoral chapters of the NID and compiled in CRT Summary3.

Various data suppliers contribute to the greenhouse gas inventory. While most data stem from official statistics either from the FOEN or from other federal offices, some data is drawn from national associations or consultancies that maintain well-established models or databases. Details on activity data and emission factors are provided in the sectoral chapters of the NID.

1.4. Description of key categories

The aim of the key category analysis (KCA) is to identify relevant categories that have a strong influence on Switzerland's GHG inventory in terms of absolute emission and removal levels, trends and uncertainties (IPCC 2006, chp. 4). The KCA is performed based on two assessments and two approaches. In approach 1 of the KCA, categories are set out in decreasing order of contribution to the inventory emissions ("level assessment") or in decreasing order of deviation from the inventory trend ("trend assessment"). The level assessment highlights categories which are the main contributors to the inventory emissions. Since the inventory trend is negative for Switzerland, the trend assessment highlights categories with a positive category trend or a pronounced negative category trend. In approach 2, this ranking is weighted by the uncertainty assigned to each category. Approach 2 therefore identifies categories mostly contributing to the inventory uncertainty. Data collection as well as quality assurance and control are prioritised for key categories during the inventory resource allocation (see also the planned improvements in chp. 10.4).

1.4.1. Methodology

The key category analysis is performed according to the 2006 IPCC Guidelines (IPCC 2006, chp. 4) and Decision 18/CMA.1 (UNFCCC 2019, paragraph 25) for 1990 and the reporting year including all GHG (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3 and indirect CO_2). A total of 192 categories (including categories from the LULUCF sector) are used to disaggregate Switzerland's total GHG emissions for the purpose of this key category analysis (see Annex 1). The disaggregation level of the categories is selected based on country specific relevance, i.e. the most important sources in Switzerland are disaggregated on a more detailed level. Note that for the KCA, four categories according to the CRF nomenclature are still used within sector 4 LULUCF: 4(II), 4(III), 4(IV) and 4(V). For submission 2025, it is planned to use categories according to the CRT nomenclature only.

Both approach 1 (with a threshold set at 95 %) and approach 2 (with a threshold set at 90 %) level and trend assessments are applied, including emissions from sector 4 LULUCF. For approach 2 of the KCA, uncertainties for emissions of each category are taken from the results of the Monte Carlo simulations (approach 2 uncertainty analysis, see details in chp. 1.6.2.2). Indirect CO_2 emissions are included in the key category analysis, indirect N_2O emissions are not.

1.4.2. Results of the key category analysis (including LULUCF categories)

For the reporting year 2022, there are 45 identified key categories among the 192 categories taken into account (see overview in Table 1-6). The large majority of the key categories are sources of direct CO_2 (see also Table 2-3 and discussion in chp. 2.2), a few of CH_4 and N_2O, one of HFCs, one of PFCs and one of indirect CO_2. There are no key categories for SF_6 and NF_3.

The detailed results of the key category analyses, approaches 1 and 2, level and trend assessments, are reported in Table 1-1 to Table 1-5. For level assessments, columns are labelled A to G according to Table 4-2 in the IPCC Guidelines (IPCC 2006, chp. 4) and for trend assessments, columns are labelled A to H according to Table 4-3 in the same guidelines. The following abbreviations are used:

- $E_{x,0}$: base year emission/removal estimate.
- $E_{x,t}$: reporting year emission/removal estimate.
- $L_{x,0}$, $L_{x,\,t}$: level assessment for the base year and the reporting year, respectively.
- $T_{x,\,t}$: trend assessment for the trend between base year and reporting year.

Approach 1

For the reporting year 2022, 31 out of 192 categories are identified as level key categories under approach 1 (see Table 1-1).

Fourteen of these key categories belong to sector 1 Energy, accounting for the largest share of CO_2 equivalent emissions in 2022 (see Table 2-1 for emission share per sector). Sector 2 Industrial processes and product use (2 key categories) and sector 3 Agriculture (5 key categories) are also significant contributors to the emissions for the year 2022 (Table 2-1), while sector 5 Waste (3 key categories) and sector 6 Other (no key category) have only marginal contributions. Sector 4 LULUCF (7 key categories) has a net positive contribution to the total emissions for the year 2022.

Within the ten most relevant key categories (level assessment), only 3A Enteric fermentation and 2A1 Cement production are not part of sector 1 Energy.

For the base year 1990, 34 categories are identified as level key categories under approach 1 (see Table 1-2). The following categories are key according to level in the base year 1990, but not anymore in the reporting year:

- 1A3a Domestic aviation, kerosene fossil, CO_2
- 1A5 Other (military), liquid fuels, CO_2
- 2B10 Chemical industry other, N_2O
- 2D Non-energy products from fuels and solvent use, indirect CO_2 from NMVOCs
- 3B1-4 Manure management, all livestock, direct, N_2O
- 4G HWP Harvested wood products, CO_2

On the other hand, the following categories are key according to level in the reporting year, but not in the base year 1990:

- 2F1 Refrigeration and air conditioning, HFCs
- 4C2 Land converted to grassland, CO_2
- 4F2 Land converted to other land, CO_2

Regarding the trend assessment between the base year 1990 and the reporting year, 34 categories are identified as trend key categories under approach 1 (see Table 1-3). Among these, 15 have an increasing trend and 19 a decreasing trend. See chp. 2.2 Emission trends by gas and chp. 2.2.2 Emission trends by sources and sinks for a further discussion.

Table 1-1 Switzerland's key categories according to approach 1 level assessment for the year 2022, including LULUCF categories and indirect CO_2 emissions, sorted by decreasing contribution. Categories in grey are not key and are given for information only.

KCA APPROACH 1 LEVEL ASSESSMENT FOR 2022						
A	B	C	D	E	F	G
Code	IPCC category	Gas	Ex, t (kt CO2 eq.)	|Ex, t| (kt CO2 eq.)	Lx, t (%)	Cumu-lative Total (%)
1A3b	Road transportation; Diesel oil	CO2	7'027	7'027	15.7	15.7
1A3b	Road transportation; Gasoline	CO2	6'162	6'162	13.8	29.4
1A4b	Residential; Liquid fuels	CO2	3'788	3'788	8.5	37.9
3A	Enteric fermentation	CH4	3'617	3'617	8.1	46.0
1A4b	Residential; Gaseous fuels	CO2	2'548	2'548	5.7	51.7
1A1	Energy industries; Other fuels	CO2	2'388	2'388	5.3	57.0
1A4a	Commercial; Liquid fuels	CO2	1'907	1'907	4.3	61.2
1A2	Manufacturing industries and construction; Gaseous fuels	CO2	1'854	1'854	4.1	65.4
2A1	Cement production	CO2	1'667	1'667	3.7	69.1
1A2	Manufacturing industries and construction; Liquid fuels	CO2	1'531	1'531	3.4	72.5
2F1	Refrigeration and air conditioning	HFCs	1'185	1'185	2.6	75.2
1A4a	Commercial; Gaseous fuels	CO2	1'029	1'029	2.3	77.5
3Da	Direct emissions from managed soils	N2O	869	869	1.9	79.4
4B1	Cropland remaining cropland	CO2	743	743	1.7	81.0
4A1	Forest land remaining forest land	CO2	-635	635	1.4	82.5
4A2	Land converted to forest land	CO2	-632	632	1.4	83.9
3B1-4	Manure management all livestock direct	CH4	615	615	1.4	85.3
5D	Wastewater treatment and discharge	N2O	509	509	1.1	86.4
1A4c	Agriculture and forestry; Liquid fuels	CO2	440	440	1.0	87.4
1A2	Manufacturing industries and construction; Other fuels	CO2	435	435	1.0	88.3
3Db	Indirect emissions from managed soils	N2O	401	401	0.9	89.2
1A1	Energy industries; Liquid fuels	CO2	387	387	0.9	90.1
1A1	Energy industries; Gaseous fuels	CO2	371	371	0.8	90.9
1A2	Manufacturing industries and construction; Solid fuels	CO2	360	360	0.8	91.7
4C2	Land converted to grassland	CO2	349	349	0.8	92.5
5A	Solid waste disposal	CH4	275	275	0.6	93.1
3B5	Manure management indirect	N2O	233	233	0.5	93.6
5D	Wastewater treatment and discharge	CH4	227	227	0.5	94.1
4E2	Land converted to settlements	CO2	225	225	0.5	94.7
4C1	Grassland remaining grassland	CO2	129	129	0.3	94.9
4F2	Land converted to other land	CO2	125	125	0.3	95.2
1A5	Non-specified; Liquid fuels	CO2	122	122	0.3	95.5
4D1	Wetland remaining wetland	CO2	112	112	0.2	95.7
1A3d	Water-borne navigation; Liquid fuels	CO2	109	109	0.2	96.0
3B1-4	Manure management all livestock direct	N2O	108	108	0.2	96.2
2B8	Petrochemical and carbon black production	CO2	104	104	0.2	96.5
1A4c	Agriculture and forestry; Gaseous fuels	CO2	98	98	0.2	96.7
1A3b	Road transportation; Diesel oil	N2O	92	92	0.2	96.9
1A3a	Domestic aviation; Kerosene fossil	CO2	69	69	0.2	97.0
Total number of key categories						31

Table 1-2 Switzerland's key categories according to approach 1 level assessment for the year 1990, including LULUCF categories and indirect CO_2 emissions, sorted by decreasing contribution. Categories in grey are not key and are given for information only.

KCA APPROACH 1 LEVEL ASSESSMENT FOR 1990						
A	B	C	D	E	F	G
Code	IPCC category	Gas	Ex, 0 (kt CO2 eq.)	|Ex, 0| (kt CO2 eq.)	Lx, 0 (%)	Cumu-lative Total (%)
1A3b	Road transportation; Gasoline	CO2	11'328	11'328	18.7	18.7
1A4b	Residential; Liquid fuels	CO2	10'099	10'099	16.7	35.4
1A2	Manufacturing industries and construction; Liquid fuels	CO2	3'974	3'974	6.6	41.9
3A	Enteric fermentation	CH4	3'930	3'930	6.5	48.4
1A4a	Commercial; Liquid fuels	CO2	3'918	3'918	6.5	54.9
1A3b	Road transportation; Diesel oil	CO2	2'632	2'632	4.3	59.2
2A1	Cement production	CO2	2'550	2'550	4.2	63.4
1A1	Energy industries; Other fuels	CO2	1'492	1'492	2.5	65.9
1A4b	Residential; Gaseous fuels	CO2	1'465	1'465	2.4	68.3
1A2	Manufacturing industries and construction; Solid fuels	CO2	1'275	1'275	2.1	70.4
4A1	Forest land remaining forest land	CO2	-1'273	1'273	2.1	72.5
4C1	Grassland remaining grassland	CO2	-1'170	1'170	1.9	74.4
4G	HWP Harvested Wood Products	CO2	-1'119	1'119	1.8	76.3
3Da	Direct emissions from managed soils	N2O	1'119	1'119	1.8	78.1
1A2	Manufacturing industries and construction; Gaseous fuels	CO2	1'100	1'100	1.8	80.0
5D	Wastewater treatment and discharge	N2O	1'058	1'058	1.7	81.7
1A4a	Commercial; Gaseous fuels	CO2	928	928	1.5	83.2
5A	Solid waste disposal	CH4	862	862	1.4	84.7
3B1-4	Manure management all livestock direct	CH4	776	776	1.3	85.9
1A4c	Agriculture and forestry; Liquid fuels	CO2	742	742	1.2	87.2
1A1	Energy industries; Liquid fuels	CO2	686	686	1.1	88.3
4A2	Land converted to forest land	CO2	-640	640	1.1	89.4
3Db	Indirect emissions from managed soils	N2O	601	601	1.0	90.3
4B1	Cropland remaining cropland	CO2	561	561	0.9	91.3
2B10	Chemical industry other	N2O	384	384	0.6	91.9
4E2	Land converted to settlements	CO2	268	268	0.4	92.3
1A3a	Domestic aviation; Kerosene fossil	CO2	253	253	0.4	92.8
1A1	Energy industries; Gaseous fuels	CO2	243	243	0.4	93.2
1A5	Non-specified; Liquid fuels	CO2	218	218	0.4	93.5
3B5	Manure management indirect	N2O	209	209	0.3	93.9
5D	Wastewater treatment and discharge	CH4	198	198	0.3	94.2
2D	Non-energy products from fuels and solvent use	Ind. CO2 (NMVOC)	194	194	0.3	94.5
1A2	Manufacturing industries and construction; Other fuels	CO2	192	192	0.3	94.8
3B1-4	Manure management all livestock direct	N2O	168	168	0.3	95.1
2A4	Other process uses of carbonates	CO2	160	160	0.3	95.4
4C2	Land converted to grassland	CO2	148	148	0.2	95.6
1A3b	Road transportation; Gasoline	N2O	143	143	0.2	95.9
2G	Other product manufacture and use	SF6	141	141	0.2	96.1
2C3	Aluminium production	CO2	139	139	0.2	96.3
1A3b	Road transportation; Gasoline	CH4	129	129	0.2	96.5
2G	Other product manufacture and use	Ind. CO2 (NMVOC)	125	125	0.2	96.7
4D1	Wetland remaining wetland	CO2	114	114	0.2	96.9
1A3d	Water-borne navigation; Liquid fuels	CO2	114	114	0.2	97.1
Total number of key categories			34			

Table 1-3 Switzerland's key categories according to approach 1 trend assessment for 1990–2022, including LULUCF categories and indirect CO_2 emissions, sorted by decreasing contribution. Categories in orange have increased emissions in 2022 compared to 1990. Categories in grey are not key and are given for information only.

KCA APPROACH 1 TREND ASSESSMENT 1990 - 2022							
A	B	C	D	E	F	G	H
Code	IPCC category	Gas	Ex, 0 (kt CO2 eq.)	Ex, t (kt CO2 eq.)	Trend Assess-ment	Contri-bution to trend assess. (%)	Cumu-lative Total (%)
1A3b	Road transportation; Diesel oil	CO2	2'632	7'027	0.081	16.2	16.2
1A4b	Residential; Liquid fuels	CO2	10'099	3'788	0.072	14.5	30.7
1A3b	Road transportation; Gasoline	CO2	11'328	6'162	0.049	9.9	40.6
1A2	Manufacturing industries and construction; Liquid fuels	CO2	3'974	1'531	0.028	5.6	46.2
4C1	Grassland remaining grassland	CO2	-1'170	129	0.025	5.1	51.2
1A4b	Residential; Gaseous fuels	CO2	1'465	2'548	0.023	4.5	55.8
4G	HWP Harvested Wood Products	CO2	-1'119	-35	0.021	4.3	60.1
1A4a	Commercial; Liquid fuels	CO2	3'918	1'907	0.021	4.2	64.2
2F1	Refrigeration and air conditioning	HFCs	0	1'185	0.020	3.9	68.1
1A1	Energy industries; Other fuels	CO2	1'492	2'388	0.020	3.9	72.1
1A2	Manufacturing industries and construction; Gaseous fuels	CO2	1'100	1'854	0.016	3.2	75.3
4A1	Forest land remaining forest land	CO2	-1'273	-635	0.015	2.9	78.2
1A2	Manufacturing industries and construction; Solid fuels	CO2	1'275	360	0.011	2.2	80.4
3A	Enteric fermentation	CH4	3'930	3'617	0.007	1.5	81.9
5A	Solid waste disposal	CH4	862	275	0.007	1.4	83.3
2A1	Cement production	CO2	2'550	1'667	0.006	1.3	84.6
5D	Wastewater treatment and discharge	N2O	1'058	509	0.006	1.1	85.7
2B10	Chemical industry other	N2O	384	1	0.005	1.0	86.8
4B1	Cropland remaining cropland	CO2	561	743	0.005	1.0	87.7
1A2	Manufacturing industries and construction; Other fuels	CO2	192	435	0.005	0.9	88.6
1A4a	Commercial; Gaseous fuels	CO2	928	1'029	0.005	0.9	89.6
4C2	Land converted to grassland	CO2	148	349	0.004	0.8	90.3
1A1	Energy industries; Gaseous fuels	CO2	243	371	0.003	0.6	90.9
1A1	Energy industries; Liquid fuels	CO2	686	387	0.003	0.6	91.5
1A4c	Agriculture and forestry; Liquid fuels	CO2	742	440	0.003	0.5	92.0
1A3a	Domestic aviation; Kerosene fossil	CO2	253	69	0.002	0.4	92.4
4A2	Land converted to forest land	CO2	-640	-632	0.002	0.4	92.9
2D	Non-energy products from fuels and solvent use	Ind. CO2 (NMVOC)	194	36	0.002	0.4	93.3
2C3	Aluminium production	CO2	139	0	0.002	0.4	93.6
1A3b	Road transportation; Gasoline	N2O	143	12	0.002	0.3	94.0
1A3b	Road transportation; Gasoline	CH4	129	14	0.001	0.3	94.3
1A3b	Road transportation; Diesel oil	N2O	5	92	0.001	0.3	94.6
3Db	Indirect emissions from managed soils	N2O	601	401	0.001	0.3	94.8
2C3	Aluminium production	PFCs	105	0	0.001	0.3	95.1
5D	Wastewater treatment and discharge	CH4	198	227	0.001	0.2	95.3
3B5	Manure management indirect	N2O	209	233	0.001	0.2	95.6
2G	Other product manufacture and use	SF6	141	52	0.001	0.2	95.8
2A4	Other process uses of carbonates	CO2	160	68	0.001	0.2	96.0
2G	Other product manufacture and use	Ind. CO2 (NMVOC)	125	40	0.001	0.2	96.2
1A4b	Residential; Biomass	CH4	104	23	0.001	0.2	96.4
4F2	Land converted to other land	CO2	84	125	0.001	0.2	96.6
1A5	Non-specified; Liquid fuels	CO2	218	122	0.001	0.2	96.7
2B2	Nitric acid production	N2O	58	0	0.001	0.2	96.9
2G3	N2O from product uses	N2O	92	28	0.001	0.2	97.1
Total number of key categories							34

Approach 2

Given that the threshold is set at 90 %, the number of key categories is smaller under approach 2 compared to approach 1 for both level and trend assessments.

Concerning the level assessment, 28 out of 192 categories are identified as key categories for the reporting year (see Table 1-4). Regarding the trend assessment between the base year 1990 and the reporting year, 7 categories are identified as trend key categories under approach 2 (see Table 1-5).

Contrary to approach 1 of the KCA, highlighting significant emission contributions from the energy sector, approach 2 is dominated by contributions from categories having a large uncertainty, mostly from sector 3 Agriculture and sector 4 LULUCF, and to a lesser extent from sector 5 Waste and sector 2 IPPU.

Table 1-4 Switzerland's key categories according to approach 2 level assessment for the year 2022, including LULUCF categories and indirect CO_2 emissions, sorted by uncertainty-weighted emission contribution (column F). Categories in grey are not key and are given for information only. Compare also with results of the sensitivity study for the year 2022, see bottom panel of Figure 1-3. Note that for the KCA, four categories are still used according to the CRF nomenclature within sector 4 LULUCF: 4(II), 4(III), 4(IV) and 4(V).

KCA APPROACH 2, UNCERTAINTY APPROACH 2, LEVEL ASSESSMENT FOR 2022						
A	B	C	D	E	F	G
Code	IPCC category	Gas	Ex, t (kt CO2 eq.)	|Ex, t| (kt CO2 eq.)	Lx, t (%)	Cumu-lative Total (%)
4C1	Grassland remaining grassland	CO2	129	129	16.5	16.5
3A	Enteric fermentation	CH4	3'617	3'617	10.2	26.8
3Da	Direct emissions from managed soils	N2O	869	869	8.9	35.6
4B1	Cropland remaining cropland	CO2	743	743	6.2	41.8
1A1	Energy industries; Other fuels	CO2	2'388	2'388	5.9	47.7
3B1-4	Manure management all livestock direct	CH4	615	615	4.7	52.4
3Db	Indirect emissions from managed soils	N2O	401	401	3.7	56.2
5D	Wastewater treatment and discharge	N2O	509	509	3.5	59.7
4A2	Land converted to forest land	CO2	-632	632	3.1	62.7
4A1	Forest land remaining forest land	CO2	-635	635	3.1	65.8
3B5	Manure management indirect	N2O	233	233	2.9	68.8
5D	Wastewater treatment and discharge	CH4	227	227	2.9	71.7
2F1	Refrigeration and air conditioning	HFCs	1'185	1'185	2.4	74.0
4D1	Wetland remaining wetland	CO2	112	112	1.8	75.8
1A4b	Residential; Gaseous fuels	CO2	2'548	2'548	1.8	77.6
4E2	Land converted to settlements	CO2	225	225	1.6	79.2
4C2	Land converted to grassland	CO2	349	349	1.5	80.7
1A2	Manufacturing industries and construction; Gaseous fuels	CO2	1'854	1'854	1.3	82.0
5A	Solid waste disposal	CH4	275	275	1.1	83.1
3B1-4	Manure management all livestock direct	N2O	108	108	1.1	84.2
2A1	Cement production	CO2	1'667	1'667	1.0	85.2
4F2	Land converted to other land	CO2	125	125	0.9	86.1
1A3b	Road transportation; Diesel oil	CO2	7'027	7'027	0.9	87.0
5C	Incineration and open burning of waste	N2O	49	49	0.9	87.8
1A4a	Commercial; Gaseous fuels	CO2	1'029	1'029	0.7	88.6
4B2	Land converted to cropland	CO2	-7	7	0.7	89.2
1A2	Manufacturing industries and construction; Other fuels	CO2	435	435	0.6	89.9
4III	Direct N2O from disturbance	N2O	37	37	0.6	90.5
1A3b	Road transportation; Gasoline	CO2	6'162	6'162	0.6	91.1
2F2	Foam blowing agents	HFCs	32	32	0.5	91.6
4E1	Settlements remaining settlements	CO2	-61	61	0.4	92.0
Total number of key categories						28

Table 1-5 Switzerland's key categories according to approach 2 trend assessment for 1990–2022, including LULUCF categories and indirect CO_2 emissions, sorted by decreasing uncertainty-weighted contribution to the trend assessment (column G). Categories in orange have an increased emission in 2022 compared to 1990. Categories in grey are not key and are given for information only.

KCA APPROACH 2, UNCERTAINTY APPROACH 2, TREND ASSESSMENT 1990 - 2022							
A	B	C	D	E	F	G	H
Code	IPCC category	Gas	Ex, 0 (kt CO2 eq.)	Ex, t (kt CO2 eq.)	Trend Assess-ment	Contri-bution to trend assess. (%)	Cumu-lative Total (%)
4C1	Grassland remaining grassland	CO2	-1'170	129	46.190	80.0	80.0
4G	HWP Harvested Wood Products	CO2	-1'119	-35	2.409	4.2	84.2
4A1	Forest land remaining forest land	CO2	-1'273	-635	1.019	1.8	85.9
1A1	Energy industries; Other fuels	CO2	1'492	2'388	0.692	1.2	87.1
2B10	Chemical industry other	N2O	384	1	0.614	1.1	88.2
4B1	Cropland remaining cropland	CO2	561	743	0.571	1.0	89.2
5D	Wastewater treatment and discharge	N2O	1'058	509	0.560	1.0	90.1
2F1	Refrigeration and air conditioning	HFCs	0	1'185	0.558	1.0	91.1
5A	Solid waste disposal	CH4	862	275	0.419	0.7	91.8
3A	Enteric fermentation	CH4	3'930	3'617	0.298	0.5	92.4
Total number of key categories							7

1.4.3. Summary of combined KCA including LULUCF categories

A summary of the key category analysis including LULUCF categories and indirect CO_2 emissions is shown in Table 1-6, considering the level assessment for 2022 and the trend assessment for 1990–2022, for both approach 1 and approach 2. A category is counted multiple times as key category if it is a key category for multiple gases.

Table 1-6 Summary of Switzerland key category analysis, including LULUCF categories and indirect CO_2 emissions. L: Level assessment (2022); T: Trend assessment (1990–2022); 1: KCA approach 1; 2: KCA approach 2. SF_6 and NF_3 are not emitted from any key category. Results of the level assessment for the base year are not reported in this table. Note that for the KCA, four categories are still used according to the CRF nomenclature within sector 4 LULUCF: 4(II), 4(III), 4(IV) and 4(V).

SUMMARIES TO IDENTIFY KEY CATEGORIES							
A	B	C & D					
Code	IPCC category	CO2	CH4	N2O	HFCs	PFCs	Ind. CO2 (NMVOC)
1A1	Energy industries; Gaseous fuels	L1, T1					
1A1	Energy industries; Liquid fuels	L1, T1					
1A1	Energy industries; Other fuels	L1, L2, T1, T2					
1A2	Manufacturing industries and construction; Gaseous fuels	L1, L2, T1					
1A2	Manufacturing industries and construction; Liquid fuels	L1, T1					
1A2	Manufacturing industries and construction; Solid fuels	L1, T1					
1A2	Manufacturing industries and construction; Other fuels	L1, L2, T1					
1A3a	Domestic aviation; Kerosene fossil	T1					
1A3b	Road transportation; Diesel oil	L1, L2, T1		T1			
1A3b	Road transportation; Gasoline	L1, T1	T1	T1			
1A4a	Commercial; Gaseous fuels	L1, L2, T1					
1A4a	Commercial; Liquid fuels	L1, T1					
1A4b	Residential; Gaseous fuels	L1, L2, T1					
1A4b	Residential; Liquid fuels	L1, T1					
1A4c	Agriculture and forestry; Liquid fuels	L1, T1					
2A1	Cement production	L1, L2, T1					
2B10	Chemical industry other			T1, T2			
2C3	Aluminium production	T1				T1	
2D	Non-energy products from fuels and solvent use						T1
2F1	Refrigeration and air conditioning				L1, L2, T1		
3A	Enteric fermentation		L1, L2, T1				
3B1-4	Manure management all livestock direct		L1, L2	L2			
3B5	Manure management indirect			L1, L2			
3Da	Direct emissions from managed soils			L1, L2			
3Db	Indirect emissions from managed soils			L1, L2, T1			
4A1	Forest land remaining forest land	L1, L2, T1, T2					
4A2	Land converted to forest land	L1, L2, T1					
4B1	Cropland remaining cropland	L1, L2, T1, T2					
4B2	Land converted to cropland	L2					
4C1	Grassland remaining grassland	L1, L2, T1, T2					
4C2	Land converted to grassland	L1, L2, T1					
4D1	Wetland remaining wetland	L2					
4E2	Land converted to settlements	L1, L2					
4F2	Land converted to other land	L1, L2					
4G	HWP Harvested Wood Products	T1, T2					
4III	Direct N2O from disturbance			L2			
5A	Solid waste disposal		L1, L2, T1				
5C	Incineration and open burning of waste			L2			
5D	Wastewater treatment and discharge		L1, L2	L1, L2, T1, T2			
Total number of key categories		27	5	10	1	1	1

1.5. General description of QA/QC plan and implementation

The national inventory system has an established and certified quality management system (QMS) that complies with the requirements of ISO 9001:2015 and the UNFCCC reporting guidelines (UNFCCC 2019, 2022a) to ensure and continuously improve transparency, consistency, comparability, completeness, accuracy, and confidence in national GHG emission and removal estimates. The quality manual (FOEN 2024a) contains all relevant information regarding the QMS. It is updated annually and made available to everyone contributing to the GHG inventory.

General QC procedures

The general QC activities as described in Table 6.1 of the IPCC reporting guidelines (IPCC 2006) are implemented in the annual cycle of inventory compilation (Table 1-7). Routine annual quality control procedures comprise checks related to new data and database operations, spot-checks for transcription errors, correct use of conversion factors and units, and correct calculations. There are checklists for the most important sectoral data suppliers and EMIS database experts.

The National Inventory Report (NIR) is subject to an internal review prior to submission. The review of every section is carried out by personnel not involved in the preparation of the reviewed section, but who is familiar with the reporting under the UNFCCC.

Table 1-7 Annual cycle of inventory planning, preparation and management. Note that for the 2024 submission the well-established procedure has been maintained. However, the submission to the UNFCCC is delayed until the reporting tables (CRT) can be finalised with the new reporting software to be provided by the UNFCCC.

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Data compilation		▨	▨	▨	▨	▨	▨	▨				
QC EMIS Experts					▨	▨	▨	▨				
QC Sectoral Experts					▨	▨	▨	▨				
UN Review					▨							
Inventory Development Plan					▨						▨	
CRT Tables								▨	▨			
QC CRT Tables									▨			
Uncertainties / KCA									▨			
NID							▨	▨	▨	▨		
Internal review NID and CRT Tables											▨	
Official consideration and approval												▨
Submission												x
Archiving												▨
Meeting of Core Group	x				x			x		x		
Meeting of Working Group												x
Meeting of NIS Supervisory Board						x					x	

Category-specific QC procedures

Quite often, sectoral and/or EMIS experts commission research to look into a particular topic in more detail. Results from these mid- to long-term projects are presented to the inventory core group, particularly with regard to whether the new data provide a better estimate given the country-specific circumstances and whether a consistent time-series can be derived from the new data. The core group then decides if and how to best implement the results and documents the agreed procedure in the inventory development plan. The general procedures regarding category-specific QC are also described in the quality manual (FOEN 2024a), while specific activities are documented in the corresponding sectoral chapters.

Quality assurance procedures

As required by ISO 9001 there are periodic internal audits covering all processes. In addition, an external organisation is mandated to do the annual audit of the ISO 9001 quality management system. Apart from these audits, there are expert peer reviews for specific sectors commissioned on a case-by-case basis. The results and suggestions for improvements from these reviews are discussed in the core group and specific tasks for future implementation are taken up into the inventory development plan.

Likewise, recommendations and encouragements from the UNFCCC expert review teams (ERT) are also added to the inventory development plan, discussed in the core group and implemented in future submissions. Specific actions resulting from suggestions from the ERT are listed in chp. 10 Recalculations.

Verification activities

In the energy sector, the standard verification activity carried out on an annual basis is the reference approach, as documented in chp. 3.2.1 of the NID and CRT Table1.A(b).

As suggested by IPCC (2019, vol. 1, chp. 6.10) verification activities are carried out. The FOEN supports a long-term monitoring programme carried out by the Swiss Federal Laboratories for Materials Science and Technology (Empa). In the frame of this programme, continuous measurements of atmospheric concentrations of various halogenated gases are made at the high-Alpine research station Jungfraujoch (3580 m a.s.l.), from which Swiss emissions of some fluorinated greenhouse gases can be estimated. These data are compared with the emissions reported in the greenhouse gas inventory. The results are briefly summarised in Annex A6.1.

Furthermore, an ongoing project is developing an independent estimate of CH_4 and N_2O emissions in Switzerland based on atmospheric measurements and inverse modelling of atmospheric transport. The results show a very good agreement between modelled emissions and emission estimates according to the greenhouse gas inventory for CH_4 and reasonable agreement within the uncertainties for N_2O. A summary of the current state of these verification activities is provided in Annex A6.2.

1.6. General uncertainty assessment

The input uncertainty estimates for the greenhouse gas inventory under the UNFCCC and the obtained results as required by UNFCCC (2019, paragraph 29) are presented hereafter.

1.6.1. Data used

Input uncertainty values are mostly given for activity data and emissions factors. For categories concerning indirect CO_2 emissions and F-gases, uncertainty values are available for emissions only.

Input uncertainty values are selected and/or computed based on available data and according to the following order of preference:

- As a first choice, specific uncertainty information from studies or from data suppliers is used, if available. This is the case for most key categories.
- As a second choice, authors of the NID chapters, FOEN experts involved and several data suppliers derived estimates of uncertainties based on the IPCC Guidelines` (IPCC 2006, 2019) default values and on information concerning the process of data collection for activity data and emission factors (import or sales statistics, surveys or modelling). Several experts from data suppliers were contacted for further information on some of the uncertainties. Industry associations/sources also provided published or unpublished uncertainty estimates for their data.
- As a last choice, for categories with no quantitative uncertainty data available, the NID provides qualitative estimates of uncertainties. The elaboration of a quantitative uncertainty assessment for these categories would present a large effort with only limited effect on the overall uncertainty and therefore it has been decided to realize a semi-quantitative assessment. This includes the definition of a list of the combined uncertainties for relevant gases and three uncertainty levels: low, medium and high (see Table 1-8). These values are motivated by the comparison of uncertainty analyses of several countries carried out by de Keizer et al. (2007), as presented at the 2nd International Workshop on Uncertainty in Greenhouse Gas Inventories (Vienna 27–28 September 2007), and by expert judgement from sectoral experts and authors.

The following sources of uncertainties are not taken into account:

- Uncertainties in the GWP values.
- Uncertainty due to unknown bias.
- Uncertainty due to neglected temporal variability when assuming constant parameters over time (e.g. emission factors).

Several uncertainty values have been changed for submission 2024 (see detailed input values in Annex A2.1):

- The uncertainty for the emission factor of category 1A Gaseous fuels CO_2 was updated.
- The uncertainties assigned to emissions of HFCs, PFCs, SF_6 and NF_3 in sector 2 IPPU were updated (yearly update).
- The uncertainties assigned to emission factors for source categories 2A4 (CO_2), 2B5 (CH_4) and 2B10 (CO_2) were reassessed (see Chapter 4 for more details).
- The uncertainties assigned to activity data and emission factors in sector 3 Agriculture for CH_4 and N_2O emissions were updated (yearly update).
- The uncertainties for the emission factors for categories 4B1, 4B2, 4C1, 4C2, 4D2 and 4F2 were updated (yearly update).
- The uncertainties for the emissions for all indirect CO_2 emissions were updated (yearly update).

The detailed data sources can be found in the relevant chapters on “Uncertainties and time-series consistency” in each of the sectoral chapters (chp. 3 to 9) below.

Table 1-8 Semi-quantitative (combined) uncertainties (U) for the emission of categories with no quantitative uncertainty data available. Note that there is no source of HFCs, PFCs, SF_6 or NF_3 for which a semi-quantitative uncertainty value is required.

Gas	Uncertainty category	Combined uncertainty
CO_2	low	2%
	medium	10%
	high	40%
CH_4	low	15%
	medium	30%
	high	60%
N_2O	low	40%
	medium	80%
	high	150%

1.6.2. Methodology

The uncertainty aggregation for the greenhouse gases is carried out for the latest submission according to approach 1 (uncertainty propagation) and approach 2 (Monte Carlo simulations).

Input uncertainty values for activity data and emission factors at the same aggregation level as required for the key category analysis are used for the computation. A total of 192 categories were considered, including LULUCF and indirect CO_2 emissions. Indirect N_2O emissions are not included in the uncertainty analysis.

Uncertainties are assessed in accordance with the IPCC Guidelines 2006 (IPCC 2006). The Monte Carlo simulations follow the recommendations by JCGM (2008, Supplement 1).

The following assumptions were applied to both approaches:

- Full correlation or no correlation can be set between the base year and the reporting year for the same input variable.
- The following statistical distributions may be used: normal, triangular, gamma. If a variable cannot physically have negative values and has an uncertainty >100 %, a gamma distribution is preferred in order to not generate negative values during Monte Carlo simulations. This is particularly relevant for emission factors.
- Asymmetric distribution: in approach 1, this is taken into account by computing the uncertainty propagation separately for each side of the mean. In approach 2, each distribution can be simulated, and asymmetric distributions are not an issue.

The following factors are not accounted for:

- Partial correlation between the base year and the reporting year for the same input variable.
- Correlations between categories (for different input variables).

For both approaches, all uncertainty results represent a 95 % confidence interval. For a symmetrical distribution, this interval is centred on the mean, from 2.5 % up to 97.5 % of the distribution. For non-symmetrical distributions obtained by Monte Carlo simulations, the reported uncertainties represent the narrowest 95 % interval, in agreement with JCGM (2008, S1). This has consequences in particular for combined uncertainties strongly influenced by input gamma distributions, with the narrowest interval having the tendency to be shifted towards the lower end of the distribution (for example, from 1 % up to 96 % of the distribution). Uncertainties are given for the lower range (from the lower edge to the mean) and the upper range (from the mean to the upper edge), expressed as a percentage of the mean.

1.6.2.1. Aggregation of uncertainties using approach 1: uncertainty propagation

The uncertainty propagation is computed using the open-source software Python (version 3.6.1, https://www.python.org/), in which the equations given in the guidelines (IPCC 2006) are programmed. Results of approach 1 for the reporting year and for the trend are summarised in Table 1-9.

1.6.2.2. Aggregation of uncertainties using approach 2: Monte Carlo simulations

The Monte Carlo simulations were performed for the base year 1990, the reporting year 2022 and the trend at the aggregation level required for the KCA (chp. 1.4). All input variables can be found in Annex A2.1. Results for each gas are summarised in Table 1-11.

The main strategy in Monte Carlo analysis is to simulate a probability distribution for each input variable (distribution type, mean and standard deviation) and propagate these probability distributions to the final value of the model, in order to obtain a realistic uncertainty envelope for the final quantity. In practice, this is achieved by generating a large set of random numbers for each input quantity according to its distribution probability and by computing the intermediate (if any) and final values according to the equations of the model. The strength of this method is to propagate uncertainties accurately even if the equations of the model are non-linear and even if the final uncertainty envelope is non-symmetric. Another advantage is that a distribution is produced to represent the final quantity, while this information is not available from approach 1.

With these chosen settings, each input quantity is, for each year, an activity data value associated with an emission factor or if applicable, a direct emission. The final quantity is the emission at the inventory level and the mathematical model is the sum of emissions from each process.

Modelling framework

The Monte Carlo simulations are programmed using the open-source software Python (version 3.6.1, https://www.python.org/). Python is run through the Anaconda installation (https://www.anaconda.com/, version 4.4.0 (64 bit)) on a Windows PC.

To generate random numbers corresponding to the selected distributions, mean and variances, the Python function `random` is used. In practice, for each input emission factor and activity data value (or direct emission, if applicable), random numbers are generated according to the input parameters. The final uncertainty envelope is obtained by computing the emissions as the product of simulated activity data and emission factors and by then adding up all simulated emissions. Intermediate sums can also be obtained, for example the sum for a given sector.

For each input quantity, 400’000 random values were generated resulting in equal numbers of values for the base year, the reporting year and the trend.

The average offset between the simulated mean for each process and the input mean is less than 0.15 %. This reflects the uncertainty introduced by the Monte Carlo method itself. This computational uncertainty remains small compared to the uncertainty introduced by activity data and emission factors.

Correlation

If two variables representing the base year (BY) and the reporting year (RY) for the same process are fully correlated, a random number is generated for the base year only, written BY_{random}. The random value for the reporting year RY_{random} is then computed as:

$$RY_{random} = BY_{random} * RY_{input,\ mean}/BY_{input,\ mean}$$

where $RY_{input,\ mean}$ and $BY_{input,\ mean}$ are the input mean values for the variables in the reporting year and the base year, respectively.

This method implicitly assumes that the uncertainty for the base year and the reporting year, expressed in percentage of the mean value, stays the same.

No correlation between activity data (or emission factors) resulting from different processes for the same year is programmed.

Sensitivity analysis

The sensitivity analysis investigates how sensitive the total emission is to each input emission. This analysis was conducted for the base year and the reporting year.

The sensitivity of a total value (total base year emission, total reporting year emission) to the variability of input quantities is computed as the correlation coefficient between total and input values, using in Python the function `corrcoef` from the `numpy` package. Each sensitivity value is computed on 400’000 pairs of points.

The sensitivity therefore has a value between -1 and +1, where a negative value indicates a negative correlation, and a positive value a positive correlation. For emissions, since the total values are a sum of input values, only positive correlations are expected.

Intuitively, the variability in the total value will be very sensitive to a process with also a high variability, compared to other processes with a smaller variability. In other words, the inventory total is expected to be mostly sensitive to processes with a high uncertainty (expressed in absolute values or in the same unit as the emissions).

Source code availability

The Python source code is available on the Github public repository with the repository name <inventory_uncertainty_UNFCCC_CLRTAP>.

1.6.3. Results of approaches 1 and 2 uncertainty evaluation

In Table 1-9 the results of the uncertainty evaluations for the previous and latest submissions are summarised, using approaches 1 and 2 for the base year, the respective reporting year and the trend, excluding and including the LULUCF sector.

Table 1-9 Relative uncertainties for Switzerland’s national total greenhouse gas emissions and removals excluding and including the LULUCF sector for the latest and previous submissions. The uncertainties are given considering a 95 % confidence interval and expressed as the distance from edge to mean, in percentage of the mean. Uncertainties are obtained by approach 1 (uncertainty propagation) and 2 (Monte Carlo simulations) for emission levels in 1990, 2022 and for the trend (1990–2022) and are detailed by lower range, upper range and mean uncertainty for submission 2024 as displayed in the upper panel. The uncertainty analyses are based on emissions and removals including indirect CO_2 emissions. For comparison purposes, the corresponding values from the previous submission are reported as well in the lower panel labelled submission 2023.

Submission 2024												
Source category	Emissions 1990				Emissions 2022				Trend 1990-2022			
	Value kt CO2 eq.	U(-)%	U(+)%	U mean %	Value kt CO2 eq.	U(-)%	U(+)%	U mean %	Value %	U(-)%	U(+)%	U mean %
Uncertainty propagation (approach 1)												
Total incl. LULUCF	52'099	4.2	4.9	4.6	42'064	4.1	4.5	4.3	-19.3	4.5	5.0	4.8
Total excl. LULUCF	55'058	2.8	3.6	3.2	41'630	2.8	3.3	3.1	-25.8	2.9	3.6	3.2
Monte Carlo simulations (approach 2)												
Total incl. LULUCF	52'099	4.5	4.7	4.6	42'064	4.3	4.4	4.3	-19.3	4.9	4.8	4.8
Total excl. LULUCF	55'058	3.1	3.3	3.2	41'630	3.0	3.1	3.1	-25.8	3.5	3.5	3.5
Submission 2023												
Source category	Emissions 1990				Emissions 2021				Trend 1990-2021			
	Value kt CO2 eq.	U(-)%	U(+)%	U mean %	Value kt CO2 eq.	U(-)%	U(+)%	U mean %	Value %	U(-)%	U(+)%	U mean %
Uncertainty propagation (approach 1)												
Total incl. LULUCF	53'581	4.2	4.3	4.2	43'374	4.8	5.2	5.0	-19.1	4.7	5.2	5.0
Total excl. LULUCF	55'345	2.7	2.9	2.8	45'249	2.6	3.3	3.0	-18.2	2.8	3.6	3.2
Monte Carlo simulations (approach 2)												
Total incl. LULUCF	53'581	4.3	4.5	4.4	43'374	4.8	4.9	4.9	-19.1	4.8	4.9	4.9
Total excl. LULUCF	55'345	3.1	3.2	3.1	45'249	2.8	2.9	2.9	-18.2	3.4	3.3	3.3

In general, mean uncertainties resulting from approaches 1 and 2 are in concordance. For the lower range uncertainty, approach 1 may result in a smaller estimate in cases where the inventory probability distribution is asymmetric. Therefore, it is recommended to take into consideration the uncertainty estimate provided by approach 2 (Monte Carlo simulations). Uncertainties including the LULUCF sector are in each case larger than excluding the LULUCF sector, as processes in the LULUCF sector have comparatively large uncertainties.

The overall level and trend uncertainties are smaller for the latest submission compared to the previous one, however such tiny changes may not be statistically significant.

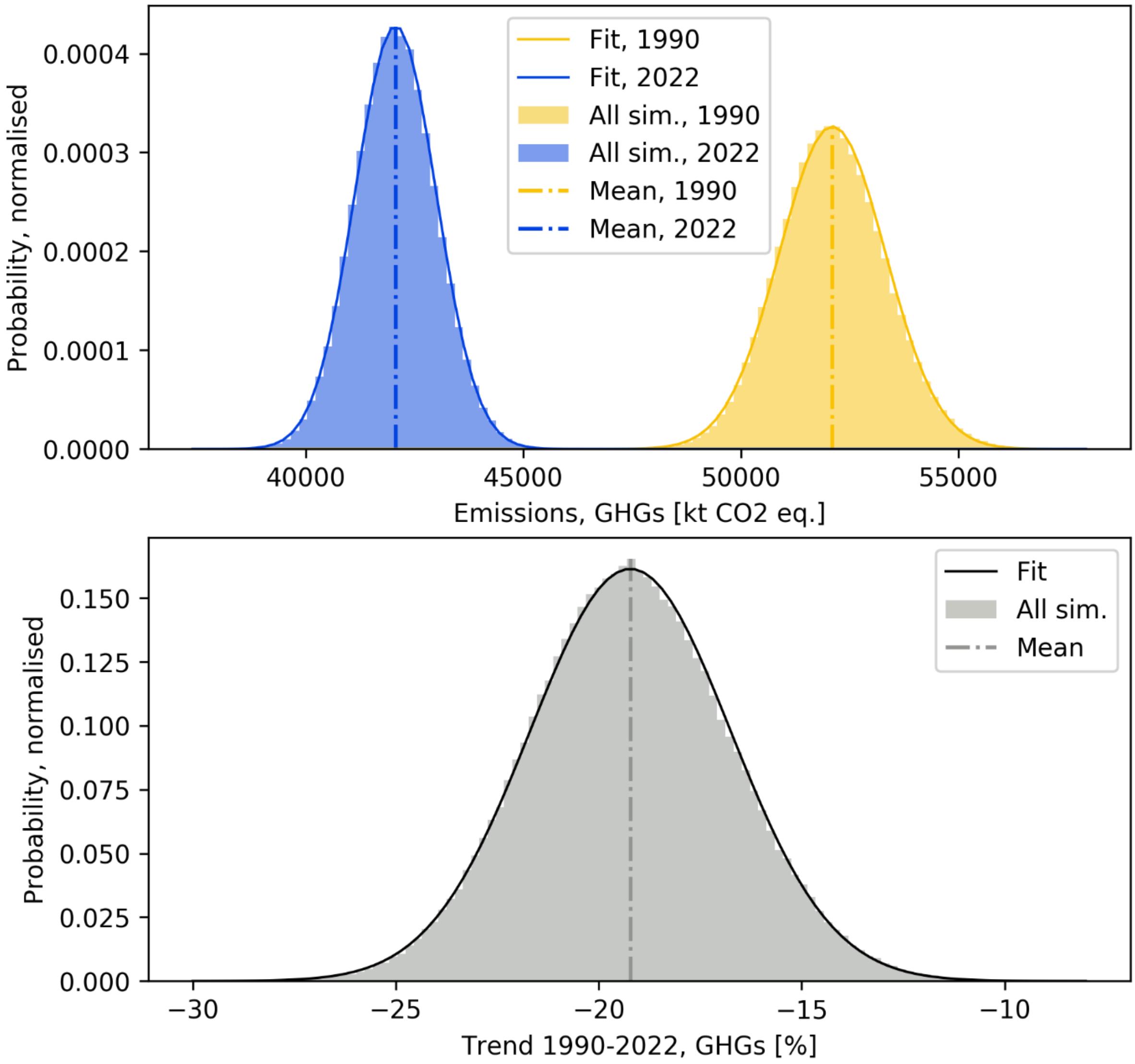

Figure 1-2 Results of Monte Carlo simulations: Distributions obtained for the inventory mean emission for all greenhouse gases, for the base year 1990 (top panel, yellow), the reporting year 2022 (top panel, blue) and the trend 1990–2022 (bottom panel, grey). All sim.: all simulations (400‘000 values for each distribution). Fit: fit of the distribution using a normal distribution. By definition, the integral of the fit (or area) has an exact numeric value of one. Mean: mean inventory emission obtained from the simulations.

Table 1-10 Overview of sector contributions to inventory uncertainties for the base year and the reporting year emissions and removals and for the trend, including indirect CO_2 emissions. Uncertainties are computed using approach 1 (uncertainty propagation) and approach 2 (Monte Carlo simulations).

IPCC category	Emissions 1990				Emissions 2022				Contribution to trend 1990-2022			
	Value kt CO2 eq.	U(-)%	U(+)%	Contrib. fraction	Value kt CO2 eq.	U(-)%	U(+)%	Contrib. fraction	Value %	U(-)%	U(+)%	Contrib. fraction
Uncertainty propagation (approach 1)												
1 Energy	41'691	0.81	0.81	0.020	31'111	1.5	1.5	0.065	-20.3	0.74	0.74	0.024
2 Industrial processes and product use	4'247	7.2	7.6	0.017	3'511	5.5	5.7	0.012	-1.41	0.49	0.52	0.011
3 Agriculture	6'852	18	22	0.34	5'888	17	21	0.37	-1.85	2.7	3.3	0.39
4 Land use land use change and forestry	-2'959	54	54	0.45	433	301	301	0.51	6.51	3.5	3.5	0.53
5 Waste	2'253	35	53	0.18	1'111	26	37	0.039	-2.19	0.79	1.1	0.041
6 Other	15	77	123	0.000044	9.9	69	111	0.000025	-0.0107	0.012	0.014	0.000008
Total, inventory	52'099	4.2	4.9	1.0	42'064	4.1	4.5	1.0	-19.3	4.5	5.0	1.0
Monte Carlo simulations (approach 2)												
1 Energy	41'691	0.82	0.80	0.020	31'111	1.5	1.5	0.065	-20.3	1.1	1.1	0.041
2 Industrial processes and product use	4'247	7.4	7.4	0.017	3'511	5.6	5.6	0.012	-1.41	0.65	0.66	0.013
3 Agriculture	6'852	20	21	0.33	5'888	19	19	0.37	-1.85	3.4	3.3	0.35
4 Land use land use change and forestry	-2'959	55	53	0.45	433	306	299	0.51	6.51	3.9	3.9	0.47
5 Waste	2'253	40	46	0.18	1'111	31	33	0.039	-2.19	2.0	1.8	0.12
6 Other	15	77	108	0.000047	9.9	73	97	0.000027	-0.0107	0.025	0.018	0.000015
Total, inventory	52'099	4.5	4.7	1.0	42'064	4.3	4.4	1.00	-19.3	4.9	4.8	1.00

Table 1-11 For each gas, net emission levels for 1990 and 2022, contribution to the inventory trend (1990–2022), and associated uncertainties obtained from Monte Carlo simulations and from uncertainty propagation, including indirect CO_2 emissions and LULUCF categories. Note that the contribution to the trend and its associated uncertainty are expressed in the same unit, in percent. As an example, for a trend contribution of -10 % with uncertainties of 2 %, the trend contribution is comprised between -12 % and -8 %.

Gas	Emissions 1990				Emissions 2022				Contribution to trend 1990-2022			
	Value kt CO2 eq.	U(-)%	U(+)%	Contrib. fraction	Value kt CO2 eq.	U(-)%	U(+)%	Contrib. fraction	Value %	U(-)%	U(+)%	Contrib. fraction
Uncertainty propagation (approach 1)												
CO2	41'101	4.0	4.0	0.47	33'183	4.2	4.2	0.58	-15.2	3.6	3.6	0.56
CH4	6'257	15	16	0.17	4'928	16	18	0.21	-2.55	2.2	2.4	0.23
N2O	4'103	28	41	0.36	2'504	27	38	0.20	-3.07	1.8	2.5	0.20
HFCs	0.023	14	14	0.000000	1'273	13	14	0.0092	2.44	0.46	0.48	0.0099
PFCs	105	9.0	9.0	0.000015	26	12	12	0.000003	-0.152	0.0083	0.0083	0.000003
SF6	141	44	57	0.00091	56	42	53	0.00021	-0.164	0.053	0.068	0.00016
NF3	NO	NO	NO	NO	0.31	78	138	0.000000	0.000586	0.00065	0.0011	0.000000
Indirect CO2 total	392	29	38	0.0031	94	29	40	0.00033	-0.572	0.075	0.10	0.00035
Total, inventory	52'099	4.2	4.9	1.0	42'064	4.1	4.5	1.0	-19.3	4.5	5.0	1.0
Monte Carlo simulations (approach 2)												
CO2	41'101	4.0	4.0	0.47	33'183	4.2	4.2	0.58	-15	3.5	3.4	0.45
CH4	6'257	16	16	0.17	4'928	17	17	0.21	-2.6	2.4	2.4	0.21
N2O	4'103	33	36	0.36	2'504	31	33	0.20	-3.1	3.1	3.0	0.33
HFCs	0.023	14	14	0.000000	1'273	14	14	0.0091	2.4	0.35	0.36	0.0046
PFCs	105	9.1	8.9	0.000016	26	12	12	0.0000028	-0.15	0.020	0.020	0.000015
SF6	141	48	52	0.00091	56	45	48	0.00021	-0.16	0.089	0.083	0.00028
NF3	NO	NO	NO	NO	0.31	88	111	0.000000	0.00059	0.00052	0.00065	0.000000015
Indirect CO2 total	392	32	34	0.0030	94	32	36	0.00032	-0.57	0.27	0.25	0.0025
Total, inventory	52'099	4.5	4.7	1.0	42'064	4.3	4.4	1.0	-19.3	4.9	4.8	1.0

Changes in total level and trend uncertainties are on one hand due to changes in uncertainties assigned to emission factors and activity data in the different categories. On the other hand, changes in activity data and emission factor values cause changes in the contribution to the total level and trend uncertainty of each category.

Contribution to level uncertainty and the uncertainty introduced to the trend in total national emissions of each category are shown in Annex A2.2 for approach 1 (uncertainty propagation) and in Annex A2.3 for approach 2 (Monte Carlo simulations).

The Monte Carlo simulations provide data to conduct a sensitivity analysis between emissions from each category and the inventory (total) emission. This analysis quantifies the influence of a change in the emission of a given category on the inventory total. The results of the sensitivity analysis for the base year and the reporting year are shown in Figure 1-3. The processes ranked in descending order of importance according to the sensitivity analysis follow almost the same order as the processes ranked according to approach 2 of the key category analysis. In both cases, results are dominated by categories from sectors 3 Agriculture and 4 LULUCF. Both methods highlight categories with large uncertainties, expressed in absolute values. The sensitivity analysis therefore confirms the results obtained by approach 2 of the KCA.

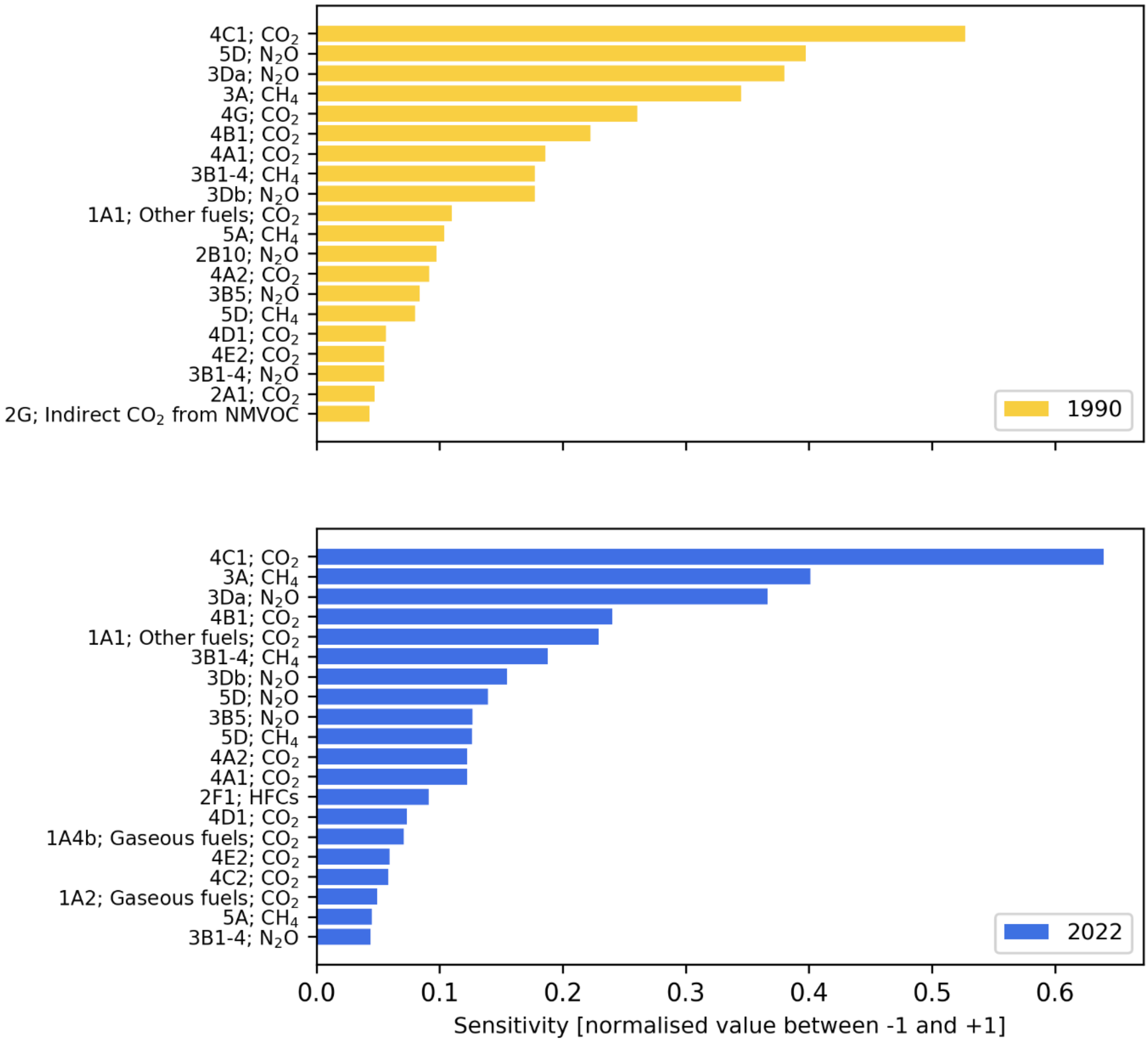

Figure 1-3 Results of the sensitivity analysis between emissions and removals from each category and inventory emissions and removals for all greenhouse gases, for the base year 1990 and the reporting year 2022. Only the twenty categories ranked first are listed. See chp. 1.6.2.2 for details and compare also with Table 1-4 (results for the key category analysis approach 2, i.e. using uncertainties).

Based on the analysis of the predominant contributions to the uncertainty of the national GHG inventory, the FOEN commissions and/or supports various projects. Planned improvements are given in the sectoral chapters and an overview list is reported in chp. 10.4.

1.7. General assessment of completeness

1.7.1. Information on completeness

The inventory is compiled using notation keys in the reporting tables as appropriate, according to the modalities, procedures and guidelines for the transparency framework under the Paris Agreement (UNFCCC 2019). Explanations for using the notation keys “NE” and “IE” are provided in CRT Table9.

Until now, the CRF reporter did not transfer the use of notation keys in tables 1.A(b) Reference approach and 1.A(d) Feedstock, reductants and other non-energy use of fuels into CRF Table9. Therefore, information on the use of notation key “IE” in tables 1.A(b) and 1.A(d) is provided here for completeness:

- 1.A(b) Reference approach, liquid fuels: Imports of refinery feedstocks are included in crude oil.
- 1.A(b) Reference approach, liquid fuels: Imports of other kerosene are included in jet kerosene.
- 1.A(b) Reference approach, liquid fuels: Carbon stored of liquefied petroleum gas, naphtha and petroleum coke are included in other oil.
- 1.A(b) Reference approach, solid fuels: Import and stock change of anthracite and coke oven/gas coke are included in other bituminous coal.
- 1.A(d) Feedstock, reductants and other non-energy use of fuels, liquid fuels: fuel quantity, C excluded from reference approach and CO_2 emissions for liquefied petroleum gas, naphtha and petroleum coke are included in other oil.

1.7.2. Description of insignificant categories

- A study commissioned by FOEN measuring greenhouse gas emissions from waste incineration plants came to the conclusion that "CH_4 emission concentrations were very low and below the background concentration of 1.8 ppm" (Mohn 2013). These measurements showed that CH_4 concentration in the exhaust air was below the CH_4 concentration in ambient air, which would indicate CH_4 removal rather than emissions. Therefore, CH_4 emissions from municipal waste incineration are reported as not estimated because they are considered insignificant (see chp. 3.2.5.2.1).
- Use of soda ash is reported for glass production (2A3) and ceramics (2A4a). A study investigating carbonate use in industry (INFRAS 2015) could not identify any other uses of soda ash. However, the amounts of soda ash used and reported in 2A3 and 2A4a are slightly smaller than net imports of soda ash. Assuming that the amount of soda ash unaccounted for in 2A3 and 2A4a caused additional CO_2 emissions in category 2A4b Other uses of soda ash, this would result in roughly 5 kt CO_2 in recent years (see chp. 4.2.2.4).

1.7.3. Total aggregate emissions considered insignificant

CH_4 emissions from waste incineration are not occurring. Based on the exhaust measurements, the process would rather destroy ambient CH_4 than release any. Therefore, this does not contribute to total aggregate emissions considered insignificant.

Potential other uses of soda ash not already accounted for in Switzerland might produce 5 kt CO_2.

National total emissions excluding LULUCF in 2022 were 41’630 kt CO_2 equivalent. Therefore, the significance threshold for aggregated emissions equals 41.6 kt CO_2 equivalent.

1.8. Metrics

The inventory is prepared using the 100-year time-horizon global warming potential (GWP) values from the IPCC Fifth Assessment Report (Myhre et al. 2013) as required by the modalities, procedures and guidelines for the transparency framework under the Paris Agreement (UNFCCC 2019).

1.9. Summary of any flexibility applied

Not applicable.

2. Trends in greenhouse gas emissions and removals

Responsibilities for Trends in greenhouse gas emissions and removals	
Authors	Michael Bock (FOEN), Regine Röthlisberger (FOEN), Nele Rogiers (FOEN; LULUCF), Andreas Schellenberger (FOEN; LULUCF), Adrian Schilt (FOEN; Energy, Indirect emissions)
Annual updates (NID text, tables, figures)	Beat Rihm (Meteotest; LULUCF), Nele Rogiers (FOEN), Felix Weber (INFRAS)
Quality control NID (annual updates)	Dominik Eggli (Meteotest), Beat Rihm (Meteotest), Andreas Schellenberger (FOEN; LULUCF)
Internal review	Michael Bock (FOEN), Daniel Bretscher (Agroscope), Martin Lindenmann (Sigmaplan), Nele Rogiers (FOEN), Andreas Schellenberger (FOEN), Adrian Schilt (FOEN)

This chapter provides an overview of Switzerland’s GHG emissions and removals in 2022 as well as trends for the period 1990–2022.

2.1. Aggregated greenhouse gas emissions and removals

Table 2-1 shows the aggregated emissions of all greenhouse gases (GHG) 2022 for each sector (including indirect CO_2) and the relative shares of the sectors. Furthermore, emission data on international aviation and marine bunkers are provided. As the table indicates, CO_2 is the main contributor to total GHG emissions followed by CH_4, N_2O and F-gases. Sector 1 Energy is the main source concerning climate-related emissions followed by sectors 3 Agriculture, 2 IPPU, 5 Waste and 6 Other. After 2000 and 2018 the year 2022 is only the third time in the whole time series that sector 4 LULUCF is a net source rather than a net sink regarding GHG net emissions and removals.

Table 2-1 Switzerland’s GHG emissions in CO_2 equivalent (kt) by gas and sector in 2022. The last column shows the share of the total for each sector including indirect CO_2 emissions (excluding LULUCF).

Sectors	**CO_2**	**CH_4**	**N_2O**	**HFCs**	**PFCs**	**SF_6**	**NF_3**	**Indirect CO_2**	**Total excl. ind.**	**Total incl. ind.**	**Share**
	CO_2 equivalent (kt)										
1 Energy	30'730	132	239					10	31'101	31'111	75%
2 Industrial processes and product use	2'028	7.7	38	1'273	26	56	0.31	83	3'428	3'511	8.4%
3 Agriculture	44	4'233	1'611						5'888	5'888	14%
5 Waste	8.1	537	565					1.1	1'110	1'111	2.7%
6 Other	8	0.47	0.28					0.77	9	10	0.024%
Total (excluding LULUCF)	32'819	4'910	2'453	1'273	26	56	0.31	94	**41'536**	**41'630**	100%
4. Land use, land-use change and forestry	365	18	51						433	433	1.0%
Total (including LULUCF)	33'183	4'928	2'504	1'273	26	56	0.31	94	**41'969**	**42'064**	101%
International aviation bunkers	*4'186*	*0.37*	*30*						*4'217*	*4'217*	
International marine bunkers	*15*	*0.0035*	*0.13*						*15*	*15*	

A breakdown of Switzerland’s total emissions by gas (excluding LULUCF) is given in Figure 2-1. Figure 2-2 charts the relative contributions of the individual sectors (excluding LULUCF) to the emissions of each GHG. Trends in GHG emissions per gas and per sector are given in chp. 2.2. The national total of 41’630 kt of CO_2 equivalent (excluding LULUCF; see Table 2-1) corresponds to 4.7 tonnes of CO_2 equivalent per capita (CO_2: 3.7 tonnes per capita) emitted to the atmosphere in 2022. Emissions per capita are calculated based on population statistics from the Federal Statistical Office (FSO 2023c).

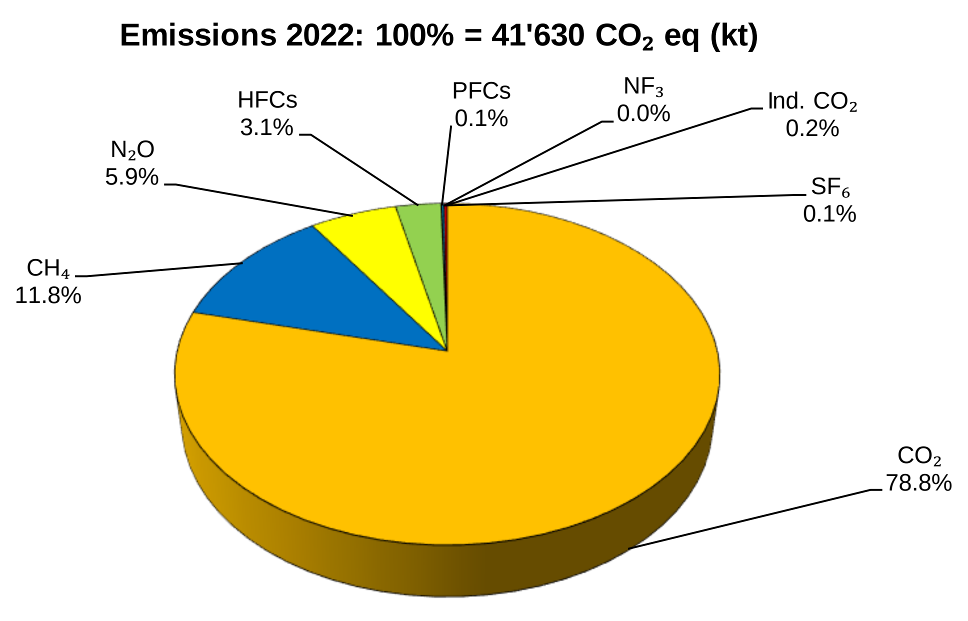

Figure 2-1 Contribution of individual gases to total greenhouse gas emissions in 2022 (excluding LULUCF).

A clear dominance of CO_2 emissions in 2022 is related to source category 1A Fuel combustion within sector 1 Energy. CH_4 and N_2O emissions mainly originate from sector 3 Agriculture, while F-gas emissions by definition only originate from sector 2 Industrial processes and product use.

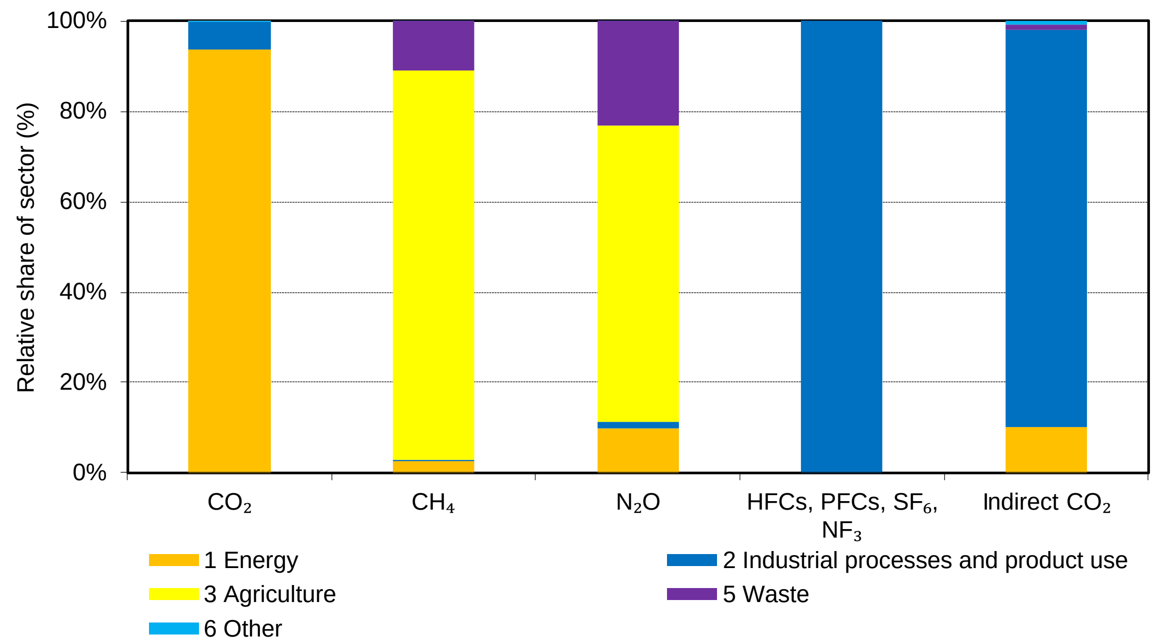

Figure 2-2 Relative contributions of the individual sectors (excluding LULUCF) to GHG emissions in 2022.

2.2. Emission and removal trends by gas and by sector

2.2.1. Emission and removal trends by gas

Emission trends by gas for the period 1990–2022 are summarised in Table 2-2.

Table 2-2 Greenhouse gas emissions in CO_2 equivalent (kt) by gas. The last column of the lower panel indicates the percentage change in emissions in the reporting year 2022 compared to the base year 1990. HFC emissions increased by more than 5 million percent when compared to 1990 levels. No NF_3 was emitted in 1990.

Greenhouse Gas Emissions	**1990**	**1995**	**2000**	**2005**	**2010**
	CO_2 equivalent (kt)				
CO_2 emissions including net CO_2 from LULUCF	41'101	39'037	47'971	42'506	41'856
CO_2 emissions excluding net CO_2 from LULUCF	44'149	43'414	43'621	45'777	45'034
CH_4 emissions including CH_4 from LULUCF	6'257	5'864	5'494	5'476	5'431
CH_4 emissions excluding CH_4 from LULUCF	6'222	5'842	5'478	5'461	5'417
N_2O emissions including N_2O from LULUCF	4'103	3'964	3'736	3'471	3'307
N_2O emissions excluding N_2O from LULUCF	4'049	3'916	3'692	3'426	3'261
HFCs	0.023	227	603	997	1'245
PFCs	105	16	54	46	36
SF_6	141	96	157	210	155
NF_3	NO	NO	NO	NO	12
Indirect CO_2	392	284	205	144	133
Total (including LULUCF)	**52'099**	**49'488**	**58'220**	**52'850**	**52'174**
Total (excluding LULUCF)	**55'058**	**53'795**	**53'809**	**56'061**	**55'293**

Greenhouse Gas Emissions	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2022 vs. 1990**
	CO_2 equivalent (kt)										%
CO_2 emissions including net CO_2 from LULUCF	41'301	38'456	37'114	37'068	36'772	36'913	36'031	33'516	34'444	33'183	-19.3%
CO_2 emissions excluding net CO_2 from LULUCF	43'171	39'221	38'719	39'172	38'165	36'859	36'721	34'228	35'780	32'819	-25.7%
CH_4 emissions including CH_4 from LULUCF	5'284	5'274	5'243	5'204	5'143	5'102	5'011	4'956	4'965	4'928	-21.2%
CH_4 emissions excluding CH_4 from LULUCF	5'270	5'260	5'228	5'186	5'128	5'088	4'998	4'943	4'952	4'910	-21.1%
N_2O emissions including N_2O from LULUCF	3'184	3'181	3'147	3'108	3'211	3'071	3'123	3'034	2'933	2'504	-39.0%
N_2O emissions excluding N_2O from LULUCF	3'137	3'134	3'100	3'059	3'162	3'023	3'075	2'986	2'885	2'453	-39.4%
HFCs	1'353	1'388	1'429	1'396	1'392	1'427	1'361	1'350	1'267	1'273	see caption
PFCs	26	21	24	18	29	33	29	34	28	26	-75.5%
SF_6	270	270	281	254	239	184	178	156	131	56	-60.5%
NF_3	0.13	0.57	0.68	0.72	0.75	0.47	0.51	0.39	0.37	0.31	see caption
Indirect CO_2	116	112	107	107	107	100	103	100	95	94	-76.0%
Total (including LULUCF)	**51'535**	**48'703**	**47'346**	**47'158**	**46'894**	**46'831**	**45'836**	**43'146**	**43'864**	**42'064**	**-19.3%**
Total (excluding LULUCF)	**53'345**	**49'407**	**48'889**	**49'194**	**48'223**	**46'714**	**46'465**	**43'797**	**45'138**	**41'630**	**-24.4%**

As shown in Table 2-2, Table 2-3, and Figure 2-3, total emissions excluding LULUCF in 2022 are clearly below base year emissions. There is no discernible trend of overall emissions in the period 1990–2005. Only from 2005 onwards, a decreasing trend starts to develop. Also when including LULUCF categories, a decreasing trend is visible compared to the base year 1990, although the net CO_2 eq removals generated by LULUCF categories were generally smaller after 1997 and LULUCF was a net source in 2022 (see Figure 2-8, Figure 2-9 and Figure 6-3). The overall emission reduction between 1990 and 2022 amounts to 24.4 % when LULUCF categories are excluded and 19.3 % when including LULUCF. The emission maximum occurred in 1991. Compared to 2021, emissions have strongly decreased in 2022 (excl. LULUCF: by 7.8 %; incl. LULUCF: by 4.1 %). This significant reduction is mainly due to winter meteorological conditions: Cold winter months led to a high number of heating degree days in 2021, whereas warm winter months in 2022 required less heating (see Figure 2-7). As a result, CO_2 emissions from source category 1A4 Other sectors strongly declined in 2022 compared to 2021.

The decrease of emissions between 2019 and 2020 can partially be interpreted as a consequence of the lockdown and subsequent measures associated with the COVID-19 pandemic that affected Switzerland from March 2020 onwards.

The trends of the different greenhouse gases can be described as follows:

- There is a strong correlation between **CO_2** emissions and winter meteorological conditions (number of heating degree days; see box 1 on page 49. However, the relative developments of heating degree days and CO_2 emissions are clearly drifting apart in the years since 2002, which indicates that additional effects like reduction measures contribute to emission reductions (see Figure 2-7).
- Between 1990 and 2022, **CH_4** emissions (excluding LULUCF) decreased. An important driver for this reduction is sector 5 Waste, where CH_4 emissions declined throughout the whole time series – in particular in source category 5A Solid waste disposal, where a change in waste legislation banning the disposal of municipal solid waste in landfills reinforced the trend since 2000. Furthermore, the development of livestock in sector 3 Agriculture is relevant for the overall reduction of CH_4 emissions, in particular cattle, where a reduction in the years 1990–2004 and 2012–2022 led to a reduction of emissions from source category 3A Enteric fermentation in the agricultural sector (see Table 5-8).
- A continuous decrease in **N_2O** emissions was achieved between 1990 and 2022 due to progress in nitrogen removal in centralised wastewater treatment plants (sector 5 Waste). In addition, N_2O emissions of sector 2 IPPU were considerably reduced due to the installation of a catalytic converter in a niacin production plant late in the year 2021. Furthermore, as a consequence of the declining livestock population and reduced input of synthetic fertilisers, N_2O emissions that mainly stem from manure management and agricultural soils decreased between 1990 and 2022 as well.
- **HFC** emissions are significantly higher in 2022 compared to the base year due to their application as substitutes for CFCs. In contrast, **PFC** emissions declined mainly due to the decrease and stop of aluminium production in Switzerland. Decreasing tendencies are found for HFC emissions since 2018 due to restrictions of HFC use in mobile air-conditioning and stationary refrigeration. **SF_6** emissions show relatively large fluctuations between 1990 and 2022. This effect bases on annual fluctuations of the market volumes in the production of electrical equipment as well as on changes in other applications. The temporary increase of SF_6 emissions between 2010 and 2018 is mainly due the disposal of soundproof windows. Although soundproof windows containing SF_6 are not produced or installed in Switzerland anymore, the disposal of old windows still leads to emissions. On the other hand, the SF_6 emissions from electrical equipment (2G1) are decreasing due to the agreement of Swissmem and FOEN on the reduction of SF_6 emissions since 2008. Further reductions are the result of the prohibition of the import of SF_6 for magnesium foundries (2C4) since 2017 and improved waste air treatment and recovery of SF_6 in further applications. **NF_3** has been used only short-term in the photovoltaic industry (around the year 2010).

Table 2-3 Contribution of individual gases to total emissions (excluding LULUCF) in CO_2 equivalent (kt) and (%).

Greenhouse Gas Emissions	**1990**		**1995**		**2000**		**2005**		**2010**	
(excluding LULUCF)	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%
CO_2	44'149	80.2%	43'414	80.7%	43'621	81.1%	45'777	81.7%	45'034	81.4%
CH_4	6'222	11.3%	5'842	10.9%	5'478	10.2%	5'461	9.7%	5'417	9.8%
N_2O	4'049	7.4%	3'916	7.3%	3'692	6.9%	3'426	6.1%	3'261	5.9%
HFCs	0.023	0.0%	227	0.4%	603	1.1%	997	1.8%	1'245	2.3%
PFCs	105	0.2%	16	0.0%	54	0.1%	46	0.1%	36	0.1%
SF_6	141	0.3%	96	0.2%	157	0.3%	210	0.4%	155	0.3%
NF_3	NO	-	NO	-	NO	-	NO	-	12	0.0%
Indirect CO_2	392	0.7%	284	0.5%	205	0.4%	144	0.3%	133	0.2%
Total (excluding LULUCF)	**55'058**	**100%**	**53'795**	**100%**	**53'809**	**100%**	**56'061**	**100%**	**55'293**	**100%**

Greenhouse Gas Emissions	**2018**		**2019**		**2020**		**2021**		**2022**	
(excluding LULUCF)	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%
CO_2	36'859	78.9%	36'721	79.0%	34'228	78.2%	35'780	79.3%	32'819	78.8%
CH_4	5'088	10.9%	4'998	10.8%	4'943	11.3%	4'952	11.0%	4'910	11.8%
N_2O	3'023	6.5%	3'075	6.6%	2'986	6.8%	2'885	6.4%	2'453	5.9%
HFCs	1'427	3.1%	1'361	2.9%	1'350	3.1%	1'267	2.8%	1'273	3.1%
PFCs	33	0.1%	29	0.1%	34	0.1%	28	0.1%	26	0.1%
SF_6	184	0.4%	178	0.4%	156	0.4%	131	0.3%	56	0.1%
NF_3	0.47	0.0%	0.51	0.0%	0.39	0.0%	0.37	0.0%	0.31	0.0%
Indirect CO_2	100	0.2%	103	0.2%	100	0.2%	95	0.2%	94	0.2%
Total (excluding LULUCF)	**46'714**	**100%**	**46'465**	**100%**	**43'797**	**100%**	**45'138**	**100%**	**41'630**	**100%**

Figure 2-3 shows Switzerland's relative GHG emission trends by gas. The base year 1990 is set to 100 %.

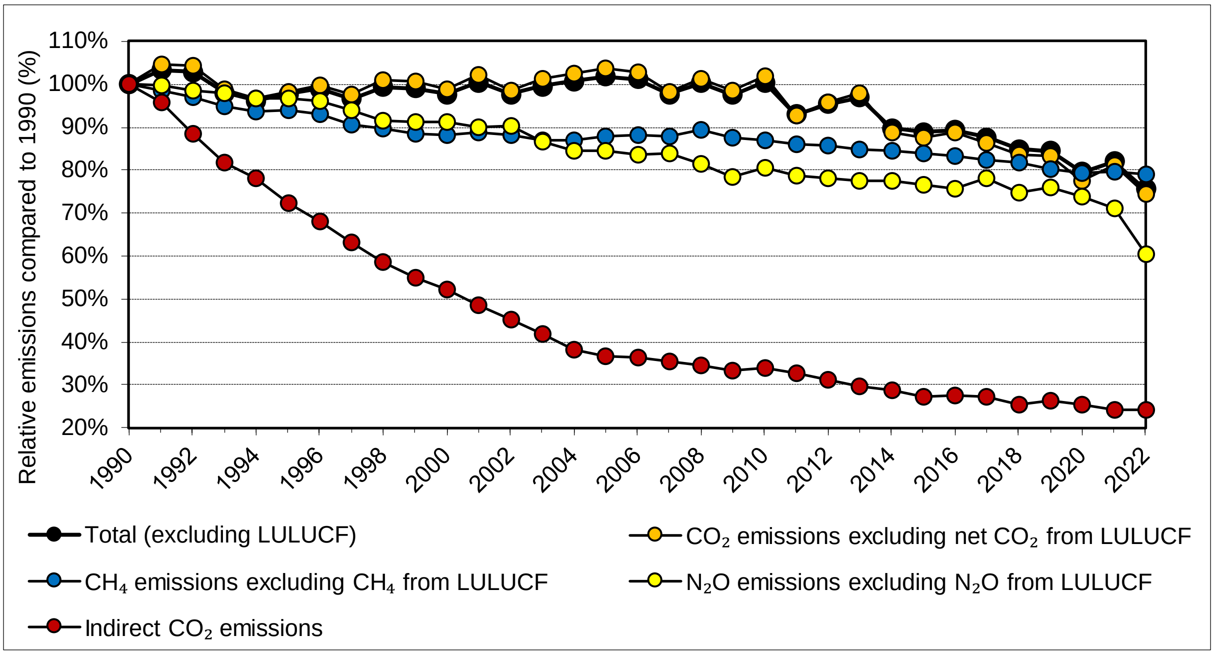

Figure 2-3 Relative trends of Switzerland's main greenhouse gas emissions (excluding LULUCF). The base year 1990 represents 100 %. F-gases are not illustrated here but included in the total (see Figure 4-3).

2.2.2. Emission and removal trends by sector

Table 2-4 shows the emission trends for all major source and sink categories. As the largest share of emissions originates from sector 1 Energy, the table includes further information concerning the contributions of energy-related source categories.

2.2.2.1. Overview

In order to understand trends within the sector **1 Energy**, the individual source categories are considered separately (see chp. 2.2.2.2 and Figure 2-6 below).

In line with economic development, overall emissions in sector **2 Industrial processes and product use (IPPU)** show a decreasing trend in the early 1990s and a gradual increase between 1997 and 2011, except for the economically difficult year 2009. After 2011, emissions from the sector remained on a similar level until 2019. Since 2019, emissions show a decreasing tendency due to a reduction of HFC emissions in category 2F Product uses as substitutes for ozone-depleting substances (ODS). The Chemical Risk Reduction Ordinance (Swiss Confederation 2005) was put in place in 2005 and regulates the use of F-gases since then. The dominant source category of sector 2 is 2A Mineral industry although the emissions decreased by approximately one third since 1990. If sources are analysed in more detail, 2A1 Cement production is the most relevant emitter in this category. Until 2021, 2B Chemical industry was an important source category, however it is less relevant since the installation of a catalytic converter in a niacin production plant late in the year 2021 that reduced N_2O emissions strongly. Emissions of 2F Product uses as substitutes for ozone-depleting substances (ODS), the second most important source in sector 2, increased by some orders of magnitude since 1990 due to the replacement of CFCs with HFCs. Source category 2G Other product manufacture and use, the third-most important source category, contains in particular SF_6 and PFC emissions from electrical equipment and other product use, as well as N_2O emissions from the application in households and hospitals. Other source categories in sector 2 are of minor importance with regard to the overall greenhouse gas emissions.

GHG emissions in sector **3 Agriculture** are driven by populations of cattle and swine and by fertiliser use. Both factors have been declining (see Table 5-8 and Table 5-24, respectively), thus leading to a decrease in CH_4 and N_2O emissions until 2004. Subsequently, CH_4 emissions increased slightly until 2008 and decreased again afterwards. N_2O emissions remained more or less near a constant level since 2004 with a decreasing trend in the last years. This general development can be explained by the development of the cattle population and the input of mineral fertilisers.

Total emissions from the source category **5 Waste** continuously decrease between 1990 and 2022. The main driver of the decreasing trend is the emission reduction in solid waste disposal (sector 5A), which was reinforced through a change of legislation in 2000 that banned disposal of combustible waste in landfills. Therefore, an increasing amount of municipal solid waste is being incinerated, with emissions reported under source category 1A1 Energy industries rather than sector 5 Waste. A similar reduction was achieved in sector 5D Wastewater treatment mainly due to improvements concerning nitrogen removal in centralised wastewater treatment plants. Altogether, “waste-related” emissions (including emissions from all waste management activities reported in sectors 1 Energy, 3 Agriculture, and 5 Waste) are increasing since 1994 and show a stagnation since 2006 (see Figure 7-3 in chp. 7.1).

The total emissions from sector **6 Other** (fire damages) show a generally decreasing trend since 2004, mostly due to a gradually decreasing number of building fires per year. The total greenhouse gas emissions of this sector show emissions of less than 20 kt CO_2 eq in each year during the reporting period and is of minor importance for the national total.

Table 2-4 Greenhouse gas emissions in CO_2 equivalent (kt) by individual source (positive numbers) and sink (negative numbers) categories.

Source and Sink Categories	**1990**	**1995**	**2000**	**2005**	**2010**
	CO_2 equivalent (kt)				
1 Energy	41'636	41'633	42'007	43'839	43'088
1A1 Energy industries	2'514	2'640	3'172	3'818	3'854
1A2 Manufacturing industries and construction	6'576	6'299	6'002	6'035	5'854
1A3 Transport	14'673	14'278	15'951	15'847	16'320
1A4 Other sectors	17'535	18'112	16'600	17'863	16'793
1A5 Other	219	163	151	139	137
1B Fugitive emissions from fuels	119	141	130	138	130
2 Industrial processes and product use	3'913	3'318	3'654	4'277	4'373
3 Agriculture	6'852	6'615	6'164	6'100	6'205
5 Waste	2'251	1'931	1'764	1'685	1'484
6 Other	14	15	16	15	11
Indirect CO_2	392	284	205	144	133
Total (excluding LULUCF)	55'058	53'795	53'809	56'061	55'293
4. Land use, land-use change and forestry	-2'959	-4'307	4'411	-3'211	-3'118
Total (including LULUCF)	52'099	49'488	58'220	52'850	52'174

Source and Sink Categories	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	***2022 vs. 1990***
	CO_2 equivalent (kt)										*%*
1 Energy	41'357	37'306	36'976	37'372	36'390	35'093	34'973	32'541	34'027	31'101	*-25.3%*
1A1 Energy industries	3'744	3'614	3'303	3'389	3'306	3'372	3'382	3'290	3'239	3'186	*26.7%*
1A2 Manufacturing industries and construction	5'491	5'090	4'971	4'975	4'947	4'790	4'703	4'500	4'595	4'219	*-35.8%*
1A3 Transport	16'170	16'063	15'327	15'164	14'902	14'908	14'866	13'563	13'752	13'581	*-7.4%*
1A4 Other sectors	15'721	12'309	13'159	13'626	13'023	11'822	11'828	10'998	12'264	9'926	*-43.4%*
1A5 Other	133	139	135	139	127	126	115	119	115	123	*-43.7%*
1B Fugitive emissions from fuels	97	91	82	79	85	76	79	71	63	65	*-45.9%*
2 Industrial processes and product use	4'359	4'366	4'323	4'282	4'385	4'273	4'268	4'094	3'939	3'428	*-12.4%*
3 Agriculture	6'100	6'231	6'135	6'122	6'074	6'014	5'913	5'883	5'925	5'888	*-14.1%*
5 Waste	1'404	1'380	1'338	1'300	1'256	1'224	1'199	1'171	1'142	1'110	*-50.7%*
6 Other	10	11	10	10	11	10	9	8	9	9	*-35.9%*
Indirect CO_2	116	112	107	107	107	100	103	100	95	94	*-76.0%*
Total (excluding LULUCF)	53'345	49'407	48'889	49'194	48'223	46'714	46'465	43'797	45'138	41'630	*-24.4%*
4. Land use, land-use change and forestry	-1'810	-704	-1'543	-2'037	-1'329	116	-629	-650	-1'274	433	*-114.6%*
Total (including LULUCF)	51'535	48'703	47'346	47'158	46'894	46'831	45'836	43'146	43'864	42'064	*-19.3%*

The percentage shares of source categories are shown for selected years in Table 2-5 whereas Figure 2-4 to Figure 2-6 are graphical representations of the data in Table 2-4. For the time series of the source categories of sector 1 Energy see chp. 3.

Table 2-5 Greenhouse gas emissions (excluding LULUCF) in CO_2 equivalent (kt) and the relative contribution (%) of individual source categories.

Source and Sink Categories	**1990**		**1995**		**2000**		**2005**		**2010**	
	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%
1 Energy	41'636	75.6%	41'633	77.4%	42'007	78.1%	43'839	78.2%	43'088	77.9%
1A1 Energy industries	2'514	*4.6%*	2'640	*4.9%*	3'172	*5.9%*	3'818	*6.8%*	3'854	7.0%
1A2 Manufacturing industries and construction	6'576	*11.9%*	6'299	*11.7%*	6'002	*11.2%*	6'035	*10.8%*	5'854	*10.6%*
1A3 Transport	14'673	*26.6%*	14'278	*26.5%*	15'951	*29.6%*	15'847	*28.3%*	16'320	*29.5%*
1A4 Other sectors	17'535	*31.8%*	18'112	*33.7%*	16'600	*30.9%*	17'863	*31.9%*	16'793	*30.4%*
1A5 Other	219	*0.4%*	163	*0.3%*	151	*0.3%*	139	*0.2%*	137	*0.2%*
1B Fugitive emissions from fuels	119	*0.2%*	141	*0.3%*	130	*0.2%*	138	*0.2%*	130	*0.2%*
2 Industrial processes and product use	3'913	7.1%	3'318	6.2%	3'654	6.8%	4'277	7.6%	4'373	7.9%
3 Agriculture	6'852	12.4%	6'615	12.3%	6'164	11.5%	6'100	10.9%	6'205	11.2%
5 Waste	2'251	4.1%	1'931	3.6%	1'764	3.3%	1'685	3.0%	1'484	2.7%
6 Other	14	0.0%	15	0.0%	16	0.0%	15	0.0%	11	0.0%
Indirect CO_2	392	0.7%	284	*0.5%*	205	0.4%	144	0.3%	133	*0.2%*
Total (excluding LULUCF)	55'058	100%	53'795	100%	53'809	100%	56'061	100%	55'293	100%

Source and Sink Categories	**2018**		**2019**		**2020**		**2021**		**2022**	
	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%	kt CO_2 eq	%
1 Energy	35'093	75.1%	34'973	75.3%	32'541	74.3%	34'027	75.4%	31'101	74.7%
1A1 Energy industries	3'372	*7.2%*	3'382	*7.3%*	3'290	*7.5%*	3'239	*7.2%*	3'186	*7.7%*
1A2 Manufacturing industries and construction	4'790	*10.3%*	4'703	*10.1%*	4'500	*10.3%*	4'595	*10.2%*	4'219	*10.1%*
1A3 Transport	14'908	*31.9%*	14'866	*32.0%*	13'563	*31.0%*	13'752	*30.5%*	13'581	*32.6%*
1A4 Other sectors	11'822	*25.3%*	11'828	*25.5%*	10'998	*25.1%*	12'264	*27.2%*	9'926	*23.8%*
1A5 Other	126	*0.3%*	115	*0.2%*	119	*0.3%*	115	*0.3%*	123	*0.3%*
1B Fugitive emissions from fuels	76	*0.2%*	79	*0.2%*	71	*0.2%*	63	*0.1%*	65	*0.2%*
2 Industrial processes and product use	4'273	9.1%	4'268	9.2%	4'094	9.3%	3'939	8.7%	3'428	8.2%
3 Agriculture	6'014	12.9%	5'913	12.7%	5'883	13.4%	5'925	13.1%	5'888	14.1%
5 Waste	1'224	2.6%	1'199	2.6%	1'171	2.7%	1'142	2.5%	1'110	2.7%
6 Other	10	0.0%	9	0.0%	8	0.0%	9	0.0%	9	0.0%
Indirect CO_2	100	0.2%	103	*0.2%*	100	0.2%	95	0.2%	94	*0.2%*
Total (excluding LULUCF)	46'714	100%	46'465	100%	43'797	100%	45'138	100%	41'630	100%

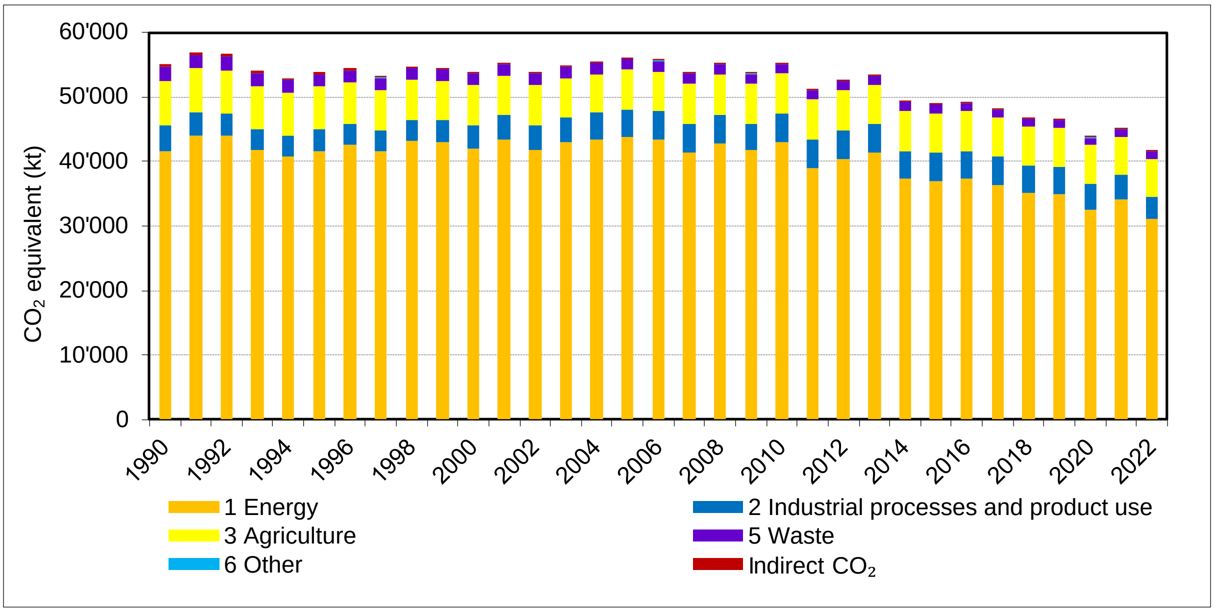

Figure 2-4 Greenhouse gas emissions in CO_2 equivalent (kt) by sectors (excluding LULUCF).

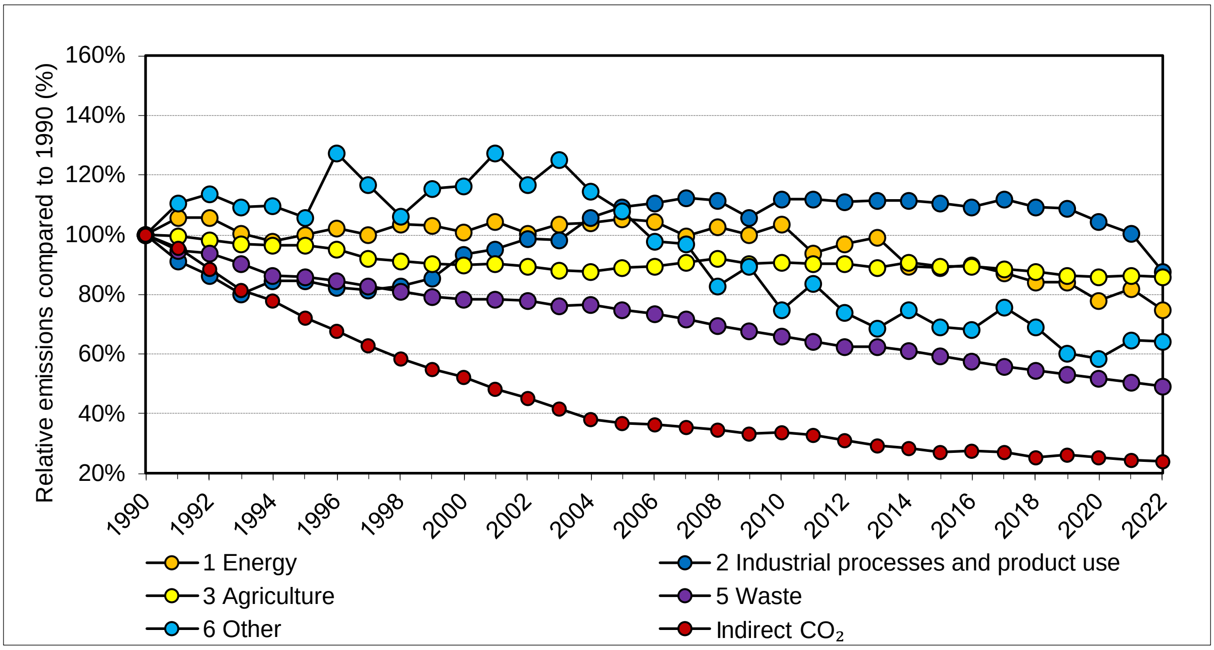

Figure 2-5 Relative emission trends (CO_2 eq) by main source categories (base year 1990 = 100 %).

2.2.2.2. Emission trends in sector 1 Energy

The main source categories within sector 1 Energy – representing the major sources of Switzerland's GHG emissions – are shown in Figure 2-6 and Table 2-5.

The following emission trends emerge within the sector 1 Energy:

- Despite differing trends of individual source categories, the overall emissions from the sector 1 Energy remain at a relatively constant level (orange/bold line in Figure 2-6) in the period 1990–2006. Afterwards, the trend is determined by a combination of effective reduction measures and a decreasing trend of heating degree days (see Figure 2-7; see further details below under 1A1 Energy industries and 1A4 Other sectors).
- It is noteworthy that due to Switzerland's electricity production structure (mainly hydroelectric and nuclear power; see SFOE (2023), Table 24), source category 1A1 Energy industries plays only a minor role. It does not represent thermal power stations as in many other countries, but primarily waste incineration plants. The increase in waste incineration is the reason why overall emissions from source category 1A1 Energy industries are higher in 2022 than in 1990. The time series shows an increase until 2006 and a decrease thereafter. Fluctuations are caused by varying combustion activities for district heating. The emission reduction in 2015 was due to the closure of one of two refineries (see Figure 2-6 and values in Table 2-5).
- Emissions from 1A2 Manufacturing industries and construction show a decreasing trend since 1990, mainly due to continuous changes in the use of fuel types for stationary combustion (see Table 3-55).
- The increasing trend of emissions in source category 1A3 Transport between 1990 and 2008 is based on increasing traffic volumes (in all different types of transport). The effect of increasing energy efficiency of vehicles was unable to counterbalance the substantial growth in transport. The decrease of transport emissions since 2008 as well as the drop from 2014 to 2015 is largely caused by decreasing "fuel tourism" (EV 2015a) (see chp. 3.2.9.2.2). The strong decrease between 2019 and 2020 can be attributed to the COVID-19 pandemic, when a lockdown and further measures reduced traffic volumes, in particular of passenger cars.

- The trend for source category 1A4 Other sectors reflects the impact of climatic variations on energy demand for heating in stationary source categories (1A4ai/bi/ci). The strong correlation with the number of “heating degree days” (see box 1 on page 49) – used as an index of meteorological conditions over the year – is apparent from Figure 2-7, which shows CO_2 emissions from source category 1A4 Other sectors (only stationary sources) and the number of heating degree days. Since 2002, heating degree days and CO_2 emissions are clearly drifting apart, which indicates that additional effects like reduction measures contribute to emission reductions (see Figure 2-7). In the period 1990–2022, the number of buildings and apartments increased as well as the average floor space per person and workplace. Both phenomena result in an increase in the total area heated by around 45 % (FOEN 2023l). Over the same period, however, higher standards were specified for insulation and for combustion equipment efficiency for both new and renovated buildings, compensating for the emissions from the additional area heated.
- CO_2 emissions from 1A5 Other mainly stem from military aircraft and therefore show almost the same decreasing trend as the use of jet kerosene within this source category (see Table 3-106).
- The development of CO_2 equivalent emissions in 1B are dominated by the trend of the CH_4 emissions from leakage in the natural gas distribution network. From 1990 to 1994, emissions increased due to network expansion. Thereafter, emissions decreased substantially due to gradual replacement of old pipelines.

Box 1: Heating degree days

Heating degree days: a standardized measure for linking heating demand and meteorological conditions. Number of degrees per day calculated as the difference between 20°C (room temperature) and the daily average outdoor temperature for such days where the daily average temperature is below 12°C (e.g. daily outdoor average equals 7°C, then for that day 20 - 7 = 13). The number of degrees per day are summed up for a year t to yield the heating degree days of year t.

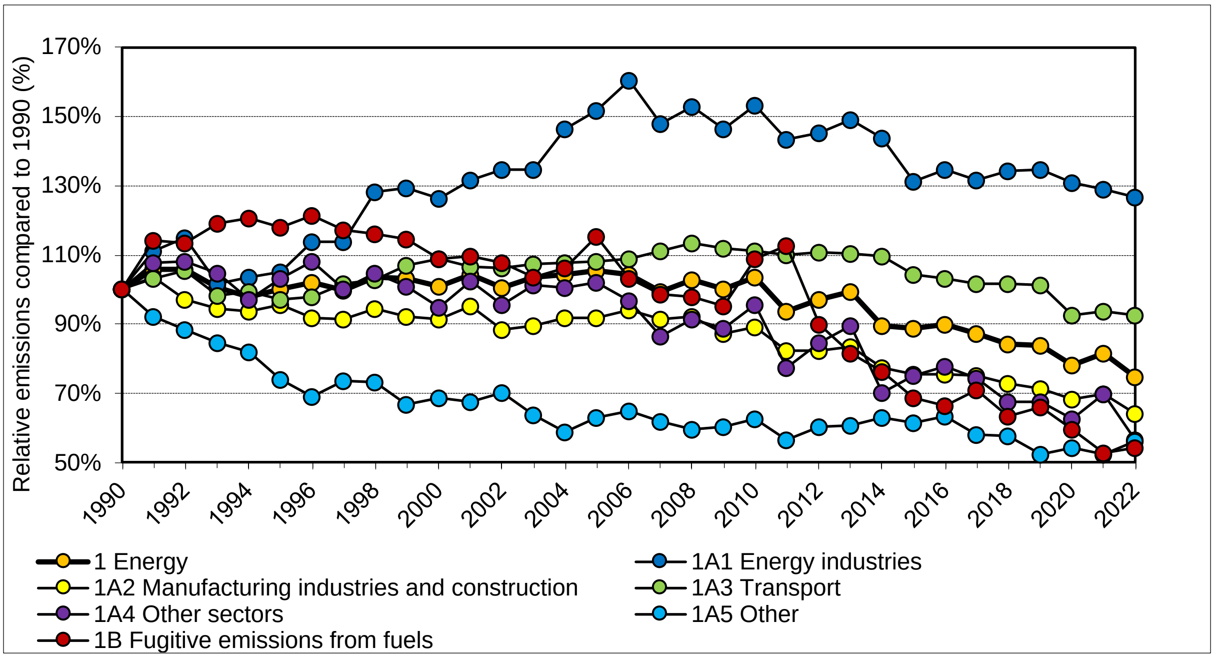

Figure 2-6 Emission trends (CO_2 eq) for the source categories in sector 1 Energy. The trend for the entire sector 1 Energy is represented by the bold line with orange bullets.

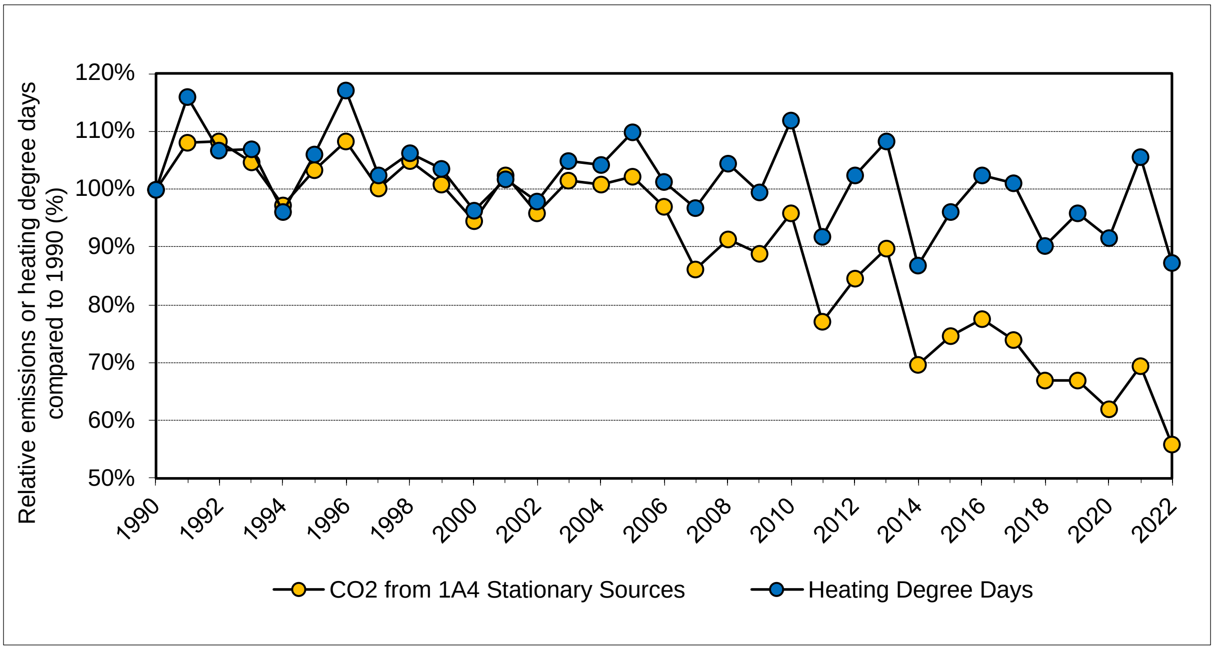

Figure 2-7 Relative trend for CO_2 emissions from 1A4 Fuel Combustion – Other Sectors (stationary sources only) compared with the number of heating degree days.

2.2.2.3. Emission and removal trends in sector 4 LULUCF

Figure 2-8 illustrates the net CO_2 eq emissions and removals in sector 4 LULUCF. Associated data are given in Table 2-4.

The GHG fluxes are reported for six main land-use categories: 4A Forest land, 4B Cropland, 4C Grassland, 4D Wetlands, 4E Settlements and 4F Other land. The carbon stock of 4G Harvested wood products made from Swiss wood is also recorded. CO_2 is the most important greenhouse gas by far in the LULUCF sector. CH_4 and N_2O from fires, soil organic matter decomposition, reservoirs and drained organic soil make a minor contribution to the emissions (see Figure 6-2). With the exception of 2000, 2018 and 2022, Switzerland’s land use resulted in more CO_2 eq being absorbed from the atmosphere by soil and vegetation than being emitted (Figure 2-8, see also Figure 2-9, Figure 6-1 and Figure 6-3). Quantitatively, most CO_2 eq removals were achieved in the decade between 1990 and 1999.

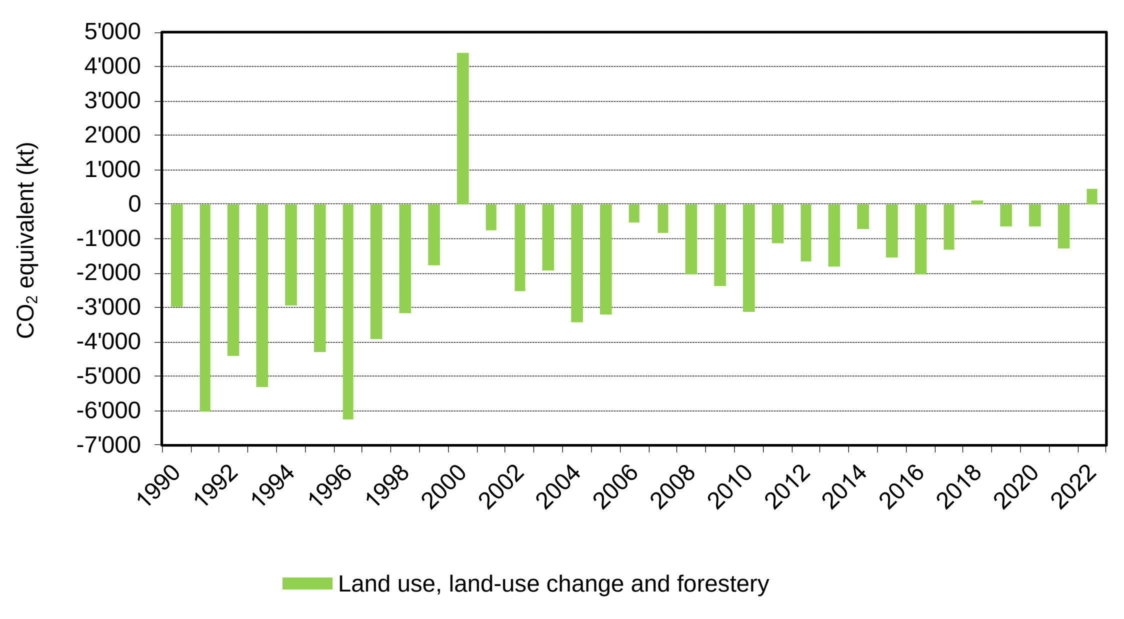

Figure 2-8 Net GHG (CO_2, CH_4, N_2O) emissions and removals of sector 4 Land use, land-use change and forestry (LULUCF), in kt CO_2 eq. Positive values refer to net emissions, negative values refer to net removals.

4A: Forest land dominates the GHG balance of Switzerland's land use. For most years, management of Forest land resulted in a distinct increase in the total carbon stocks in living biomass, dead wood, litter and forest soils (i.e., a net removal of CO_2 from the atmosphere; Figure 2-9). The exceptionally high net CO_2 eq emissions in 2000 and the small net removals in the following year 2001 originate from winter storm Lothar (December 1999, see https://s.geo.admin.ch/hh3tdskqvzq1), which caused large-scale damages in forest stands and increased losses of living biomass due to salvage logging. This also applies to a somewhat lesser extent to the storm Vivian in February 1990. Harvesting rates in Swiss forests gradually increased between 1991 and 2007; peak values in 2006 and 2007 resulted in small net removals. In 2008 harvesting rates dropped (Table 6-15), and the subsequent downward trend was reinforced by international and domestic economic framework conditions. Relatively small net removals in 2011, 2014 and 2018 were due to relatively high harvesting rates combined with above-average losses in the litter pool (related to weather conditions). Since 2019 harvesting rates tend to increase again. These fluctuations of the main driving forces are reflected in the year-to-year variability of net CO_2 eq emissions and removals from Forest land.

4G: In terms of climate policy, sustainable forest management can be achieved by using the wood grown in a cascade, firstly for long-lived harvested wood products and subsequently for energy purposes. In almost all years since 1990, more wood has been incorporated into new products (such as construction timber or wood panels) than has been released from old ones. However, the size of the annual net CO_2 removals from harvested wood products decreased clearly since 2011. In 2013, 2017, 2019 and 2020 HWP fluxes resulted in small net CO_2 emissions (see Figure 2-9 and Figure 6-21 for details).

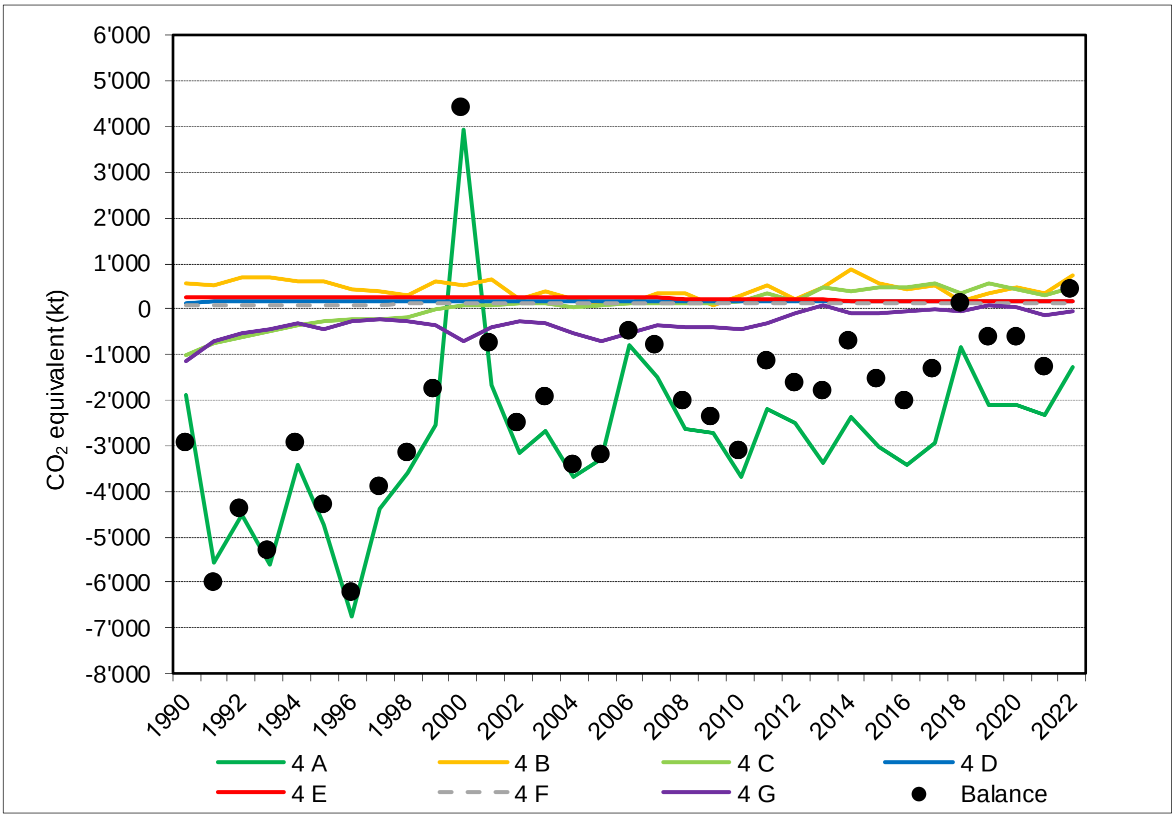

Figure 2-9 Net GHG (CO_2, CH_4, N_2O) emissions and removals in the LULUCF sector (in kt CO_2 eq) broken down by categories 4A-4G. Balance indicates the annual net total. Positive values refer to net emissions, negative values refer to net removals.

4B, 4C: The agricultural use of Cropland and Grassland affects the carbon stock in soils. For example, ploughing promotes the decomposition of soil organic matter, whereas spreading farmyard manure or leaving harvest residues on the fields increases soil carbon stocks. Along with the management method, the crops grown and the weather conditions are the main factors influencing the annual fluctuations of CO_2 fluxes. The case of drained former peatlands is a special one. When subjected to intense agricultural use, these organic soils release large amounts of CO_2 and N_2O. In both categories 4B Cropland and 4C Grassland, consequently, the curves of net CO_2 eq emissions and removals are shifted upwards by persistently high emissions from organic soils (Figure 6-10 and Figure 6-14, respectively; Figure 2-9). Overall, category 4B shows weakly to moderately fluctuating net CO_2 eq emissions at an intermediate level over the inventory period, while category 4C acts as a steadily decreasing sink in the first decade, to later resemble the signal of category 4B as a net emitter (Figure 2-9).

4D: Unproductive wetlands only account for a small part of the land area. As most remaining peatlands are impaired by the consequences of previous use (particularly drainage), many organic soils are now net GHG sources. CO_2 eq emissions in category 4D are comparatively low and increased by 18 % over the inventory period (Figure 2-9; Figure 6-18).

4E: The development of new settlements and infrastructure resulted in comparatively low CO_2 eq emissions since 1990. Emissions in category 4E are mainly produced by the loss of plant biomass and soil organic carbon during construction work. In contrast, increasing greening in the sealed areas over the last two decades has helped to curb emissions. Overall, the change in net CO_2 eq emissions between 1990 and 2022 was -26 % (Figure 2-9; Figure 6-19).

4F: CO_2 eq emissions in 4F2 Land converted to other land increased by 49 % between 1990 and 2022 (Figure 2-9; Figure 6-20). Mudflows, erosion, landslides, and dynamic changes in stream beds were identified as the main processes causing these land-use changes. The contribution to the GHG balance of the LULUCF sector remains small.

2.2.3. Emission trends for precursor gases

The methodologies concerning calculation of emissions of the precursor gases NO_x, CO, NMVOC and SO_2 (IPCC 2006, Volume 1, Chapter 7) are provided in detail in Switzerland's Informative Inventory Report (FOEN 2024b). Emission trends for precursor gases show a very pronounced decline (see Table 2-6 and Figure 2-10). A strict air pollution control policy and the implementation of a large number of emission reduction measures led to decreasing emissions of precursor gases over the period 1990–2022.

Overall, the most effective reduction measures were the abatement of exhaust emissions from road vehicles and stationary installations and the incentive taxes on VOC (since 2000) and on fossil combustible fuels (since 2008). The latter measure was (jointly) responsible for the significant shift in the fuel mix of standard fossil fuels in industry from solid and liquid fuels to natural gas and the complete disappearance of residual fuel oil. As a result, NO_x, NMVOC and CO emissions clearly declined between 1990 and 2022.

In addition, the legal restrictions of the sulphur content in liquid fuels and the switch from gas oil to natural gas in residential heating are important for the significant decrease in SO_x emissions (SO_x = SO_2 + SO_3, expressed as SO_2 equivalents) observed. The lowering of the maximum sulphur content in liquid fuels is shown in Table A – 16. Annual fluctuations of SO_x emissions occur mainly due to annual variations of heating degree days, which affects the consumption of gas oil.

Table 2-6 Emissions of precursor gases (kt) (excluding NOx, CO and NMVOC from LULUCF).

Precursor gases and SO_2	**1990**	**1995**	**2000**	**2005**	**2010**
	kt				
NO_x	144	115	102	94	83
CO	817	532	419	321	253
NMVOC	305	211	157	115	99
SO_2	39	26	16	14	10

Precursor gases and SO_2	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	***2022 vs. 1990***
	kt										*%*
NO_x	80	76	72	70	66	62	59	52	51	47	*-67%*
CO	214	193	184	184	179	169	169	153	153	143	*-83%*
NMVOC	89	85	81	78	78	76	75	73	74	73	*-76%*
SO_2	7.8	6.7	5.7	5.0	4.7	4.5	4.2	3.6	3.5	3.1	*-92%*

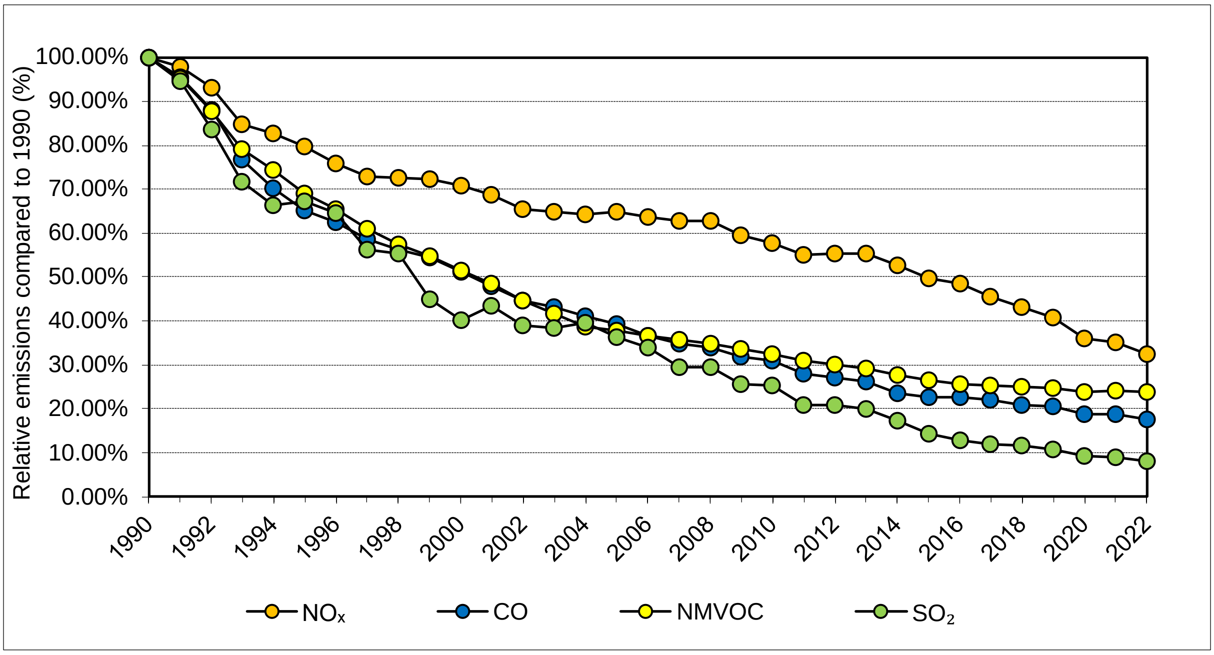

Figure 2-10: Relative trends for precursor gas emissions (excluding NO_x, CO and NMVOC from LULUCF; base year 1990 = 100 %).

Sector 1 Energy is by far the largest source of precursor gas emissions (see Table 2-7), with the only exception being NMVOC, where sector 4 LULUCF is the dominant source followed by sector 2 Industrial processes and product use (see Figure 2-11).

Table 2-7: Precursor gas emissions (kt) by source category in 2022. Totals include LULUCF emissions.

Sectors	**NO_x**		**CO**		**NMVOC**		**SO_2**	
	kt	%	kt	%	kt	%	kt	%
1 Energy	43	91.3%	136	94.5%	16	10.5%	2.7	87.2%
2 IPPU	0.22	0.5%	4.9	3.4%	37	24.6%	0.35	11.3%
3 Agriculture	3.7	7.8%	NA	NA	18	11.9%	NA	NA
4 LULUCF	0.038	0.1%	1.1	0.8%	78	51.8%	0.012	0.4%
5 Waste	0.12	0.3%	1.4	1.0%	1.7	1.2%	0.029	0.9%
6 Other sources	0.014	0.0%	0.47	0.3%	0.07	0.0%	0.007	0.2%
Total	**47**	**100%**	**144**	**100%**	**150**	**100%**	**3.1**	**100%**

Figure 2-11 shows the relative contributions of the various sectors for each individual precursor gas excluding LULUCF (data deduced from Table 2-7).

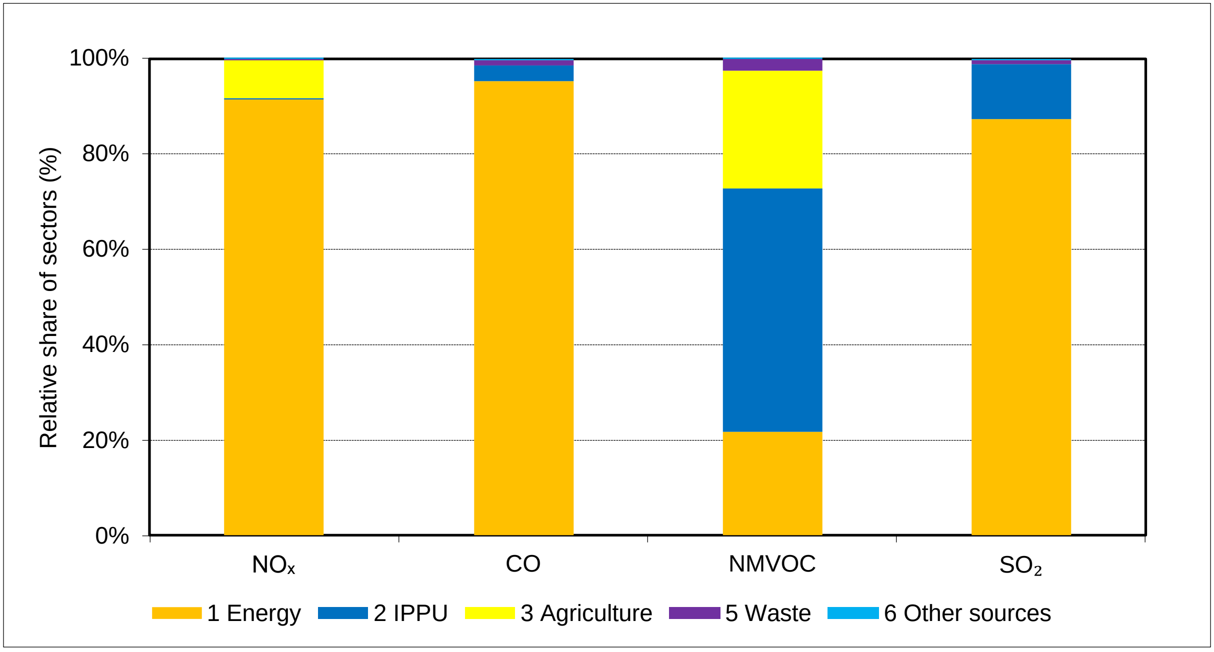

Figure 2-11: Relative contributions of individual sectors to precursor gas emissions in 2022 (excluding LULUCF, note data given in Table 2-7 especially for NMVOC).

3. Energy

Responsibilities for sector Energy	
Overall responsibility	Anouk-Aimée Bass (FOEN)
Experts for source-categories	Anouk-Aimée Bass (FOEN; Overview, Stationary sources in 1A1, 1A4, Bunker fuels, Country-specific issues, Mobile sources in 1A2-1A5), Peter Bonsack (FOEN; Model for stationary engines and gas turbines), Myriam Guillevic (FOEN; Waste related processes), Harald Jenk (FOEN; Road transportation), Daiana Leuenberger (FOEN; Waste related processes), Benedikt Notter (INFRAS; Non-road and Road transportation), Theo Rindlisbacher (FOCA; Civil Aviation), Sabine Schenker (FOEN; Sectoral/Reference Approach, Feedstocks and non-energy use of fuels, Wood combustion, 1A2 (stationary)), Adrian Schilt (FOEN; Country-specific issues Fuel consumption, Industry Model)
EMIS database operation	Anouk-Aimée Bass (FOEN), Myriam Guillevic (FOEN), Sabine Schenker (FOEN)
Annual updates (NID text, tables, figures)	Dominik Eggli (Meteotest), Anna Ehrler (INFRAS), Fabio Fasel (Meteotest), Beat Rihm (Meteotest), Regine Röthlisberger (FOEN), Adrian Schilt (FOEN), Felix Weber (INFRAS)
Quality control NID (annual updates)	Dominik Eggli (Meteotest), Regine Röthlisberger (FOEN), Adrian Schilt (FOEN), Felix Weber (INFRAS)
Internal review	Anouk-Aimée Bass (FOEN), Peter Bonsack (FOEN; Model for stationary engines and gas turbines), Harald Jenk (FOEN; Road transportation), Simone Krähenbühl (FOEN), Daiana Leuenberger (FOEN; Waste related processes), Benedikt Notter (INFRAS; Non-road and Road transportation), Theo Rindlisbacher (FOCA; Civil Aviation), Regine Röthlisberger (FOEN), Sabine Schenker (FOEN), Adrian Schilt (FOEN)

3.1. Overview

This chapter provides information on the estimation of the greenhouse gas emissions from the sector 1 Energy. The following source categories are reported:

- 1A Fuel combustion
- 1B Fugitive emissions from fuels

In Switzerland, the sector 1 Energy is the most relevant source of greenhouse gases. The emissions of the period 1990–2022 are illustrated in Figure 3-1 and Table 3-1.

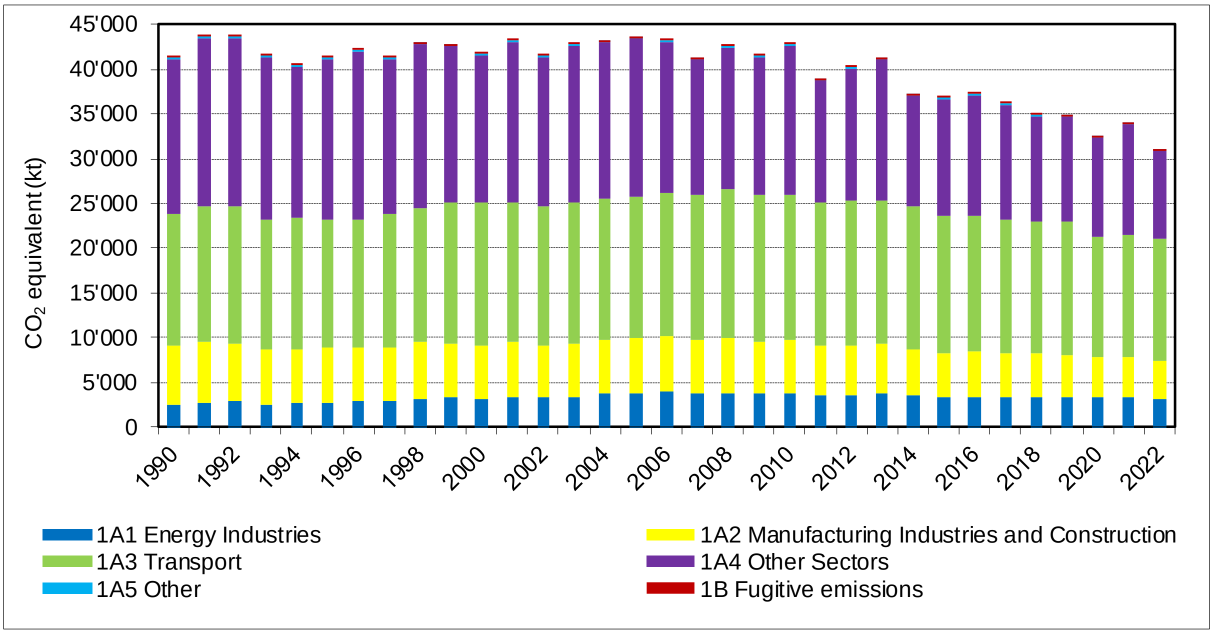

Figure 3-1 Switzerland's GHG emissions of sector 1 Energy in CO_2 equivalent (kt).

Considering total emissions of sector 1 Energy, fluctuations with no trend are observed in the period 1990–2005. From 2006 onwards, a decreasing trend can be identified, again superposed by fluctuations. The years 2020 and 2022 show the lowest values of the entire period 1990–2022. The following source categories contribute to the total emissions (see also Figure 2-6 and explanations in chp. 2.2.2.2):

- 1A3 Transport and 1A4 Other sectors are the main sources of the sector 1 Energy with 1A3 Transport being the most important category over the last years. Emissions in 1A3 Transport increased after 1990, reaching a maximum in 2008 and decreasing again below 1990 level thereafter. Emissions from 1A4 Other sectors are strongly influenced by meteorological conditions in winter. A systematic decrease of emissions from 1A4 is observed since 2005.
- 1A1 Energy industries and 1A2 Manufacturing industries and construction contribute to total emissions as well, but are less important. Emissions in 1A1 Energy industries increased until 2006 with no clear trend since then except for a stepwise reduction in 2015, when one of two refineries closed. Emissions from 1A2 Manufacturing industries are gradually decreasing since 1990.
- 1A5 Other and 1B Fugitive emissions from fuels play only a minor role. Both categories show a decrease since 1990.

The trends of the individual gases are given in Table 3-1 and Figure 3-2:

- By far the most important gas emitted from sector 1 Energy is CO_2. Fluctuations reflect inter alia the climatic variability in Switzerland (see Figure 2-7 and related comments). A decreasing trend is observed since approximately 2005, predominantly due to the decrease in 1A4 Other sectors, but also due to decreasing fuel tourism and the closure of one refinery in 2015. The strong reduction of CO_2 emissions in 2020 compared to previous years is a result of the measures to contain the COVID-19 pandemic leading to reduced CO_2 emissions from source category 1A3b Road transportation and mild winter temperatures leading to reduced emissions from source category 1A4 Other sectors.

- The decreasing trend of CH_4 emissions in the energy sector since 1990 is the result of improved gas transmission and distribution networks, resulting in substantially lower fugitive emissions, and reduced emissions from gasoline passenger cars due to catalytic converters. Furthermore, improved combustion technologies in 1A4 Other sectors – stationary sources also contribute to the decreasing trend.
- The changes in N_2O emissions can mainly be explained by changes in the emission of road transportation due to changes in emission factors for diesel oil and gasoline combustion. The first generation of catalytic converters generated N_2O as an unintended by-product in the exhaust gases, leading to an increase in N_2O emissions until 1997. With new converter materials being used, the emission factors are decreasing since 1999 with strongest reduction in the course of the introduction of the Euro 3 standard during 2003 and 2004 (see Figure 3-2). The massive effective reduction of the maximum sulphur content of the fuels from 2003 to 2004 led to a higher efficiency of the catalytic converters, which additionally strengthened the effect (see Table A – 17). Since 2007, the N_2O emissions are slightly increasing in line with increasing mileages (see Table 3-88). For further details, see chp. 3.2.9.2.2..

Table 3-1 GHG emissions of source category 1 Energy by gas in CO_2 equivalent (kt)

Gas	1990	1995	2000	2005	2010
	CO_2 equivalent (kt)				
CO_2	40'924	40'940	41'362	43'359	42'623
CH_4	427	367	308	273	247
N_2O	284	327	337	208	218
Sum	41'636	41'633	42'007	43'839	43'088

Gas	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2021 vs. 2022	1990 vs. 2022
	CO2 equivalent (kt)										%	
CO_2	40'931	36'922	36'590	36'978	35'994	34'705	34'583	32'166	33'635	30'730	-8.6%	-25%
CH_4	199	170	169	169	167	154	150	141	147	132	-10.1%	-69%
N_2O	227	214	217	226	229	235	240	235	244	239	-2.3%	-16%
Sum	41'357	37'306	36'976	37'372	36'390	35'093	34'973	32'541	34'027	31'101	-8.6%	-25%

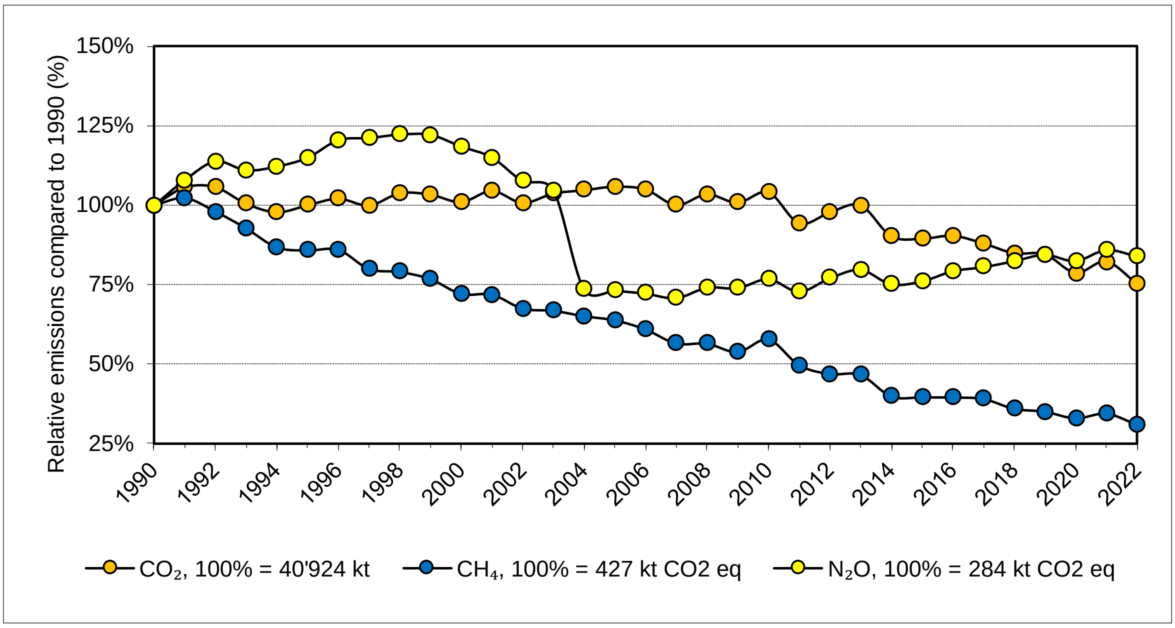

Figure 3-2 Relative trends of the greenhouse gas emissions of sector 1 Energy. The base year 1990 represents 100 %.

The following table summarises the emissions of sector 1 Energy in 2022. The table also includes two additional lines with emissions from international bunkers (aviation and marine) as well as CO_2 emissions from biomass burning, which both are not accounted for under the UNFCCC but are included in the reporting tables.

Table 3-2 Summary of sector 1 Energy, emissions in 2022 in kt CO_2 equivalent (Total: rounded values). For full biomass CO_2 emissions see Table 3-33.

Sector Energy	**CO_2**	**CH_4**	**N_2O**	***Total***
	CO_2 equivalent (kt)			
1 Energy	30'730	132	239	*31'101*
1A Fuel combustion	30'708	89	239	*31'037*
1A1 Energy industries	3'145	0.99	40	*3'186*
1A2 Manufacturing industries and construction	4'179	4.0	36	*4'219*
1A3 Transport	13'447	23	111	*13'581*
1A4 Other sectors	9'814	61	51	*9'926*
1A5b Other (mobile)	122	0.041	0.96	*123*
1B Fugitive emissions from fuels	22	43	0.000070	*65*
International bunkers	4'201	0.37	31	*4'232*
CO_2 emissions from biomass	8'236	-	-	*8'236*

In 2022, a total of 45 key source categories are identified in the Swiss greenhouse gas inventory (Table 1-6). Amongst these, 18 belong to sector 1 Energy. The key categories for approaches 1 and 2 (according to level and trend) from sector 1 Energy are shown in Figure 3-3. While 18 categories are identified as key according to approach 1, only 6 categories are also identified as key according to approach 2. Indeed, Sector 1 Energy is the major sector in terms of emissions, while sector 3 Agriculture and 4 LULUCF dominate the uncertainty contribution (see also Figure 5-3 to compare with sector 3 Agriculture).

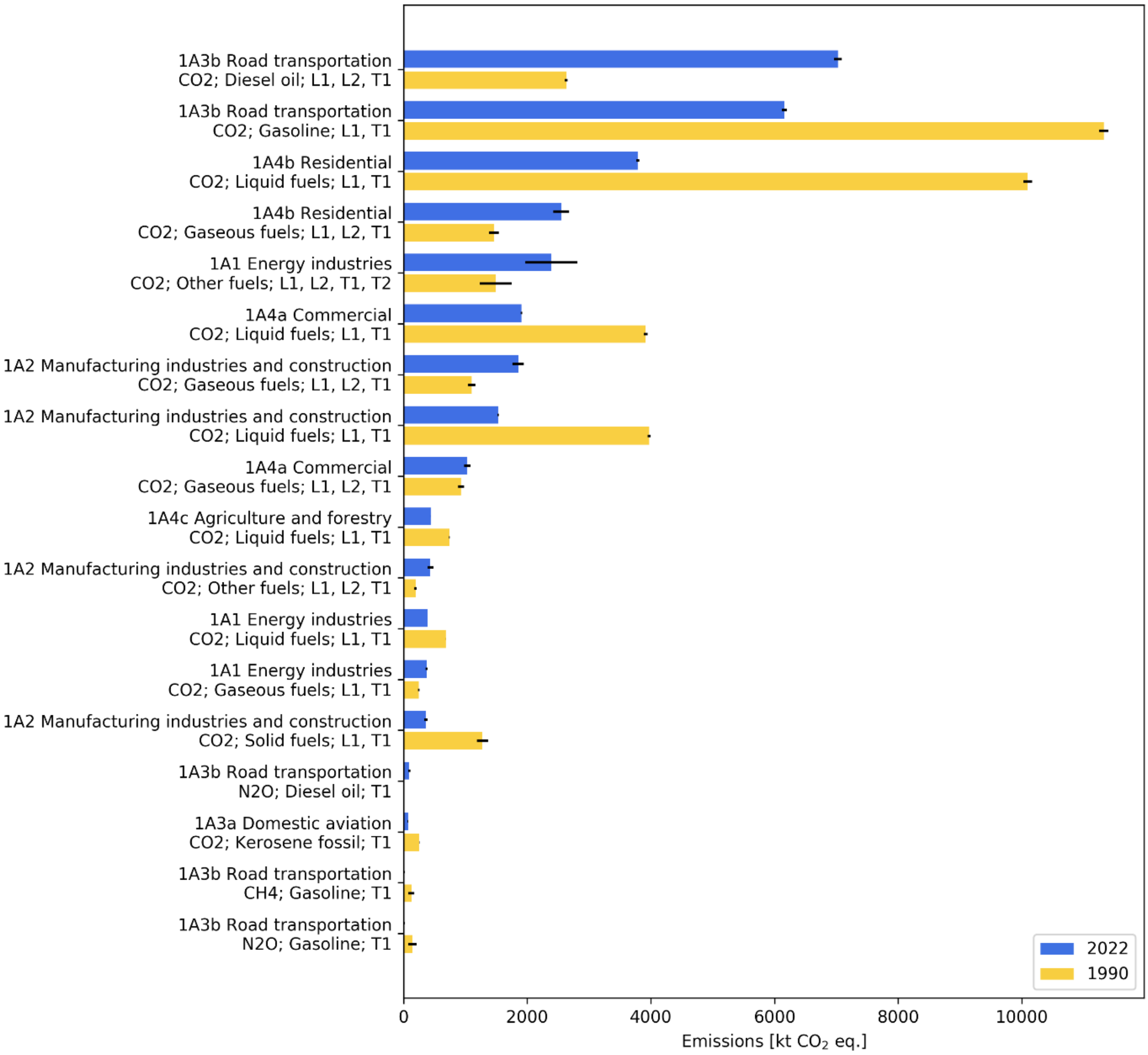

Figure 3-3 Key categories in the Swiss GHG inventory from sector 1 Energy determined by the key category analyses, approaches 1 and 2. Categories are set out in order of decreasing emissions in 2022. L1: key category according to approach 1 level in 2022; L2: same for approach 2; T1: key category according to approach 1 trend 1990–2022; T2: same for approach 2. Black uncertainty bars represent the narrowest 95 % confidence interval obtained by Monte Carlo simulations (see chp. 1.6 for details).

3.2. Source category 1A – Fuel combustion activities

3.2.1. Comparison of the Sectoral Approach with the Reference Approach

Two methods are applied for modelling CO_2 emissions from the sector 1 Energy, the Sectoral Approach and the Reference Approach. The Sectoral Approach is based on sectoral energy consumption data from the Swiss overall energy statistics (SFOE 2023) and additional source-specific information. In the Sectoral Approach, fossil fuel consumption statistics are combined with bottom-up data and modelling of fuel consumption. A detailed description of the Sectoral Approach is provided in chp. 3.2.4.

The Reference Approach corresponds to a top-down approach based on net quantities of fuel imported into Switzerland as listed in the energy supply statistics of the Swiss overall energy statistics (SFOE 2023). Apparent consumption (in tonnes) is derived from imports and exports of primary fuels (crude oil, natural gas, coal), secondary fuels (gasoline, diesel oil etc.) and stock changes. For crude oil, a constant value for carbon content and net calorific value is applied for the entire time period, although these properties may vary depending on origin. For solid, gaseous, secondary liquid and other fuels, the same carbon content values and net calorific values are applied as in the Sectoral Approach (see Table 3-10 and Table 3-11, Table 3-13 and Table 3-14 in chp. 3.2.4.2 and 3.2.4.5). After the deduction of feedstocks and non-energy use of fuels (see chp. 3.2.3), the net carbon emissions and effective CO_2 emissions are calculated for the Reference Approach as shown in the reporting tables 1.A(b)–1.A(d). The oxidation factor is set to one (see chp. 3.2.4.5.1).

Figure 3-4 shows the input data used and the disaggregation of fuel types for each of the two approaches.

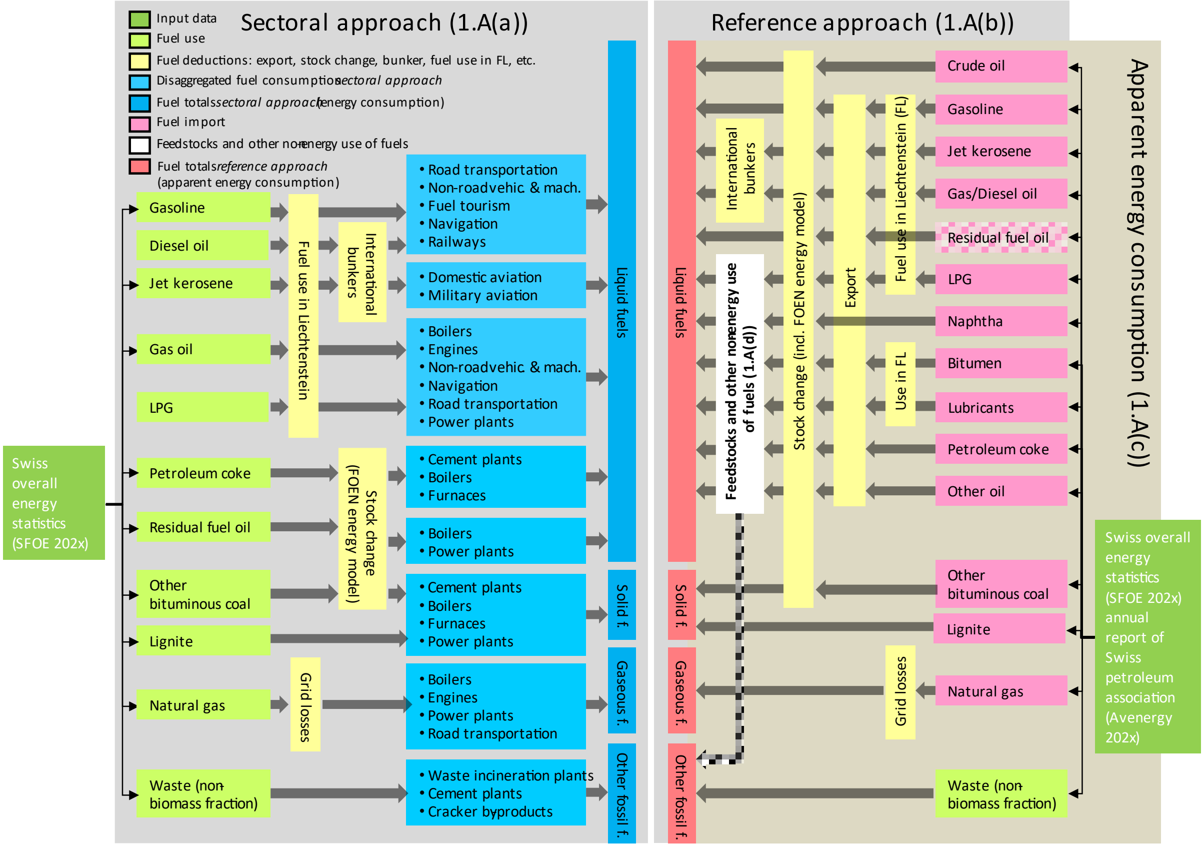

Figure 3-4 Calculation of Reference and Sectoral Approach. The input data for both approaches stem from the Swiss overall energy statistics (SFOE 2023). For the Reference Approach, additional information from Avenergy Suisse (formerly Swiss Petroleum Association) (Avenergy 2023) is used. While the Reference Approach considers the net import/export balance, the Sectoral Approach considers the fuel consumption. The dark grey arrows represent fuel deductions where occurring. The dashed arrow from the Feedstock use to Other fossil fuels stands for the CO_2 emissions from cracker by-products (originating from feedstock use of liquefied petroleum gas and naphtha) which are accounted for under Other fossil fuels. The graphic box of the import of Residual fuel oil is dashed since there is no more import of residual fuel oil. Coke oven coke and anthracite are included under other bituminous coal.

All necessary data for calculating the Reference Approach are implemented in the EMIS database and all the data on import, export, bunkers, stock changes, apparent consumption, carbon emission factors, carbon stored and actual emissions are calculated in the EMIS database under the following conditions:

- For the Reference Approach, gas oil and diesel oil are reported together, since the reporting table template structure requires this aggregation. Accordingly, a weighted average NCV is calculated based on values given in Table 3-10. In contrast, marine bunkers consist of diesel oil only and are reported using the country-specific NCV as of Table 3-10.
- Liechtenstein’s liquid fossil fuel consumption is subtracted from the input figures in SFOE (2023), as the Swiss overall energy statistics includes Liechtenstein’s liquid fuel consumption as well (customs union with Switzerland) (see also chp. 3.2.4). The same holds for the non-energy use of bitumen and lubricants.

The differences in energy consumption and CO_2 emissions between Reference and Sectoral Approach are calculated within the EMIS database. For the entire period, they are below 1 % for energy consumption and in the range of about 1 % for CO_2 emissions, as shown in Table

3-3 and in Figure 3-5. Various effects influence the difference between Reference and Sectoral Approach. On the one hand, energy and carbon contents of crude oil may vary over time. However, no data are available to quantify this effect. On the other hand, the efficiency of refineries and the market share of secondary fuel imports potentially influence the difference between the Reference and Sectoral Approach. Apparent differences between the Reference Approach and the IEA energy statistics are discussed in Annex A3.2.

Table 3-3 Differences in energy consumption and CO_2 emissions between the Reference and the Sectoral Approach. The difference is calculated according to [(RA-SA)/SA] * 100 % with RA = Reference Approach, SA = Sectoral Approach.

	1990	**1995**	**2000**	**2005**	**2010**
			%		
Energy consumption	0.7	0.8	0.5	0.5	0.5
CO_2 emissions	0.8	1.0	0.8	0.9	1.0

	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
					%					
Energy consumption	0.4	0.4	0.2	0.6	0.3	0.1	0.7	0.1	-0.1	-0.1
CO_2 emissions	0.9	1.0	0.6	1.1	0.8	0.8	1.2	0.7	0.4	0.4

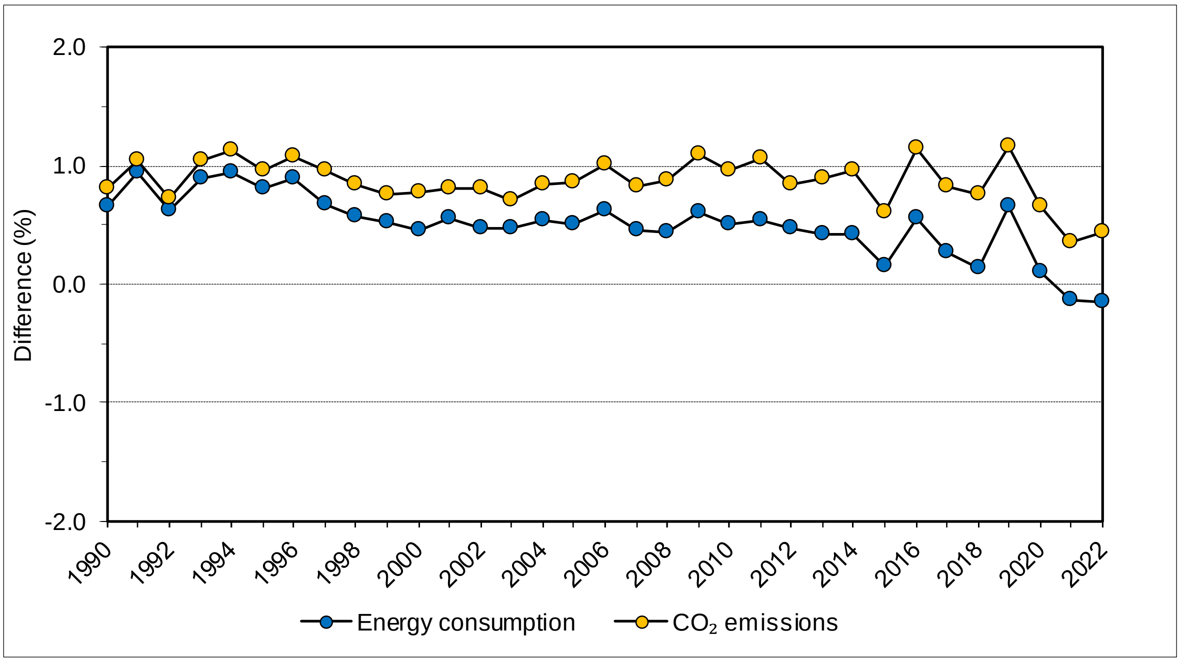

Figure 3-5 Time series for the differences between Reference and Sectoral Approach. Numbers are taken from Table 3-3. See caption there for further information.

3.2.1.1. Category-specific recalculations for the Reference Approach

The following recalculations were implemented in submission 2024. Recalculations are also described in the relevant chapters of the sectoral approach or the chapter on feedstock and non-energy use of fuels if they have an impact.

- 1AB: Recalculations in exports and stock change of bitumen in 2020 and 2021 due to revised data in the annual report of the Swiss petroleum association (Avenergy 2023).

3.2.2. International bunker fuels (1D)

3.2.2.1. Source category description for 1D

With Switzerland being a landlocked country, international aviation dominates emissions from bunker fuels by far. International navigation is limited to activities on the river Rhine (Basel – Rotterdam) and navigation on Lake Geneva (bordering France) and Lake Constance (bordering Germany and Austria).

Table 3-4 Source category description of international bunkers.

1D	Source category	Specification
1D1	International aviation (aviation bunkers)	Bunker fuels include fuel used for international aviation only.
1D2	International navigation (marine bunkers)	Marine bunkers of the Rhine river and navigation on the Lake Geneva and the Lake Constance.

3.2.2.2. Methodological issues for 1D

3.2.2.2.1. International aviation / aviation bunkers (1D1)

Following the decision tree of the 2006 IPCC Guidelines (IPCC 2006, Volume 2 Energy, chp. 3 Mobile Combustion, Figure 3.6.1), the emissions from aviation bunkers are calculated with a Tier 3A method because of availability of data on the origin and destination of flights and also on air traffic movements delivered by the Federal Office of Civil Aviation (FOCA).

The Tier 3A method follows standard modelling procedures at the level of single aircraft movements based on detailed movement statistics. For international aviation (aviation bunkers), the flights departing from Switzerland to a destination abroad are selected. The emission factors are country-specific based on measurement and analyses of fuel samples. The activity data of the international aviation bunker are summarised in Table 3-6 (see also Table 3-85). Given that detailed information about activity data is available, the resulting fuel consumption is considered complete. In spite of this, there remain small differences between the fuel consumption modelled bottom-up and the total fuel sold (SFOE 2023, FOCA 2023). In 1990, the modelled consumption adds up to 1.01 million tonnes, whereas 1.05 million tonnes of fuel were sold. Such difference of 4 % is considered acceptable, because discrepancies up to 10 % can easily result from fuelling strategies of airlines (FOCA 2006a). Investigation showed, that airlines are calculating whether it is economically beneficial to refuel at a place with lower fuel price. In order to match the bottom-up calculation with the fuel quantity sold, any occurring difference is attributed to international bunker emissions. The factor between calculated international fuel consumption and adjusted international fuel consumption is used to scale the bunker emissions linearly. For instance, in 2022, the bunker fuel consumption and the emissions had to be expanded by the factor 1.04, the correction factor was 0.959 (FOCA 2023). For the years 2020 and 2021, the overestimation of emissions from international aviation was very high compared to previous years because the modelling of aircraft fuel consumption is based on practically fully loaded aircraft (high load). Due to exceptional measures to contain the COVID-19 pandemic during the years 2020 and 2021, many flights were very lightly loaded which in terms of aircraft led to slightly lower fuel consumption per route. More direct flight paths (low traffic volume) may be another reason. These effects relate almost exclusively to international flights. In 2022, aircraft seat load factors increased to high values again, with aircraft operating at their usual weights. Thus, overestimation of the fuel burn from the model decreased again. For the more recent years, the modelled and actual total fuel sales are listed in Table 3-5.

Table 3-5 Comparison between modelled and actual fuel sales in bunker fuel consumption (FC) for aviation.

Modelled and actual fuel sales	**Unit**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Modelled fuel sales domestic	FC in t	43'968	37'627	39'626	39'252	42'047	43'414
Modelled fuel sales international	FC in t	1'287'062	1'391'656	1'345'919	1'395'428	1'511'279	1'527'522
Actual fuel sales SFOE minus modelled fuel sales domestic	FC in t	1'289'152	1'382'835	1'324'224	1'390'824	1'488'805	1'523'116
Correction factor for emission international		0.967	0.967	0.954	0.969	0.957	0.969
Overestimation emission international (modelled)	%	3.3%	3.3%	4.6%	3.1%	4.3%	3.1%

Modelled and actual fuel sales	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Modelled fuel sales domestic	FC in t	42'064	44'462	43'680	44'716	37'985	36'561	36'357	24'449	18'763	21'845
Modelled fuel sales international	FC in t	1'528'863	1'561'678	1'590'013	1'711'227	1'741'752	1'818'355	1'836'385	727'941	818'030	1'388'366
Actual fuel sales SFOE minus modelled fuel sales domestic	FC in t	1'539'963	1'549'228	1'602'319	1'679'034	1'723'717	1'823'917	1'846'453	677'093	756'549	1'352'840
Correction factor for emission international		0.980	0.964	0.980	0.955	0.968	0.983	0.986	0.897	0.902	0.959
Overestimation emission international (modelled)	%	2.0%	3.6%	2.0%	4.5%	3.2%	1.7%	1.4%	10.3%	9.8%	4.1%

Table 3-6 International bunker fuels (1D1): aviation bunkers. Consumption of jet kerosene in TJ (Liechtenstein's jet kerosene consumption is subtracted, see chp. 3.2.4).

1D1 International aviation	**1990**	**1995**	**2000**	**2005**	**2010**
	Fuel consumption in TJ				
1D1 International aviation	41'884	49'918	63'726	47'775	58'334
1990 = 100%	100%	119%	152%	114%	139%

1D1 International aviation	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	Fuel consumption in TJ									
1D1 International aviation	64'709	65'006	67'333	70'603	72'824	77'214	78'196	28'194	31'847	57'499
1990 = 100%	154%	155%	161%	169%	174%	184%	187%	67%	76%	137%

3.2.2.2.2. International navigation / navigation bunkers (1D2)

According to the decision tree concerning navigation bunkers (IPCC 2006, Volume 2 Energy, chp. 3 Mobile Combustion, Figure 3.5.1), emissions from international navigation are calculated with a Tier 2 approach for CO_2 (with country-specific carbon contents) and with a Tier 1 approach for CH_4 and N_2O using IPCC default emission factors. On the river Rhine and on Lake Geneva and Lake Constance, some of the boats cross the border and go abroad (Germany, France). Fuels bought in Switzerland will therefore become bunker fuel. Accordingly, the amount of bunker diesel oil is reported as a memo item "International bunker / navigation".

- Only diesel oil is relevant for navigation on the river Rhine. Since there is an exemption from fuel taxation, activity data on marine river bunkers on the Rhine are well documented by the customs administration for the years 1997–2022 (SFOE 2023f).
- For navigation on two border lakes (Lake Constance, Lake Geneva), bunker fuel consumption was reported in INFRAS (2011a) after having performed surveys among the shipping companies involved. Activity data of these bunkers is summarised in Table 3-7. Data from 1995–2012 have been provided by the three navigation companies concerned as documented in INFRAS (2011a), data from 2013 onwards are constant around the 2013 level. The values from INFRAS 2011 have been adapted to the new measures of the net calorific value of diesel oil for the year 2013 as shown in table 3-10. For the years 1990 to 1994, proxies such as passenger data on a national basis had to be consulted. As marine lake bunkers provided only a minor share of the total international navigation in the early 1990s (about 7 %) this approach is justified. The emission factor for CO_2 is country-specific and in accordance with Table 3-13.

Table 3-7 International bunker fuels (1D2): Navigation. Consumption of diesel oil in TJ.

1D2 International navigation	**1990**	**1995**	**2000**	**2005**	**2010**
	Fuel consumption in TJ				
1D2 International navigation	821	739	531	493	471
1990 = 100%	100%	90%	65%	60%	57%

1D2 International navigation	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	Fuel consumption in TJ									
1D2 International navigation	342	299	342	299	256	200	197	189	228	207
1990 = 100%	42%	36%	42%	36%	31%	24%	24%	23%	28%	25%

3.2.2.3. Uncertainties and time-series consistency for 1D

International bunker fuels: see general remarks in chp. 3.2.4.9.

Consistency: Time series of 1D are all considered consistent.

3.2.2.4. Category-specific QA/QC and verification for 1D

The general QA/QC procedures are described in chp. 1.5. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.10.

3.2.2.5. Category-specific recalculations for 1D

There were no recalculations implemented in submission 2024.

3.2.2.6. Category-specific planned improvements for 1D

No category-specific improvements are planned.

3.2.3. Feedstocks and non-energy use of fuels

The Swiss overall energy statistics (SFOE 2023) reports feedstocks and non-energy fuel use on an aggregated level only. Some disaggregation is provided by the petroleum balance of the annual report of Avenergy Suisse (formerly Swiss petroleum association, EV) (Avenergy 2023). To complement this source, bottom-up data from annual monitoring reports of the Swiss emissions trading scheme (ETS) and from surveys of individual companies are used to provide a detailed breakdown into specific petroleum products and coal types. For submission 2015, a more differentiated breakdown of feedstocks and non-energy use of fuels was developed, which is described in an internal documentation (FOEN 2015g).

Feedstocks and non-energy use of fuels is reported in reporting tables 1.A(d) and differentiated in the following fuel types:

- Liquefied petroleum gas and naphtha are exclusively used in one single Swiss plant as feedstocks in the thermal cracking process for the production of ammonia and ethylene (see source categories 2B1 and 2B8b under chp. 4.3.2.1 and 4.3.2.4, respectively). Accordingly, activity data for liquefied petroleum gas and naphtha are confidential and included in fuel type Other oil in reporting table 1.A(d).

- Bitumen is the most important petroleum product which is used as a feedstock in Switzerland. It is mainly used for road paving with asphalt and to a lower extent in asphalt roofing (see source category 2D3 under 4.5.2.2).
- Lubricants are used in a variety of processes, including the blending with gasoline for 2-stroke engines. Two different ways of lubricant use are considered: lubricants used in 2-stroke engines are assumed to be 100 % oxidised, whereas the use of all other lubricants is partly emissive. According to the 2006 IPCC Guidelines (IPCC 2006), 20 % of those lubricants are oxidized during use (ODU). All CO_2 emissions from use of lubricants are reported under source category 2D1, see chp. 4.5.2.1.
- Petroleum coke is used as a feedstock by two consumers only, i.e. for the production of silicium carbide and graphite as well as of anodes in primary aluminium production (up to 2006) in source categories 2B5 and 2C3, respectively (see chp. 4.3.2.3 and 4.4.2.2). Apart from bottom-up information from these two consumers, top-down information is provided by Avenergy Suisse (Avenergy 2023). Activity data are confidential and included in fuel type Other oil in reporting table 1.A(d).
- Paraffin waxes for non-energy use are reported under Other oil, since there is no separate category for paraffin waxes in reporting table 1.A(d). The information used stems from the statistics of Avenergy Suisse (Avenergy 2023). Use of paraffin waxes is considered partly emissive (see source category 2D2 under chp. 4.5.2.1). According to the 2006 IPCC Guidelines (IPCC 2006), 20 % of paraffin waxes are oxidized during use (ODU).
- Other oil comprises all other unspecified petroleum products for non-energy use. The net consumption of non-energy use of fuels reported in the Swiss overall energy statistics includes also sulphur produced by the refineries. This amount of sulphur is subtracted, resulting in lower fuel quantities for non-energy use of other oil for the entire time series compared to the Swiss overall energy statistics.
- Anthracite is also used as feedstock in the Swiss production plant for silicium carbide and graphite in source category 2B5 (chp. 4.3.2.3). Accordingly, activity data for anthracite are confidential and thus denoted as “C” in reporting tables 1.A(d). Based on personal communication with the relevant experts for the Swiss overall energy statistics, the feedstock use of anthracite is included in the stock changes of other bituminous coal.

Table 3-8 This table is only available in the confidential version of this chapter. It provides a complete time series of the fuel quantity, carbon excluded and the reported CO_2 emissions from feedstocks and non-energy use of fuels.

3.2.3.1. Category-specific recalculations for 1AD

1AD: CO_2 emissions from lubricants use (reported under 2D1) changed due to recalculated gasoline consumption of 2-stroke motorcycles (1A3biv) from 2001 onwards.

3.2.4. Country-specific issues of 1A Fuel combustion

3.2.4.1. System boundaries: Differences between UNFCCC and CLRTAP reporting

Switzerland uses the same data base for the Swiss greenhouse gas inventory as for the Swiss air pollution inventory and reports its greenhouse gas emissions according to the requirements of the UNFCCC as well as air pollutants according to the requirements of the CLRTAP. The nomenclature for both types of reporting is (almost) the same (NFR), but there are differences concerning the system boundaries. Under the UNFCCC, the national total for assessing compliance is based on fuel sold within the national territory, whereas under the CLRTAP, the national total for assessing compliance is based on fuel used within the territory.

One difference occurs for 1A3b Road transportation as can be seen from Table 3-9, columns “National total” of “CLRTAP / NFR tables” and of “UNFCCC / CRT tables” compared to the column “National total for compliance” of “CLRTAP / NFR tables”. The “National total for compliance” of “CLRTAP / NFR tables” does not contain the amount of fuel sold in Switzerland but consumed abroad, which is called “Fuel tourism and statistical difference”, and which is accounted for in Switzerland’s GHG inventory, but not in the reporting under the CLRTAP (see chp. 3.2.9.2.2). The difference between the two approaches amounts to several percent, with considerable variation from year to year due to fluctuating fuel price differences between Switzerland and its neighbouring countries. Note that the fuel tourism and statistical difference from 1A3b Road transportation is reported differently in the tables for the GHG inventory and the ones for the air pollutant inventory. In the air pollutant inventory, fuel tourism is allocated to the source categories 1A3bi-iii in proportion to annual fuel consumption within the respective vehicle categories (see FOEN 2024b, chp. 3.2.6.2.2). In the GHG inventory, the allocation is different for gasoline, diesel oil, gaseous fuels and biomass due to a problem with the CRF reporter (see chp. 3.2.9.2.2).

Also, emissions from civil aviation are reported differently under the UNFCCC and the CLRTAP: Only emissions from domestic flights are accounted for in the GHG inventory, while emissions from international flights are reported as aviation bunker, i.e. as memo item (1D1 International aviation). For the reporting of air pollutants under the CLRTAP, landing and take-off (LTO) cycle emissions of domestic and international flights are accounted for, while emissions of international and domestic cruise flights are reported as memo items only (Table 3-9). Note that emissions from overflights without landing in Switzerland are not considered in any of the approaches.

Table 3-9 Accounting rules for emissions from 1A3a Domestic aviation and 1A3b Road transportation under the CLRTAP and the UNFCCC.

Differences between reporting under CLRTAP and UNFCCC concerning the accounting to the national total			CLRTAP / NFR tables			UNFCCC / CRT tables	
			accounted to				
			National total	National total for compliance	Separated information / Memo items	National total	Bunker (1D)
Road transportation (1A3b)	Fuels sold (1A3b)	Fuel used (1A3bi–v)	Yes	Yes	Yes	Yes	No
		Fuel tourism and statistical differences	Yes	No	No	Yes	No
Aviation (1A3a)	Civil and domestic aviation	Landing and Take-Off (LTO)	Yes	Yes	No	Yes	No
		Cruise	No	No	Yes	Yes	No
	International aviation	Landing and Take-Off (LTO)	Yes	Yes	No	No	Yes
		Cruise	No	No	Yes	No	Yes

3.2.4.2. Net calorific values (NCVs)

Table 3-10 summarises the net calorific values (NCVs) which are used in order to convert from energy amounts in tonnes into energy quantities in gigajoules (GJ). More detailed explanations including information about the origin of the NCVs of the different fuels are given below.

Table 3-10 Net calorific values (NCVs) of various fuels. Where values for two years are indicated, the NCV is interpolated between these two years and constant NCVs are used before the first and after the second year (corresponding to the two indicated values). For the NCV of wood, a range covering all facility categories and years is provided. For the NCVs of natural gas and biogas see Table 3-11.

Fuel	Year		NCV	Unit	Data sources
Fossil fuel					
Gasoline	until	1998	42.5	GJ/t	EMPA (1999)
	from	2013	42.6	GJ/t	SFOE/FOEN (2014)
Jet kerosene	until	1998	43.0	GJ/t	EMPA (1999)
	from	2013	43.2	GJ/t	SFOE/FOEN (2014)
Diesel oil	until	1998	42.8	GJ/t	EMPA (1999)
	from	2013	43.0	GJ/t	SFOE/FOEN (2014)
Gas oil	until	1998	42.6	GJ/t	EMPA (1999)
	from	2013	42.9	GJ/t	SFOE/FOEN (2014)
Residual fuel oil	from	1990	41.2	GJ/t	EMPA (1999)
Liquefied petroleum gas	from	1990	46.0	GJ/t	SFOE (2023)
Petroleum coke	until	1998	35.0	GJ/t	SFOE (2023)
	from	2010	31.8	GJ/t	Cemsuisse (2010a)
Other bituminous coal	until	1998	28.052	GJ/t	SFOE (2023)
	from	2010	25.5	GJ/t	Cemsuisse (2010a)
Lignite	until	1998	20.097	GJ/t	SFOE (2023)
	from	2010	23.6	GJ/t	Cemsuisse (2010a)
Biofuel					
Biodiesel	from	1990	32.7	GJ/m3	SFOE (2023)
Bioethanol	from	1990	21.1	GJ/m3	SFOE (2023)
Wood	from	1990	8.6-14.6	GJ/t	SFOE (2023b)

Gasoline, jet kerosene, diesel oil and gas oil

For gasoline, jet kerosene, diesel oil and gas oil, the NCV for 1998 and 2013 are based on national measurement campaigns and are the same as used by the Swiss Federal Office of Energy (SFOE 2023). A first campaign was conducted by the Swiss Federal Laboratories for Materials Science and Technology (Empa) in 1998 (EMPA 1999). Since earlier data are not available, the values for 1990–1998 are assumed to be constant at the 1998 levels. A second campaign, commissioned by the Swiss Federal Office of Energy (SFOE) and the Swiss Federal Office for the Environment (FOEN), was conducted in 2013 (SFOE/FOEN 2014). This study was based on representative samples covering summer and winter fuel qualities from the main import streams. The sampling started in July 2013 and lasted six months. Samples were taken fortnightly from nine different sites (large-scale storage facilities and the two refineries operating at that time in Switzerland) and analysed for carbon contents and NCVs amongst other. These updated values are used from 2013 onwards, while the NCVs for 1999–2012 are linearly interpolated between the measured values of 1998 and 2013.

Residual fuel oil

Residual fuel oil plays only a minor role in the Swiss energy supply. Therefore, this fuel was not analysed in the most recent measurement campaign in 2013 (SFOE/FOEN 2014). Thus, the respective NCV refers to the measurement campaign in 1998 (EMPA 1999). The NCV for residual fuel oil, which is the same as used by the Swiss Federal Office of Energy (SFOE 2023), is assumed to be constant over the entire reporting period. The same approach is applied for the CO_2 emission factor (see Table 3-13).

Liquefied petroleum gas

The NCV of liquefied petroleum gas is the same as used by the Swiss Federal Office of Energy (SFOE 2023) and is – as in the Swiss overall energy statistics – constant over the entire reporting period. It is assumed that liquefied petroleum gas is a mixture of propane and butane in equal proportions.

3.2.4.3. Petroleum coke, other bituminous coal, lignite

For the entire reporting period, the NCVs of petroleum coke, other bituminous coal and lignite are the same as used by the Swiss Federal Office of Energy (SFOE 2023). For these fuels, the Swiss overall energy statistics contains NCVs for the years 1998 and 2010. Values in between are interpolated, with values before the first and after the last year of available data held constant. The NCVs for 2010 are based on measured samples taken from Switzerland's cement plants as they are the largest consumers of these fuels in Switzerland. Samples from the individual plants were taken from January to September 2010 and analysed for NCVs by an independent analytical laboratory (Cemsuisse 2010a). For each fuel, the measurements from the individual plants were weighted according to the relative consumption of each plant.

Natural gas, biogas

The NCV of natural gas (and also the CO_2 emission factor of natural gas, see Table 3-14) is calculated based on measurements of gas properties and corresponding import shares of individual gas import stations. Measurements of gas properties are available from the Swiss Gas and Water Industry Association (SGWA) on an annual basis since 2009 and for selected years before. The latest report is SGWA (2023). Import shares are available for 1991, 1995, 2000, 2005, 2007 and from 2009 onwards on an annual basis. Estimated import shares for the years 1991, 1995 and 2000 are taken from Quantis (2014). Values for the years in between are interpolated. The calculation procedure is documented in FOEN (2023i). The NCV of biogas is assumed to be equal to the NCV of natural gas since the raw biogas is treated to fulfil the same quality level including its energetic properties as natural gas.

Table 3-11 Net calorific values (NCVs) of natural gas and biogas for years with available data. Values for the years in between are linearly interpolated. Data source: Annual reports of the Swiss Gas and Water Industry Association (SGWA), the latest report is SGWA (2023). Spreadsheet to determine national averages: FOEN (2023i).

Year	NCV of natural gas and biogas [GJ/t]
1990	46.5
1991	46.5
1995	47.5
2000	47.2
2005	46.6
2007	46.3
2009	46.4
2010	46.3
2011	46.1
2012	45.8
2013	45.7
2014	45.7
2015	46.6
2016	47.1
2017	47.4
2018	47.6
2019	47.5
2020	47.6
2021	48.2
2022	48.0

Wood

The NCV of wood depends on the type of wood fuel (e.g. log wood, wood chips, pellets) and is based on the Swiss wood energy statistics (SFOE 2023b). Table 3-10 illustrates the range of the NCVs of all wood fuel types.

Bioethanol and biodiesel

The NCVs of bioethanol and biodiesel are the same as used by the Swiss Federal Office of Energy (SFOE 2023) and are – as in the Swiss overall energy statistics – constant over the entire reporting period.

3.2.4.4. Swiss energy model and final energy consumption

3.2.4.4.1. Swiss overall energy statistics

The fundamental data on final energy consumption is provided by the Swiss overall energy statistics (SFOE 2023). However, since Switzerland and Liechtenstein form a customs and monetary union governed by a customs treaty, data regarding liquid fuels in the Swiss overall energy statistics also cover liquid fuel consumption in Liechtenstein. In order to calculate the correct Swiss fuel consumption, Liechtenstein’s liquid fossil fuel consumption, given by Liechtenstein’s energy statistics (OS 2023), is subtracted from the numbers provided by the Swiss overall energy statistics. In all years of the reporting period, the sum of liquid fossil fuels used in Liechtenstein was less than half a percent of the Swiss consumption.

The energy-related activity data in the energy model and thus in the GHG inventory correspond to the energy balance provided in the Swiss overall energy statistics (SFOE 2023). The energy statistics are updated annually and contain all relevant information about primary and final energy consumption. This includes annual aggregated consumption data for various fuels and main consumers such as households, transport, energy industries, industry, and services (see energy balance in Annex A3.1).

The main data sources of the Swiss overall energy statistics are:

- The Swiss organization for the compulsory stockpiling of oil products (Carbura) and Avenergy Suisse (formerly Swiss petroleum association, EV) for data on import, export, sales, stocks of oil products and for processing of crude oil in refineries.
- Annual import data for natural gas from the Swiss Gas Industry Association (VSG).
- Annual import data for petroleum products and coal from the Federal Office for Customs and Border Security (FOCBS).
- Data provided by industry associations (GVS, SGWA, Cemsuisse, VSG, VSTB, etc.).
- Swiss electricity statistics (SFOE 2023g).
- Swiss renewable energy statistics (SFOE 2023a).
- Swiss wood energy statistics (SFOE 2023b).
- Swiss statistics on combined heat and power generation (SFOE 2023c).

As can be seen in Figure 3-6, fossil fuels amount to slightly less than half of primary energy consumption (i.e. of the total energy demand including losses during transformation and distribution; the losses during transformation and distribution are larger for nuclear fuel and hydro power than for fossil fuels). The main end-users of fossil fuels are the transport and the housing sector, as electricity generation is predominantly based on hydro and nuclear power stations. The most recent energy balance is given in Annex A3.1.

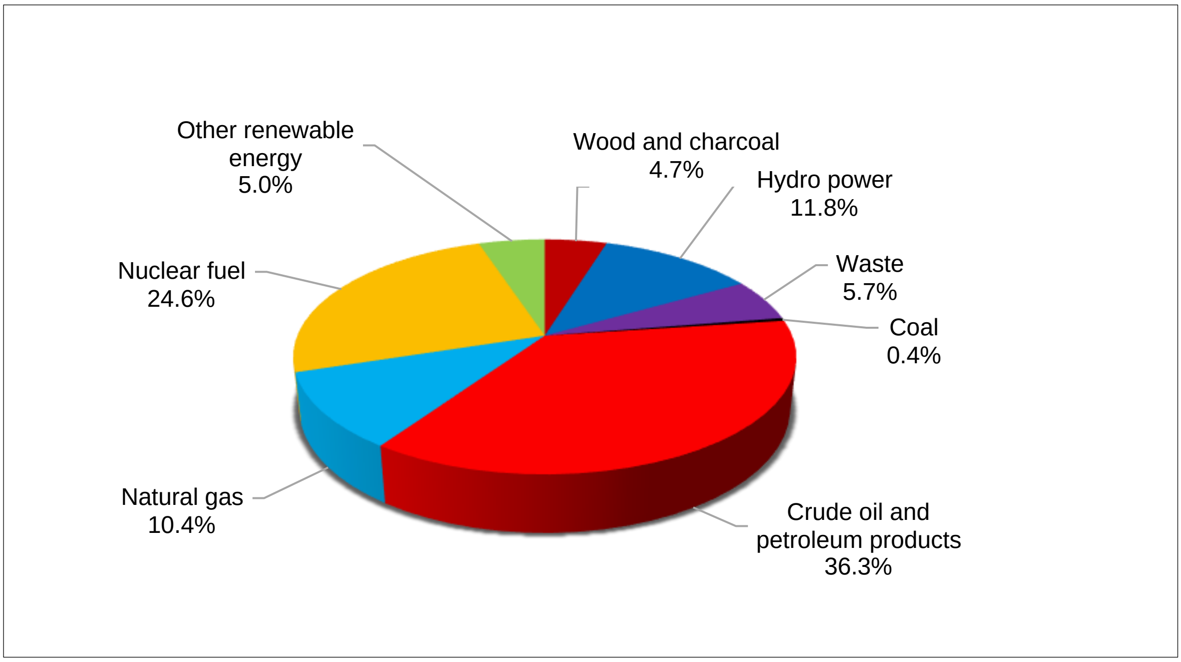

Figure 3-6 Switzerland’s primary energy consumption in 2022 by fuels (see corresponding data in SFOE 2023).

Table 3-12 shows primary energy consumption excluding nuclear fuel and hydro power. On the one hand, the combined effect of decreasing consumption of gasoline and increasing consumption of jet kerosene and diesel oil led to an increasing trend until about 2010 and a stabilization thereafter in the transport sector. On the other hand, consumption of liquid fuels in the residential and services sectors (mainly gas oil) as well as in the industry sector (mainly gas oil and residual fuel oil) substantially decreased. Natural gas consumption increased since 1990, compensating to some extent the decreasing use of gas oil and residual fuel oil in the various sectors. Due to the restrictions related to the COVID-19 pandemic the years 2020 and 2021 are exceptional, with lower fuel consumption, especially in the transport sector. Compared to 2021, total fuel consumption strongly declined in 2022. In particular gas oil and natural gas consumption was lower compared to the previous years due to the warm winter and precautionary energy saving measures in anticipation of a potential energy shortage.

Table 3-12 Switzerland’s energy consumption by fuel type. Only those fuels are shown that are implemented in the EMIS database (no hydro and nuclear power). The numbers are based on the fuels sold principle; thus, they include gasoline, diesel oil and biofuels consumption from fuel tourism, as well as all jet kerosene sold for domestic and international aviation. Natural gas and gasoline losses due to fugitive emissions (reported in sector 1B) are not included.

Year	Gasoline	**Jet kerosene (fossil)** domestic aviation	**Jet kerosene (fossil)** international aviation (bunker)	Diesel oil	**Diesel oil** international navigation (bunker)	Gas oil	Residual fuel oil	Refinery gas & Liquefied petroleum gas	Petroleum coke	Solid fuels	**Natural gas** excl. natural gas losses	Other fuels	Bio fuels	**Total** as reported in CRT reporting tables	**Total** incl. bunker
	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ	TJ
1990	155'703	6'183	41'884	46'736	821	218'510	23'342	8'890	1'400	14'901	68'426	19'074	46'826	609'989	652'695
1991	162'063	5'690	40'872	47'417	737	238'602	23'590	12'437	980	12'162	76'724	18'514	48'816	646'995	688'604
1992	168'037	5'600	43'499	45'926	780	236'809	24'170	11'492	315	8'758	80'627	18'931	47'753	648'417	692'697
1993	155'808	5'434	45'342	44'197	781	225'920	17'165	12'388	1'120	7'442	84'574	19'048	48'086	621'179	667'302
1994	155'797	5'269	46'840	46'924	824	207'141	17'860	13'455	1'470	7'632	83'402	19'069	46'036	604'054	651'719
1995	151'094	5'029	49'918	47'865	739	217'523	17'278	12'756	1'260	7'962	91'942	19'588	48'093	620'389	671'046
1996	155'033	4'778	51'975	44'946	651	226'289	15'097	13'939	1'015	5'456	99'530	20'443	51'670	638'197	690'823
1997	161'031	4'791	53'983	46'728	657	212'223	12'581	14'236	280	4'590	96'083	21'498	48'546	622'587	677'227
1998	162'315	4'669	56'599	48'681	528	222'407	15'882	15'259	455	3'960	98'890	23'586	50'153	646'257	703'384
1999	167'815	4'419	60'824	51'626	558	212'349	11'058	15'805	521	4'105	102'415	24'189	50'928	645'232	706'615
2000	168'009	4'334	63'726	55'146	531	196'137	7'923	13'649	551	6'120	101'800	26'294	50'600	630'565	694'822
2001	163'442	4'055	60'153	56'262	447	213'089	9'942	14'069	410	6'233	105'966	26'796	53'877	654'142	714'742
2002	160'276	3'870	55'536	58'389	333	196'655	6'446	15'584	679	5'565	104'007	27'624	53'440	632'535	688'404
2003	159'512	3'598	49'840	61'808	443	208'040	7'061	13'642	202	5'663	109'957	27'361	56'031	652'876	703'159
2004	156'708	3'458	46'983	66'447	446	203'370	7'561	16'429	1'819	5'420	113'459	28'518	56'976	660'165	707'594
2005	151'966	3'326	47'775	72'572	493	205'729	5'805	16'432	2'906	5'940	116'493	28'849	59'148	669'167	717'434
2006	147'344	3'338	50'233	78'606	457	195'926	6'419	18'578	3'324	6'467	113'264	30'846	62'272	666'385	717'074
2007	145'923	3'473	53'692	84'420	465	171'313	5'179	15'587	2'730	7'196	110'252	29'617	61'331	637'020	691'177
2008	142'713	3'128	58'023	92'670	473	178'833	4'581	16'288	3'616	6'562	117'451	30'385	65'531	661'757	720'253
2009	138'883	3'239	55'426	94'143	425	173'219	3'530	16'301	3'254	6'193	112'674	29'296	65'704	646'436	702'288
2010	133'953	3'286	58'334	97'776	471	182'295	2'967	15'463	3'498	6'208	125'846	30'627	70'576	672'495	731'300
2011	128'775	3'235	62'461	100'449	428	143'760	2'292	14'856	2'957	5'792	111'617	30'269	66'255	610'258	673'147
2012	124'229	3'402	63'903	106'611	385	154'448	2'780	12'247	3'148	5'269	122'398	30'555	72'159	637'247	701'536
2013	118'572	3'359	64'709	111'482	342	162'532	1'959	15'053	2'735	5'567	128'912	30'249	75'870	656'288	721'340
2014	113'820	3'535	65'006	114'385	299	122'694	1'581	14'473	3'148	5'704	111'660	30'608	70'270	591'878	657'183
2015	105'540	3'454	67'333	112'808	342	129'349	862	9'822	1'145	5'205	119'314	31'398	73'701	592'599	660'274
2016	102'250	3'559	70'603	114'079	299	132'325	378	9'136	890	4'795	125'355	32'835	79'968	605'571	676'472
2017	99'112	3'110	72'824	113'750	256	123'726	350	8'770	763	4'609	125'602	32'515	83'389	595'697	668'776
2018	97'545	3'036	77'214	115'283	200	111'225	87	8'890	781	4'285	118'931	33'605	83'274	576'943	654'357
2019	96'748	2'874	78'196	115'347	197	108'625	111	8'108	777	3'812	121'941	34'044	85'855	578'240	656'633
2020	85'681	2'421	28'194	109'312	189	97'246	76	7'627	700	3'664	118'782	33'733	85'018	544'258	572'642
2021	87'541	2'112	31'847	110'489	228	107'991	139	7'543	604	3'697	129'321	32'826	91'886	574'149	606'224
2022	85'025	2'366	57'499	110'334	207	86'970	0	9'646	731	3'847	106'250	32'631	88'565	526'367	584'072

3.2.4.4.2. Energy model – Conceptual overview

For the elaboration of the greenhouse gas and air pollutants inventories, information about energy consumption is needed at a much more detailed level than provided by the Swiss overall energy statistics (SFOE 2023). Activity data in sector 1 Energy are therefore calculated and disaggregated by the Swiss energy model, which is an integral part of the emission database EMIS. The model is developed and updated annually by the Swiss Federal Office for the Environment (FOEN). It relies on the Swiss overall energy statistics and is complemented with further data sources, e.g. Liechtenstein’s liquid fuel sales (OS 2023), the Swiss renewable energy statistics (SFOE 2023a), the energy consumption statistics in the industry and services sectors (SFOE 2023d), as well as additional information from the industry. As wood energy consumption is not based on the Swiss overall energy statistics but directly on the figures from the Swiss wood energy statistics (SFOE2023b), its activity data are derived in a separate but analogous model.

The Swiss overall energy statistics are not only the main data input into the energy model, but also serve as calibration and quality control instrument. The total energy consumption given by the Swiss overall energy statistics has to be equal to the sum of the disaggregated activity data of all source categories within the energy sector (including memo items/bunker). Differences are explicitly taken into account as “statistical differences” (see chp. 3.2.4.1).

As shown in Figure 3-7, the energy model consists of several sub-models, such as the industry model, the civil aviation model, the road transportation model, the non-road transportation model, and the model of stationary engines and gas turbines. A brief overview of each of these models is given below. However, depending on the scope of these sub-models, they are either described in the chapter dedicated to the corresponding source category or in an overarching chapter preceding the detailed description of the individual source categories. In chp. 3.2.4.4.3, the resulting sectoral disaggregation is shown separately for each fuel type (including the disaggregation of the separate model for wood energy combustion).

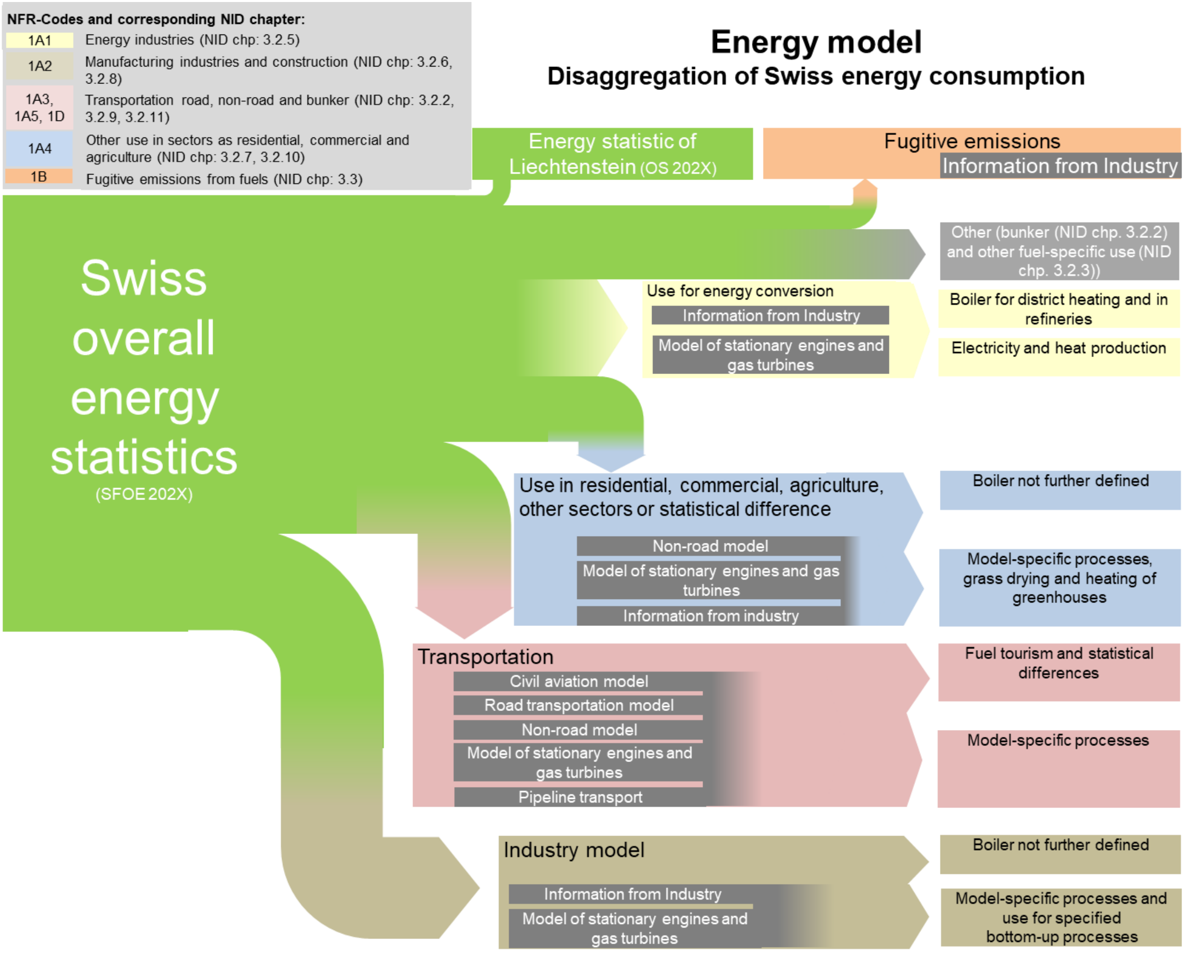

Figure 3-7 Overview of Switzerland’s energy model. In the abbreviations SFOE 202X and OS 202X the “X” refers to the latest edition of the respective statistics.

Industry model (Details are given in chp. 3.2.6.2.1)

The industry model disaggregates the total fuel consumption in the industry sector (SFOE 2023) by source category and fuel type. It is based on the following two pillars. First, the energy consumption statistics in the industry and services sectors (SFOE 2023d) provide a comprehensive annual survey of fuel consumptions for all years since 1999 or 2002 (depending on the fuel type). These statistics are consistently extended back to 1990 based on a bottom-up industry model (Prognos 2013). Second, further disaggregation is achieved by using plant-level industry data for specific processes, as far as available.

Civil aviation model (Details are given in chp. 3.2.2.2.1 and 3.2.9.2.1)

The civil aviation model is developed and updated by the Federal Office for Civil Aviation (FOCA). It aggregates single aircraft movements according to detailed movement statistics of the Swiss airports. Differentiation of domestic and international aviation is based on the information on departure and destination of each flight in the movement database.

Road transportation model (Details are given in chp. 3.2.9.2.2)

The road transportation model is a territorial model, accounting for traffic on Swiss territory only. The model is based on detailed vehicle stock data from the vehicle registration database of the Federal Roads Office (FEDRO), mileage per vehicle category differentiated into different driving patterns, and specific consumption and emission factors. The difference between fuel sales and the territorial model (road and non-road transportation models combined) is considered as fuel tourism and statistical differences, emissions of which are included in the most appropriate categories (see 3.2.9.2.2).

Non-road transportation model (Details are given in chp. 3.2.4.6.1)

The non-road transportation model covers all remaining mobile sources, i.e. industrial vehicles, construction machinery, agricultural and forestry machinery, gardening machinery as well as railways, navigation and military vehicles, except for military aviation, which is considered separately (see chp. 3.2.11.2.1). The model combines vehicle or machinery numbers, their operation hours, engine power, and load factors to derive specific fuel consumption, emission factors and resulting emissions. Data stem from surveys among producers, various user associations, and the national database of non-road vehicles run by FEDRO.

Model of stationary engines and gas turbines (Details are given in chp. 3.2.4.6.2)

The model of stationary engines and gas turbines (INFRAS 2022a) in 1A Fuel combustion activities is based on a new inventory of installed capacities, technologies and operating hours of engines and gas turbines throughout Switzerland. The inventory is based on a survey with the cantonal authorities, information from websites and annual reports from industry, as well as from direct enquiries with the operators. The fuel consumption per engine and turbine type was derived from the inventory and the emissions are calculated using corresponding emission factors from different references.

Model for wood energy combustion (Details are given in chp. 3.2.4.6.2)
Based on the Swiss wood energy statistics (SFOE 2023b), total wood consumption is disaggregated into source categories (public electricity and heat production, industry, commercial/institutional, residential, agriculture/forestry/fisheries) and into 24 different combustion installations (ranging from open fireplaces to large-scale automatic boiler or heat and power plants). Where available, industry data on wood combustion is taken into account to allocate parts of the wood consumption as given by the Swiss wood energy statistics to a specific source category.

3.2.4.4.3. Disaggregation of the energy consumption by source category and fuel types

The energy model as outlined above disaggregates total energy consumption as provided by the Swiss overall energy statistics (SFOE 2023) into the relevant source categories 1A1–1A5. Figure 3-9 to Figure 3-18 visualize for each fuel type separately the disaggregation process of the energy model (as shown schematically in Figure 3-7), the interaction between the different sub-models as well as additional data sources.

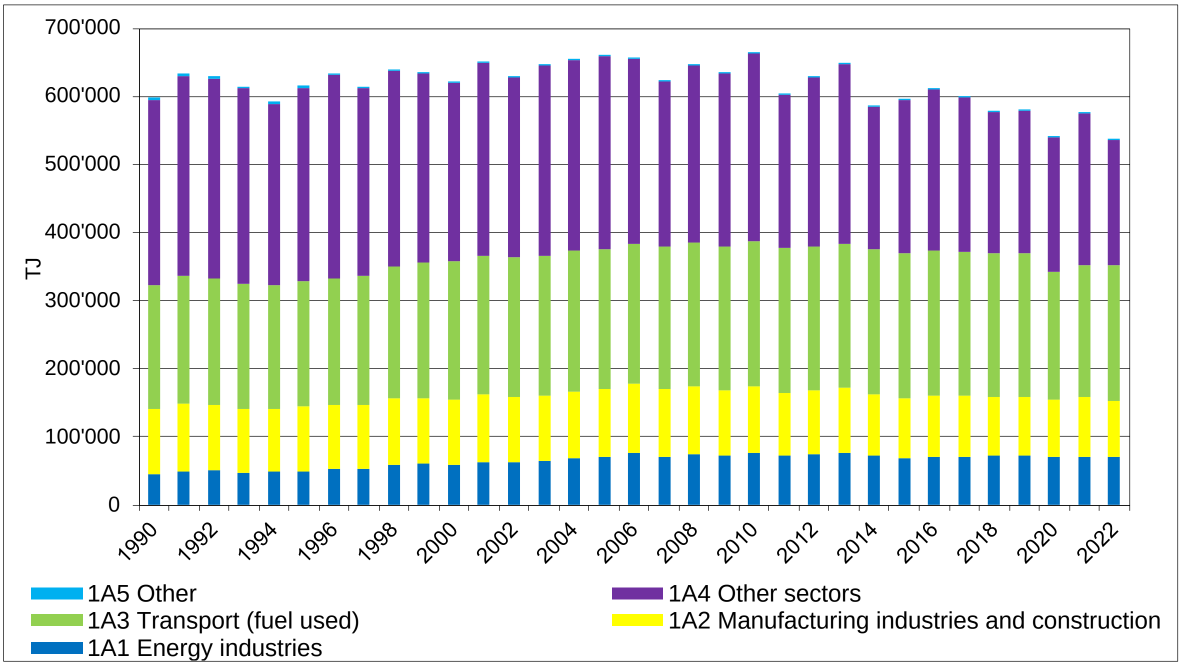

Figure 3-8 Switzerland's energy consumption in the source categories 1A1–1A5 according to the Swiss energy model. Since 1990 population has increased by about one third, industrial production by about three quarters and the motor vehicle fleet by about two thirds (SFOE 2023, table 43a).

Starting from the total energy consumption from the Swiss overall energy statistics for each fuel type, the energy is assigned to the relevant source categories based on the various sub-models of the energy model (mentioned in chp. 3.2.4.4.2 above). In addition, the following assignments are considered as well:

- For source category 1A4ci Other sectors – Agriculture/forestry/fishing, specific bottom-up industry information is available for grass drying and heating of greenhouses. The fuel consumption for grass drying is provided by the Swiss association of grass drying plants (VSTB). Further, based on annual energy consumption data from the Energy Agency of the Swiss Private Sector (EnAW) regarding agricultural greenhouses exempt from the CO_2 levy, total energy consumption of all greenhouses within Switzerland is extrapolated.

The fuel consumption for grass drying and greenhouses is subtracted from the total fuel consumption of residential, commercial, agriculture and statistical differences (see Figure 3-7).

- In order to report all energy consumption, the statistical differences as reported in the Swiss overall energy statistics are allocated to source category 1A4ai Other sectors – Commercial/institutional (stationary combustion) and 1A3bviii Fuel tourism and statistical differences. In the greenhouse gas inventory, emissions from 1A3bviii Fuel tourism and statistical differences are reported in the source categories 1A3bi, 1A3bii, and 1A3biii (see chp. 3.2.9.2.2 for a more detailed description).

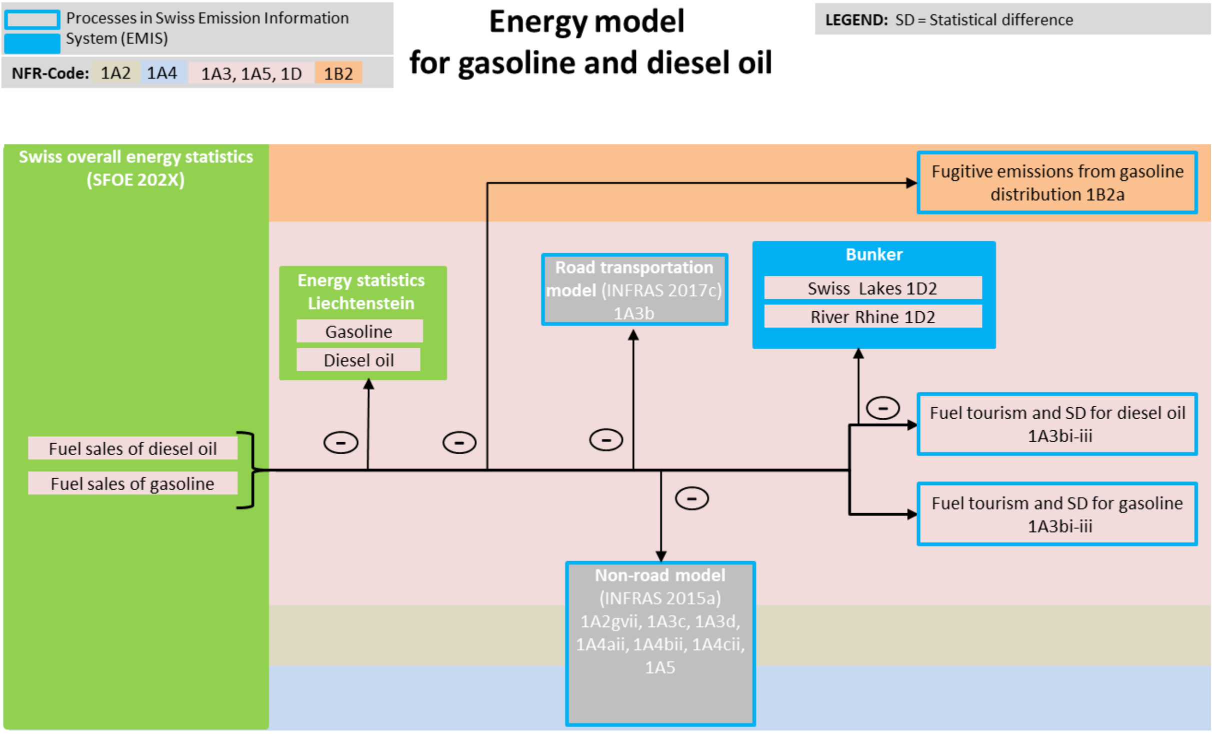

Figure 3-9 Schematic disaggregation of fuel consumption for gasoline and diesel oil. Marine bunker fuel consumption is based on the national customs statistics (see chp. 3.2.2.2.2). In the greenhouse gas inventory, emissions from 1A3bviii Fuel tourism and statistical differences are reported in the source categories 1A3bi, 1A3bii, and 1A3biii (see chp. 3.2.9.2.2 for a more detailed description).

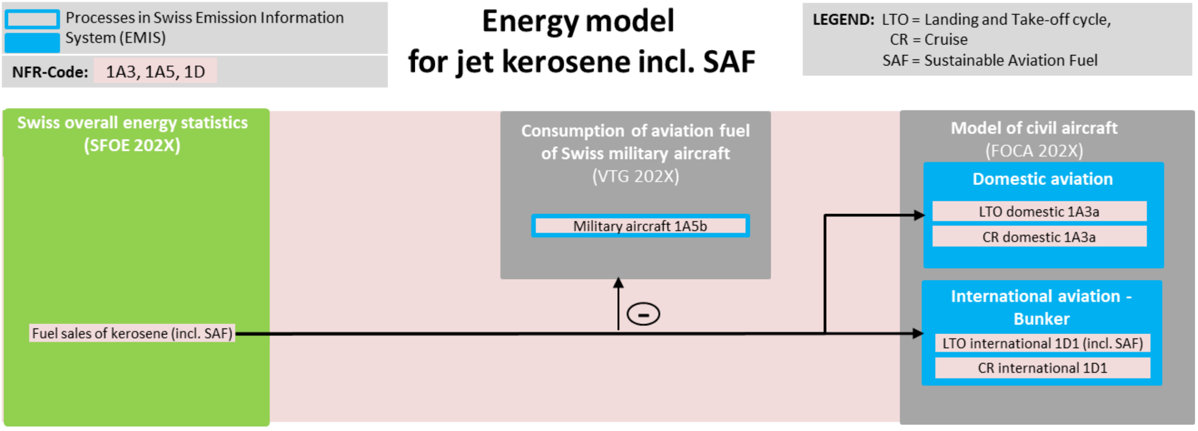

Figure 3-10 Schematic disaggregation of fuel consumption for jet kerosene. Fuel consumption for military aircraft is provided by the Swiss Air Force (part of the Swiss Armed Forces, VTG). The differentiation between domestic and international aviation as well as between CR and LTO is provided by the civil aviation model (see chp. 3.2.2.2.1).

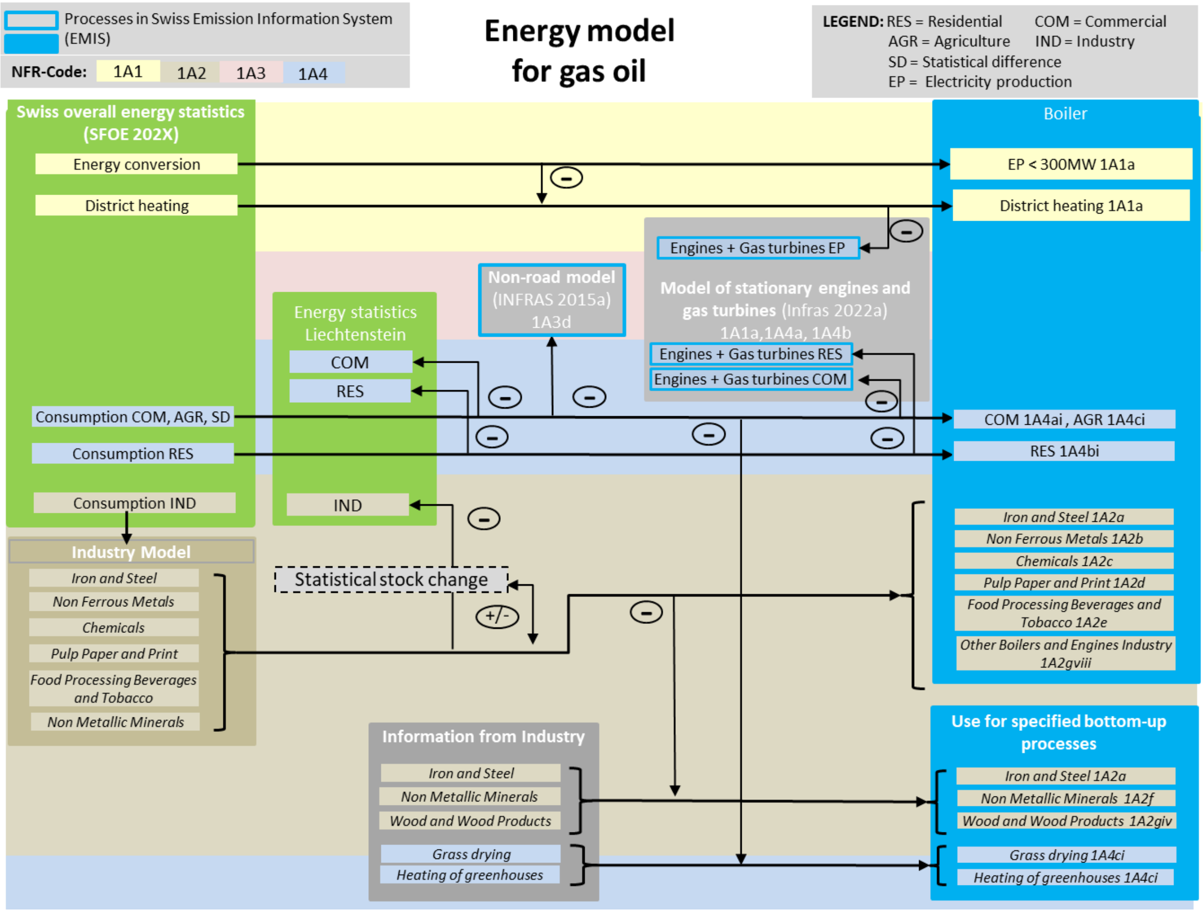

Figure 3-11 Schematic disaggregation of fuel consumption for gas oil. The Swiss overall energy statistics provides gas oil use for energy conversion and the amount thereof being used for district heating. Based on this information, gas oil use is split into the source categories 1A1ai Electricity generation and 1A1aiii Heat plants. According to the non-road model, a small amount of gas oil is consumed in source category 1A3d navigation (steam-powered vessels).

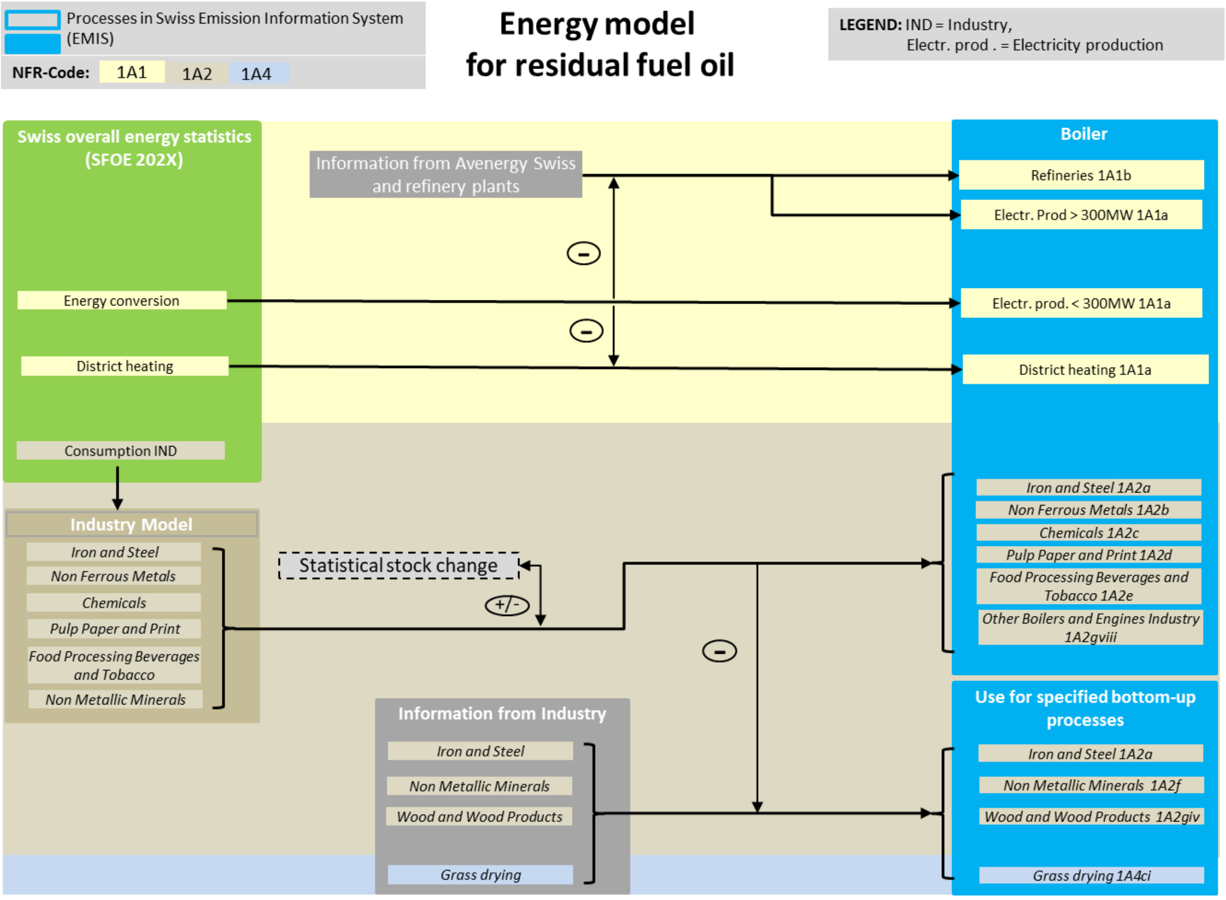

Figure 3-12 Schematic disaggregation of fuel consumption for residual fuel oil. The Swiss overall energy statistics reports residual fuel oil use in energy conversion and the amount thereof consumed in electricity production (one single fossil fuel power station, operational from 1985 to 1994), district heating, and in petroleum refineries. Based on this information, residual fuel oil use in Energy industries is split into the source categories 1A1ai Electricity generation, 1A1aiii Heat plants and 1A1b Petroleum refining.

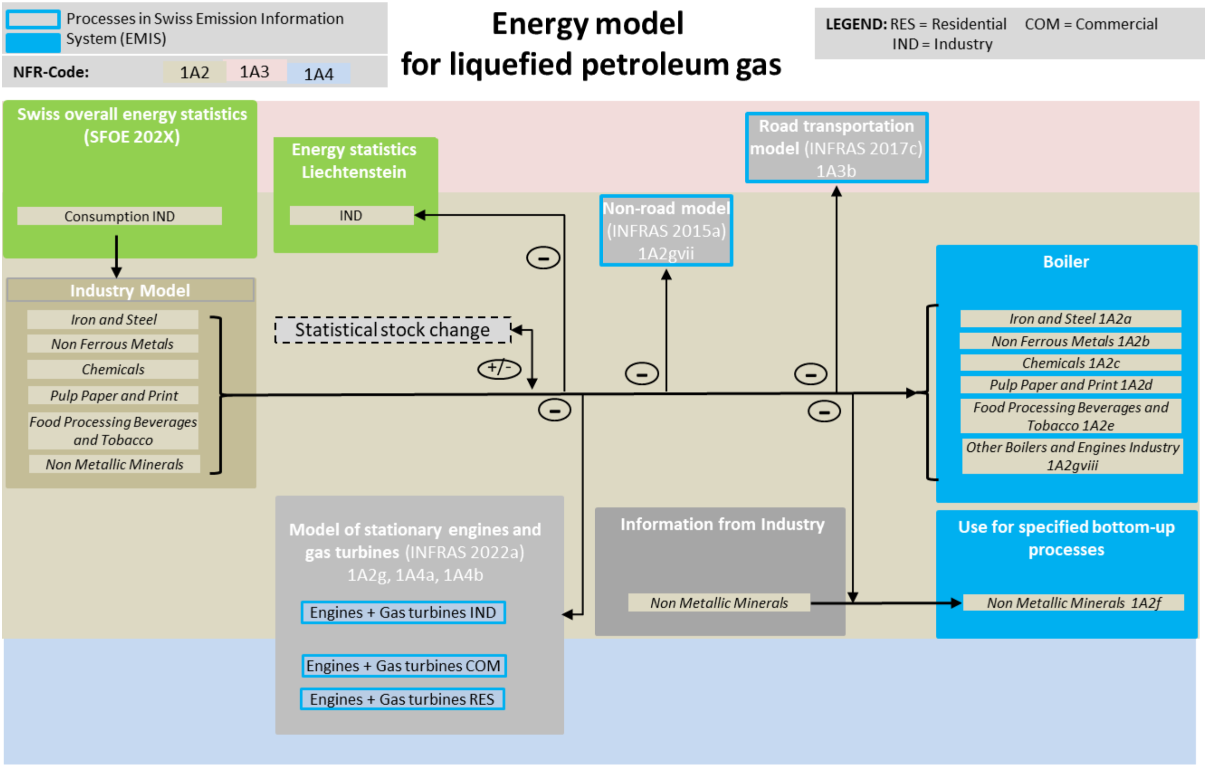

Figure 3-13 Schematic disaggregation of fuel consumption for liquefied petroleum gas.

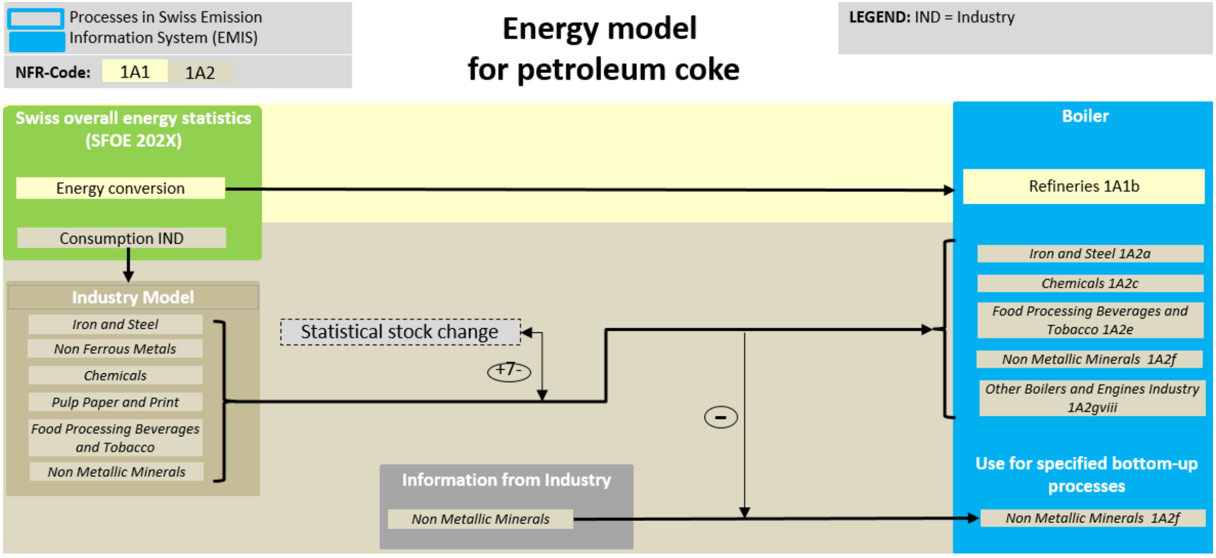

Figure 3-14 Schematic disaggregation of fuel consumption for petroleum coke.

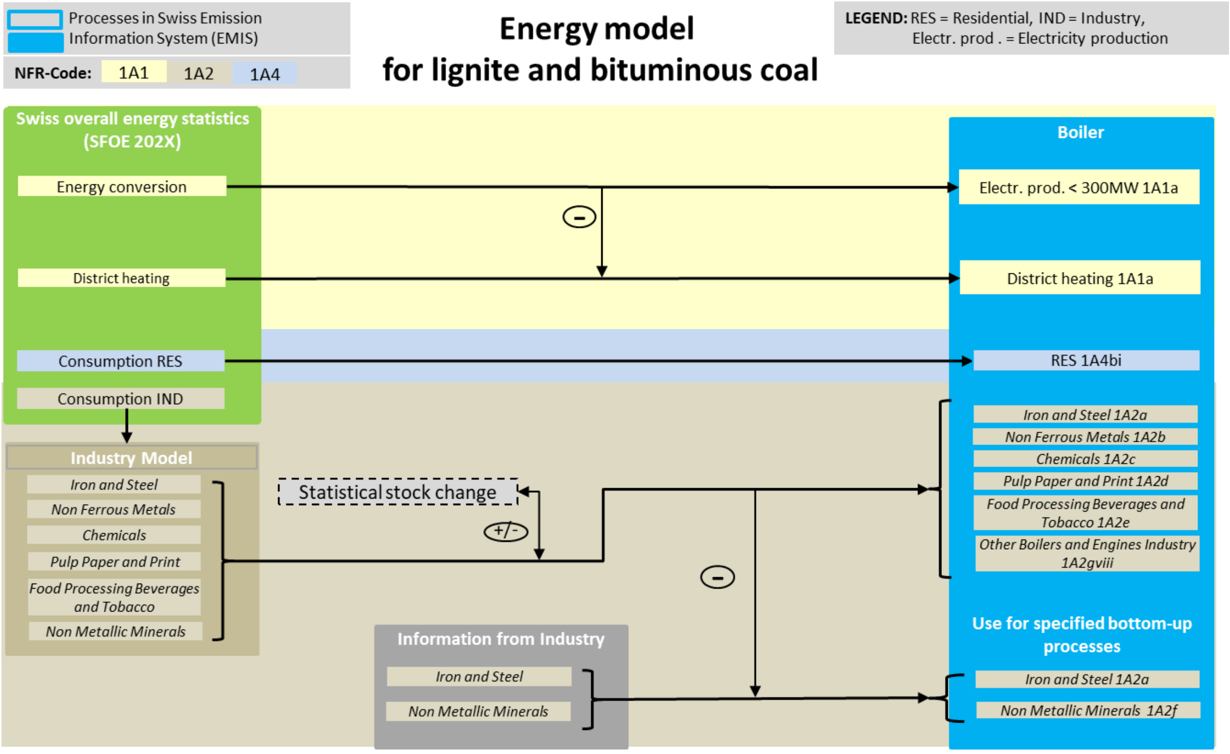

Figure 3-15 Schematic disaggregation of fuel consumption for lignite and bituminous coal. The Swiss overall energy statistics provides bituminous coal use for energy conversion and the amount thereof being used for district heating. Based on this information, use of bituminous coal in Energy industries is split into the source categories 1A1ai Electricity generation and 1A1aiii Heat plants up to 1995. Coal consumption for public electricity and heat production ceased thereafter.

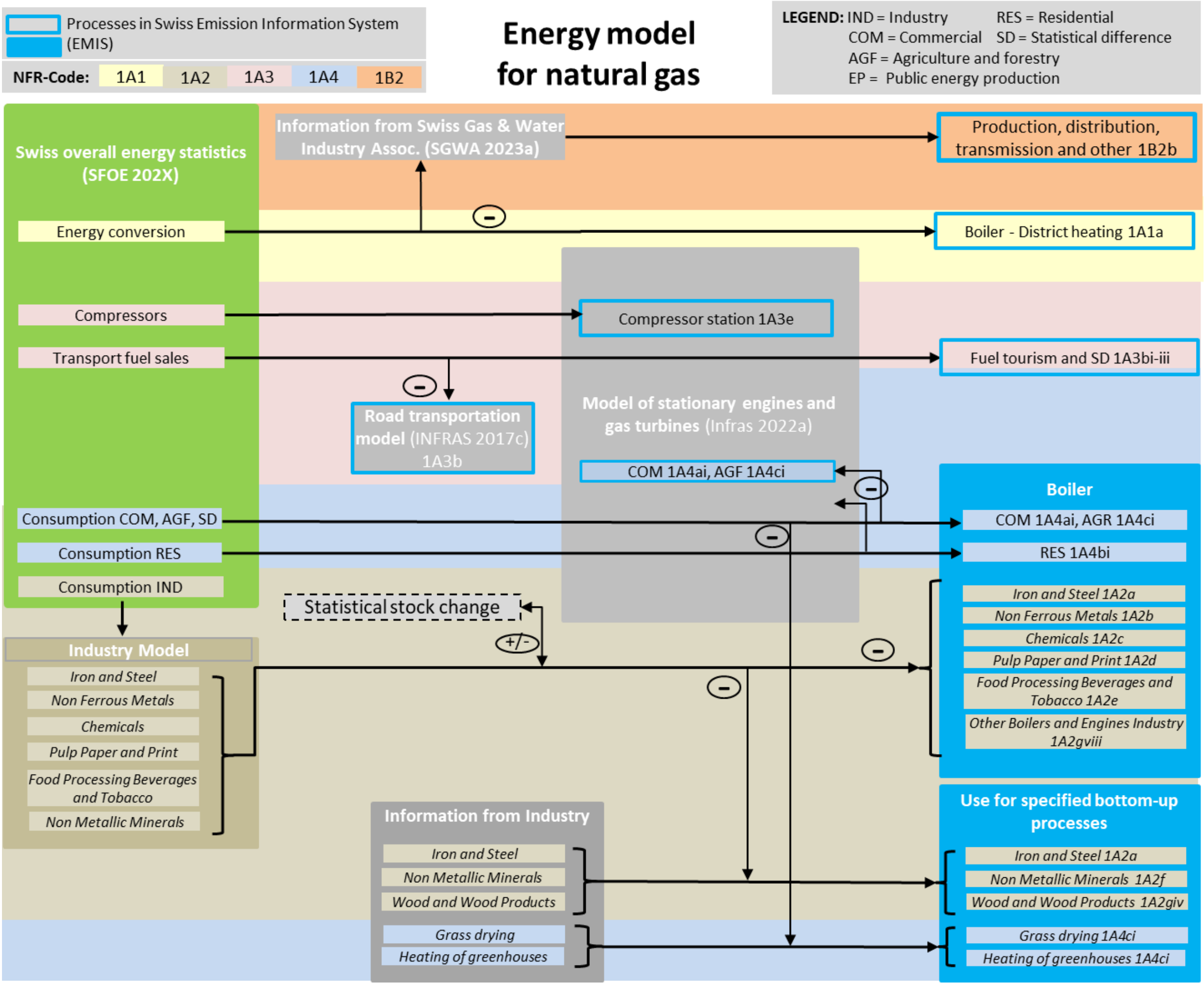

Figure 3-16 Schematic disaggregation of fuel consumption for natural gas. The Swiss overall energy statistics (SFOE 2023) provides gas use in the transformation sector (energy conversion and distribution losses). Distribution losses as estimated by the Swiss Gas and Water Industry Association (SGWA) are subtracted and reported under source category 1B2 Fugitive emissions from fuels. The remaining fuel consumption for natural gas is reported under source category 1A1a Public electricity and heat production. In the greenhouse gas inventory, emissions from 1A3bviii Fuel tourism and statistical differences are reported in the source categories 1A3bi, 1A3bii, and 1A3biii (see chp. 3.2.9.2.2 for a more detailed description).

A corresponding Figure 3-16b is available in the confidential version of this chapter, providing more details.

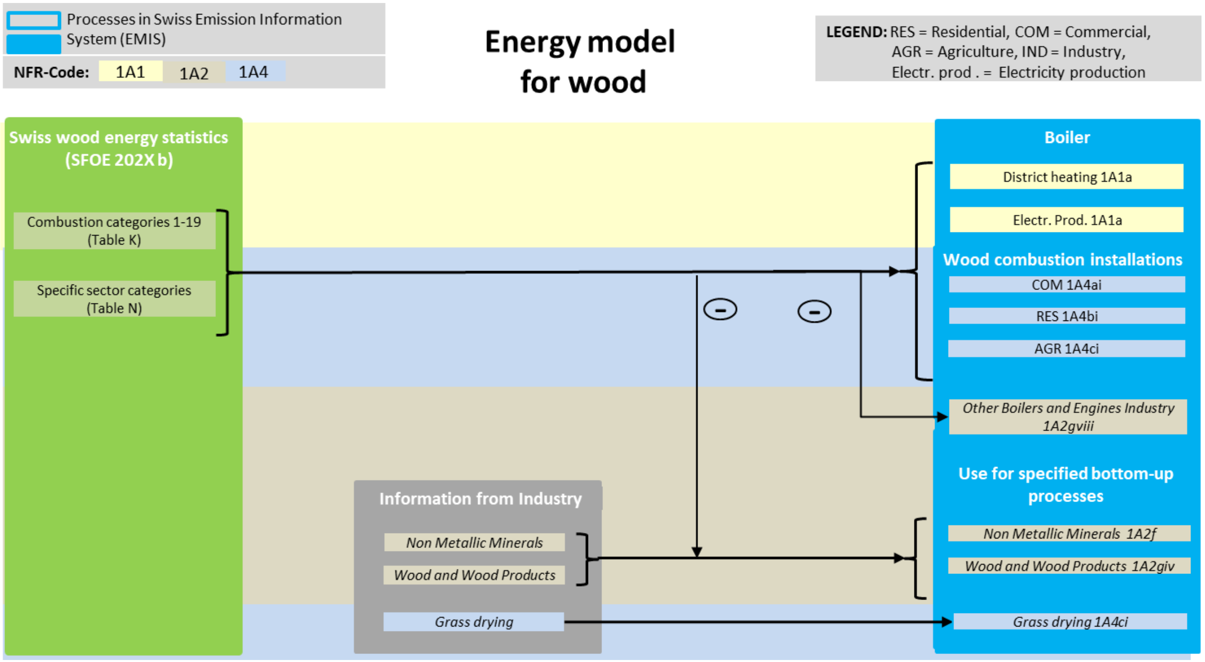

Figure 3-17 Schematic disaggregation of fuel consumption for wood (see chp. 3.2.4.6.2.)

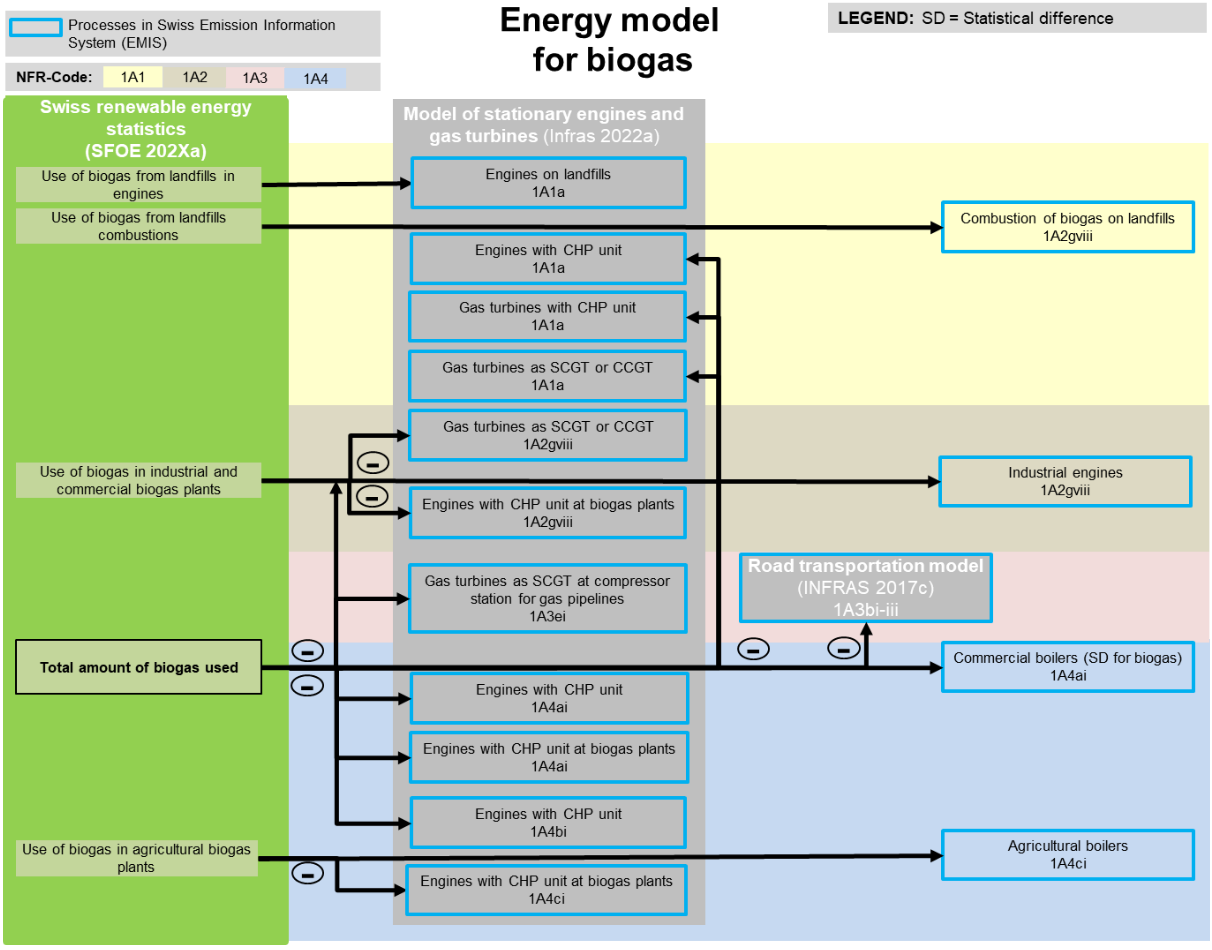

Figure 3-18 Schematic disaggregation of fuel consumption for biogas.

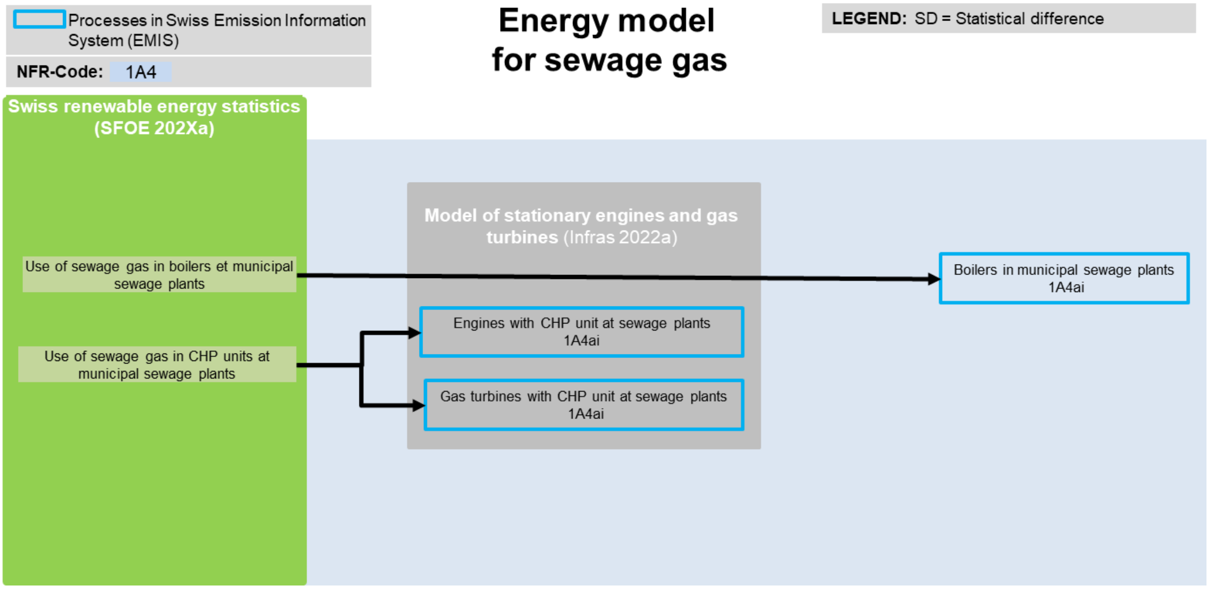

Figure 3-19 Schematic disaggregation of fuel consumption for sewage gas.

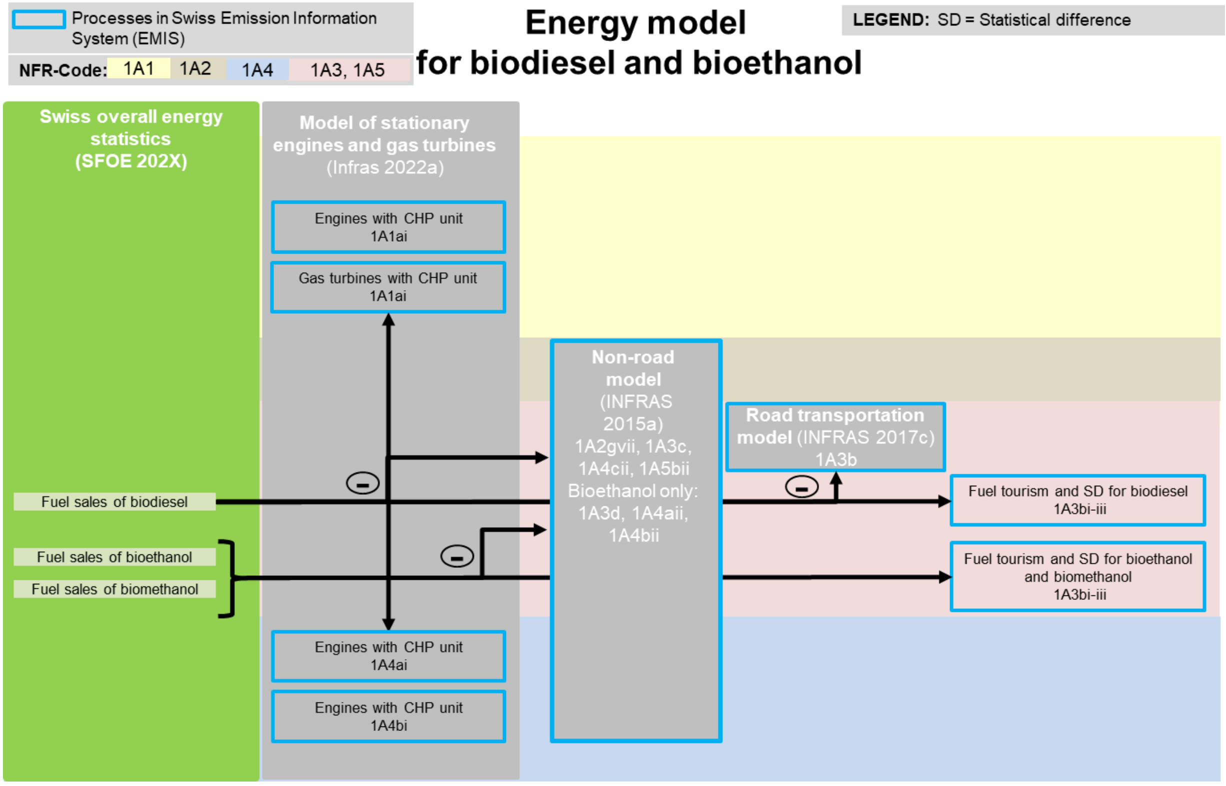

Figure 3-20 Schematic disaggregation of fuel consumption for biodiesel and bioethanol.

Statistical stock change

In a few years the quantity of a fuel sold in a year according to total energy statistics may be smaller (or larger) than the quantity effectively used in the same year as reported from bottom-up data. The reason for such deviations is due to further stocks which are not taken into consideration at the level of the Swiss energy statistics and are managed at the individual plant level. Some plants manage their own intermediate fuel stocks, which they may carry over for use in later years. To mitigate the difference between less fuel sold (according to the total energy statistics) than fuel used (according to bottom-up information) in one year, so-called “stock shifts” are assumed in the energy model. Stockpiling can only be performed in the years in which more fuel was sold according to total energy statistics than was used based on bottom-up information. Stock which was accumulated in such years can be used in later years to level out the deviations between the total energy statistics and bottom-up data. Currently, stocks are formed in different years for residual fuel oil, petroleum coke and other bituminous coal:

- For residual fuel oil stock was built up in the years 2008–2010, 2014, 2015 and used in the years 2011, 2012, 2016–2021.
- For petroleum coke stock was built up in the years 2007, 2018 and used in the years 2008, 2019.
- For other bituminous coal stock was built up in the years 1991, 1996, 2003, 2005–2007 and used in the years 1993, 1994, 1998–2001, 2011, 2012.

3.2.4.5. Emission factors of 1A Fuel combustion

3.2.4.5.1. Oxidation factor for 1A Fuel combustion

For the emission calculation, an oxidation factor of 100 % is assumed for all fossil fuel combustion processes, since the technical standards for combustion installations in Switzerland are high and the small fraction of originally non-oxidised carbon retained in ash, particulates or soot is likely to be oxidized later. This is consistent with the 2006 IPCC Guidelines (IPCC 2006) and the EU and Swiss guidelines for the Emissions Trading Scheme (ETS), where also a default oxidation factor of 100 % is applied.

Because an oxidation factor of 100 % is assumed, indirect CO_2 emissions from CH_4, CO and NMVOC are implicitly reported as direct CO_2 emissions in source category 1A Energy. Therefore, from this source category no indirect CO_2 emissions are included in CRT Table6 as documented in chp. 9.

3.2.4.5.2. CO_2 emission factors for 1A Fuel combustion

General CO_2 emission factors

The CO_2 emission factors applied for the time series 1990–2022 are given in Table 3-13. Detailed information regarding the underlying data and assumptions are provided in chp. 3.2.4.2 Net calorific values (NCV), since in most cases, NCVs and carbon content were determined jointly.

Table 3-13 CO_2 emission factors 1990–1998 and years from 2013 onwards. For years between 1998 and 2013, the factors are linearly interpolated. Data source SGWA stands for annually updated reports of the Swiss Gas and Water Industry Association (SGWA).

CO_2 emission factors			**1990–1998**	**2013–2022**
Fossil fuel	**CS/D**	**Data sources**	t CO_2 / TJ	t CO_2 / TJ
Gasoline	CS	EMPA (1999), SFOE/FOEN (2014)	73.8	73.8
Jet kerosene	CS	EMPA (1999), SFOE/FOEN (2014)	72.8	72.8
Diesel oil	CS	EMPA (1999), SFOE/FOEN (2014)	73.3	73.3
Gas oil	CS	EMPA (1999), SFOE/FOEN (2014)	73.7	73.7
Residual fuel oil	CS	EMPA (1999)	77.0	77.0
Liquefied petroleum gas	CS	FOEN (2019k)	65.5	65.5
Petroleum coke	CS	Cemsuisse (2010a)	91.4	91.4
Other bituminous coal	CS	Cemsuisse (2010a)	92.7	92.7
Lignite	CS	Cemsuisse (2010a)	96.1	96.1
Natural gas	CS	SGWA	*see table below*	
Biofuel	**CS/D**	**Data sources**		
Biodiesel	CS	assumed equal to diesel oil	73.3	73.3
Bioethanol	CS	assumed equal to gasoline	73.8	73.8
Biogas	CS	assumed equal to natural gas	*see table below*	
Wood	CS	Cemsuisse (2010a)	99.9	99.9

CO_2 emission factors for natural gas and biogas

CO_2 emission factors of natural gas and biogas are given in Table 3-14.

Table 3-14 Time series of CO_2 emission factors of natural gas and biogas. SGWA refers to annual updates of properties of natural gas that are provided by the Swiss Gas and Water Industry Association (SGWA).

CO_2 emission factors			**1990**	**1995**	**2000**	**2005**	**2010**
Fuel	**CS/D**	**Data sources**	t CO_2 / TJ				
Natural gas/Biogas	CS	SGWA	56.1	55.7	56.2	56.4	56.5

CO_2 emission factors			**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Fuel	**CS/D**	**Data sources**	t CO_2 / TJ									
Natural gas/Biogas	CS	SGWA	56.4	56.5	56.4	56.4	56.3	56.2	56.4	56.2	55.9	56.0

CO_2 emission factors for wood

The CO_2 emission factor for wood combustion activities is taken from Cemsuisse (2010a).

3.2.4.5.3. CH_4 emission factors for 1A Fuel combustion

General CH_4 emission factors

An overview of the default CH_4 emission factors for stationary combustion according to the 2006 IPCC Guidelines (IPCC 2006) is given in Table 3-15. These default CH_4 emission factors, which depend on the fuels and the source categories, are used for most stationary combustion processes for the entire time period. Exceptions, e.g. for motors and gas turbines, are discussed in the chapters of the respective source categories. In Table 3-15, the respective cells (fuel/source category) are highlighted in blue, indicating that the default CH_4 emission factors are not applied in this case. A blue/white highlighting means that for the respective fuel and source category there are processes that use the default CH_4 emission factors according to Table 3-15 as well as processes that use a different CH_4 emission factor as discussed in the chapters of the respective source categories. Where default CH_4 emission factors of fuels are not used at all in the respective source categories, the notation key “NO” is indicated in Table 3-15. For other bituminous coal, the default CH_4 emission factor for source category 1A2 is also used for source category 1A1 (highlighted purple and indicated with an arrow); this corresponds better to the situation in Switzerland, as there are no coal-fired power plants. For wood combustion, country-specific CH_4 emission factors are used (see details below, in particular Table 3-16). CH_4 emission factors related to transport activities (aviation, road and non-road transportation) are category-specific and given in the corresponding sectoral chapters.

Table 3-15 Default CH_4 emission factors for stationary combustion according to the 2006 IPCC Guidelines (IPCC 2006, Table 2.2 for 1A1, Table 2.3 for 1A2, Table 2.4 for 1A4ai and Table 2.5 for 1A4bi and 1A4ci) as well as the range of country-specific CH_4 emission factors for wood combustion according to Zotter and Nussbaumer (2022), see also Table 3-16. See text for further information and an explanation of the colour code. Where other than default CH_4 emissions factors are (also) used, this is indicated by the notation key “CS” and details are described in the chapters of the respective source categories.

CH_4 emission factors			**1990–2022**			
			1A1	**1A2**	**1A4ai**	**1A4bi, 1A4ci**
Fuel	**D/CS**	**Data sources**	g CH_4 / GJ			
Gas oil	D	IPCC (2006)	3 / CS	3	10 / CS	10 / CS
Residual fuel oil	D	IPCC (2006)	3	3	NO	NO
Liquefied petroleum gas	D	IPCC (2006)	NO	1 / CS	CS	CS
Petroleum coke	D	IPCC (2006)	NO	3	NO	NO
Other bituminous coal	D	IPCC (2006)	10 ←	10	NO	300
Lignite	D	IPCC (2006)	NO	10	NO	NO
Natural gas	D	IPCC (2006)	1 / CS	1 / CS	5 / CS	5 / CS
Biofuel	**D/CS**	**Data Sources**	g CH_4 / GJ			
Biodiesel	D	IPCC (2006)	CS	CS	CS	CS
Biogas	D	IPCC (2006)	CS	CS	5 / CS	CS
Wood	CS	Zotter and Nussbaumer (2022)	0.19–230			

CH_4 emission factors for wood

There are many different combustion installations in use which have very different CH_4 emission factors. A detailed overview of all applied wood related CH_4 emission factors for the entire time series is given in Table 3-16. For mobile pellet combustion installations in source category 1A4ai that are used for temporary applications, the same CH_4 emission factors are assumed as for the installation category automatic pellet boilers 50-300 kW.

The CH_4 emission factors are based on a country-specific emission factor model for wood energy that was completely revised for the submission 2021 (Zotter and Nussbaumer 2022). The model is based on a large number of air pollution control measurements, laboratory and field measurements, literature data (e.g. beReal, emission factors in the Nordic countries) and the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA 2019) and covers the entire time series. The CH_4 emission factors are modelled based on VOC emissions of each combustion installation type and a mean CH_4 to VOC ratio of 0.3.

The CH_4 emission factor for the different combustion installations varies depending on the year, rated thermal input and technology used. The CH_4 emission factor of a single category represents the emission characteristics of a large number of combustion installations with a range of technology types, maintenance and operating conditions at a given time. According to their lifespan, existing combustion installations are gradually replaced by installations of new technology with better combustion, resulting in gradually decreasing CH_4 emission factors.

Table 3-16 CH_4 emission factors for wood combustion installations.

1A Wood combustion	**1990**	**1995**	**2000**	**2005**	**2010**
	g CH_4/GJ				
Open fireplaces	160	154	149	143	133
Closed fireplaces, log wood stoves	160	152	143	135	127
Pellet stoves	NO	NO	16	13	10
Log wood hearths	230	222	213	205	187
Log wood boilers	70	62	53	45	37
Log wood dual chamber boilers	230	222	213	205	187
Automatic chip boilers < 50 kW	60	52	43	35	27
Automatic pellet boilers < 50 kW	NO	NO	14	12	10
Automatic chip boilers 50–300 kW w/o wood proc. companies	30	27	24	22	17
Automatic pellet boilers 50–300 kW	NO	NO	7.8	6.7	5.0
Automatic chip boilers 50–300 kW within wood proc. companies	30	27	24	22	17
Automatic chip boilers 300–500 kW w/o wood proc. companies	30	27	24	22	17
Automatic pellet boilers 300–500 kW	NO	NO	NO	6.7	5.0
Automatic chip boilers 300–500 kW within wood proc. companies	30	27	24	22	17
Automatic chip boilers > 500 kW w/o wood proc. companies	10	8.9	7.8	6.7	5.0
Automatic pellet boilers > 500 kW	NO	NO	NO	3.0	2.3
Automatic chip boilers > 500 kW within wood proc. companies	12	11	10	9.5	7.0
Combined chip heat and power plants	NO	0.89	0.78	0.67	0.47
Plants for renewable waste from wood products	4.0	3.7	3.4	3.2	2.3

1A Wood combustion	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	g CH_4/GJ									
Open fireplaces	123	120	120	120	120	120	120	120	117	114
Closed fireplaces, log wood stoves	122	120	118	117	115	113	112	110	107	104
Pellet stoves	7.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	5.8	5.6
Log wood hearths	167	160	158	157	155	153	152	150	146	143
Log wood boilers	32	30	30	30	30	30	30	30	29	29
Log wood dual chamber boilers	167	160	158	157	155	153	152	150	148	146
Automatic chip boilers < 50 kW	22	20	20	20	20	20	20	20	19	19
Automatic pellet boilers < 50 kW	10	10	9.3	8.7	8.0	7.3	6.7	6.0	5.7	5.5
Automatic chip boilers 50–300 kW w/o wood proc. companies	12	10	10	10	10	10	10	10	9.7	9.5
Automatic pellet boilers 50–300 kW	3.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9	2.9
Automatic chip boilers 50–300 kW within wood proc. companies	12	10	10	10	10	10	10	10	9.7	9.5
Automatic chip boilers 300–500 kW w/o wood proc. companies	12	10	10	10	10	10	10	10	9.7	9.5
Automatic pellet boilers 300–500 kW	3.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9	2.9
Automatic chip boilers 300–500 kW within wood proc. companies	12	10	10	10	10	10	10	10	9.7	9.5
Automatic chip boilers > 500 kW w/o wood proc. companies	3.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9	2.9
Automatic pellet boilers > 500 kW	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Automatic chip boilers > 500 kW within wood proc. companies	4.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9	2.9
Combined chip heat and power plants	0.27	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.19	0.19
Plants for renewable waste from wood products	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.97	0.95

3.2.4.5.4. N_2O emission factors for 1A Fuel combustion

An overview of the default N_2O emission factors for stationary combustion according to the 2006 IPCC Guidelines (IPCC 2006) is given in Table 3-17. These default N_2O emission factors, which depend on the fuels and the source categories, are used for most stationary combustion processes for the entire time period. Exceptions, e.g. for motors and gas turbines, are discussed in the chapters of the respective source categories. In Table 3-17, the respective cells (fuel/source category) are highlighted in blue, indicating that the default N_2O emission factors are not applied in this case. A blue/white highlighting means that for the respective fuel and source category there are processes that use the default N_2O emission factors according to Table 3-17 as well as processes that use a different N_2O emission factor as discussed in the chapters of the respective source categories. Where default N_2O emission factors of fuels are not used at all in the respective source categories the notation key “NO” is indicated in Table 3-17. N_2O emission factors related to transport activities (aviation, road and non-road transportation) are category-specific and given in the corresponding sectoral chapters.

Table 3-17 Default N_2O emission factors for stationary combustion according to the 2006 IPCC Guidelines (IPCC 2006, Table 2.2 for 1A1, Table 2.3 for 1A2, Table 2.4 for 1A4ai and Table 2.5 for 1A4bi and 1A4ci). See text for further information and an explanation of the colour code. Where other than default N_2O emissions factors are (also) used, this is indicated by the notation key “CS” and details are described in the chapters of the respective source categories.

N_2O emission factors			**1990–2022**			
			1A1	**1A2**	**1A4ai**	**1A4bi, 1A4ci**
Fuel	**CS/D**	**Data sources**	g N_2O / GJ			
Gas oil	D	IPCC (2006)	0.6 / CS	0.6	0.6 / CS	0.6 / CS
Residual fuel oil	D	IPCC (2006)	0.6	0.6	NO	NO
Liquefied petroleum gas	D	IPCC (2006)	NO	0.1 / CS	CS	CS
Petroleum coke	D	IPCC (2006)	NO	0.6	NO	NO
Other bituminous coal	D	IPCC (2006)	1.5	1.5	NO	1.5
Lignite	D	IPCC (2006)	NO	1.5	NO	NO
Natural gas	D	IPCC (2006)	0.1 / CS	0.1 / CS	0.1 / CS	0.1 / CS
Biofuel	**CS/D**	**Data Sources**	g N_2O / GJ			
Biodiesel	D	IPCC (2006)	CS	CS	CS	CS
Biogas	D	IPCC (2006)	0.1 / CS	CS	0.1 / CS	CS
Wood	D	IPCC (2006)	4	4	4	4

3.2.4.6. Models overlapping more than one source category

3.2.4.6.1. Non-road transportation model (excl. aviation)

Choice of method

- The GHG emissions are calculated by a Tier 3 method based on the decision tree in Fig. 3.3.1 in chp. 3. Mobile Combustion in IPCC (2006), complemented with:
    - Tier 2 for railways CO_2, Fig. 3.4.1 in IPCC (2006)
    - Tier 3 for railways CH_4, N_2O and precursors, Fig. 3.4.2 in IPCC (2006)
    - Tier 2 for navigation, Fig. 3.5.1 (Box 1) in IPCC (2006)

Methodology

The emissions of the non-road sector underwent an extended revision in 2014/2015, resulting in an update of GHG emissions including precursors. Results are documented in FOEN (2015j). The non-road categories considered are listed in Table 3-18. All of them include several technologies, fuels (diesel oil, 2- or 4-stroke gasoline, liquefied petroleum gas, gas oil), and emission standards according to the classification shown in Figure 3-21.

Table 3-18 Non-road categories as specified in FOEN (2015j) and the corresponding code in the reporting tables (CRT).

Non-road categories (by Corinair)	**Nomenclature CRT**
Construction machinery	1.A.2.g.vii Off-road vehicles and other machinery
Industrial machinery	1.A.2.g.vii Off-road vehicles and other machinery
Railway machinery	1.A.3.c Railways
Navigation machinery	1.A.3.d Domestic Navigation
Garden-care/professional appliances	1.A.4.a.ii Commercial/institutional, Off-road vehicles and other machinery
Garden-care/hobby appliances	1.A.4.b.ii Residential, Off-road vehicles and other machinery
Agricultural machinery	1.A.4.c.ii Agriculture/forestry/fishing, Off-road vehicles and other machinery
Forestry machinery	1.A.4.c.ii Agriculture/forestry/fishing, Off-road vehicles and other machinery
Military machinery (excl. aviation)	1.A.5.b Other, mobile, Military

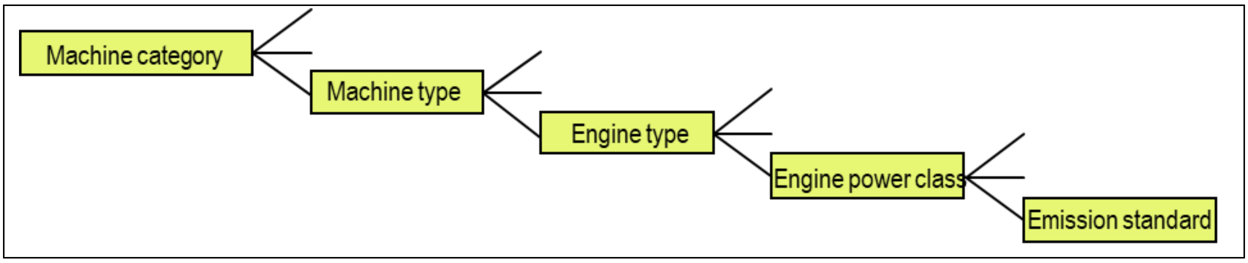

Figure 3-21 Each non-road vehicle is classified by its machine category, machine type, engine type and engine-power class and emission standard (FOEN 2015j, INFRAS 2015a).

The emission modelling is based on activity data and emission factors by means of the following equation, which holds on the most disaggregated level of engine power class (Figure 3-21):

$$Em = N \cdot H \cdot P \cdot \lambda \cdot \varepsilon \cdot CF_1 \cdot CF_2 \cdot CF_3$$

with

Em = emission per engine type (in g/a)

N = number of vehicles (--)

H = number of operation hours per year (h/a)

P = engine power output (kW)

λ = effective load factor (--)

ε = emission factor (g/kWh)

CF_1 = correction factor for the effective load (--)

CF_2 = correction factor for dynamical engine use (--)

CF_3 = degradation factor due to aging (--)

With this equation, the emissions of the following gases and also the fuel consumption are calculated:

- GHG: CH_4, N_2O
- Precursor gases: NO_x, CO
- Air pollutant: VOC
- Fuel consumption: in this case, ε represents the consumption instead of emission factor (in g/kWh)

For other gases, the following method is applied:

- CO_2 is calculated as product of fuel consumption and CO_2 emission factors (according to Table 3-13)
- SO_2 is calculated as product of fuel consumption and SO_2 emission factors (according to Table A – 18)

- NMVOC is calculated as the difference between VOC and CH_4
- CO_2 emissions from the use of lubricants as an additive in gasoline for 2-stroke engines are modelled separately and the corresponding CO_2 emissions from the lubricants are reported under 2D1 Lubricant use (chp. 4.5.2.1). Non-CO_2 emissions from the combustion of lubricants in 2-stroke engines however are reported in the energy sector (1A2gvii, 1A3b, 1A3d, 1A4aii, 1A4bii, 1A4cii, 1A5bii).

The total emission and consumption per non-road category are calculated by taking the sum over all engine-power classes, engine types, machine types and emission standards.

Emissions are only calculated in steps of 5 years from 1980 to 2050. Emissions for years in-between are interpolated linearly. A more detailed description of the analytical details is given in the Annex of FOEN (2015j).

Emission factors

Emission factors are taken from FOEN (2015j). They have been derived from various sources based on measurements, modelling and literature:

- CO_2 and SO_2 emission factors are country-specific, see Table 3-13 and Table A – 18.
- For other gases, the main data sources are USEPA (2010), IFEU (2010), EMEP/EEA (2016), EMEP/EEA (2019) and Integer (2013).

For a detailed description of emission factors and their origin, see tables in the annex of FOEN (2015j) and online in the database developed by INFRAS (2015a).

Activity data

Activity data were collected by surveys among producers and several user associations in Switzerland (FOEN 2015j), and by evaluating information from the national information system for traffic admission (IVZ, formerly MOFIS) run by the Federal Roads Office (FEDRO 2014). In addition, several publications serve as further data sources:

- SBV (2013) for agricultural machinery
- SFSO (2013a) for agricultural machinery
- Jardin Suisse (2012) for garden care /hobby and professional appliances
- KWF (2012) for forestry machinery
- The national statistics on imports/exports of non-road vehicles was assessed by FCA (2015c)
- Off-Highway Research (2005, 2008, 2012) provided information on the number of non-road vehicles.
- Federal Department of Defence, Civil Protection and Sport: List of military machinery with vehicle stock, engine-power classes and operating hours (DDPS 2014a).

From these data sources, all necessary information like size distributions, fleet turnover, annual operating hours (age-dependent), load factors, year of market entry, and age distributions, was derived. Details are documented in FOEN (2015j). All activity data (vehicle stock, operating hours, consumption factors) can be downloaded by query from the online non-road database INFRAS (2015a), which corresponds to the data described in FOEN (2015j). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels.

3.2.4.6.2. Model for wood energy combustion

Choice of method

The emissions from wood combustion in 1A Fuel combustion are calculated by a Tier 2 method (with the exception of a Tier 1 method for N_2O) based on the decision tree for stationary fuel combustion (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1 on page 2.15).

Methodology

The Swiss wood energy statistics (SFOE 2023b) distinguish 24 wood combustion installation types (excl. municipal solid waste plants) that are fired with logwood, pellets, chips or so-called renewable waste from wood products and provide both the annual wood consumption for the individual categories of combustion installation types (table K, categories 1–19, see Table 3-19), and the allocations of the installation types to the sectoral consumer categories (table N, household, agriculture/forestry, industry, services, electricity and district heating). This allows for assigning the annual wood consumption at the level of combustion installation categories directly to the source categories 1A1a Public electricity and heat production, 1A2gviii Other, 1A4ai Commercial/institutional, 1A4bi Residential and 1A4ci Agriculture/forestry/fishing (EMIS 2024/1A Holzfeuerungen). Installation types of the wood energy statistics with the same emission behaviour are grouped into one category in Table 3-19. For information purposes, the category numbers according to the statistics are listed in parentheses.

Table 3-19 Categories of wood combustion installations based on the Swiss wood energy statistics (SFOE 2022b). The category numbers according to the statistics are listed in parentheses.

1A Wood combustion, categories
Open fireplaces (1)
Closed fireplaces, log wood stoves (2, 3, 4a, 5)
Pellet stoves (4b)
Log wood hearths (6, 7)
Log wood boilers (8, 9)
Log wood dual chamber boilers (10)
Automatic chip boilers < 50 kW (11a)
Automatic pellet boilers < 50 kW (11b)
Automatic chip boilers 50–300 kW w/o wood processing companies (12a)
Automatic pellet boilers 50–300 kW (12b)
Automatic chip boilers 50–300 kW within wood processing companies (13)
Automatic chip boilers 300–500 kW w/o wood processing companies (14a)
Automatic pellet boilers 300–500 kW (14b)
Automatic chip boilers 300–500 kW within wood processing companies (15)
Automatic chip boilers > 500 kW w/o wood processing companies (16a)
Automatic pellet boilers > 500 kW (16b)
Automatic chip boilers > 500 kW within wood processing companies (17)
Combined chip heat and power plants (18)
Plants for renewable waste from wood products (19)

Emission factors

Emission factors are described in chp. 3.2.4.5.2 for CO_2, 3.2.4.5.3 for CH_4, and 3.2.4.5.4 for N_2O.

Activity data

Total activity data are based on the Swiss wood energy statistics (SFOE 2023b). As additional data source, specific bottom-up information from the industry is used in order to allocate wood combustion emissions directly to a particular source category. Thus, activity data of wood combustion within 1A2f, 1A2giv and 1A4ci are allocated on the basis of industry information (see Figure 3-17 and EMIS 2024/1A Holzfeuerungen):

- Wood energy consumption in the source categories 1A2f Brick and tile production (2000–2012), 1A2f Cement production and 1A2giv Fibreboard are subtracted from the activity data of 1A2gviii Automatic chip boiler >500 kW without wood processing companies and 1A2gviii Plants for renewable waste from wood products, respectively.
- From 2013 onwards, also the wood energy consumption in 1A4ci Grass drying is available and is subtracted from the activity data in 1A4ci Automatic chip boiler >500 kW without wood processing companies.

Table 3-20 Wood energy consumption in 1A Fuel combustion.

1A Wood combustion	**1990**	**1995**	**2000**	**2005**	**2010**
	TJ				
Total	28'219	29'649	27'426	31'413	40'135
Open fireplaces	226	270	195	181	124
Closed fireplaces, log wood stoves	7'273	7'166	6'487	7'036	8'519
Pellet stoves	NO	NO	7.0	48	151
Log wood hearths	8'520	7'017	4'737	4'020	2'348
Log wood boilers	5'307	5'564	5'105	5'357	4'909
Log wood dual chamber boilers	1'964	1'777	977	480	273
Automatic chip boilers < 50 kW	239	433	550	753	1'008
Automatic pellet boilers < 50 kW	NO	NO	56	804	2'106
Automatic chip boilers 50–300 kW w/o wood proc. companies	464	858	1'161	1'862	2'735
Automatic pellet boilers 50–300 kW	NO	NO	3.0	114	601
Automatic chip boilers 50–300 kW within wood proc. companies	895	1'186	1'216	1'365	1'533
Automatic chip boilers 300–500 kW w/o wood proc. companies	237	521	713	1'000	1'503
Automatic pellet boilers 300–500 kW	NO	NO	NO	19	195
Automatic chip boilers 300–500 kW within wood proc. companies	412	570	588	632	674
Automatic chip boilers > 500 kW w/o wood proc. companies	314	1'096	1'732	2'400	4'483
Automatic pellet boilers > 500 kW	NO	NO	NO	9.0	186
Automatic chip boilers > 500 kW within wood proc. companies	1'389	2'128	2'368	2'768	2'960
Combined chip heat and power plants	NO	3.0	186	127	2'756
Plants for renewable waste from wood products	979	1'060	1'345	2'439	3'070

1A Wood combustion	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	TJ									
Total	44'200	37'314	38'920	42'573	43'570	41'149	43'374	42'649	49'732	47'345
Open fireplaces	84	62	64	68	67	62	62	58	59	42
Closed fireplaces, log wood stoves	8'604	6'824	7'446	7'862	7'540	6'926	6'943	6'375	7'280	6'056
Pellet stoves	190	159	181	199	196	186	187	175	198	166
Log wood hearths	1'454	978	1'006	992	900	792	763	675	748	617
Log wood boilers	3'901	2'820	2'970	3'032	2'852	2'597	2'596	2'320	2'523	2'039
Log wood dual chamber boilers	182	125	119	112	88	67	57	42	38	27
Automatic chip boilers < 50 kW	946	739	786	798	742	667	644	559	582	455
Automatic pellet boilers < 50 kW	2'511	2'099	2'376	2'610	2'619	2'538	2'676	2'489	2'909	2'719
Automatic chip boilers 50–300 kW w/o wood proc. companies	3'183	2'645	3'032	3'350	3'372	3'252	3'379	3'241	3'828	3'275
Automatic pellet boilers 50–300 kW	917	857	1'091	1'310	1'451	1'498	1'635	1'659	2'084	1'845
Automatic chip boilers 50–300 kW within wood proc. companies	1'540	1'282	1'400	1'489	1'486	1'426	1'425	1'374	1'543	1'343
Automatic chip boilers 300–500 kW w/o wood proc. companies	1'751	1'436	1'644	1'816	1'820	1'742	1'817	1'744	2'040	1'746
Automatic pellet boilers 300–500 kW	269	239	279	337	355	352	365	352	433	366
Automatic chip boilers 300–500 kW within wood proc. companies	684	570	600	632	623	617	615	596	658	569
Automatic chip boilers > 500 kW w/o wood proc. companies	5'893	5'015	5'843	6'575	6'778	6'525	6'980	7'083	8'325	7'185
Automatic pellet boilers > 500 kW	297	281	317	364	362	346	370	354	423	361
Automatic chip boilers > 500 kW within wood proc. companies	2'905	2'407	2'568	2'653	2'546	2'397	2'425	2'328	2'613	2'285
Combined chip heat and power plants	5'421	5'325	3'830	3'970	4'887	4'696	5'921	6'319	6'795	7'294
Plants for renewable waste from wood products	3'468	3'450	3'367	4'404	4'887	4'463	4'513	4'906	6'653	8'954

3.2.4.7. Model of stationary engines and gas turbines

Choice of method

The emissions from stationary engines and gas turbines in 1A Fuel combustion activities are calculated by a Tier 2 method based on the decision tree for stationary fuel combustion (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1 on page 2.15).

Methodology

The model for calculating emissions from stationary engines and gas turbines underwent an extensive revision during the years 2021 to 2022 and the revised model was implemented for the submission in 2024. To calculate the final fuel consumption for each category of stationary engines and gas turbines, an inventory of power output values, distribution of exhaust gas technologies, average load factors and operating hours was elaborated. For large installations including engines and gas turbines with combined heat and power generation (CHP) along with gas turbines in simple cycle (SCGT) and combined cycle (CCGT) configuration, the available information was compiled individually for each unit. Most of the information was obtained from the cantonal air pollution control authorities, from publicly accessible websites and annual reports from industry, as well as from direct enquiries with the operators. Further details and results are documented in INFRAS (2022a). Emissions are calculated using the resulting fuel consumption for each category of stationary engines and gas turbines within 1A – Fuel consumption activities and multiplied with the respective emission factors.

Emission factors

Emission factors are based on the following sources according to INFRAS (2022a):

- CO_2 emission factors base on measurements as described in chp. 3.2.4.5.2.
- CH_4 as well as N_2O emission factors originate from table 87 of the National Inventory Report for the German Greenhouse Gas Inventory 1990–2018 (UBA 2020).

Table 3-21 Emission factors of engines and gas turbines in 1A1 Energy industries in 2022.

1A1a Public electricity and heat production (engines and gas turbines)	**CO_2 fossil**	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_x**	**NMVOC**	**SO_2**	**CO**
	t/TJ		kg/TJ					
Gas turbines as SCGT or CCGT								
Gas oil	73.7	NA	1.2	2.9	83	0.18	2.0	2.6
Natural gas	56.0	NA	5.2	0.69	31	1.6	0.18	13
Biogas	NA	56.0	5.2	0.69	48	1.6	0.5	13
Gas turbines with CHP unit								
Gas oil	73.7	NA	1.2	2.9	83	0.18	2.0	2.6
Natural gas	56.0	NA	5.2	0.69	32	1.6	0.18	10
Biodiesel	NA	73.3	1.2	2.9	83	0.18	0.31	2.6
Biogas	NA	56.0	5.2	0.69	48	1.6	0.5	10
Engines with CHP unit								
Gas oil	73.7	NA	1.2	2.9	136	50	2.0	136
Natural gas	56.0	NA	5.2	0.69	72	89	0.18	54
Biodiesel	NA	73.3	1.2	2.9	406	50	0.31	132
Biogas	NA	56.0	5.2	0.69	97	89	0.5	88
Engines used as emergency generators								
Gas oil	73.7	NA	1.2	2.9	942	50	2.0	137
Engines on landfills								
Natural gas	NO	NO	NO	NO	NO	NO	NO	NO
Biogas	NA	56.0	5.2	0.69	101	89	0.5	129
1A1b Petroleum refining (gas turbines)	t/TJ		t/TJ					
Gas turbines as SCGT at refineries								
Refinery gas	NO	NO	NO	NO	NO	NO	NO	NO

Table 3-22 Emission factors of engines and gas turbines in 1A2 Manufacturing industry and construction in 2022.

1A2d Pulp, paper and print (gas turbines)	**CO_2 fossil**	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_x**	**NMVOC**	**SO_X**	**CO**
	t/TJ		kg/TJ					
Gas turbines as SCGT or CCGT								
Natural gas	NO	NO	NO	NO	NO	NO	NO	NO
1A2gviii Other (engines and gas turbines)	t/TJ		kg/TJ					
Gas turbines as SCGT or CCGT								
Natural gas	56.0	NA	5.2	0.69	95	1.6	0.18	9.4
Biogas	NA	56.0	5.2	0.69	48	1.6	0.5	9.4
Gas turbines with CHP unit								
Liquefied petroleum gas	65.5	NA	5.2	0.69	48	1.6	0.5	4.8
Engines with CHP unit								
Liquefied petroleum gas	65.5	NA	5.2	0.69	135	89	0.5	56
Engines with CHP unit at biogas plants								
Biogas	NA	56.0	5.2	0.69	101	89	0.5	136

Table 3-23 Emission factors of engines and gas turbines in 1A3 Transport in 2022.

1A3ei Pipeline transport (gas turbines)	**CO_2 fossil**	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_x**	**NMVOC**	**SO_X**	**CO**
	t/TJ		kg/TJ					
Gas turbines as SCGT at compressor station for gas pipelines								
Natural gas	56.0	NA	5.2	0.69	32	1.6	0.18	10
Biogas	NA	56.0	5.2	0.69	48	1.6	0.5	10

Table 3-24 Emission factors of engines and gas turbines in 1A4ai Other sectors: commercial/institutional in 2022.

1A4ai Other sectors (stationary): Commercial/institutional (engines and gas turbines)	**CO_2 fossil**	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_x**	**NMVOC**	**SO_X**	**CO**
	t/TJ		kg/TJ					
Engines with CHP unit								
Gas oil	73.7	NA	1.2	2.9	136	50	2.0	136
Natural gas	56.0	NA	5.2	0.69	72	89	0.18	54
Liquefied petroleum gas	65.5	NA	5.2	0.69	135	89	0.5	56
Biodiesel	NA	73.3	1.2	2.9	406	50	0.31	132
Biogas	NA	56.0	5.2	0.69	97	89	0.5	88
Engines with CHP unit at biogas plants								
Liquefied petroleum gas	NO	NO	NO	NO	NO	NO	NO	NO
Biodiesel	NA	73.3	1.2	2.9	156	50	0.31	136
Biogas	NA	56.0	5.2	0.69	101	89	0.5	136
Engines used as emergency generators								
Gas oil	73.7	NA	1.2	2.9	915	50	2.0	137
Gas turbines at sewage plants								
Natural gas	56.0	NA	5.2	0.69	53	1.6	0.18	25
Sewage gas	NA	56.0	5.2	0.69	48	1.6	0.5	10
Engines with CHP unit at sewage plants								
Natural gas	56.0	NA	5.2	0.69	310	89	0.18	76
Sewage gas	NA	56.0	5.2	0.69	103	89	0.5	144

Table 3-25 Emission factors of engines and gas turbines in 1A4bi Other sectors: residential in 2022.

1A4bi Other sectors (stationary): Residential (engines)	**CO_2 fossil**	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_x**	**NMVOC**	**SO_X**	**CO**
	t/TJ		kg/TJ					
Engines with CHP unit								
Gas oil	73.7	NA	1.2	2.9	136	50	2.0	136
Natural gas	56.0	NA	5.2	0.69	72	89	0.18	54
Liquefied petroleum gas	65.5	NA	5.2	0.69	135	89	0.5	56
Biodiesel	NA	73.3	1.2	2.9	406	50	0.31	132
Biogas	NA	56.0	5.2	0.69	97	89	0.5	88

Table 3-26 Emission factors of engines and gas turbines in 1A4ci Other sectors: agriculture/forestry/fishing in 2022.

1A4ci Agriculture/forestry/fishing (engines)	**CO_2 fossil**	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_x**	**NMVOC**	**SO_X**	**CO**
	t/TJ		kg/TJ					
Engines used as emergency generators								
Gas oil	73.7	NA	1.2	2.9	942	50	2.0	137
Engines with CHP unit at biogas plants								
Natural gas	NO	NO	NO	NO	NO	NO	NO	NO
Biogas	NA	56.0	5.2	0.69	100	89	0.5	111

Activity data

Activity data were collected by surveys among the cantonal air pollution control authorities. For engines used as emergency generators, their proof of gas oil use, which is deposited with the Federal Office for Customs and Border Security (FOCBS), were the most important source of data. Furthermore, the statistics by the SFOE about the thermal electricity production including combined heat and power generation (CHP) in Switzerland (SFOE 2021c) served as the basis for activity data modelling. For large installations including engines as well as simple cycle gas turbines (SCGT) and combined cycle gas turbines (CCGT), the websites and annual reports of the operators provided relevant information on technical data, operating hours or fuel consumption. From these data sources, all necessary information like modelling of the quantity of installations, annual operating hours, load factors and rated thermal input were derived. Details are documented in INFRAS (2022a).

The activity data of engines using landfill gas in 1A1a Public electricity and heat production, engines using biogas in 1A2gviii Other - Manufacturing industries, 1A4ai Other – Commercial/institutional and 1A4ci Other – Agriculture/forestry /fishing, as well as gas turbines at the compressor station in 1A3ei Pipeline transport using natural gas is updated annually with newest available information concerning fuel consumption from SFOE 2023a and SFOE 2023 respectively.

Table 3-27 Activity data of engines and gas turbines in 1A1 Energy industries.

1A1a Public electricity and heat production (engines and gas turbines)	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Total fuel consumption	TJ	421	1'907	2'276	2'377	3'280
Gas turbines as SCGT or CCGT	TJ	28	811	873	1143	2443
Gas oil	TJ	24	33	33	33	33
Natural gas	TJ	3.5	779	840	1'110	2'410
Biogas	TJ	NO	NO	NO	NO	NO
Gas turbines with CHP unit	TJ	73	34	NO	47	47
Gas oil	TJ	6.7	3.6	NO	8.1	3.6
Natural gas	TJ	66	31	NO	39	42
Biodiesel	TJ	NO	NO	NO	0.10	0.64
Biogas	TJ	NO	NO	NO	NO	NO
Engines with CHP unit	TJ	81	451	834	969	726
Gas oil	TJ	7.5	47	179	167	55
Natural gas	TJ	73	405	655	799	661
Biodiesel	TJ	NO	NO	NO	2.1	10
Biogas	TJ	NO	NO	NO	NO	NO
Engines used as emergency generators	TJ	1.4	1.4	1.5	1.5	1.6
Gas oil	TJ	1.4	1.4	1.5	1.5	1.6
Engines on landfill sites	TJ	238	609	568	218	63
Natural gas	TJ	NO	NO	NO	14	14
Biogas	TJ	238	609	568	204	49
1A1b Petroleum refining (gas turbines)	TJ	NO	NO	2'575	2'270	1'808
Gas turbines as SCGT at refineries	TJ	NO	NO	2'575	2'270	1'808
Refinery gas	TJ	NO	NO	2'575	2'270	1'808

1A1a Public electricity and heat production (engines and gas turbines)	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total fuel consumption	TJ	3'044	1741	2921	4709	3748	3643	3649	3566	3577	3718
Gas turbines as SCGT or CCGT	TJ	2'361	1'114	2'339	4'187	3'278	3241	3293	3216	3228	3352
Gas oil	TJ	33	33	33	33	33	33	33	7.2	7.2	7.5
Natural gas	TJ	2'328	1'082	2'306	4'154	3'245	3'208	3'260	3'208	3'083	3'167
Biogas	TJ	NO	NO	NO	NO	NO	NO	NO	NO	137	177
Gas turbines with CHP unit	TJ	15	14	13	6.9	3.7	3.4	3.0	3.0	3.0	3.1
Gas oil	TJ	0.70	0.69	0.59	0.29	0.20	0.12	0.16	0.16	0.15	0.15
Natural gas	TJ	14	13	12	6.5	3.5	3.2	2.8	2.7	2.7	2.8
Biodiesel	TJ	0.22	0.22	0.19	0.10	0.065	0.057	0.057	0.055	0.054	0.055
Biogas	TJ	NO	NO	NO	NO	NO	NO	NO	0.11	0.12	0.15
Engines with CHP unit	TJ	613	568	546	501	459	391	343	342	341	352
Gas oil	TJ	29	27	25	21	24	14	18	18	17	17
Natural gas	TJ	576	532	513	473	426	370	319	305	304	311
Biodiesel	TJ	8.9	8.8	8.0	7.6	8.0	6.6	6.4	6.3	6.1	6.2
Biogas	TJ	NO	NO	NO	NO	NO	NO	NO	13	14	17
Engines used as emergency generators	TJ	1.7	1.7	1.7	1.7	1.7	1.8	1.8	1.7	1.8	1.8
Gas oil	TJ	1.7	1.7	1.7	1.7	1.7	1.8	1.8	1.7	1.8	1.8
Engines on landfill sites	TJ	53	43	21	12	7	6.0	8.4	4.0	4.0	8.4
Natural gas	TJ	15	11	NO	NO	NO	NO	NO	NO	NO	NO
Biogas	TJ	38	31	21	12	6.5	6.0	8.4	4.0	4.0	8.4
1A1b Petroleum refining (gas turbines)	TJ	1'748	1'879	293	NO	NO	NO	NO	NO	NO	NO
Gas turbines as SCGT at refineries	TJ	1'748	1'879	293	NO	NO	NO	NO	NO	NO	NO
Refinery gas	TJ	1'748	1'879	293	NO	NO	NO	NO	NO	NO	NO

Table 3-28 Activity data of engines and gas turbines in 1A2 Manufacturing industry and construction.

1A2d Pulp, paper and print (gas turbines)	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Total fuel consumption	TJ	NO	477	808	245	211
Gas turbines as SCGT or CCGT	TJ	NO	477	808	245	211
Natural gas	TJ	NO	477	808	245	211
1A2gviii Other (engines and gas turbines)	TJ	655	821	969	1233	1588
Gas turbines as SCGT or CCGT	TJ	613	721	810	1073	1355
Natural gas	TJ	613	721	810	1073	1355
Biogas	TJ	NO	NO	NO	NO	NO
Gas turbines with CHP unit	TJ	0.68	0.87	NO	1.5	2.3
Liquefied petroleum gas	TJ	0.68	0.87	NO	1.5	2.3
Engines with CHP unit	TJ	0.75	11	33	30	35
Liquefied petroleum gas	TJ	0.75	11	33	30	35
Engines with CHP unit at biogas plants	TJ	41	87	126	128	195
Biogas	TJ	41	87	126	128	195

1A2d Pulp, paper and print (gas turbines)	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total fuel consumption	TJ	289	304	341	NO	NO	NO	NO	NO	NO	NO
Gas turbines with CHP unit	TJ	289	304	341	NO	NO	NO	NO	NO	NO	NO
Natural gas	TJ	289	304	341	NO	NO	NO	NO	NO	NO	NO
1A2gviii Other (engines and gas turbines)	TJ	1'388	548	429	451	415	353	354	346	359	393
Gas turbines as SCGT or CCGT	TJ	1115	238	145	145	145	145	145	145	145	151
Natural gas	TJ	1'115	238	145	145	145	145	145	145	139	143
Biogas	TJ	NO	NO	NO	NO	NO	NO	NO	NO	6.2	8.0
Gas turbines with CHP unit	TJ	0.71	0.79	0.66	0.54	0.12	0.081	0.066	0.064	0.063	0.064
Liquefied petroleum gas	TJ	0.71	0.79	0.66	0.54	0.12	0.081	0.066	0.064	0.063	0.064
Engines with CHP unit	TJ	29	31	28	39	14	9.4	7.4	7.3	7.1	7.2
Liquefied petroleum gas	TJ	29	31	28	39	14	9.4	7.4	7.3	7.1	7.2
Engines with CHP unit at biogas plants	TJ	243	278	256	267	256	199	201	194	206	235
Biogas	TJ	243	278	256	267	256	199	201	194	206	235

Table 3-29 Activity data of engines and gas turbines in 1A3 Transport.

1A3ei Pipeline transport (gas turbines)	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Total fuel consumption	TJ	560	310	340	1070	830
Gas turbines as SCGT at compressor station for gas pipelines	TJ	560	310	340	1'070	830
Natural gas	TJ	560	310	340	1'070	830
Biogas	TJ	NO	NO	NO	NO	NO

1A3ei Pipeline transport (gas turbines)	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total fuel consumption	TJ	410	830	760	340	470	490	600	540	143	430
Gas turbines as SCGT at compressor station for gas pipelines	TJ	410	830	760	340	470	490	600	540	143	430
Natural gas	TJ	410	830	760	340	470	490	600	540	120	400
Biogas	TJ	NO	NO	NO	NO	NO	NO	NO	NO	23	30

Table 3-30 Activity data of engines and gas turbines in 1A4a Other sectors: commercial/institutional.

1A4ai Other sectors (stationary): Commercial/institutional (engines and gas turbines)	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Total fuel consumption	TJ	1'572	2973	4524	5062	4603
Engines with CHP unit	TJ	401	1614	2852	3236	2407
Gas oil	TJ	44	171	580	539	178
Natural gas	TJ	355	1'407	2'169	2'596	2'089
Liquefied petroleum gas	TJ	2.4	36	103	95	109
Biodiesel	TJ	NO	NO	NO	6.5	31
Biogas	TJ	NO	NO	NO	NO	NO
Engines with CHP unit at biogas plants	TJ	NO	32	113	144	420
Liquefied petroleum gas	TJ	NO	2.9	5.6	NO	NO
Biodiesel	TJ	NO	NO	26	1.4	26
Biogas	TJ	NO	29	82	143	394
Engines used as emergency generators	TJ	383	383	391	396	405
Gas oil	TJ	383	383	391	396	405
Gas turbines at sewage plants	TJ	179	169	66	NO	18
Natural gas	TJ	NO	0.23	0.073	NO	0.019
Sewage gas	TJ	179	169	66	NO	18
Engines with CHP unit at sewage plants	TJ	610	776	1'102	1'286	1'353
Natural gas	TJ	NO	1.0	1.2	1.4	1.4
Sewage gas	TJ	610	775	1'100	1'284	1'351

1A4ai Other sectors (stationary): Commercial/institutional (engines and gas turbines)	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total fuel consumption	TJ	4'521	4'349	4'260	4'181	4'008	3'813	3'643	3'639	3'621	3'716
Engines with CHP unit	TJ	2'019	1'881	1'784	1'681	1'470	1'244	1'091	1'085	1'082	1'118
Gas oil	TJ	92	88	77	66	76	44	57	55	54	54
Natural gas	TJ	1'809	1'668	1'596	1'469	1'325	1'151	991	948	945	968
Liquefied petroleum gas	TJ	91	97	87	121	44	29	23	23	22	23
Biodiesel	TJ	28	27	25	24	25	21	20	19	19	19
Biogas	TJ	NO	NO	NO	NO	NO	NO	NO	39	42	54
Engines with CHP unit at biogas plants	TJ	732	724	762	806	827	843	830	823	804	913
Liquefied petroleum gas	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Biodiesel	TJ	24	23	24	25	20	24	17	17	16	16
Biogas	TJ	709	701	738	780	807	818	813	807	787	897
Engines used as emergency generators	TJ	410	412	413	415	417	420	421	413	411	409
Gas oil	TJ	410	412	413	415	417	420	421	413	411	409
Gas turbines at sewage plants	TJ	18	25	25	27	26	34	34	34	34	33
Natural gas	TJ	0.020	0.027	0.029	0.25	0.23	0.24	0.23	0.21	0.20	0.19
Sewage gas	TJ	18	25	25	26	26	34	33	34	34	33
Engines with CHP unit at sewage plants	TJ	1'341	1'308	1'276	1'253	1'268	1'272	1'268	1'284	1'290	1'243
Natural gas	TJ	1.5	1.4	1.5	12	11	8.8	8.6	8.0	7.7	7.3
Sewage gas	TJ	1'340	1'306	1'274	1'241	1'257	1'264	1'259	1'276	1'282	1'236

Table 3-31 Activity data of engines and gas turbines in 1A4b Other sectors: residential.

1A4bi Other sectors (stationary): Residential (engines)	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Total fuel consumption	TJ	45	179	317	360	267
Engines with CHP unit	TJ	45	179	317	360	267
Gas oil	TJ	4.9	19	64	60	20
Natural gas	TJ	39	156	241	288	232
Liquefied petroleum gas	TJ	0.26	4.0	11	11	12
Biodiesel	TJ	NO	NO	NO	0.72	3.4
Biogas	TJ	NO	NO	NO	NO	NO

1A4bi Other sectors (stationary): Residential (engines)	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total fuel consumption	TJ	224	209	198	187	163	138	121	121	120	124
Engines with CHP unit	TJ	224	209	198	187	163	138	121	121	120	124
Gas oil	TJ	10	10	8.5	7.4	8.4	4.8	6.4	6.2	6.0	6.0
Natural gas	TJ	201	185	177	163	147	128	110	105	105	108
Liquefied petroleum gas	TJ	10	11	10	14	4.9	3.3	2.6	2.5	2.5	2.5
Biodiesel	TJ	3.1	3.1	2.8	2.6	2.8	2.3	2.2	2.2	2.1	2.2
Biogas	TJ	NO	NO	NO	NO	NO	NO	NO	4.3	4.7	6.0

Table 3-32 Activity data of engines and gas turbines in 1A4c Other sectors: agriculture/forestry/fishing.

1A4ci Agriculture/forestry/fishing (engines)	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Total fuel consumption	TJ	61	51	64	130	499
Engines used as emergency generators	TJ	2.1	2.1	2.1	2.1	2.1
Gas oil	TJ	2.1	2.1	2.1	2.1	2.1
Engines with CHP unit at biogas plants	TJ	59	49	62	128	497
Natural gas	TJ	2.7	1.3	2.5	2.3	NO
Biogas	TJ	59	49	62	128	497

1A4ci Agriculture/forestry/fishing (engines)	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total fuel consumption	TJ	814	930	1043	1194	1274	1405	1614	1764	1911	1948
Engines used as emergency generators	TJ	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
Gas oil	TJ	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
Engines with CHP unit at biogas plants	TJ	812	928	1041	1192	1272	1403	1612	1762	1909	1946
Natural gas	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Biogas	TJ	812	928	1041	1192	1272	1403	1612	1762	1909	1946

3.2.4.8. Emissions from biomass (memo item)

According to the 2006 IPCC Guidelines (IPCC 2006), CO_2 emissions from biomass do not count for the national total emissions and therefore are a memo item only. The CO_2 emissions from biomass as reported in the reporting tables are incomplete as the following CO_2 emissions from biomass are not foreseen for reporting in the reporting tables: 2G4 Use of tobacco, 2H2 Food and beverages, 5A Solid waste disposal, 5B Biological treatment of solid waste, 5D Wastewater treatment and discharge as well as 6 Other. In contrast, CO_2 emissions from biomass from source category 5C Incineration and open burning of waste are included in CRT Table5.C, but not accounted for in the total CO_2 emissions from biomass as shown in CRT Summary1.As3, CRT Summary2, CRT Table10s1 and CRT Table10s2 (these tables include CO_2 emissions from biomass from sector 1 Energy only). Similarly, CO_2 emissions from biomass from international aviation (source category 1D1) are included in CRT Table1.D but not accounted for elsewhere.

Table 3-33 provides an overview of latest effective CO_2 emissions from biomass and their reporting in the reporting tables (without land use, land-use change and forestry). For further information on the CO_2 emissions from biomass refer to the chapters of the respective source categories.

Table 3-33 Effective CO_2 emissions from biomass in the reporting year and their representation in the reporting tables.

CO_2 emissions from biomass	**2022**	**Note**
	kt	
1A1 Energy industries (without MSW incineration)	548	Included in reporting tables
1A1 Energy generation from MSW Incineration	2'194	Included in reporting tables
1A2 Manufacturing industries and construction	1'813	Included in reporting tables
thereof use of waste derived fuels in cement production	83	
thereof use of biofuels (1A2gvii)	30	
1A3 Transport	450	Included in reporting tables
1A4 Other sectors (Commercial/institutional, residential)	3'231	Included in reporting tables
1A5 Other	0.89	Included in reporting tables
2H2 Food and beverages industry	14	Not included in reporting tables
2G Other product use (Consumption of tabacco)	10	Not included in reporting tables
5A Solid waste disposal	33	Not included in reporting tables
5B Biological treatment of solid waste (composting and anaerobic digestion)	159	Not included in reporting tables
5C Incineration and open burning of waste (without MSW incineration)	114	Included in CRT Table5.C, but not accounted for in the summary reporting tables
5D Wastewater treatment and discharge	4.7	Not included in reporting tables
6 Other	1.6	Not included in reporting tables
Total CO_2 emissions from biomass in Switzerland in 2022	8'572	Without international aviation
Total CO_2 emissions from biomass included in the following summary reporting tables (energy-related CO_2 emissions from biomass combustion included in sector 1 Energy): CRT Summary1, CRF Summary2, CRT Table10s1 and CRT Table10s2	8'236	
International aviation (aviation bunkers)	0.026	Included in CRT Table1.D, but not accounted for in the summary reporting tables

3.2.4.9. Uncertainty and time series consistency for source category 1A

In the following, basic uncertainties of activity data and CO_2 emission factors by fuel type are presented for source category 1A Fuel combustion.

Table 3-34 Uncertainties of activity data, CO_2 emission factors and CO_2 emissions for 1A Fuel combustion.

Fuel type	Uncertainties		
	Activity data	CO_2 emission factors	CO_2 emissions
	%		
Jet kerosene	0.96	0.16	0.97
Gasoline	0.69	0.13	0.70
Diesel oil	0.88	0.068	0.88
Liquid fuels	0.69	0.081	0.69
Solid fuels	5	5.1	7.1
Gaseous fuels	5	0.37	5.0
Other fuels	5	9.2	10
Biomass	10	--	--

Liquid fuels

Uncertainty of the CO_2 emission factors

In 2013, a large measurement campaign was carried out to determine the CO_2 emission factors of the dominant liquid fuels (SFOE/FOEN 2014). From the standard deviation presented in this study, the 95 % uncertainties are derived and shown in Table 3-35 as lower and upper values as well as relative uncertainties.

For mobile combustion, the 2006 IPCC Guidelines provide default uncertainties for the CO_2 emission factors of 2 % for jet kerosene, 4 % for gasoline and 1 % for diesel oil (IPCC 2006, vol. 2, TABLE 3.2.1). The Swiss measurements indicate much lower uncertainties. For stationary combustion, the 2006 IPCC Guidelines give no default values but show instead a summary of an uncertainty assessment of CO_2 emission factors for selected countries (IPCC 2006, vol. 2, TABLE 2.13). The values lie in the range between 0.5 % and 3 % and are again higher than the values derived from the Swiss measurements.

Table 3-35 Uncertainties of aggregated results of measurements of the CO_2 emission factors of selected liquid fuels (SFOE/FOEN 2014).

Fuel type	CO_2 emission factors (measurements)			95% uncertainties emission factors (CO_2)		no. samples
	mean	lower	upper	absolute	relative	
	t/TJ	t/TJ	t/TJ	t/TJ	%	
Jet kerosene	72.81	72.70	72.93	0.12	0.16%	24
Gasoline	73.80	73.71	73.90	0.10	0.13%	138
Diesel oil	73.30	73.25	73.35	0.05	0.07%	75
Gas oil	73.67	73.61	73.73	0.06	0.08%	138

Uncertainties of activity data

The values shown in Table 3-36 are based on a written message of SFOE to FOEN (SFOE 2012a). It lists two kinds of relevant sources of uncertainties: measurement uncertainties and uncertainties of the conversion from mass to energy units. For diesel oil, the transformation to other products represents a third source of uncertainty. Since the used equations are multiplications, the relative uncertainties have to be summed up.

Table 3-36 Sources of uncertainties contributing to the total uncertainty of the activity data of selected liquid fuels (SFOE 2012a).

Source of uncertainty	**Jet kerosene**	**Gasoline**	**Diesel oil**	**Gasoil**
	activity data uncertainty in %			
Measurement	0.39%	0.39%	0.39%	0.39%
Conversion mass to energy	0.57%	0.29%	0.29%	0.29%
Product transformation	-	-	0.20%	-
Total Uncertainty	0.96%	0.69%	0.88%	0.69%

Gaseous fuels

Uncertainty of the CO_2 emission factor

The composition of the imported gas is analysed in detail at the import stations. From this information, the FOEN annually calculates the CO_2 emission factor for each import station and the weighted mean. To estimate the uncertainty of the emission factor, the weighted standard deviation is calculated and is multiplied by a factor of 1.96 to represent a 95 % uncertainty interval. This calculation has been carried out for all years with available data (selected years between 1990 and 2009 and all years thereafter). The uncertainties fluctuate from year to year. For the uncertainty analysis, the following values for the uncertainty of the CO_2 emission factor for gaseous fuels are used: 1.48 % for 1990 and of 0.37 % for 2022.

Uncertainty of activity data

There is no country-specific estimate of the uncertainty for the consumption of natural gas. It is taken from the 2006 IPCC Guidelines (IPCC 2006, vol. 2, Table 2.15), which give a range of 2 % to 5 % for industrial combustion and 3 % to 5 % for commercial, institutional and residential combustion. For Switzerland, an overall value of 5 % is used.

Solid fuels

Uncertainty of the CO_2 emission factor

There is no country-specific uncertainty available. The 2006 IPCC Guidelines suggest a range from 0.5 % to 10 % (IPCC 2006, vol. 2, Table 2.13). For Switzerland, an uncertainty of 5 % is chosen (mean of suggested range).

Uncertainty of activity data

There is no country-specific estimate of the uncertainty for the consumption of coal. It is taken from the 2006 IPCC Guidelines (IPCC 2006, vol. 2, Table 2.15), which give a range of 2 % to 5 % for industrial combustion and 3 % to 5 % for commercial, institutional and residential combustion. For Switzerland, an overall value of 5 % is used (as for natural gas).

Other fuels (waste-to-energy)

Uncertainty of the CO_2 emission factor

There are two factors influencing the uncertainty of CO_2 emissions from municipal solid waste incineration (1A1a), namely the carbon content of waste and the fossil carbon fraction of the carbon content.

- The carbon content is determined according to a study by Fellner et al. (2007). The relation between the calorific value of waste and the carbon content is derived therein, including upper and lower limits. The relation is verified by measurements. The relative difference between upper and lower limits (5.9 %) is interpreted as 95 % confidence interval for the carbon content.

- The fossil fraction of the carbon content was determined in a study by Mohn et al. (2011). The radiocarbon (^{14}C) method was used to determine the ratio of fossil versus biogenic CO_2 emissions from five waste-to-energy plants. Gas samples for $^{14}CO_2$ analysis were taken at the plants during miscellaneous seasons. Six field campaigns of three weeks were carried out for three plants and three field campaigns, again of three weeks, were carried out for two plants, leading to a total sampling duration of 72 weeks. The field campaigns provided a median and (absolute) 95 % confidence interval of the fossil fraction of (47.7±7.5) % (Table 3-37). The relative uncertainty was thus 15.8 %. The results fit well to former field campaigns on three plants, which yielded a mean fossil fraction of 48.0 % (Mohn et al. 2008). For the greenhouse gas inventory and its uncertainty analysis the latest results from Mohn et al. (2011) are used.
- The emission factor for fossil CO_2 results from the multiplication of the carbon content and the fossil fraction. The relative uncertainty of the CO_2 emission factor is thus computed using uncertainty propagation: $[(5.9\ \%)^2 + (15.8\ \%)^2]^{0.5} = 16.9\ \%$.

Table 3-37 Fossil fractions of municipal solid waste measured at five different incineration plants. The absolute uncertainty values (3rd column) are expressed in the same unit as the shares, in %.

Plant	**Fossil shares**	**Uncertainty (95% confidence interval)**		**Field campaigns**
		absolute	relative	(duration)
	%	%	%	weeks
Buchs	47.7			6 * 3 = 18
Winterthur	43.4			6 * 3 = 18
Linthgebiet	50.6			6 * 3 = 18
Linthgebiet	54.5			3 * 3 = 9
Zuchwil	45.9			3 * 3 = 9
Median / sum	47.7	7.5	15.8	72

Uncertainty of activity data

There is no country-specific estimate of the uncertainty for the combustion of waste. It is taken from the 2006 IPCC Guidelines (IPCC 2006, vol. 2, p. 2.40), which state: “Experts believe that the uncertainty resulting from the two errors (*systematic, random*) combined is probably in the range of ±5 % for most developed countries.” In accordance with that statement, the value of 5 % is used.

Biomass

Uncertainty of the CO_2 emission factor

For CO_2 emissions of biomass burning, no uncertainty is estimated (memo item).

Uncertainty of activity data

No country-specific uncertainty of the activity data is available. The 2006 IPCC Guidelines suggest 2 % to 5 % for industrial, institutional and residential combustion and 10 % to 30 % for biomass burning in small sources (IPCC 2006, vol. 2, Table 2.15). An average uncertainty of 10 % is applied for biomass burning in all source categories.

Uncertainty of CH_4 and N_2O emission factors

Since the CO_2 emissions vastly dominate the GHG emissions of source category 1A (almost 99 % of total emissions), the uncertainty evaluation of the non-CO_2 emissions is carried out on a semi-quantitative level (see Table 3-38).

Only for **1A3b Road transportation**, a quantitative analysis has been performed. Following a study for the road transportation in Germany (IFEU/INFRAS 2010), where the same handbook of emission factors is used as in Switzerland, the uncertainties for the CH_4 and N_2O emission factors have been determined (see rows 1A3b gasoline and diesel oil in Table 3-38). The uncertainties of CH_4 and N_2O emissions of CNG (1A3b), which were not investigated in IFEU/INFRAS (2010), have been estimated qualitatively as “medium” according to Table 1-8. For the source categories **1A1, 1A2, 1A3a, 1A3c, 1A3d, 1A3e, 1A4a, 1A4b, 1A4c, 1A5** the uncertainties of CH_4 and N_2O emissions have similarly been estimated qualitatively (see Table 3-38).

Summary

Table 3-38 provides a summary of the uncertainties of 1A Fuel combustion as derived in the preceding sections. The combined uncertainty assigned to the CO_2 emissions is computed by propagating the uncertainties of the activity data and the emission factors.

Table 3-38 Uncertainties of 1A Fuel combustion categories for activity data, emission factors and combined uncertainties for 2022. The latter are calculated by uncertainty propagation (approach 1). For 1A2/Other Fuels a mean uncertainty is assumed based on semi-quantitative estimations from Table 1-8. The emission factor uncertainty is calculated “backward” ($U(EF) = \sqrt{U(EM)^2 - U(AD)^2}$) from the combined and the activity data uncertainty. CH_4 and N_2O: semi-quantitative uncertainties are used (see Table 1-8). For 1990, uncertainties are generally the same as for 2022, except for the CO_2 emission factor for gas (1.48 % for 1990).

1A Fuel Combustion Categories	Fuel type	Uncertainties				
		Activity data	CO_2 em. factors	CO_2 emissions	CH_4 emissions	N_2O emissions
		%	%	%	--	--
1. Energy industries	liquid fuels	0.69	0.081	0.69	medium	medium
1. Energy industries	solid fuels	5.0	5.1	7.1	medium	medium
1. Energy industries	gaseous fuels	5.0	0.37	5.0	medium	medium
1. Energy industries	other fuels	5.0	9.2	10	medium	medium
2. Manufacturing industries and construction	liquid fuels	0.69	0.081	0.69	medium	medium
2. Manufacturing industries and construction	solid fuels	5.0	5.1	7.1	medium	medium
2. Manufacturing industries and construction	gaseous fuels	5.0	0.37	5.0	medium	medium
2. Manufacturing industries and construction	other fuels	5.0	9.2	10	medium	medium
3a. Transport; Domestic aviation	kerosene	0.96	0.16	0.97	high	high
3b. Transport; Road transportation	gasoline	0.69	0.13	0.70	37%	50%
3b. Transport; Road transportation	diesel oil	0.88	0.068	0.88	20%	22%
3b. Transport; Road transportation	gaseous fuels	5.0	0.37	5.0	medium	medium
3c. Transport; Railways	diesel oil	0.88	0.068	0.88	medium	high
3d. Transport; Domestic navigation	liquid fuels	0.69	0.081	0.69	medium	high
3e. Transport; Other transportation	gaseous fuels	5.0	0.37	5.0	medium	medium
4a. Other sectors; Commercial/institutional	liquid fuels	0.69	0.081	0.69	medium	medium
4a. Other sectors; Commercial/institutional	gaseous fuels	5.0	0.37	5.0	medium	medium
4b. Other sectors; Residential	liquid fuels	0.69	0.081	0.69	medium	medium
4b. Other sectors; Residential	solid fuels	5.0	5.1	7.1	medium	medium
4b. Other sectors; Residential	gaseous fuels	5.0	0.37	5.0	medium	medium
4c. Other sectors; Agriculture/forestry/fishing	liquid fuels	0.69	0.081	0.69	medium	medium
4c. Other sectors; Agriculture/forestry/fishing	gaseous fuels	5.0	0.37	5.0	medium	medium
5. Other	liquid fuels	0.69	0.081	0.69	medium	high
1A Stationary sources	biomass	10	--	--	medium	medium
1A Mobile sources	biomass	10	--	--	high	high

Time series consistency 1A

Time series for 1A Fuel combustion are all considered consistent.

3.2.4.10. Category-specific QA/QC and verification for 1A

Various QA/QC activities are relevant for all source categories in 1A. Therefore, they are briefly described here and not repeated in the chapters dealing with the source categories 1A1 to 1A5.

Comparison of emission estimates using different approaches

At the level of total energy-related CO_2 emissions, a quality control consists in the comparison of emissions modelled using the sectoral approach with emissions calculated based directly on fuel consumption according to the Swiss overall energy statistics (SFOE 2023). The differences in total CO_2 emissions for the entire time period are negligible, indicating the completeness of the inventory.

The cross-check of the Reference and Sectoral Approach is also used for an assessment of emissions related to the consumption of fuels in the energy sector. Again, a good agreement between the two approaches is found (see chp. 3.2.1).

Activity data checks

The SFOE constructs a national commodity balance expressed in mass and in energy units including mass balances of fuel conversion industries.

The gross carbon supply in the Reference Approach has been adjusted for fossil fuel carbon destined for non-energy use. The numbers in the Swiss overall energy statistics (SFOE 2023) are consistent with those provided by international organisations, e.g. IEA.

Emission factor check and review

Emission factors for the main fossil fuels have been reassessed for submission 2015. In 2013, the Swiss Federal Office of Energy (SFOE) and the Swiss Federal Office for the Environment (FOEN) launched an in-depth investigation into the NCVs and CO_2 emission factors of gas oil, diesel oil, gasoline, and jet kerosene (SFOE/FOEN 2014, see chp. 3.2.4.2). The most recent results differ only marginally from previously used values. The CO_2 emission factors compare well with the IPCC default values (see Table 3-39).

Table 3-39 Comparison of default CO_2 emission factors from IPCC (2006) with current country-specific values of Switzerland for selected fuels.

CO_2 emission factors	**IPCC 2006**			**Switzerland**
	lower	upper	default	CS
	t CO_2 /TJ			t CO_2 /TJ
Gasoline	67.5	73.0	69.3	73.8
Jet kerosene	69.7	74.4	71.5	72.8
Diesel oil	72.6	74.8	74.1	73.3
Gas oil	72.6	74.8	74.1	73.7

Switzerland's country-specific CO_2 emission factor for gasoline is higher than the upper limit of the IPCC range (Table 3-39). However, the value is based on more than 100 fuel samples taken from July to December 2013 (SFOE/FOEN 2014) and is in agreement with earlier measurements (EMPA 1999). Accordingly, the value is considered to correctly represent national circumstances.

For natural gas, the CO_2 emission factor is annually assessed. A country-specific CO_2 emission factor is calculated based on measurements of gas properties and corresponding import shares of individual gas import stations (see chp. 3.2.4.5). The resulting values are largely consistent with the CO_2 emission factor used by the countries from which gas is imported (i.e. Germany, the Netherlands, Norway, France, Italy and Denmark, with implied emission factors between 55.5 and 58.5 t CO_2/TJ, based on submissions in 2023).

For submission 2021, the CH_4 emission factors from combustion of wood were scrutinized and revised based on Zotter and Nussbaumer (2022). The range of country-specific values is not entirely consistent with the lower IPCC default values (1A1, 1A2, Table 3-40). However, as the country-specific emission factors are based on an extensive measurement campaign, they are considered representative for Swiss circumstances.

Table 3-40 Comparison of default CH_4 emission factors from the 2006 IPCC Guidelines (IPCC 2006) with country-specific values for wood/wood waste.

CH_4 emission factors	**IPCC 2006**			**Switzerland**
	lower	upper	default	CS
	kg CH_4 /TJ			kg CH_4 /TJ
Wood/wood waste	10 (1A1, 1A2) 100 (1A4)	100 (1A1, 1A2) 900 (1A4)	30 (1A1, 1A2) 300 (1A4)	0.19–230

Further QC procedures

The general QC procedures as described in chp. 1.5 (e.g. annual internal review, expert peer review, etc.) also apply to source category 1A.

3.2.4.11. Planned improvements for source category 1A in general

Currently, Switzerland considers CO_2 emissions from biofuels as completely fossil-free. It is planned to assess the origin of biofuels in order to identify and separate fossil from biogenic feedstocks (e.g. in case fossil-fuel derived methanol is used for biodiesel production).

3.2.5. Source category 1A1 – Energy industries (stationary)

3.2.5.1. Source category description for 1A1 (stationary)

Table 3-41 Key categories of 1A1 Energy industries. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
1A1	Energy industries; Gaseous fuels	CO2	L1, T1
1A1	Energy industries; Liquid fuels	CO2	L1, T1
1A1	Energy industries; Other fuels	CO2	L1, L2, T1, T2

Source category 1A1 Energy industries comprises emissions from fuels combusted by the fuel extraction and energy-producing industries. The most important source category is 1A1a Public electricity and heat production, followed by 1A1b Petroleum refining. Activities in source category 1A1c Manufacture of Solid Fuels and other energy industries are virtually not occurring in Switzerland (apart from a tiny charcoal production activity in historic trade).

Within source category 1A1a, heat and electricity production in waste incineration plants cause the largest emissions, as electricity production in Switzerland is dominated by hydroelectric power plants and nuclear power stations (SFOE 2023). Emissions from industries producing heat and/or electricity (CHP) for their own use are included in category 1A2 Manufacturing Industries and Construction.

Table 3-42 Specification of source category 1A1 Energy Industries.

1A1	Source category	Specification
1A1a	Public electricity and heat production	Main sources are waste incineration plants with heat and power generation (Other fossil and bioegene fuels) and public district heating systems including boilers, and boilers with combined heat and power generation not further defined, as well as engines and gas turbines with fossil fuels and biogas, and engines on landfill sites or emergency generators. The only fossil fuelled public electricity generation unit “Vouvry” (300 MW_e; no public heat production) ceased operation in 1999.
1A1b	Petroleum refining	Combustion activities supporting the refining of petroleum products, excluding evaporative emissions. Use of refinery gas in gas turbines with SCGT at refineries.
1A1c	Manufacture of solid fuels and other energy industries	Emissions from charcoal production

3.2.5.2. Methodological issues for 1A1 (stationary)

3.2.5.2.1. Public electricity and heat production (1A1a)

Public electricity and heat production in Switzerland encompasses different plant types where various fuels are used (Table 3-43). Energy recovery from municipal solid waste and special waste incineration is mandatory in Switzerland (Swiss Confederation 2015, Art. 27) and plants are equipped with energy recovery systems. The emissions from municipal solid waste and special waste incineration plants are therefore reported under category 1A1a.

There was a single fossil fuel power station operating with residual fuel oil in Vouvry. However, the power station closed down in 1999.

Table 3-43 Plant type and fuels used in source category 1A1a.

Plant type	Fuel type
Heat plants for renewable wastes	wood waste (biomass)
Heating boilers > 300 MW (Vouvry)	residual fuel oil
Heating boilers < 300 MW	gas oil, residual fuel oil, bituminous coal
Central heating boilers for district heating	natural gas, gas oil, residual fuel oil, bituminous coal
Wood combined heat and power generation	wood, wood waste (biomass)
Engines and gas tubrines	natural gas, gas oil, biogas, biodiesel
Engines on landfill sites	natural gas, landfill gas (biogas)
Municipal solid waste incineration plants	municipal solid waste (other, waste-to-energy)
Special waste incineration plants	special wastes (other, waste-to-energy)

Methodology (1A1a)

For CO_2 emissions in source category 1A1a Public electricity and heat production, a country-specific approach is used combining Tier 2 and Tier 3 methods (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1). For CH_4 emissions, a Tier 2 method was applied using IPCC default emission factors (IPCC 2006), except for biomass, where country-specific emission factors are used. For N_2O IPCC default values are used (Tier 1, IPCC 2006), except for municipal solid waste and special waste incineration plants, where country-specific emission factors are used (Tier 2).

Emission factors (1A1a)

Table 3-44 presents the emission factors used in 1A1a. Emission factors for gas oil, natural gas, biomass and biogas (highlighted green in Table 3-44) are further explained in chp. 3.2.4.5. The use of fossil and biogenic fuels in engines and gas turbines is described in the specific model description in chp. 3.2.4.7.

Table 3-44 Emission factors for 1A1a Public Electricity and Heat Production in 2022.

1A1a Public electricity and heat production	CO_2	CO_2 biog.	CH_4	N_2O	NO_x	NMVOC	SO_2	CO
	t/TJ		kg/TJ					
Gas oil	73.7	NA	2.9	0.7	41	4	2.0	12
Residual fuel oil	NO	NA	NO	NO	NO	NO	NO	NO
Petroleum coke	NO	NA	NO	NO	NO	NO	NO	NO
Natural gas	56.0	NA	3.2	0.4	26	6	0.2	13
Other (waste-to-energy, MSW), fossil	92.0	NA	NE	1.1	32	2.4	4.4	6.1
Other (waste-to-energy, special waste), fossil	73.9	NA	NE	15	38	7.6	1.2	12
Other (waste-to-energy, MSW), biogenic	NA	92.0	NE	1.1	32	2.4	4.4	6.1
Biomass (wood, wood waste)	NA	99.9	0.3	4.0	57	0.44	4.6	19
Biogas (engines, co-generation from landfills and gas turbines)	NA	56.0	5	0.7	54	13	0.5	24

Emission factors for waste incineration and landfill gas use

Specific emission factors within 1A1a Public electricity and heat production apply for municipal solid waste incineration, special waste incineration and for landfill gas use. The emission factors for CO_2, NO_x, CO, NMVOC and SO_2 are country-specific and based on measurements and expert estimates. Emission factors for CH_4 and N_2O are IPCC default values (IPCC 2006), with the exception of waste and biomass as fuel, where country-specific emission factors are applied. Emission factors are documented in EMIS 2024/1A1a Kehrichtverbrennungsanlagen, EMIS 2024/1A1a Sondermüllverbrennungsanlagen and EMIS 2024/1A1a & 5A Kehrichtdeponien.

Source-specific CO_2 emission factors for municipal solid waste incineration plants

C-content of waste is calculated based on the net calorific value, which is deduced by a standard method and published on a yearly basis since 2009 by SFOE for each municipal solid waste incineration plant and as a Swiss average (FOEN/SFOE/VBSA 2022). In deviation from the general description of oxidation factors in chp. 3.2.4.5.1, an oxidation factor of 0.99 is assumed here. The assumption is based on measurements in two municipal solid waste incineration plants in Zurich (AWEL 2009) and on a study in Austria (Zeschmar-Lahl 2004), where the municipal solid waste incineration plants have the same standards as in Switzerland. The measurements in Zurich showed transfer coefficients into air of 0.96–0.99 and the ones in Austria stated a transfer coefficient into clean air of 0.989.

The fossil fraction of waste incinerated in municipal solid waste incineration plants is based on a study conducted in the year 2014 (Rytec 2014). The study uses data from three measurement campaigns during which the waste composition has been analysed (FOEN 2014o) and measurements of the radioactive isotope carbon-14 (^{14}C) in the flue gas for calibration have been made (Mohn et al. 2011). The CO_2 emission factor in municipal solid waste incineration plants fluctuates over the reporting period because of gradual changes in the net calorific values of the waste (Table 3-45).

Table 3-45 Emission factor CO_2 total, share of CO_2 fossil and net calorific value (NCV) in municipal solid waste incineration plants (MSWIP).

1A1a Public electricity and heat production, Other fossil fuels	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
CO_2 total (MSWIP)	t/TJ	92.80	91.86	91.09	91.49	92.32	92.76	92.43	92.28	92.01	91.92	91.90	91.85	91.86	92.04	91.96
Share of CO_2 fossil (MSWIP)	1	0.497	0.505	0.513	0.505	0.486	0.478	0.478	0.478	0.478	0.478	0.478	0.478	0.478	0.478	0.478
NCV of waste (MSWIP)	TJ/t	0.0114	0.0119	0.0124	0.0121	0.0117	0.0114	0.0116	0.0117	0.0118	0.0119	0.0119	0.0119	0.0119	0.0118	0.0119

Sodium bicarbonate and calcium carbonate are used in some municipal solid waste incineration plants for flue gas treatment. Sodium bicarbonate is used since 2013 and calcium carbonate was used between 1990 and 2005. According to IPCC (2006), the corresponding emissions are reported in source category 2A4d.

Source-specific CO_2 emission factors for special waste incineration plants

Based on detailed information regarding waste composition and estimated emission factors in the years 1992–2004, a weighted average emission factor for special waste incineration was calculated. Special waste is assumed to be of entirely fossil origin. Overall, a specific emission factor of 1.45 t CO_2/t waste results for special waste. This value is considerably higher than the one reported in SAEFL (2000). As there is no newer data on the special waste composition, the emission factor deduced as described above is used for the whole period from 1990 until today. See documentation in EMIS 2024/1A1a Sondermüllverbrennungsanlagen.

Source-specific CH_4 emission factors in municipal and special waste incineration plants

Emissions of CH_4 are not occurring in waste incineration plants because of the high temperatures and the long dwell time in the combustion chamber as confirmed by Mohn (2013). In the year 2013, Empa assessed the N_2O and CH_4 emission factors for municipal solid waste incineration plants (Mohn 2013). In this study, Empa evaluated measurements that were performed in 2011 in five Swiss municipal solid waste incineration plants with different Denox techniques (SCR, SNCR). For most of the measurements, CH_4 concentrations were below the detection limit of 0.3 ppm. The study concluded that "CH_4 emission concentrations were very low and below the background concentration of 1.8 ppm". These measurements, which showed that CH_4 concentration in the exhaust air was below the CH_4 concentration in ambient air, would point to CH_4 removal rather than emissions occurring. Therefore, CH_4 emissions from municipal waste incineration are reported as not estimated because they are considered insignificant. The same fact applies for special waste incineration.

Source-specific N_2O emission factors for municipal solid waste incineration

In 2013, a study evaluated N_2O measurements that have been performed in the years 2010–2011 in the flue gas of five Swiss municipal waste incineration plants (Mohn 2013) and derived plant-specific emission factors for Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) equipped installations.

Average Swiss emission factors have been calculated according to the state of equipment of all Swiss waste incineration plants (with two types of Denox-equipment (SCR, SNCR) and without Denox-equipment). For installations without Denox-equipment, the emission factor comes from SAEFL (2000). According to the state of equipment of all Swiss waste incineration plants in the years 1990, 1994, 1998, 2004, 2008, 2012, 2016 and 2020, weighted average N_2O emission factors have been calculated, based on the amounts of waste burnt in every plant. For the years in between, the N_2O emission factors were linearly interpolated. Since 2020, the emission factor is assumed to be constant (however the emission factor related to energy changes by reason of the conversion with the net calorific value of waste). It is planned to calculate new weighted averages for the N_2O emission factors periodically every four years, depending on data available; see documentation in EMIS 2024/1A1a Kehricht- und Sondermüllverbrennungsanlagen. The emission factor is therefore not constant over time. For the entire time series, equal numeric values are used for emission factors of the fossil and the biogenic fraction.

Source-specific N_2O emission factors for special waste incineration

The emission factor of special waste for the year 1990 is based on SAEFL (2000). It is assumed that this value (3.1 g/GJ) then increases until 2003 (6.1 g/GJ) due to the installation of Denox-equipment. From the year 2018 onwards, a country-specific emission factor of 14.6 g/GJ based on measured data is used (TBF 2021). The emission factor values for all years following 2018 are assumed equal. Data between 2003 and 2018 are linearly interpolated.

Table 3-46 N_2O emission factors of municipal solid (MSWIP) and special waste incineration plants (SWIP) in 1A1a Public electricity and heat production.

1A1a Public electricity and heat production, Other fossil fuels	Unit	1990	1995	2000	2005	2010
N_2O (MSWIP)	kg/TJ	5.26	2.96	2.06	1.44	1.40
N_2O (SWIP)	kg/TJ	3.06	4.23	5.41	7.11	9.60

1A1a Public electricity and heat production, Other fossil fuels	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
N_2O (MSWIP)	kg/TJ	1.37	1.29	1.21	1.13	1.13	1.13	1.12	1.12	1.13	1.13
N_2O (SWIP)	kg/TJ	11.09	11.59	12.08	12.58	13.08	14.57	14.57	14.57	14.57	14.57

Activity data (1A1a)

Activity data for liquid, gaseous, solid fuels and wood are based on the Swiss overall energy statistics (SFOE 2023) and additional data sources as described in chp. 3.2.4.4. Activity data for ‘Other fuels’ are based on the amount of waste incinerated in MSWIPs and SWIPs (FOEN 2023h, see Table 3-48). Activity data for combined heat and power generation in landfills are taken from the Swiss renewable energy statistics (SFOE 2023a).

Please note that waste-to-energy activities in CRT Table1.A(a)s1 are allocated to fuel types ‘Other fossil fuels’ and ‘Biomass’. ‘Other fossil fuels’ encompasses emissions from the fossil shares of MSWIP and SWIP, whereas ‘Biomass’ covers emissions from wood, waste wood, landfill gas use in co-generation and biogenic share from MSWIP.

The use of fossil and biogenic fuels in engines and gas turbines is described in the specific model description in chp. 3.2.4.7.

Table 3-47 Activity data in 1A1a Public Electricity and Heat Production.

1A1a Public electricity and heat production	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Total fuel consumption		40'379	39'179	49'913	56'978	61'751
Gas oil	TJ	980	554	790	1'300	490
Residual fuel oil	TJ	3'214	1'813	340	290	40
Petroleum coke	TJ	NO	NO	NO	NO	NO
Other bituminous coal	TJ	530	46	NO	NO	NO
Lignite	TJ	NO	NO	NO	NO	NO
Natural gas	TJ	4'339	5'422	8'292	9'827	9'926
Other (waste-to-energy, MSW), fossil	TJ	13'995	13'664	17'790	20'197	21'062
Other (waste-to-energy, special waste), fossil	TJ	2'610	3'206	4'692	4'514	4'941
Biomass	TJ	14'711	14'473	18'009	20'850	25'292
Other (waste-to-energy), biogenic	TJ	14'163	13'394	16'889	19'797	22'275
Biomass (wood, wood waste)	TJ	301	466	547	844	2'958
Biogas (engines, co-generation from landfills and gas turbines)	TJ	247	614	573	207	49
Biodiesel (engines and gas turbines)	TJ	NO	NO	NO	2.2	10.6

1A1a Public electricity and heat production	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total fuel consumption		63'303	59'325	61'386	65'017	64'752	65'311	66'482	65'554	66'138	63'389
Gas oil	TJ	670	770	660	430	490	380	450	340	420	420
Residual fuel oil	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Petroleum coke	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other bituminous coal	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Lignite	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas	TJ	8'409	5'032	7'050	8'926	7'907	8'111	8'444	7'501	8'551	6'568
Other (waste-to-energy, MSW), fossil	TJ	20'593	21'163	21'717	22'678	22'789	22'984	23'137	23'195	22'745	21'843
Other (waste-to-energy, special waste), fossil	TJ	5'145	4'886	5'115	4'979	4'641	5'013	5'148	4'722	4'276	5'127
Biomass	TJ	28'485	27'473	26'843	28'004	28'925	28'823	29'303	29'796	30'147	29'430
Other (waste-to-energy), biogenic	TJ	22'489	23'112	23'716	24'765	24'886	25'100	25'267	25'331	24'838	23'854
Biomass (wood, wood waste)	TJ	5'949	4'321	3'098	3'218	4'024	3'710	4'022	4'443	5'147	5'366
Biogas (engines, co-generation from landfills and gas turbines)	TJ	39	31	21	13	6.5	6.0	8.4	17	155	203
Biodiesel (engines and gas turbines)	TJ	9.1	9.1	8.1	7.7	8.0	6.7	6.5	6.3	6.2	6.3

Since 1990 the use of waste-derived fuels increased considerably. This is due to the fact that since 1st of January 2000, disposal of combustible wastes in landfill sites is prohibited by law (Swiss Confederation 2015 (VVEA, Art. 25), and Swiss Confederation 1990 (the preceding Ordinance TVA, Art. 32)). The increase is also partly due to municipal solid waste imported from neighbouring countries to optimize the load factor of MSWIPs. During the reporting period, the consumption of natural gas increased, and the consumption of liquid fuels decreased. This is due to a fuel shift in combined heat and power generation and the closure of the only power station located in Vouvry that has been operated with residual fuel oil in the 1990s.

Municipal solid waste incineration and special waste incineration

Figure 7-5 in Sector 5 Waste gives an overview over the waste amounts, their treatment and their reporting in the Swiss greenhouse gas inventory. Municipal solid waste includes waste generated in households and waste of similar composition from other sources.

The amount of municipal solid waste reported in Table 3-48 is the total amount of waste burnt (it includes fossil and biogenic shares). The same quantities are reported both in kt and in TJ.

Special waste is composed of special wastes with high calorific value, wastewater and sludge with organic load, inorganic solids and dusts, inorganic sludge containing heavy metals, acids and alkalis, PCB-containing wastes, non-metallic shredder residues, contaminated soil, filter materials and chemicals residues and others.

Table 3-48 Activity data for 1A1aiv Other: Municipal solid waste and special waste incinerated with heat and/or power generation. The same amount of waste burned is reported in TJ and in kt.

1A1aiv Public electricity and heat production, Other	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Total waste	TJ	30'768	30'264	39'371	44'508	48'277
Municipal solid waste fossil	TJ	13'995	13'664	17'790	20'197	21'062
Municipal solid waste biogenic	TJ	14'163	13'394	16'889	19'797	22'275
Special waste	TJ	2'610	3'206	4'692	4'514	4'941
Total waste	kt	2'603	2'433	3'040	3'527	3'968
Municipal solid waste (fossil and biogenic)	kt	2'470	2'270	2'801	3'297	3'717
Special waste	kt	133	163	239	230	252

1A1aiv Public electricity and heat production, Other	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total waste	TJ	48'228	49'161	50'548	52'422	52'316	53'097	53'552	53'248	51'859	50'825
Municipal solid waste fossil	TJ	20'593	21'163	21'717	22'678	22'789	22'984	23'137	23'195	22'745	21'843
Municipal solid waste biogenic	TJ	22'489	23'112	23'716	24'765	24'886	25'100	25'267	25'331	24'838	23'854
Special waste	TJ	5'145	4'886	5'115	4'979	4'641	5'013	5'148	4'722	4'276	5'127
Total waste	kt	4'035	4'066	4'150	4'264	4'248	4'297	4'322	4'312	4'245	4'115
Municipal solid waste (fossil and biogenic)	kt	3'773	3'817	3'889	4'010	4'011	4'042	4'059	4'072	4'027	3'853
Special waste	kt	262	249	261	254	236	255	262	241	218	261

3.2.5.2.2. Petroleum refining (1A1b)

Methodology (1A1b)

Up to 2015, two refineries were in operation in Switzerland. Since one of the refineries ceased operation in 2015, the data are considered confidential since 2014. Data are available to reviewers on request. Based on the generalised decision tree Fig. 2.1 for stationary combustion (IPCC 2006, vol.2, chp. 2), Switzerland applies a Tier 3 approach with country-specific emission factors for CO_2 emissions. The calculations are based on measurements and data from the refining industry as documented in the EMIS database (EMIS 2024/1A1b Heizkessel Raffinerien).

Emission factors (1A1b)

CO_2 emission factors of residual fuel oil, petroleum coke and refinery gas are estimated based on measurements from the refineries for the years 2005–2011 and 2013–2022 provided in the framework of the Swiss emissions trading system. From 2005 onwards, the measured emission factors are applied. The emission factors for 2012 are interpolated between 2011 and 2013. In years before 2005, the emission factors of residual fuel oil and petroleum coke are based on the weighted mean of the available data (2005–2011 and 2013–2015). The CO_2 emission factor of refinery gas is based on an estimate provided by one of the two refining plants for the years 1990–2004, which is assumed to be constant. Since 2013 the annual emission factor is derived from annual monitoring reports and the allocation report (2005–2011), which provide plant-specific data.

The resulting CO_2 emission factor of refinery gas is higher than the IPCC default value (IPCC 2006).

Table 3-49 Emission factors for 1A1b Petroleum refining in 2022.

1A1b Petroleum refining	Unit	CO_2	CH_4	N_2O	NO_x	NMVOC	SO_2	CO
Residual fuel oil	kg/TJ	NO	NO	NO	NO	NO	NO	NO
Refinery gas	kg/TJ	C	C	C	C	C	C	C
Petroleum coke	kg/TJ	NO	NO	NO	NO	NO	NO	NO
Natural gas	kg/TJ	C	C	C	C	C	C	C

Activity data (1A1b)

Activity data on fuel combustion for 1A1b Petroleum refining is provided by the Swiss overall energy statistics (SFOE 2023) and by the industry (bottom-up data). The data from the industry is collected by Carbura and forwarded to the Swiss Federal Office of Energy for inclusion in the Swiss overall energy statistics (SFOE 2023). As one of the refineries ceased operation in 2015, the data are considered confidential since 2014. Data are available to reviewers on request.

Refinery gas is the most important fuel used in source category 1A1b. Energy consumption, in particular use of refinery gas, has increased substantially since 1990 because one of the two Swiss refineries operated at reduced capacity in 1990 and resumed full production in later years. In 2012, one of the refineries was closed over six months due to insolvency and the search for a new buyer (EV 2014). Between 2004 and 2015, one of the Swiss refineries was also using petroleum coke as a fuel and since 2015 natural gas is used additionally to residual fuel oil and refinery gas. From the year 2019 onwards only refinery gas and natural gas are used.

Net calorific values are provided by the annual monitoring reports of the refining industries for the years 2005–2011 and 2013–2022 that are required under the Swiss Federal Act and Ordinance on the Reduction of CO_2 Emissions (Swiss Confederation 2011, Swiss Confederation 2012). For years with missing data (1990–2004 and 2012), the weighted mean of the net calorific value is applied for residual fuel oil and petroleum coke. The net calorific value of refinery gas is based on an estimate provided by one of the two refining plants for the years 1990–2004, which is assumed to be constant. The use of a plant-specific net calorific value leads to a slight difference to the energy consumption data provided by the Swiss overall energy statistics (SFOE 2023).

Table 3-50 Activity data for 1A1b Petroleum refining.

1A1b Petroleum refining	Unit	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total fuel consumption	TJ	5'629	9'836	9'636	14'548	14'176	13'834	14'173	7'232	6'355	6'298	6'627	5'911	5'987	5'160	6'575
Residual fuel oil	TJ	1'259	1'786	1'908	902	891	1'094	1'330	C	C	C	C	NO	NO	C	NO
Refinery gas	TJ	4'370	8'050	7'728	11'833	11'282	11'055	10'935	C	C	C	C	C	C	C	C
Petroleum coke	TJ	NO	NO	NO	1'813	2'003	1'685	1'908	C	NO	NO	NO	NO	NO	NO	NO
Natural gas	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	C	C	C	C	C	C

3.2.5.2.3. Manufacture of solid fuels and other energy industries (1A1c)

Methodology (1A1c)

In source category 1A1c Manufacture of solid fuels and other energy industries, only the emissions from charcoal production are reported as no other activities occur in Switzerland.

Based on the generalised decision tree in Fig. 2.1 for stationary combustion (IPCC 2006, vol.2, chp. 2), emissions are estimated using a Tier 2 approach.

Emission factors (1A1c)

The CO_2 emission factor is based on literature (USEPA 1995, chapter 10.7). CH_4 as well as emission factors for precursors NO_x, NMVOC and CO are taken from the revised 1996 IPCC Guidelines (IPCC 1997c, EMIS 2024/1A1c).

Table 3-51 Emission factors for 1A1c Manufacture of solid fuels and other energy industries in 2022. The CO_2 emission factor refers to CO_2 of biogenic origin.

1A1c Charcoal	**Unit**	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_x**	**NMVOC**	**SO_2**	**CO**
Charcoal production	kg/TJ	16'900	1'000	NA	10	1'700	NE	7'000

Activity data (1A1c)

The annual amount of charcoal produced is based on detailed queries with the few remaining sites where charcoal is produced. The main producer is the Köhlerverein Romoos, small quantities are produced at individual traditional local trade shows (Karthause Ittingen, Freilichtmuseum Ballenberg), as documented in EMIS 2024/1A1c. The FAO database contained values that differ substantially from these detailed bottom-up data. FAO has been informed about the discrepancy and was provided with the data used in the greenhouse gas inventory.

The charcoal is not used in the industry anymore but mainly for barbecues. Production has increased between 1990 and 2016 due to two regular charcoal production sites starting operation in 2004, low wood prices and increased demand for local charcoal in Switzerland (Koehlerei 2014).

Table 3-52 Activity data for 1A1c Manufacture of Solid Fuels and other energy industries.

1A1c Charcoal	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Charcoal production	TJ	1.3	1.4	2.2	3.4	3.6

1A1c Charcoal	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Charcoal production	TJ	3.3	4.3	3.8	4.1	3.9	4.3	5.1	3.9	4.0	3.4

3.2.5.3. Uncertainties and time-series consistency for 1A1 (stationary)

The uncertainty of emission estimates for source category 1A1 (stationary) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.9.

Time series for 1A1 Energy industries are all considered consistent.

3.2.5.4. Category-specific QA/QC and verification for 1A1 (stationary)

The general QA/QC procedures are described in chp. 1.5. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.10.

Concerning activity data and emission factors in the refinery sector, emissions and fuel combustion statistics are collected at large combustion plants for pollution legislation purposes. This plant-level data is used to cross-check national energy statistics from this sector for representativeness.

3.2.5.5. Category-specific recalculations for 1A1 (stationary)

The following recalculations were implemented in submission 2024. Major recalculations, which contribute significantly to the total differences in GHG emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1A1a: Activity data of source category 1A1a Combined heat and power plants using wood chips have been revised for 1990-2021 due to recalculations in the Swiss wood energy statistics (SFOE 2023b).
- 1A1a Special waste incineration plants: A new country-specific emission factor for N_2O for source category 1A1a Special waste incineration plants has been established for the year 2018 based on published data from the report "LEA III". The emission factor values for all years following 2018 are assumed equal. Values from 2004 until 2017 have been linearly interpolated. Emissions for the years 2004-2021 increased by approximately tenfold.
- 1A1a and 1A1b: A new model for stationary engines and gas turbines was implemented (INFRAS 2022a). The new allocation of the engines and gas turbines surveyed to the various source categories entails several changes in fuel consumption of fossil (diesel oil, gas oil, natural gas and liquefied gas in refineries) and of biogenic (biodiesel, biogas and sewage gas) fuels in source categories 1A1a, 1A1b, 1A2d, 1A2gviii, 1A3e and 1A4ai/bi/ci. All emission factors for these engines and gas turbines were also revised in the model. This results in recalculations for all years 1990-2021.
- 1A1c: The activity data of source category 1A1c Charcoal production was updated for 2021 due to a corrected production quantity of a charcoal burning plant.

3.2.5.6. Category-specific planned improvements for 1A1 (stationary)

No category-specific improvements are planned.

3.2.6. Source category 1A2 – Manufacturing industries and construction (stationary, without 1A2gvii)

3.2.6.1. Source category description for 1A2 (stationary)

Table 3-53 Key categories of 1A2 Manufacturing industries and construction. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	**IPCC category**	**Gas**	**Identification criteria**
1A2	Manufacturing industries and construction; Gaseous fuels	CO2	L1, L2, T1
1A2	Manufacturing industries and construction; Liquid fuels	CO2	L1, T1
1A2	Manufacturing industries and construction; Solid fuels	CO2	L1, T1
1A2	Manufacturing industries and construction; Other fuels	CO2	L1, L2, T1

[Source category 1A2 contains the sum of emissions of stationary and mobile sources – the statement on key categories holds for the aggregated emissions only. The CO_2 emissions of 1A2 from Liquid Fuels are dominated by the stationary sources, however, 41 % (2022) of the CO_2 emissions stem from mobile sources 1A2gvii.]

The source category 1A2 Manufacturing industries and construction comprises all emissions from the combustion of fuels in stationary boilers and cogeneration facilities within manufacturing industries and construction. This includes use of conventional fossil fuels as well as waste-derived fuels and biomass. Use of fossil fuels as feedstocks or other non-energy use of fuels as for example bitumen and lubricants are reported in CRT Table1.A(d) and described in chp. 3.2.3.

Table 3-54 Specification of source category 1A2 Manufacturing industries and construction.

1A2	**Source category**	**Specification**
1A2a	Iron and steel	Iron and steel industry: boilers, cupola furnaces in iron foundries and electric arc furnaces and heating furnaces in steel production
1A2b	Non-ferrous metals	Non-ferrous metals industry: secondary aluminium production, copper alloys production
1A2c	Chemicals	Chemical industry: production of chemicals such as. ammonia, niacin, nitric acid (ceased in 2018), ethylene, acetic acid and sulphuric acid as well as silicon carbide (amongst others)
1A2d	Pulp, paper and print	Pulp, paper and print industry: furnaces of cellulose production (ceased in 2008), boilers and gas turbines
1A2e	Food processing, beverages and tobacco	Food processing, beverages and tobacco industry: meat production, milk products, convenience food, chocolate, sugar and baby food (amongst others).
1A2f	Non-metallic minerals	Fine ceramics, container glass, glass, glass wool, lime, rock wool, mixed goods, cement, brick and tile
1A2giv	Wood and wood products	Fibreboard production
1A2gviii	Other	Industrial boilers, engines and gas turbines using fossil fuels and biomass (wood and biogas).

3.2.6.2. Methodological issues for 1A2 (stationary)

3.2.6.2.1. Methodology (1A2) and industry model

For CO_2 emissions from fuel combustion in source category 1A2 Manufacturing industries and construction, Tier 2 and 3 methods are applied (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) using country-specific emission factors – except for other fossil fuels (gasolio, heating gas, and synthesis gas) in 1A2c Chemicals, where plant-specific emission factors are used from 2018 onwards.

For all fuel combustion in 1A2f Cement production, and for wood combustion in 1A2f Brick and tile production (2000–2012), 1A2giv and 1A2gviii as well as for engines and gas turbines in 1A2d and 1A2gviii, CH_4 emissions are calculated by a Tier 2 approach using country-specific emission factors. For CH_4 emissions from all other fuel combustion processes in source category 1A2 Manufacturing industries and construction, a Tier 1 method is applied (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) using default emission factors from the 2006 IPCC Guidelines.

For N_2O emissions from fuel combustion in source category 1A2 Manufacturing industries and construction, a Tier 1 method is applied (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) using default emission factors from the 2006 IPCC Guidelines.

Overview industry model

As a sub-model of the Swiss energy model (see chp. 3.2.4.4), the industry model disaggregates, for each fuel type, the total fuel consumption in the industry sector provided by the Swiss overall energy statistics (SFOE 2023, see also description in chp. 3.2.4.4) into the source categories and processes under 1A2 Manufacturing industries and construction. As visualized in Figure 3-22, the industry model is based on two pillars. First, the energy consumption statistics in the industry and services sectors (SFOE 2023d) provide a comprehensive annual survey of fuel consumptions for all years since 1999 or 2002 (depending on the fuel type, see paragraph “Energy consumption statistics in the industry and services sectors” below). These statistics are consistently extended back to 1990 based on a bottom-up industry model (Prognos 2013, see paragraph “Modelling of industry categories” below). Second, further disaggregation is achieved by using plant-level industry data for specific processes, as far as available (see paragraph “Bottom-up industry data” below).

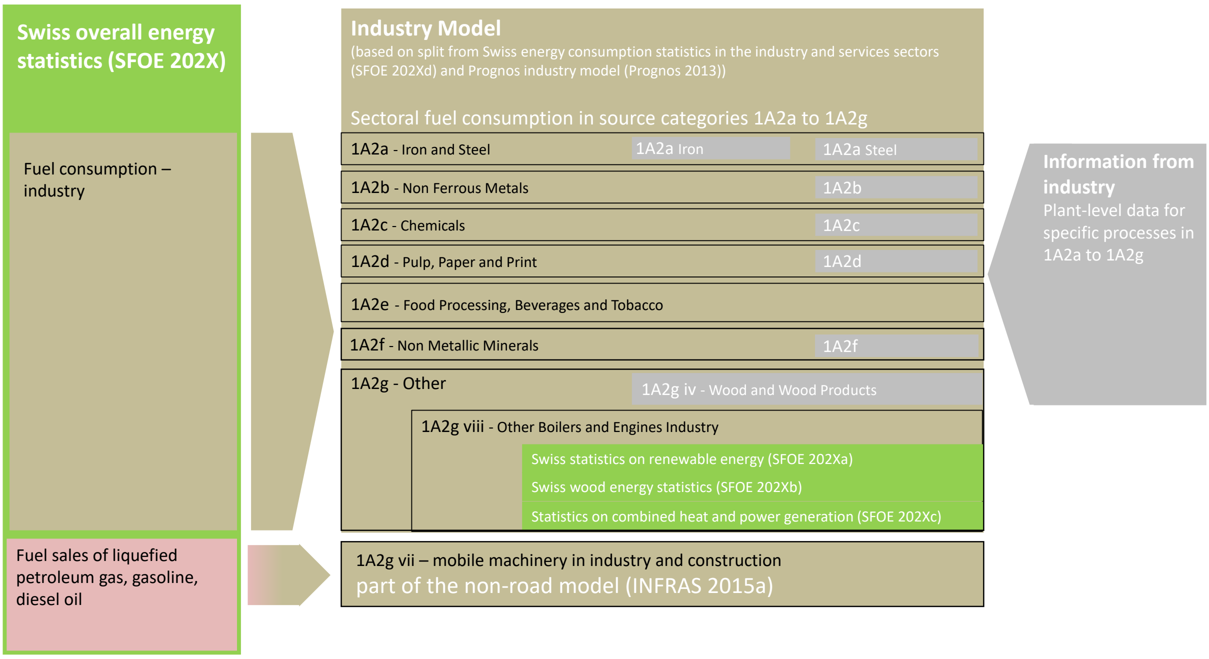

Figure 3-22 Schematic presentation of the data sources used for the industrial sectors 1A2a–1A2g. The references SFOE 202X, 202Xa, 202Xb and 202Xc refer to the 2023 edition of the corresponding energy statistics. For each fuel type, the Swiss overall energy statistics provide the total fuel consumption in the industry sector (SFOE 2023). The total fuel consumption is then distributed to the different source categories based on the energy consumption statistics in the industry and services sectors (SFOE 2023d) for all years since 1999 or 2002 (depending on the fuel type), consistently extended back to 1990 based on a bottom-up industry model (Prognos 2013). The grey boxes on the right show the further disaggregation achieved by using plant-level industry data for specific processes.

Energy consumption statistics in the industry and services sectors

The energy consumption statistics in the industry and services sectors (SFOE 2023d) refer to representative annual surveys with about 13’000 workplaces in the industry and services sectors that are then grossed up or extrapolated to the entire industry branch. For certain sectors and fuel types (i.e. industrial waste, residual fuel oil, other bituminous coal and lignite) the surveys represent a census covering all fuel consumed. The surveys are available since 1999 for gas oil and natural gas. For all other fossil fuels (i.e. residual fuel oil, liquefied petroleum gas, petroleum coke, other bituminous coal and lignite) data are available since 2002.

In 2015, a change in the survey method of the energy consumption statistics in the industry and services sectors was implemented (SFOE 2015d). The business and enterprise register, which forms the basis for the samples of the surveys, was revised. While previously the business and enterprise register was based on direct surveys with work places, it is now based on annual investigations of registry data (e.g. from the old-age and survivors’ insurance). In the course of this revision, a comparative assessment was conducted for the year 2013. This comparison showed that the energy consumption in the source categories of 1A2 stationary are modified by less than one percent, but also that the differences between the new and the old results for 2013 are not statistically significant (SFOE 2015d). As these statistics are only used for allocation of total energy consumption to different source categories, the impact on the different source categories solely consists of a reallocation of the energy consumption and does not affect the total of the sector. Moreover, only consumption of gas oil and natural gas is affected. For all these reasons, the time series consisting of data based on the previous (1990–2012) and latest (since 2013) survey method are considered consistent.

Modelling of industry categories

As mentioned above, the energy consumption statistics in the industry and services sectors (SFOE 2023d) are available since 1999 or 2002. In order to get consistent time series starting in 1990, a bottom-up industry model (Prognos 2013) is used. The model is based on 164 individual industrial processes and further 64 processes related to infrastructure in industry. Fuel consumption of a specific process is calculated by multiplication of the process activity data with the process-specific fuel consumption factor.

The model provides data on the disaggregation of total fuel consumption according to different industries and services between 1990 and 2012. For the time period where the two disaggregation methods (i.e. surveys and model) overlap, systematic differences between the two time series can be detected. These two data sets have been combined in order to obtain consistent time series of the shares of each source category 1A2a–1A2g for each fuel type. For this purpose, the approach to generate consistent time series from overlapping time series is used according to the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019, Volume 1, chp. 5.3.3.1, overlap). To illustrate the approach, an example for gas oil attributed to source category 1A2c is provided in Figure 3-23. A detailed description for all fuel types and source categories (1A2a–1A2g), including further assumptions, is provided in the underlying documentation of the EMIS database (EMIS 2024/1A2 Sektorgliederung Industrie).

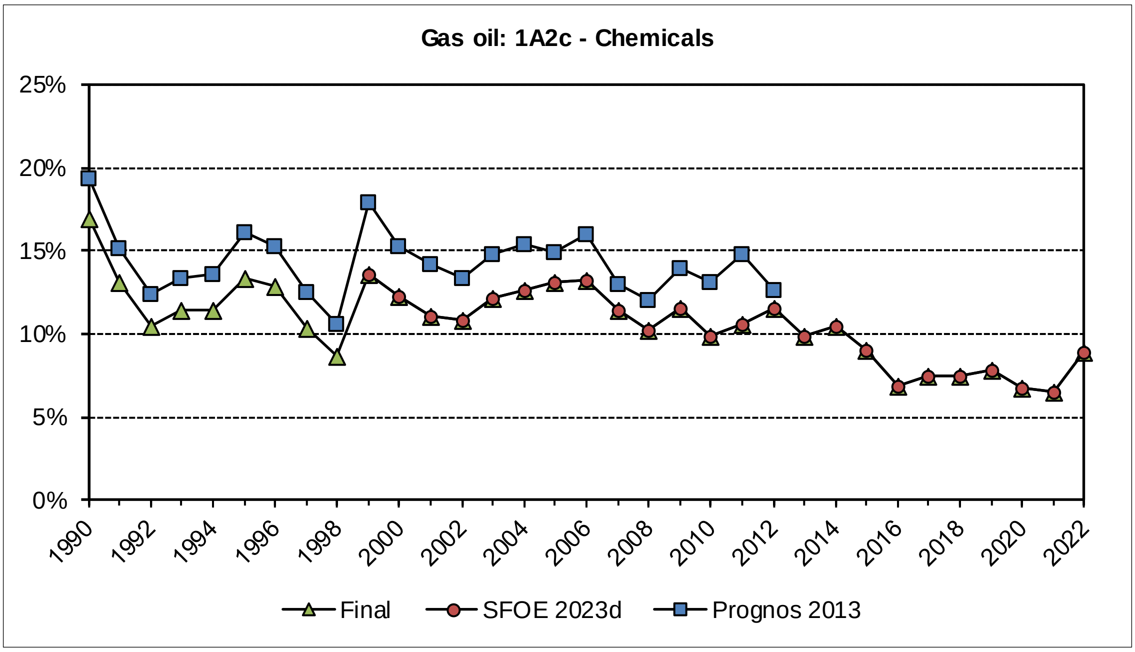

Figure 3-23 Illustrative example for combining time series with consistent overlap according to the 2019 Refinement (IPCC 2019, Volume 1, chp. 5.3.3.1, overlap). The y-axis indicates the share of source category 1A2c in total gas oil consumption in the industry sector. The green triangles correspond to the share finally used to calculate the fuel consumption in 1A2c, based on the combination of the shares from the energy consumption statistics in the industry and services sectors (SFOE 2023d, orange dots, since 1999) and the bottom-up industry model (Prognos 2013, blue squares, from 1990 to 2012). Similar calculations are performed for each source category and fuel type.

Bottom-up industry data

Grey coloured boxes in Figure 3-22 represent source categories (i.e. 1A2a–d, 1A2f and 1A2g) for which bottom-up data from the industry are used in order to further disaggregate the fuel consumption within a particular source category. These data consist of validated and verified monitoring data from the Swiss emissions trading scheme implemented under the Ordinance for the Reduction of CO_2 Emissions (Swiss Confederation 2012) and are discussed in depth in the following chapters 3.2.6.2.2 to 3.2.6.2.8.

The bottom-up information provides activity data for specific industrial production processes and forms a subset of the total fuel consumption allocated to each source category by the approach described above. Therefore, the fuel consumptions of the bottom-up industry processes are subtracted from the total fuel consumption of the respective source category and the remaining fuel consumptions are considered as fuels used in boilers of each source category. This method ensures that the sum of fuel consumption over all processes of a source category corresponds to the total fuel consumption assigned based on the energy consumption statistics in the industry and services sectors (SFOE 2023d) and the bottom-up industry model (Prognos 2013).

There is a difference in calculating the emissions of precursors from boilers and bottom-up industry processes. For boilers, fuel consumption is used as activity data whereas for bottom-up processes production data is used.

Further specific statistical data

The share of fuel used for co-generation in turbines and engines within 1A2 is derived from a model of stationary engines developed by INFRAS 2022a (chp. 3.2.4.7) for the statistics on combined heat and power generation (SFOE 2023c).

Fuel consumption of wood, wood waste and biogas in manufacturing industries is based on the Swiss wood energy statistics (SFOE 2023b) as well as on data from the Swiss renewable energy statistics (SFOE 2023a) and the statistics on combined heat and power generation in Switzerland (SFOE 2023c), respectively. Emissions from these sources are reported under 1A2gviii Other due to insufficient information regarding sectoral disaggregation.

Emission factors (1A2)

The following table presents the emission factors of fuel consumption in source category 1A2 Manufacturing industries and construction (see also chp. 3.2.4.5).

Table 3-55 Emission factors for 1A2 Manufacturing industries and construction in 2022. Values that are highlighted in green are described in more detail in chp. 3.2.4.5.

1A2 Emission factors for GHG (mix of bottom-up and top-down approach (modelling); without source category 1A2gvii Off-road vehicles and machinery)	**CO_2 fossil**	**CO_2 biog.**	**CH_4**	**N_2O**
	t/TJ	t/TJ	kg/TJ	kg/TJ
Gas oil	73.7		<3 *(lower IEF than default emission factor)*	0.6
Residual fuel oil	NO		NO	NO
Liquefied petroleum gas	65.5		<1 *(lower IEF than default emission factor)*	0.1
Petroleum coke	91.4		<3 *(lower IEF than default emission factor)*	0.6
Other bituminous coal	92.7		<10 *(lower IEF than default emission factor)*	1.5
Lignite	96.1		<10 *(lower IEF than default emission factor)*	1.5
Natural gas	56.0		<1 *(lower IEF than default emission factor)*	0.1
Other fossil fuels (including solvents, plastics, waste tyres and rubber (see 1A2c and 1A2f))	76.8		4.4	3.4
Biomass (wood, biogas and other biogenic waste)		98.0	2.1	4.0

Other fossil fuels comprise various fossil waste-derived fuels used in 1A2f Cement production as well as cracker by-products, i.e. gasolio, heating gas and synthesis gas used for steam production in a chemical plant in source category 1A2c. The emission factors of CO_2, CH_4 and N_2O are implied emission factors based on the fossil waste fuel mix. In addition, the CH_4 emission factor includes the total CH_4 emissions of the cement industry based on direct exhaust measurements at the chimneys of the cement plants (see documentation in EMIS 2024/1A2f Zementwerke_Feuerung), based on industry data and emission declarations according to the Ordinance on Air Pollution Control (Swiss Confederation 1985). Implied CH_4 emission factors of source category 1A2 for residual fuel oil (1990–2021), petroleum coke, other bituminous coal and lignite are lower than the default emission factors of source category 1A documented in chp. 3.2.4.5.3 (see detailed description below in chapter Cement (1A2f)).

The emission factors of the precursor gases NO_x, CO, NMVOC and SO_2 for all fuels in source category 1A2 are provided in Switzerland’s Informative Inventory Report (FOEN 2024b, chp. 3.2.3.2.1). The emission factors for NO_x and CO for natural gas and gas oil used in boilers are derived from a large number of air pollution control measurements of combustion installations (Leupro 2012). This study analysed a large dataset from various cantons in Switzerland that was collected between 2000 and 2011. The emission factors for NO_x and CO for residual fuel oil, petroleum coke, other bituminous coal and lignite used in boilers are country-specific and documented in the Handbook on emission factors for stationary sources (SAEFL 2000). The implied emission factors for NO_x decreased significantly over the reporting period. NMVOC and SO_2 emission factors are country-specific and documented in SAEFL (2000).

In contrast to combustion in boilers, emission factors of precursors for fuel combustion in bottom-up industry processes are based on bottom-up industry data. Production-weighted emission factors based on various air pollution control measurements under the Ordinance on Air Pollution Control (Swiss Confederation 1985) are used to derive the corresponding process-specific emission factors.

Activity data (1A2)

Table 3-56 shows the total fuel consumption reported in source category 1A2 as described above in the industry model, and displays the fuel switch within Swiss industry over the reporting period. Since 1990, the use of residual fuel oil and other bituminous coal has decreased strongly, and in 2022 the use of residual fuel oil ceased. In the same period, natural gas consumption has about doubled, but a larger decrease of consumption was observed from 2021 to 2022 (presumably related to high gas prices and the risk of a gas shortage due to the war in Ukraine). Currently, natural gas consumption accounts for the largest share of fuels used within Swiss industry, followed by biomass and gas oil.

Currently, source category 1A2gviii Other comprising emissions from boilers and engines and 1A2f Non-metallic minerals are the two largest fuel consumers within source category 1A2 Manufacturing Industries and construction. 1A2e Food processing, beverages and tobacco and 1A2c Chemicals are the third and fourth largest fuel consumers, respectively.

Table 3-56 Activity data for fuel consumption in 1A2 Manufacturing industries and construction.

1A2 Manufacturing industries and constr. (stationary sources)	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Total fuel consumption	TJ	88'849	89'256	87'412	90'688	89'351
Gas oil	TJ	22'910	24'471	25'892	25'317	21'137
Residual fuel oil	TJ	18'870	13'678	5'675	4'613	2'036
Liquefied petroleum gas	TJ	4'350	4'403	5'475	4'171	3'754
Petroleum coke	TJ	1'400	1'260	551	1'093	1'495
Other bituminous coal	TJ	13'476	7'303	5'866	4'799	4'348
Lignite	TJ	265	153	124	742	1'460
Natural gas	TJ	19'610	28'700	32'000	34'870	38'420
Other fossil fuels	TJ	2'469	2'718	3'812	4'138	4'625
Biomass	TJ	5'500	6'570	8'018	10'944	12'077

1A2 Manufacturing industries and constr. (stationary sources)	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total fuel consumption	TJ	85'625	80'165	78'724	79'781	80'236	77'425	77'054	74'229	78'333	73'126
Gas oil	TJ	18'007	12'444	12'725	12'812	11'489	10'871	10'071	8'854	9'074	8'725
Residual fuel oil	TJ	848	231	196	155	123	34	111	76	55	NO
Liquefied petroleum gas	TJ	3'609	3'148	3'215	2'577	3'068	3'009	2'893	2'766	2'910	2'914
Petroleum coke	TJ	1'049	1'240	795	890	763	781	777	700	604	731
Other bituminous coal	TJ	3'910	2'403	1'946	1'517	1'634	1'665	1'450	1'153	1'155	1'331
Lignite	TJ	1'357	3'102	3'060	3'078	2'876	2'520	2'262	2'410	2'442	2'466
Natural gas	TJ	39'710	40'310	39'450	39'960	41'000	39'320	39'560	38'180	39'690	33'100
Other fossil fuels	TJ	4'510	4'558	4'566	5'178	5'085	5'608	5'759	5'815	5'806	5'660
Biomass	TJ	12'624	12'729	12'772	13'613	14'198	13'616	14'171	14'275	16'597	18'197

The following chapters describe the fuel consumption of the different source categories 1A2a–1A2gviii, the specific industrial production processes based directly on bottom-up industry data, and additional source-specific emission factors. Further information is documented in the respective EMIS documentation (EMIS 2024/1A2a-g).

3.2.6.2.2. Iron and steel (1A2a)

The source category 1A2a Iron and steel consists both of fuels used in boilers and specific industrial production processes, i.e. reheating furnaces in steel plants and cupola furnaces in iron foundries.

There is no primary iron and steel production in Switzerland. Only secondary steel and iron production using recycled steel scrap occurs. Iron is produced in 14 iron foundries. About 75 % of the iron is processed in induction furnaces and 25 % in cupola furnaces using other bituminous coal as fuel. Part of the other bituminous coal acts also as carburization material as well as reducing agent. Since other bituminous coal first of all acts as fuel in cupola furnaces it was decided to report its CO_2 emissions in source category 1A2a. Furthermore, this allows to be consistent with the fuel use of other bituminous coal provided by the Swiss overall energy statistics (SFOE 2023). Additionally, also limestone is used as flux in cupola furnaces yielding geogenic CO_2 emissions. These emissions are reported in source category 2A4d Other carbonate uses. The share of induction furnaces increased since 1990 with a sharp increase in 2009 due to the closure of at least one cupola furnace. Induction furnaces use electricity for the melting process and therefore only process emissions occur, which are reported in source category 2C1 Iron and steel production. Due to the reduced iron production and the switch from cupola to induction furnaces in iron foundries, the consumption of other bituminous coal has decreased.

Today, steel is only produced in two steel production plants after closure of two plants in 1994. Both plants use electric arc furnaces (EAF) with carbon electrodes for melting the steel scrap. In these electric arc furnaces also so-called injection coal and petroleum coke for slag formation as well as natural gas are used. These fuel consumptions are reported under source category 1A2a Electric arc furnaces of steel production based on plant-specific data from monitoring reports of the Swiss ETS for the years 2005–2011 and from 2013 onwards. In addition, emissions from the reheating furnaces are reported in source category 1A2a. Since 1995, these furnaces use natural gas only for reheating the ingot moulds prior to the rolling mills. Process emissions from steel production are included in source category 2C1 Iron and steel production. Steel production and the related natural gas consumption was significantly reduced in 1995 and the use of residual fuel oil ceased with the closure of two steel companies. Since 1995, steel production increased continuously until 2004 to reach the same production level as 1990. Since then, steel production is about constant. Only in 2009, the production was considerably lower due to the economic crisis. One steel producer switched its production to high quality steel and therefore the specific energy use per tonne of steel produced increased between 1995 and 2000. This led to higher natural gas consumption.

Today fuel consumption of source category 1A2a consists mainly of natural gas but also liquefied petroleum gas, other bituminous coal and gas oil are used.

Table 3-57 Activity data fuel consumption in 1A2a Iron and steel.

1A2a Iron and steel	Unit	1990	1995	2000	2005	2010
Total fuel consumption	TJ	3'581	2'745	3'590	3'662	4'110
Gas oil	TJ	480	262	338	401	315
Residual fuel oil	TJ	346	131	20	39	51
Liquefied petroleum gas	TJ	408	193	286	217	219
Petroleum coke	TJ	85	46	56	72	47
Other bituminous coal	TJ	606	406	439	346	346
Lignite	TJ	NO	NO	NO	NO	NO
Natural gas	TJ	1'656	1'707	2'451	2'586	3'132

1A2a Iron and steel	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total fuel consumption	TJ	3'856	4'014	4'294	4'177	4'630	4'776	4'440	4'447	4'388	4'072
Gas oil	TJ	139	86	136	134	123	127	97	81	80	59
Residual fuel oil	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Liquefied petroleum gas	TJ	438	387.7	393	327	368	358	342	327	342	342
Petroleum coke	TJ	53	81	69	78	77	71	57	43	NO	NO
Other bituminous coal	TJ	321	325	313	303	321	319	307	285	258	209
Lignite	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas	TJ	2'904	3'135	3'383	3'335	3'742	3'902	3'637	3'710	3'708	3'462

3.2.6.2.3. Non-ferrous metals (1A2b)

The source category 1A2b Non-ferrous metals consists both of fuels used in boilers and specific industrial production processes, i.e. secondary aluminium production and non-ferrous metal foundries, producing mainly copper alloys.

Until 1993, secondary aluminium production plants have been in operation using gas oil. Emissions from primary aluminium production in Switzerland are reported in source category 2C3 as induction furnaces have been used. The last primary aluminium production site closed down in April 2006.

Regarding non-ferrous metal industry in Switzerland, only casting and no production of non-ferrous metals occur. There is one large company and several small foundries, which are organized within the Swiss foundries association (Schweizerischer Giessereiverband, GVS) providing production data.

Fuel consumption of source category 1A2b represents only a small amount of the total fuel consumption in source category 1A2. Fuels consumed in 2022 are mainly natural gas as well as gas oil and small amounts of liquefied petroleum gas. Fuel consumption within this source category decreased since 1990 due to the closing down of the secondary aluminium production and the strong reduction of the non-ferrous metal production since 2000.

Table 3-58 Activity data fuel consumption in 1A2b Non-ferrous metals.

1A2b Non-ferrous metals	Unit	1990	1995	2000	2005	2010
Total fuel consumption	TJ	2'392	1'980	1'566	980	1'221
Gas oil	TJ	587	347	236	125	112
Residual fuel oil	TJ	NO	NO	NO	NO	0.024
Liquefied petroleum gas	TJ	27	17	15	7.1	7.7
Petroleum coke	TJ	NO	NO	NO	NO	NO
Other bituminous coal	TJ	NO	NO	NO	NO	NO
Lignite	TJ	NO	NO	NO	NO	NO
Natural gas	TJ	1'779	1'616	1'315	848	1'101

1A2b Non-ferrous metals	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total fuel consumption	TJ	1'596	1'921	1'796	1'686	1'643	1'749	1'966	1'816	2'019	1'837
Gas oil	TJ	128	90	78	76	78	55	61	49	66	70
Residual fuel oil	TJ	23	NO	44	NO	3.7	NO	NO	NO	NO	NO
Liquefied petroleum gas	TJ	11	9.8	9.9	8.3	9.3	9.0	8.6	8.3	8.6	8.6
Petroleum coke	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other bituminous coal	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Lignite	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas	TJ	1'434	1'821	1'664	1'602	1'552	1'686	1'897	1'758	1'944	1'759

3.2.6.2.4. Chemicals (1A2c)

In Switzerland, there are more than thirty chemical companies mainly producing fine chemicals and pharmaceuticals. Fossil fuels are mostly used for steam production and process heat. The process emissions from the production of chemicals such as ammonia, niacin, nitric acid, ethylene, acetic acid and sulphuric acid as well as silicon carbide are reported in source category 2B, see chp. 4.3.

There is one large company producing ammonia and ethylene by thermal cracking of liquefied petroleum gas and light virgin naphtha (see also descriptions in chp. 3.2.3 for feedstock use). As by-products from the cracking process, so-called heating gas and gasolio are produced, which are used thermally for steam production within the same plant. In 2018 the cracker process and the subsequent integrated production chain were modified yielding synthesis gas as additional cracker by-product. For reasons of confidentiality, fuel consumption and emissions of these by-products are included in Other fossil fuels of 1A2f in the reporting tables. The CO_2 emission factors of gasolio, heating gas and synthesis gas are plant specific based on monitoring reports of the Swiss ETS. In 2017 the fuel quality of gasolio and heating gas have been re-analysed by the production plant yielding new net calorific values and CO_2 emission factors. Due to changes in the cracker operation the composition of the heating gas has changed considerably. The further process modification in 2018 resulted again in changes of both net calorific value and CO_2 emission factor mainly for heating gas.

Since the fuel quality of gasolio and heating gas are of similar quality as residual fuel oil and gas oil, respectively, the same default IPCC emission factors (IPCC 2006) are assumed for CH_4 and N_2O (see Table 3-15 and Table 3-17). For synthesis gas the same default IPCC emission factor as of natural gas is assumed for N_2O (IPCC 2006). Whereas no CH_4 emissions are supposed from the combustion of synthesis gas.

Table 3-59 Emission factors for 1A2c Chemicals are documented in the confidential NID, which is available to reviewers on request.

The fuels consumed in 2022 include mainly natural gas as well as minor amounts of gas oil. Fuel consumption in this source category has decreased by more than 30 % between 1990 and 2022. Consumption of gas oil and residual fuel oil has decreased or been stopped in that period, while natural gas consumption has increased.

Table 3-60 Activity data fuel consumption in 1A2c Chemicals.

1A2c Chemicals	Unit	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total fuel consumption	TJ	14'511	15'236	13'544	15'515	11'836	14'153	12'155	12'551	14'401	13'834	13'312	11'834	10'956	10'730	9'116
Gas oil	TJ	3'942	3'313	3'215	3'345	2'103	1'797	1'321	1'167	881	860	825	799	602	593	789
Residual fuel oil	TJ	1'434	693	252	36	66	1.2	NO	NO	NO	NO	NO	NO	NO	NO	NO
Liquefied petroleum gas	TJ	15	13	12	10	7.5	10	8.9	9.0	7.5	8.4	8.2	7.9	7.5	7.9	7.9
Petroleum coke	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other bituminous coal	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Lignite	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas	TJ	9'119	11'217	10'065	12'124	9'660	12'345	10'825	11'375	13'512	12'966	12'479	11'026	10'346	10'130	8'318
Other fossil fuels	TJ	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

3.2.6.2.5. Pulp, paper and print (1A2d)

Around ten paper producers and several printing facilities exist in Switzerland. The only cellulose production plant was closed in 2008. Thermal energy is mainly used for provision of steam used in the drying process within paper production. Emissions from use of carbonate in flue gas treatment in cellulose production is reported in 2A4d Other process use of carbonates.

Fuel consumption in 1A2d consists both of fuels used in boilers and specific industrial production processes. From 1992 to 2015 natural gas was also used in gas turbines (chp. 3.2.4.7, Table 3-28). In this source category only biomass (biogenic waste) from cellulose production (until 2008) is included, based on data from the only production site. The emissions were calculated using a country-specific CO_2 emission factor (EMIS 2024/1A2d Zellulose-Produktion) and default factors for CH_4 and N_2O (IPCC 2006, vol. 2, chp.2, table 2.3, sulphite lyes). Biomass (e.g. wood and wood waste) used in paper production is reported in source category 1A2gviii, because no statistical data exists to allocate biomass consumption to the specific industry sectors within 1A2 as explained in chp. 3.2.4.6.2. Therefore, from 2009 onwards, emissions from biomass are reported as ”IE” in CRT Table1.A(a)s2.

The overall fuel consumption within the Swiss pulp and paper industry has considerably decreased since 1990, due to the closure of the cellulose production plant in 2008 and of several paper producers in the last years. The fuels used in 2022 are mainly natural gas as well as gas oil and small amounts of liquefied petroleum gas.

Table 3-61 Activity data of fuel consumption in 1A2d Pulp, paper and print.

1A2d Pulp, paper and print	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Total fuel consumption	TJ	11'786	13'752	11'610	11'397	6'786
Gas oil	TJ	1'188	1'751	1'403	1'456	852
Residual fuel oil	TJ	5'250	3'061	1'417	2'092	279
Liquefied petroleum gas	TJ	86	141	148	100	61
Petroleum coke	TJ	NO	NO	NO	NO	NO
Other bituminous coal	TJ	NO	NO	NO	NO	NO
Lignite	TJ	NO	NO	NO	NO	NO
Natural gas	TJ	3'177	7'441	6'949	5'696	5'594
Biomass	TJ	2'085	1'358	1'694	2'053	NO

1A2d Pulp, paper and print	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total fuel consumption	TJ	5'485	4'654	3'663	2'988	2'857	2'077	2'155	2'071	2'267	1'948
Gas oil	TJ	711	297	383	410	288	293	345	284	247	364
Residual fuel oil	TJ	0.018	22	19	9.0	8.8	NO	NO	NO	NO	NO
Liquefied petroleum gas	TJ	67	60	60	50	57	55	53	50	53	53
Petroleum coke	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other bituminous coal	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Lignite	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas	TJ	4'707	4'275	3'200	2'518	2'504	1'729	1'757	1'737	1'968	1'531
Biomass	TJ	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

3.2.6.2.6. Food processing, beverages and tobacco (1A2e)

In Switzerland, the source category 1A2e Food, beverages and tobacco includes around 200 companies. According to the national food industry association, the major part of revenues is provided by meat production, milk products and convenience food. Further productions comprise chocolate, sugar or baby food (Fial 2013). Fossil fuels are used for steam production and drying processes. Fuel consumption in 1A2e is exclusively based on information from the energy consumption statistics in the industry and services sectors (SFOE 2023d) and Prognos (2013). Biomass (e.g. wood and wood waste) used in 1A2e Food processing, beverages and tobacco is reported in source category 1A2gviii, because no statistical data exists to allocate biomass consumption to the specific industry sectors within 1A2 as explained in chp. 3.2.4.6.2. Therefore, activity data and emissions from biomass are reported as ”IE” in the CRT Table1.A(a)s2.

In 2022, the fuels used in this category were mainly natural gas as well as gas oil and small amounts of liquefied petroleum gas (Table 3-62). Overall, there was an increase in fuel consumption of approximately 30 % between 1990 and 2010. This was due to the increased production in this sector. Since 2010, the total consumption is fluctuating. The consumption of residual fuel oil ceased and gas oil consumption has decreased, while natural gas and liquefied petroleum gas consumption has increased significantly until 2014 and are fluctuating since then. In 2022, the consumption of natural gas decreased sharply compared to 2021.

Table 3-62 Activity data fuel consumption in 1A2e Food processing, beverages and tobacco.

1A2e Food processing, beverages and tobacco	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Total fuel consumption	TJ	9'867	8'802	10'457	10'256	13'181
Gas oil	TJ	7'410	5'511	5'515	4'070	3'778
Residual fuel oil	TJ	1'160	466	137	NO	NO
Liquefied petroleum gas	TJ	204	308	535	534	659
Petroleum coke	TJ	NO	NO	NO	NO	NO
Other bituminous coal	TJ	NO	NO	NO	NO	NO
Lignite	TJ	NO	NO	NO	NO	NO
Natural gas	TJ	1'094	2'517	4'270	5'653	8'744
Biomass	TJ	IE	IE	IE	IE	IE

1A2e Food processing, beverages and tobacco	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total fuel consumption	TJ	13'098	12'463	11'591	10'992	11'231	10'843	11'851	11'928	12'266	10'204
Gas oil	TJ	3'681	2'395	2'522	2'503	2'110	1'925	2'119	2'009	2'298	2'249
Residual fuel oil	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Liquefied petroleum gas	TJ	935	828	838	699	785	763	731	699	731	731
Petroleum coke	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other bituminous coal	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Lignite	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas	TJ	8'482	9'241	8'230	7'790	8'337	8'155	9'001	9'220	9'238	7'224
Biomass	TJ	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

3.2.6.2.7. Non-metallic minerals (1A2f)

The source category 1A2f Non-metallic minerals includes several large fuel consumers within mineral industry, e.g. cement, brick and tile, glass, and rock wool production. All fuel consumptions of these specific industrial production processes are based on bottom-up industry data.

The fuels consumed in this source category are very diverse, depending on the fuel use within the specific industry process (see detailed documentation below). Except for brick and tile production (from 2013 onwards), bottom-up information is also available on the amount of biomass consumed. Therefore, all emissions from biomass used in these processes are reported in source category 1A2f.

Between 1990 and 2022, there has been a switch in fuel consumption from other bituminous coal and residual fuel oil (ceased in 2022) to other fossil fuels, biomass, natural gas and lignite. The most important emission source within this category is cement production. Information on bottom-up data of fuel consumption and some source-specific emission factors are described in the following. Detailed data at process level cannot be provided, since they are mostly confidential. Therefore, aggregated data for 1A2f are shown in Table 3-63.

Table 3-63 Activity data fuel consumption in 1A2f Non-metallic minerals.

1A2f Non-metallic minerals	Unit	1990	1995	2000	2005	2010
Total fuel consumption	TJ	25'613	19'885	18'055	17'832	18'196
Gas oil	TJ	1'871	1'629	1'642	1'389	1'269
Residual fuel oil	TJ	5'382	5'578	3'649	2'420	1'519
Liquefied petroleum gas	TJ	523	498	468	324	102
Petroleum coke	TJ	550	300	480	638	1'130
Other bituminous coal	TJ	12'665	6'758	5'415	4'364	3'992
Lignite	TJ	265	153	124	737	1'348
Natural gas	TJ	1'769	1'566	1'496	1'861	2'048
Other fossil fuels	TJ	2'469	2'718	3'812	4'138	4'625
Biomass	TJ	119	685	970	1'962	2'162

1A2f Non-metallic minerals	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total fuel consumption	TJ	17'119	17'677	16'484	16'518	16'536	16'766	16'581	16'257	16'623	16'715
Gas oil	TJ	1'174	1'204	1'098	1'020	1'118	1'078	1'054	997	995	1'059
Residual fuel oil	TJ	801	209	130	139	106	31	109	72	52	NO
Liquefied petroleum gas	TJ	113	45	52	44	44	45	45	39	41	63
Petroleum coke	TJ	815	1'052	622	658	574	542	552	591	583	547
Other bituminous coal	TJ	3'478	1'973	1'498	1'089	1'210	1'256	1'085	767	879	1'098
Lignite	TJ	1'283	2'912	2'856	2'881	2'694	2'367	2'120	2'266	2'304	2'331
Natural gas	TJ	2'506	3'111	3'121	2'952	2'970	2'972	2'997	2'820	2'804	2'912
Other fossil fuels	TJ	4'510	4'558	4'566	5'178	5'085	5'608	5'759	5'815	5'806	5'660
Biomass	TJ	2'440	2'613	2'542	2'557	2'735	2'867	2'860	2'890	3'158	3'044

Cement (1A2f)

Methodology

In Switzerland, there are six plants producing clinker and cement. The Swiss plants are rather small and do not exceed a production capacity of 3’000 tonnes of clinker per day. All of them use modern dry process technology. Cement industry emissions occur by incinerating a wide variety of fuels: standard fossil fuels as well as mixed, biogenic and fossil, waste-derived fuels are used to generate the high temperatures needed for the calcination process. The fossil and biogenic shares are reflected in the activity data. Specific activity data have been created for the fossil and biogenic contributions, for each of the fuels. Equal numeric values are used for emission factors of the fossil and the biogenic fraction.

Emission factors

The CH_4 emission factor includes the overall CH_4 emissions of the cement industry based on direct exhaust measurements at the chimneys of the cement plants. Therefore, these CH_4 emissions are reported under the fuel type other fossil fuels in the reporting tables.

Table 3-64 Emission factors for cement industry in 2022. Emission factors for CO_2 and N_2O are fuel specific (see Table 3-13, Table 3-17 and Table 3-65).

Cement industry (part of 1A2f)	CO_2	N_2O	CH_4	NO_x	NMVOC	SO_2	CO
	t/TJ		g/t clinker				
Cement	fuel specific		7	790	67	280	2'600

The emission factors for CO_2 and N_2O for standard fossil fuels are the same as used elsewhere (Table 3-13, Table 3-17). Regarding waste derived fuels, the NCVs and CO_2 emission factors for waste oil, solvents and residues from distillation, plastics, mix of special waste with saw dust (CSS), sewage sludge, wood waste, animal meal and saw dust are based on a study of Cemsuisse (Cemsuisse 2010a) providing measured values for the year 2010. A follow-up study of Cemsuisse (Cemsuisse 2018) provided measured values for the year 2017 for the three most relevant waste derived fuels – i.e. waste oil, solvents and residues from distillation and plastics – as well as for mix of special waste with saw dust (CSS). Emission factors between 2010 (the year of the previous assessment) and 2017 are interpolated, while constant values are used before the first and after the last year with available data.

The values for waste tyres and rubber are taken from Hackl and Mauschitz (2003). The biogenic fraction of waste tyres and rubber is based on an Austrian study and published by the German Ministry of Environment (UBA 2006). The emission factor of N_2O is the same for all waste derived fuels and is taken from the IPCC Guidelines (IPCC 2006, vol. 2, chp. 2 table 2.3 industrial wastes).

Table 3-65 NCVs, fossil fractions as well as CO_2 (fossil and biogenic) and N_2O emission factors of waste derived fuels (Other fossil fuels and Biomass) used in the cement industry. Where data for more than one year is available, values in between are interpolated and constant values are used before the first and after the last year with available data.

Cement industry (part of 1A2f) Waste derived fuel	**Data sources**	**For the years**		**NCV**	**Fossil fraction**	**EF CO_2 fossil, biog.**	**EF N_2O**
				GJ/t	%	t CO_2/TJ	kg N_2O/TJ
Waste oil	Cemsuisse (2010a)	until	2010	32.5	100	74.4	4
	Cemsuisse (2018)	from	2017	31.0	92.7	73.2	4
Waste coke from coke filters	Cemsuisse (2001) Hackl and Mauschitz (2003)	all		23.7	100	97	4
Mixed industrial waste	Cemsuisse, FOEN	all		18.3	100	74	4
Other fossil waste fuels	Cemsuisse, FOEN	all		20.9	100	97	4
Solvents and residues from distillation	Cemsuisse (2010a)	until	2010	23.6	99.1	74.0	4
	Cemsuisse (2018)	from	2017	23.5	89.7	70.7	4
Waste tyres and rubber	Hackl and Mauschitz (2003) UBA (2006)	all		26.4	73	84	4
Plastics	Cemsuisse (2010a)	until	2010	25.2	72.3	84.7	4
	Cemsuisse (2018)	from	2017	23.6	76.6	84.5	4
Mix of special waste with saw dust (CSS)	Cemsuisse (2010a)	until	2010	9.2	21.5	102.4	4
	Cemsuisse (2018)	from	2017	9.1	27.0	112.2	4
Sewage sludge (dried)	Cemsuisse (2010a)	all		9.4	0	94.5	4
Wood waste	Cemsuisse (2010a)	all		16.3	0	99.9	4
Animal meal	Cemsuisse (2010a)	all		16.8	0	86.7	4
Agricultural waste / other biomass	Cemsuisse, FOEN	all		12.7	0	110.0	4

Activity data

Data on fuel consumption is provided by the industry, for recent years based on monitoring reports of the Swiss ETS as documented in the EMIS database (EMIS 2024/1A2f Zementwerke Feuerung).

In 2022, the Swiss cement industry used about two-thirds of waste derived fuels and one-third of standard fossil fuels. Today, fossil fuels used in cement industry are mainly lignite, plastics, solvents and residues from distillation, waste oil, other bituminous coal and petroleum coke. Biogenic wastes contain mainly wood waste, sewage sludge and (bio)plastics. The main fossil fuel used in 1990 was other bituminous coal, but residual fuel oil, and waste oil were also of importance.

Fuel consumption in cement plants has decreased between 1990 and 2022. This is partly due to a decrease in production since 1990 and an increase in energy efficiency. In the same period, the fuel mix has changed significantly from mainly standard fossil fuels to the above-mentioned mix of fuels.

In the reporting tables, the biogenic waste derived fuels are reported under fuel type Biomass, whereas fossil waste derived fuels are reported under fuel type Other fossil fuels.

Table 3-66 Activity data: Overview on fuel use in cement industry (part of 1A2f). The waste derived fuel is split into Other fossil fuels and Biomass.

Cement industry (part of 1A2f)	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Total fuel consumption	TJ	17'194	12'774	11'017	11'623	12'388
Cement fossil without waste	TJ	15'319	9'993	7'332	6'208	6'278
Gas oil	TJ	NO	NO	NO	72	5.4
Residual fuel oil	TJ	1'907	2'825	1'530	637	112
Petroleum coke	TJ	550	300	480	638	1'130
Other bituminous coal	TJ	12'235	6'547	5'176	4'120	3'662
Lignite	TJ	265	153	124	737	1'348
Natural gas	TJ	362	168	22	3.9	21
Cement, waste derived fuel	TJ	1'874	2'781	3'685	5'415	6'109
Other fossil fuels	TJ	1'755	2'096	2'755	3'544	4'021
Industrial waste	TJ	NO	NO	NO	NO	NO
Mix of special waste with saw dust (CSS)	TJ	5.0	29	34	29	26
Other fossil waste fuels	TJ	NO	NO	NO	NO	45
Plastics	TJ	NO	40	413	608	905
Solvents and residues from distillation	TJ	281	180	422	967	1'178
Waste coke from coke filters	TJ	59	59	59	58	NO
Waste oil	TJ	1'170	1'485	1'520	1'411	1'253
Waste tyres	TJ	241	303	307	471	614
Biomass	TJ	119	685	930	1'871	2'088
Agricultural waste	TJ	NO	NO	NO	NO	7.3
Animal meal	TJ	NO	NO	198	856	624
Mix of special waste with saw dust (CSS)	TJ	18	106	124	105	97
Other biomass	TJ	NO	NO	NO	NO	5.7
Plastics	TJ	NO	15	158	233	347
Sewage sludge (dried)	TJ	9.4	128	333	494	477
Solvents and residues from distillation	TJ	2.5	1.6	3.8	8.8	11
Waste oil	TJ	NO	NO	NO	NO	NO
Waste tyres and rubber	TJ	89	112	114	174	227
Wood waste	TJ	NO	322	NO	NO	292

Cement industry (part of 1A2f)	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total fuel consumption	TJ	11'866	12'339	11'348	11'583	11'476	11'524	11'416	11'248	11'609	11'600
Cement fossil without waste	TJ	5'512	5'847	4'917	4'544	4'354	4'015	3'673	3'500	3'617	3'833
Gas oil	TJ	88	75	87	50	56	63	43	54	61	93
Residual fuel oil	TJ	86	58	45	90	59	NO	63	35	52	NO
Petroleum coke	TJ	815	1'052	622	658	574	542	552	591	583	547
Other bituminous coal	TJ	3'203	1'713	1'267	826	938	987	831	528	587	780
Lignite	TJ	1'283	2'912	2'856	2'881	2'694	2'367	2'120	2'266	2'304	2'331
Natural gas	TJ	38	37	41	39	34	56	65	26	28	82
Cement, waste derived fuel	TJ	6'354	6'492	6'431	7'039	7'122	7'509	7'743	7'748	7'992	7'766
Other fossil fuels	TJ	3'923	3'884	3'895	4'486	4'393	4'645	4'885	4'861	4'834	4'722
Industrial waste	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Mix of special waste with saw dust (CSS)	TJ	23	25	20	26	21	20	16	0	0.584	0.67
Other fossil waste fuels	TJ	25	19	12	11	5.7	5.4	NO	NO	13	NO
Plastics	TJ	963	1'016	887	890	1'071	1'319	1'246	1'558	1'688	1'692
Solvents and residues from distillation	TJ	1'345	1'193	1'194	1'397	1'254	1'238	1'456	1'155	1'107	1'265
Waste coke from coke filters	TJ	NO	NO	NO	NO	66	61	48	52	48	30
Waste oil	TJ	848	884	1'083	1'469	1'215	1'239	1'359	1'353	1'253	1'009
Waste tyres	TJ	719	746	699	694	760	763	760	743	726	725
Biomass	TJ	2'432	2'608	2'536	2'553	2'729	2'864	2'858	2'887	3'158	3'044
Agricultural waste	TJ	NO	NO	NO	NO	9.2	NO	NO	NO	NO	NO
Animal meal	TJ	479	457	412	409	470	522	475	441	454	317
Mix of special waste with saw dust (CSS)	TJ	73	78	60	72	57	53	43	0.12	1.58	1.8
Other biomass	TJ	32	21	42	8	5.6	5.4	30.7	36	147	175
Plastics	TJ	336	343	290	281	327	403	381	476	516	517
Sewage sludge (dried)	TJ	418	428	420	479	499	519	512	553	572	578
Solvents and residues from distillation	TJ	70	80	98	137	144	142	167	133	127	145
Waste oil	TJ	27	39	60	98	96	98	107	107	99	79
Waste tyres and rubber	TJ	266	276	259	257	281	282	281	275	269	268
Wood waste	TJ	732	886	896	811	840	840	861	867	973	962

Lime (1A2f)

In Switzerland there is only one plant producing lime. Fossil fuels are used for the burning process (calcination) of limestone. From 1990 to 1993, other bituminous coal was the primary fuel. Between 1994 and 2012, bituminous coal was replaced by residual fuel oil. In 2013, the main kiln has been switched to natural gas.

Container glass (1A2f)

Today, there exists only one production plant for container glass in Switzerland. Fuel consumption has drastically decreased over the reporting period due to a reduction in production. Until 2003, only residual fuel oil was used. From 2004 onwards, the share of natural gas has increased, reaching a stable share between 2006 and 2012. In autumn 2013, the plant has switched its glass kiln completely to natural gas.

Tableware glass (1A2f)

Today, there exists only one production plant for tableware glass in Switzerland. Fuel consumption for tableware glass currently includes only liquefied petroleum gas, as residual fuel oil was eliminated in 1995. Since 1990, fuel consumption has strongly decreased because of the closure of one production plant in 2006.

Glass wool (1A2f)

Glass wool is produced in two plants. Currently, fuel consumption for glass wool production includes only natural gas. Production of glass wool has increased since 1990.

Fine ceramics (1A2f)

In Switzerland, the main production of fine ceramics is sanitary ware produced by one big and some small companies. In earlier years, also other ceramics were produced as for example glazed ceramic tiles, electrical porcelain and earthenware. Since 2001, only sanitary ware is produced.

Until 2001, the fuel mix consisted of natural gas and gas oil. Since then, gas oil consumption decreased continuously, so that from 2010 onwards (with exception in 2021), only natural gas is consumed. Compared to the production of other fine ceramics, the production of sanitary ware is more energy-intensive. Therefore, the specific energy use per tonne of produced fine ceramics increased considerably between 1990 and 2001. This results in a lower reduction of fuel consumption compared to the reduction in production between 1990 and 2022.

Brick and tile (1A2f)

In Switzerland there are currently about 15 plants producing bricks and tiles. Mainly fossil fuels but also paper production residues, animal grease and wood are used for drying and burning of the clay blanks.

Emission factors

The CO_2 emission factors for wood and animal grease are based on a study of Cemsuisse (Cemsuisse 2010a), see Table 3-65, whereas the one for paper production residues is taken from a German study on secondary fuels (UBA 2006) as documented in the EMIS database (EMIS 2024/1A2f Ziegeleien).

For CH_4 and N_2O, emission factors of paper production residues and animal grease default values for wood waste and other liquid fuels, respectively, according to IPCC 2006 are used. For wood, the CH_4 emission factor according to the energy model for wood combustion (automatic chip boiler >500 kW, w/o wood processing companies), see chp. 3.2.4.6.2, and the default N_2O emission factor from IPCC 2006 are used.

Activity data

Since 2013, plant-specific activity data – except for biomass – are available from monitoring reports of the Swiss ETS. Fuels used in the brick and tile production in 2022 are almost exclusively natural gas and very little gas oil and liquefied petroleum gas. Apart from a production recovery in the years around 2004, the production has gradually decreased from 1990 to 2022, which is also represented in the overall fuel consumption decrease. Regarding the fuels used, there has been a considerable shift from residual fuel oil to natural gas from 1990 onwards as well as to a lesser extent, a shift from liquefied petroleum gas and gas oil to natural gas from 2004 onwards. Small amounts of paper production residues, wood and animal grease were used from 2000 onwards and reported up to 2017, 2012 and 2020, respectively.

Rock wool (1A2f)

In Switzerland there is one single producer of rock wool. Cupola furnaces are used for the melting of rocks at a temperature of 1500°C.

Currently, other bituminous coal and natural gas are used in the production process. Until 2004, also gas oil and liquefied petroleum gas were used. In 2005, these fuels were substituted by natural gas.

Mixed goods (1A2f)

The production of mixed goods mainly includes the production of bitumen for road paving. A total of 110 production sites are producing mixed goods at stationary production sites. The main fuels used are gas oil and increasingly also natural gas.

3.2.6.2.8. Other (1A2g stationary)

Methodology (1A2g stationary)

Source category 1A2giv Wood and wood products includes fuel consumption of fibreboard production. Fibreboards were produced in two companies in Switzerland until 2019, where thermal energy is used for heating and drying processes. Since 2020 only one plant is left.

Source category 1A2gviii Other covers fossil fuel combustion in boilers not further specified in manufacturing industries and construction, as well as combustion of wood and wood waste in all manufacturing industries. Methodologically, the fossil fuel consumption in boilers of 1A2gviii represents the residual entities of the industry installations that could not be allocated to any other source categories in 1A2a–f.

The use of fossil fuels and biogas in engines and gas turbines is described in the specific model description in chp. 3.2.4.7.

This source category accounts for nearly 40 % of the overall fuel consumption in 2022 of 1A2 Manufacturing industries and construction (stationary).

Emission factors (1A2g stationary)

The CO_2 emission factors for wood waste and animal grease in 1A2giv Wood and wood products are based on a study by Cemsuisse (2010a), see Table 3-65. For wood waste, the respective CH_4 and N_2O emission factors of the energy model for wood combustion, see chp. 3.2.4.6.2, and IPCC 2006, respectively, are taken, whereas for animal grease, the default values of IPCC 2006 for other liquid biofuels are used.

Activity data (1A2g stationary)

1A2giv Wood and wood products

In source category 1A2giv Wood and wood products, mainly wood waste as well as natural gas are used (Table 3-67). Since 1990, the production of fibreboard and thus the fuel consumption have increased significantly. The fuel mix has strongly shifted from fossil fuels to biomass (wood waste) between 1990 and 2022. Between 2001 and 2013, also animal grease was used for fibreboard production. Since 2004, data on annual fuel consumption is taken from monitoring reports of the industry as documented in the EMIS database (EMIS 2024/1A2giv).

1A2gviii Other Boilers and Engines Industry

Activity data for wood combustion is based on Swiss wood energy statistics (SFOE 2023b) whereas biogas consumption in engines and gas turbines at industrial and commercial biogas plants is based on the model of stationary engines and gas turbines (INFRAS 2022a, chp. 3.2.4.7) and data from the Swiss renewable energy statistics (SFOE 2023a). Further information on wood energy consumption is provided in chp. 3.2.4.6.2.

Since 1990, the consumption of residual fuel oil (ceased in 2022) and liquefied petroleum gas has decreased, and since 2005 also that of gas oil. Solid fossil fuel consumption remained quite stable with fluctuations, whereas biomass and natural gas consumption increased significantly.

Table 3-67 Activity data fuel consumption in 1A2giv Wood and wood products and 1A2gviii Other (stationary).

1A2giv: Wood and wood products, 1A2gviii: Other (stationary)	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Total fuel consumption	TJ	21'099	26'856	28'589	31'045	34'021
Gas oil	TJ	7'431	11'657	13'542	14'531	12'707
Residual fuel oil	TJ	5'298	3'749	199	26	122
Liquefied petroleum gas	TJ	3'087	3'233	4'011	2'979	2'697
Petroleum coke	TJ	765	914	15	383	318
Other bituminous coal	TJ	205	140	12	88	11
Lignite	TJ	NO	NO	NO	4.7	111
Natural gas	TJ	1'018	2'637	5'456	6'102	8'140
Other fossil fuels	TJ	NO	NO	NO	NO	NO
Biomass	TJ	3'296	4'527	5'354	6'930	9'915

1A2giv: Wood and wood products, 1A2gviii: Other (stationary)	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total fuel consumption	TJ	30'317	27'281	28'345	29'020	29'505	27'901	28'227	26'754	30'039	29'234
Gas oil	TJ	10'377	7'050	7'342	7'788	6'913	6'568	5'597	4'831	4'794	4'135
Residual fuel oil	TJ	22	0.33	2.8	7.9	4.3	2.2	2.4	3.7	2.8	NO
Liquefied petroleum gas	TJ	2'035	1'809	1'852	1'441	1'798	1'772	1'705	1'635	1'726	1'709
Petroleum coke	TJ	181	108	104	155	113	168	169	65	21	185
Other bituminous coal	TJ	110	105	134	125	102	91	58	101	18	24
Lignite	TJ	75	189	204	197	182	153	141	144	138	135
Natural gas	TJ	7'333	7'903	8'477	8'251	8'930	8'397	9'244	8'588	9'899	7'893
Other fossil fuels	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Biomass	TJ	10'184	10'116	10'230	11'056	11'464	10'749	11'310	11'385	13'439	15'153

3.2.6.3. Uncertainties and time-series consistency for 1A2 (stationary)

The uncertainty of emission estimates for source category 1A2 (stationary) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.9.

Time series for 1A2 Manufacturing industries and construction are all considered consistent.

3.2.6.4. Category-specific QA/QC and verification for 1A2 (stationary)

The general QA/QC procedures are described in chp. 1.5. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.10.

3.2.6.5. Category-specific recalculations for 1A2 (stationary)

The following recalculations were implemented in submission 2024. Major recalculations, which contribute significantly to the total differences in GHG emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1A2: Due to the revised model of natural gas losses in 1B2b Natural gas, the changes also have an impact on final natural gas consumption and therefore on all source categories in 1A2 (as well as on 1A4ai and 1A4bi) for the years 1990–2021.
- 1A2d and 1A2g: A new model for stationary engines and gas turbines was implemented (INFRAS 2022a). The new allocation of the engines and gas turbines surveyed to the various source categories entails various changes in fuel consumption for fossil (diesel oil, gas oil, natural gas and liquefied gas in refineries) and biogenic (biodiesel, biogas and sewage gas) fuels in source categories 1A1a, 1A1b, 1A2d, 1A2gviii, 1A3e and 1A4ai/bi/ci. All emission factors for these engines and gas turbines were also revised in the model. This results in recalculations for all years 1990–2021.
- 1A2f (CO_2 fossil, N_2O): The activity data for 1A2f for gas oil consumption in cement production for the year 2019 was erroneously reported and was corrected, resulting in a reduction of the value by 59 %.
- 1A2f (CO_2 fossil, N_2O): The activity data for 1A2f for consumption of other bituminous coal in cement production for the year 2018 was erroneously reported and was corrected, resulting in a 5 % increase of the value.
- 1A2f (CO_2 biogenic, CO_2 fossil, N_2O): the activity data for 1A2f Cement production for all biogenic fuels as well as for waste-derived fuels has changed for the year 2021 due to rounding, resulting in less than 0.1 % change for each value.
- 1A2f: The gas oil consumption of source category 1A2f Fine ceramics production was revised for 2021 based on plant information.
- 1A2gviii: Activity data of automatic wood combustion installations in source category 1A2gviii have been revised for 1990–2021 due to recalculations in the Swiss wood energy statistics (SFOE 2023b). The biggest changes were in automatic boilers >500 kW and combined chip heat and power plants in 2021.
- 1A2gviii: The activity data (gas oil) of source category 1A2f Fine ceramics production was revised for 2021 based on plant information, which consequently yields revised activity data (gas oil) in source category 1A2gviii Boiler - Other for 2021 as well.
- 1A2gviii (CH_4, N_2O, CO_2 biogenic): The activity data of source category 1A2gviii Other for combustion of biogas is now reported in the database directly in GJ instead of GWh and with additional significant digits. In addition, erroneously reported values for the years 1996–1999 have also been corrected, causing emission changes from -9 % up to +10 %.

3.2.6.6. Category-specific planned improvements for 1A2 (stationary)

No category-specific improvements are planned.

3.2.7. Source category 1A4 – Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

3.2.7.1. Source category description for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

Table 3-68 Key categories of 1A4 Other sectors. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
1A4a	Commercial; Gaseous fuels	CO2	L1, L2, T1
1A4a	Commercial; Liquid fuels	CO2	L1, T1
1A4b	Residential; Gaseous fuels	CO2	L1, L2, T1
1A4b	Residential; Liquid fuels	CO2	L1, T1
1A4c	Agriculture and forestry; Liquid fuels	CO2	L1, T1

Each of the source categories 1A4a, 1A4b, 1A4c contain the sum of emissions of stationary and mobile sources – the above statements on key categories hold for the aggregated emissions of 1A4a etc. only. The CO_2 emissions of 1A4a and 1A4b from Liquid Fuels are vastly dominated by the stationary sources, which means that the emissions of 1A4aii and 1A4bii only play a minor role within category 1A4a and 1A4b. For 1A4c, however, the emissions of 1A4cii are more important than those of 1A4ci (see also chp. 3.2.10.1.)

Table 3-69 Specification of source category 1A4 Other sectors.

1A4	Source category	Specification
1A4ai	Commercial/institutional: Stationary	Stationary fuel combustion in commercial and institutional buildings as different wood combustions, boilers and engines with combined heat and power generation unit, engines and gas turbines at biogas and sewage plants, emergency generators
1A4bi	Residential: Stationary	Stationary fuel combustion in households, including different wood combustion installations, boilers and engines
1A4ci	Agriculture/Forestry/Fishing: Stationary	Stationary fuel combustion in agriculture, including different wood combustion installations, engines at biogas plants, emergency generators, heating of greenhouses and grass drying

3.2.7.2. Methodological issues for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

Methodology (1A4 stationary)

CO_2 emissions from stationary combustion in source categories 1A4ai, 1A4bi and 1A4ci are estimated based on country-specific emission factors using a Tier 2 approach according to the decision tree for stationary combustion of the IPCC Guidelines (IPCC 2006, Volume 2 Energy, chp. 2 Stationary Combustion, Figure 2.1) for liquid, solid, gaseous fuels, biogas, wood (including bonfires), wood waste and animal grease.

A Tier 1 approach is applied with IPCC default emission factors for CH_4 emissions of residual fuel oil and gas oil for boilers and for N_2O emissions of all fuels and technologies (IPCC 2006). CH_4 emissions of gas oil used in engines, gaseous fuels, biogas, wood and wood waste are calculated by a Tier 2 approach using country-specific emission factors. In 1A4ci Grass drying, also small amounts of crop residues are used as fuel; their emissions are calculated with default IPCC emission factors (IPCC 2006).

For the calculation of the emissions from the use of gas oil and natural gas the following sources are differentiated: (a) heat only boilers, (b) combined heat and power production in turbines and (c) combined heat and power production in engines. A considerable part (10–20 %) of the fuel consumption consists of wood and wood wastes. Source category 1A4ai also includes emissions from mobile pellet combustion installations (from 2017 onwards) that are used for temporary applications such as construction drying, events in large marquees or as emergency solutions in the event of heating failures.

The use of fossil and biogenic fuels in engines and gas turbines is described in the specific model description in chp. 3.2.4.7.

Emissions from 1A4ci Other sectors (stationary) – Agriculture/Forestry/Fishing originate from fuel combustion for the heating of greenhouses and grass drying, as well as from wood combustion for heating in agriculture and forestry. For grass drying, information is provided by the Swiss association of grass drying plants (VSTB). For greenhouses, information is provided by the Energy Agency of the Swiss Private Sector (EnAW).

Emission factors (1A4 stationary)

Table 3-70 Emission factors for stationary combustion in 1A4ai Other sectors commercial/institutional in 2022. Emission factors that are highlighted in green are described in chp. 3.2.4.5.

1A4ai Other sectors:	**CO_2 fossil**	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_x**	**NMVOC**	**SO_2**	**CO**
	t/TJ		kg/TJ					
Gas oil (weighted average)	73.7	NA	10	0.64	46	6.79	2.0	8.2
Gas oil heat only boilers	73.7	NA	10	0.6	32	6	2.0	5.9
Gas oil engines	73.7	NA	1.2	2.9	824	50	2.0	137
Natural gas (weighted average)	56.0	NA	5.0	0.13	19	6.6	0.18	11
NG heat only boilers	56.0	NA	5.0	0.1	16	2	0.18	8.9
NG turbines	56.0	NA	5.2	0.69	53	1.6	0.18	25
NG engines	56.0	NA	5.2	0.69	74	89	0.18	55
Liquefied petroleum gas (engines)	65.5	NA	5.2	0.69	135	89	0.5	56
Biomass (weighted average)	NA	91	14	3.3	107	44	4.4	431
Biodiesel (engines)	NA	73.3	1.2	2.9	293	50	0.31	134
Wood and wood waste (various furnaces)	NA	99.9	16	4	111	36	5.4	507
Biogas (engines and heat only boilers)	NA	56.0	5.2	0.69	101	89	0.5	133
Sewage gas (engines, gas turbines and heat only boilers)	NA	56	4.3	0.57	84	69	0.5	112

Table 3-71 Emission factors for stationary combustion in 1A4bi Other sectors residential in 2022. Emission factors that are highlighted in green are described in chp. 3.2.4.5.

1A4bi Other sectors: Residential	**CO_2 fossil**	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_x**	**NMVOC**	**SO_2**	**CO**
	t/TJ		kg/TJ					
Gas oil (weighted average)	73.7	NA	10	0.60	33	6.0	2.0	11
Gas oil heat only boilers	73.7	NA	10	0.6	33	6	2.0	11
Gas oil engines	73.7	NA	1.2	2.9	136	50	2.0	136
Natural gas (weighted average)	56.0	NA	5.0	0.1	15	4.2	0.18	12
NG heat only boilers	56.0	NA	5.0	0.1	15	4	0.18	12
NG engines	56.0	NA	5.2	0.69	72	89	0.18	54
Liquefied petroleum gas (engines)	65.5	NA	5.2	0.7	135	89	0.5	56
Other bituminous coal	92.7	NA	300	1.5	65	100	350	1'000
Biomass (weighted average)	NA	100	46	3.9	94	107	7.8	1'311
Biodiesel	NA	73.3	1.2	3	406	50	0.31	132
Biogas	NA	56.0	5.2	0.69	97	89	0.50	88
Wood and wood waste (various furnaces)	NA	99.9	41	4	95	92	8	1'231
Use of charcoal	NA	112	200	1	50	600	11	4'000
Wood (bonfires)	NA	99.9	300	4	50	600	11	4'000

Table 3-72 Emission factors for stationary combustion in 1A4ci Agriculture/forestry/fishing in 2022. Emission factors that are highlighted in green are described in chp. 3.2.4.5.

1A4ci Agriculture/forestry/fishing	**CO_2 fossil**	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_X**	**NMVOC**	**SO_2**	**CO**
	t/TJ		kg/TJ					
Grass drying (fossil, biogenic) (weighted average)	60	100	2.1	0.95	73	99	83	567
Gas oil	73.7	NA	3	0.6	NA	NA	NA	NA
Residual fuel oil	NO	NA	NO	NO	NA	NA	NA	NA
Natural gas	56.0	NA	1	0.1	NA	NA	NA	NA
Biomass (crop residues, fat, wood)	NA	100	4.6	3.9	NA	NA	NA	NA
Heating of greenhouses (weighted average)	62	NA	1.7	0.3	23	2	0.8	6.4
Gas oil	73.7	NA	3	0.6	31	2	2.0	5.9
Natural gas	56.0	NA	1	0.1	18	2	0.2	6.7
Other fossil combustion (weighted average)	73.7	NA	1.2	2.9	942	50	2	137
Gas oil (engines)	73.7	NA	1.2	2.9	942	50	2.0	137
Natural gas (engines)	NO	NA	NO	NO	NA	NA	NA	NA
Other biomass combustion (weighted average)	NA	72	6.5	1.9	101	63	2	224
Biogas engines	NA	56.0	5.2	0.69	100	89	0.5	111
Wood and wood waste (various furnaces)	NA	99.9	9	4	103	19	5.4	424

Charcoal use, bonfires and mobile pellet combustion installations

Emission factors concerning CO_2, CH_4 and N_2O emissions of charcoal use in the residential source categories (1A4bi) are taken from the IPCC Guidelines (IPCC 2006). Default emission factors according to the guidelines are also applied for CH_4 and N_2O emissions resulting from bonfires. The CO_2 emission factor for bonfires is based on the value for wood combustion; see chp. 3.2.4.5. Emission factors of precursors are taken from the EMEP/EEA guidebook (2019) (Table 3.39). The mobile pellet combustion installations which are also reported in source category 1A4ai (see Table 3-70) under biomass (wood and wood waste) have the same emission factors as the category 12b, automatic pellet boilers 50–300 kW (see chp. 3.2.4.5.2 for CO_2, 3.2.4.5.3 for CH_4, and 3.2.4.5.4 for N_2O).

Activity data (1A4 stationary)

General energy sources

Activity data about the energy sources gas oil, residual fuel oil, natural gas and biomass are calculated by the Swiss energy model (see chp. 3.2.4.4 for further information). For other energy sources such as other bituminous coal, activity data are provided directly by the Swiss overall energy statistics (SFOE 2023). The activity data on fuel consumption in 1A4ai Mobile pellet combustion installations used for temporary applications are based on information from the Swiss wood energy statistics publication (SFOE 2023b, chp. 1.4) and are reported in Table 3-73 under biomass (wood). However, they are not part of the wood energy statistics model. Grass drying activities for source category 1A4ci are reported by the Swiss association of grass drying plants (VSTB) (as standard tonne of dried grass) as documented in the EMIS database (EMIS 2024/1A4ci Grastrocknung). The fuel consumption for the heating of greenhouses is extrapolated from the information provided by the Energy Agency of the Swiss Private Sector (EnAW) as documented in the EMIS database (EMIS 2024/1A4ci Gewächshäuser).

Table 3-73 Activity data in 1A4a Commercial/Institutional (stationary).

1A4ai Other sectors (stationary): Commercial/institutional	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Total fuel consumption	TJ	73'725	81'713	78'706	85'366	81'751
Gas oil	TJ	52'975	54'377	48'775	51'195	46'523
Gas oil heat only boilers	TJ	52'548	53'823	47'804	50'261	45'940
Gas oil engines	TJ	427	554	971	935	583
Natural gas	TJ	16'551	22'006	23'668	26'802	25'371
NG heat only boilers	TJ	16'196	20'597	21'497	24'205	23'281
NG turbines	TJ	NO	0.23	0.073	NO	0.019
NG engines	TJ	355	1'408	2'170	2'597	2'090
Liquefied petroleum gas (engines)	TJ	2.4	39	108	95	109
Biomass	TJ	4'198	5'292	6'156	7'274	9'748
Biodiesel (engines)	TJ	NO	NO	26	7.9	56
Wood and wood waste (various furnaces)	TJ	2'940	3'870	4'451	5'427	7'533
Biogas (engines and heat only boilers)	TJ	1.3	30	83	144	396
Sewage gas (engines, gas turbines and heat only boilers)	TJ	1'257	1'392	1'595	1'695	1'762

1A4ai Other sectors (stationary): Commercial/institutional	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total fuel consumption	TJ	79'918	63'561	69'557	72'926	70'414	63'895	64'366	61'620	70'351	57'306
Gas oil	TJ	42'724	32'990	35'151	36'438	34'220	30'877	30'271	27'594	31'347	25'616
Gas oil heat only boilers	TJ	42'223	32'491	34'661	35'957	33'727	30'414	29'793	27'126	30'883	25'154
Gas oil engines	TJ	501	499	490	481	493	463	478	468	465	463
Natural gas	TJ	26'407	20'294	23'161	24'390	24'017	21'222	21'805	21'096	24'175	18'370
NG heat only boilers	TJ	24'596	18'624	21'564	22'909	22'680	20'062	20'806	20'139	23'222	17'394
NG turbines	TJ	0.020	0.027	0.029	0.25	0.23	0.24	0.23	0.21	0.20	0.19
NG engines	TJ	1'810	1'670	1'597	1'481	1'336	1'159	999	956	953	976
Liquefied petroleum gas (engines)	TJ	91	97	87	121	44	29	23	23	22	23
Biomass	TJ	10'697	10'179	11'158	11'976	12'133	11'767	12'267	12'908	14'806	13'298
Biodiesel (engines)	TJ	51	51	49	49	45	45	37	36	35	35
Wood and wood waste (various furnaces)	TJ	8'195	7'720	8'702	9'516	9'642	9'258	9'783	10'375	12'284	10'702
Biogas (engines and heat only boilers)	TJ	711	703	740	783	810	821	816	848	832	954
Sewage gas (engines, gas turbines and heat only boilers)	TJ	1'740	1'706	1'667	1'628	1'636	1'643	1'631	1'648	1'654	1'607

Table 3-74 Activity data in 1A4b Residential (stationary).

1A4bi Other sectors (stationary): Residential	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Total fuel consumption	TJ	185'560	189'596	170'753	186'290	182'296
Gas oil	TJ	136'887	133'548	116'295	124'024	111'731
Gas oil heat only boilers	TJ	136'882	133'529	116'231	123'964	111'712
Gas oil engines	TJ	4.87	19.0	64	60	20
Natural gas	TJ	26'115	34'391	36'511	42'843	48'427
NG heat only boilers	TJ	26'075	34'234	36'270	42'555	48'195
NG engines	TJ	39	156	241	288	232
Liquefied petroleum gas (engines)	TJ	0	4	11	11	12
Other bituminous coal	TJ	630	460	130	400	400
Biomass	TJ	21'928	21'193	17'805	19'013	21'726
Biodiesel	TJ	NO	NO	NO	1	3
Biogas	TJ	NO	NO	NO	NO	NO
Wood and wood waste (various furnaces)	TJ	21'457	20'741	17'353	18'540	21'222
Charcoal use	TJ	311	291	292	313	344
Wood (bonfires)	TJ	160	160	160	160	160

1A4bi Other sectors (stationary): Residential	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Total fuel consumption	TJ	172'809	135'296	145'010	151'174	145'048	133'301	134'218	124'773	139'974	114'538
Gas oil	TJ	99'373	75'136	79'406	81'340	76'113	67'901	66'642	59'375	66'048	51'247
Gas oil heat only boilers	TJ	99'363	75'126	79'398	81'332	76'104	67'896	66'635	59'369	66'042	51'241
Gas oil engines	TJ	10	10	9	7	8	5	6	6	6	6
Natural gas	TJ	51'162	42'554	46'295	49'026	48'527	46'120	47'781	47'414	53'284	45'494
NG heat only boilers	TJ	50'961	42'369	46'118	48'862	48'380	45'992	47'671	47'309	53'179	45'386
NG engines	TJ	201	185	177	163	147	128	110	105	105	108
Liquefied petroleum gas (engines)	TJ	10	11	10	14	5	3	3	3	2	3
Other bituminous coal	TJ	300	200	200	200	100	100	100	100	100	50
Biomass	TJ	21'964	17'396	19'099	20'595	20'303	19'177	19'692	17'882	20'539	17'745
Biodiesel	TJ	3	3	3	3	3	2	2	2	2	2
Biogas	TJ	NO	NO	NO	NO	NO	NO	NO	4	5	6
Wood and wood waste (various furnaces)	TJ	21'457	16'878	18'582	20'099	19'766	18'661	19'205	17'311	20'008	17'223
Charcoal use	TJ	343	354	354	334	374	354	325	404	364	353
Wood (bonfires)	TJ	160	160	160	160	160	160	160	160	160	160

Table 3-75 Activity data in 1A4ci Agriculture/forestry/fishing (stationary).

1A4ci Other sectors (stationary): Agriculture/forestry/fishing	Unit	1990	1995	2000	2005	2010
Total fuel consumption	TJ	6'387	6'110	5'804	5'531	5'656
Drying of grass	TJ	1'895	1'544	1'223	994	739
Gas oil	TJ	1'156	942	746	607	451
Residual fuel oil	TJ	NO	NO	NO	NO	NO
Natural gas	TJ	739	602	477	388	288
Biomass (crop residues, fat, wood)	TJ	NO	NO	NO	NO	NO
Heating of greenhouses	TJ	4'000	4'000	4'000	3'735	3'677
Gas oil	TJ	3'490	3'490	3'490	3'133	1'803
Natural gas	TJ	510	510	510	601	1'874
Other fossil combustion	TJ	4.86	3.41	4.57	4.46	2.12
Gas oil (engines)	TJ	2.1	2.12	2.12	2.12	2.12
Natural gas (engines)	TJ	2.7	1.29	2.45	2.34	NO
Other biomass combustion	TJ	487	563	577	797	1'239
Biogas (engines)	TJ	59	49	62	128	497
Wood and wood waste (various furnaces)	TJ	428	514	515	669	741

1A4ci Other sectors (stationary): Agriculture/forestry/fishing	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total fuel consumption	TJ	5'300	4'764	4'937	5'442	5'962	5'488	5'827	5'943	6'371	5'623
Drying of grass	TJ	458	524	431	492	610	545	684	721	630	559
Gas oil	TJ	106	104	89	86	118	116	124	148	94	99
Residual fuel oil	TJ	17	20	22	18	25	13	NO	NO	NO	NO
Natural gas	TJ	220	264	233	279	338	296	427	435	410	347
Biomass (crop residues, fat, wood)	TJ	114	136	88	109	129	120	132	138	126	113
Heating of greenhouses	TJ	3'389	2'800	2'900	2'899	3'238	2'754	2'732	2'537	2'753	2'114
Gas oil	TJ	1'496	1'095	1'165	1'066	1'145	930	916	788	861	717
Natural gas	TJ	1'893	1'705	1'735	1'834	2'093	1'824	1'816	1'749	1'892	1'397
Other fossil combustion	TJ	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
Gas oil (engines)	TJ	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
Natural gas (engines)	TJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other biomass combustion	TJ	1'452	1'438	1'605	2'048	2'112	2'187	2'409	2'683	2'985	2'949
Biogas (engines)	TJ	812	928	1'041	1'192	1'272	1'403	1'612	1'762	1'909	1'946
Wood and wood waste (various furnaces)	TJ	639	510	564	856	840	784	797	921	1'076	1'003

Charcoal and bonfires

Besides the main fuels, also charcoal use and bonfires are accounted for in source category 1A4bi Other sectors (Stationary) – Residential. Charcoal is only used for charcoal grills. The total charcoal consumption under 1A4bi Other sectors (Stationary) – Residential is very small compared to other fuels used for heating purposes. The activity data are the sum of Swiss charcoal production as reported under 1A1c Manufacture of solid fuels and other energy industries and net imports provided by the Swiss overall energy statistics (SFOE 2023).

As the Swiss wood energy statistics (SFOE 2023b) cover wood used for heating and energy purposes only, no figures are available on wood burnt in source category 1A4bi Bonfires. The activity data of bonfires are thus expert judgements based on a per capita consumption. Two types of bonfires are considered: (public) traditional bonfires such as on national day and (private) bonfires for barbecuing. The number of traditional bonfires has declined, as fewer communities are holding national day bonfires. With the increasing use of gas barbecues, there has also been a decrease in bonfires for barbecuing. Overall, a constant wood consumption was therefore assumed for bonfires due to the declining per capita consumption and increasing population (EMIS 2024/1A4bi Lagerfeuer).

3.2.7.3. Uncertainties and time-series consistency for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

The uncertainty of emission estimates for source category 1A4 (stationary) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.9.

Time series for 1A4 Other sectors are all considered to be consistent.

3.2.7.4. Category-specific QA/QC and verification for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

The general QA/QC procedures are described in chp. 1.5. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.10.

3.2.7.5. Category-specific recalculations for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

The following recalculations were implemented in submission 2024. Major recalculations which contribute significantly to the total differences in GHG emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1A4: A new model for stationary engines and gas turbines was implemented (INFRAS 2022a). The new allocation of the engines and gas turbines surveyed to the various source categories entails various changes in fuel consumption for fossil (diesel oil, gas oil, natural gas and liquefied gas in refineries) and biogenic (biodiesel, biogas and sewage gas) fuels in source categories 1A1a, 1A1b, 1A2d, 1A2gviii, 1A3e and 1A4ai/bi/ci. All emission factors for these engines and gas turbines were also revised in the model. This results in recalculations for all years 1990–2021.
- 1A4ai, 1A4bi: Due to the revised model of natural gas losses in 1B2b Natural gas, the changes also have an impact on final natural gas consumption and therefore on 1A4ai and 1A4bi (as well as on all source categories in 1A2) for the years 1990–2021.
- 1A4: Activity data of automatic wood combustion installations in source categories 1A4ai, 1A4bi and 1A4ci have been revised for 1990-2021 due to recalculations in the Swiss wood energy statistics (SFOE 2023b). The biggest changes were in automatic boilers >50 kW after 2018.
- 1A4ai: Due to a mistake during import in the database the CO_2 emission factor for sewage gas was not the same as for natural gas and biogas in the year 2021. It was still the same value as for 2020 (56'200 g/GJ) instead of 55'900 g/GJ for 2021. This leads to very small recalculation of biogenic CO_2 emissions in 2021.
- 1A4ai: Source category 1A4ai now also includes emissions from mobile pellet combustion installations from 2017 onwards that are used for temporary applications such as construction drying, events in large marquees or as emergency solutions in the event of heating failures. The fuel consumption is based on information from the Swiss wood energy statistics publication (SFOE 2023b, chp. 1.4), but is not part of the wood energy statistics model.
- 1A4ai: The CH_4 emission factors for source categories 1A4ai Heat only boiler (natural gas and biogas) have been adjusted from 1 g/GJ to 5 g/GJ for the entire time series. They are now based on Table 2.4 instead of Table 2.3 of the 2006 IPCC Guidelines (vol. 2, chp. 2.).
- 1A4bi: The CH_4 emission factor for source category 1A4bi Natural gas boiler (heat only) has been adjusted from 1 g/GJ to 5 g/GJ for the entire time series. It is now based on Table 2.5 instead of Table 2.3 of the 2006 IPCC Guidelines (vol. 2, chp. 2.).
- 1A4bi: The activity of source category 1A4bi Charcoal consumption was revised for 2021 due to the correction of a typing error in the import figure and an updated value of 1A1c Charcoal production (364 TJ instead of 40 TJ).

- 1A4bi: Last year's correction of the CH_4 emission factor for single-room furnaces burning logwood was made up for 1A4bi Closed fireplaces.
- 1A4ci: The CH_4 emission factor for source category 1A4ci Biogas boiler (heat only) has been adjusted from 1 g/GJ to 5 g/GJ for the entire time series. It is now based on Table 2.5 instead of Table 2.3 of the 2006 IPCC Guidelines (vol. 2, chp. 2.).
- 1A4ci (CH_4, N_2O, CO_2 biogenic): The activity data of source category 1A4ci for combustion of biogas is now reported in the database directly in GJ instead of GWh and with additional significant digits, causing emission changes of less than 0.1 % for the entire time series.

3.2.7.6. Category-specific planned improvements for 1A4 Stationary combustion in other sectors (commercial, residential, agriculture and forestry)

No category-specific improvements are planned.

3.2.8. Source category 1A2 – Manufacturing industries and construction (mobile 1A2gvii)

3.2.8.1. Source category description for 1A2 Manufacturing industries and construction (mobile 1A2gvii)

Note for Key categories 1A2: See chp. 3.2.6 and note that source category 1A2 contains the sum of emissions of stationary and mobile sources – the statement on key categories holds for the aggregated emission only. The CO_2 emissions of 1A2 from Liquid Fuels are dominated by the stationary sources. Less than the half of the CO_2 emissions of Liquid Fuels from 1A2 stem from mobile sources 1A2gvii.

Table 3-76 Specification of source category 1A2 Manufacturing industries and construction (mobile).

1A2	Source category	Specification
1A2gvii	Mobile Combustion in manufacturing industries and construction	Industry sector: forklifts and snow groomers etc. construction machines: excavators, loaders, dump trucks, mobile compressors etc.

3.2.8.2. Methodological issues for 1A2 Manufacturing industries and construction (mobile 1A2gvii)

Methodology (1A2gvii)

Based on the decision tree Fig. 3.3.1 in chp. “3. Mobile Combustion” in IPCC (2006) the emissions of industry and construction vehicles and machinery are calculated by a Tier 3 method with the non-road transportation model described in chp. 3.2.4.6.1.

CO_2 emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO_2 emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported under source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, CH_4 and N_2O emissions from lubricant use in 2-stroke engines are reported in source category 1A2gvii, since the emission factors are based on measurements including 2-stroke engines.

Emission factors (1A2gvii)

- The CO_2 emission factors applied for the time series 1990–2022 for diesel oil, gasoline, liquefied petroleum gas and biodiesel and bioethanol are country-specific and are given in Table 3-13.
- The CH_4 and N_2O emission factors are country-specific and are shown in Table 3-77 to Table 3-79 for diesel oil, gasoline and liquefied petroleum gas engines for all emission standards.
- For SO_2 from diesel oil, gasoline, gas oil and liquefied petroleum gas see Table A – 18 in Annex A5.1.4.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).
- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and CH_4 emissions.
- The implied emission factors for the reporting year are shown in Table 3-80.

All emission factors (GHG, precursors) can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels.

Table 3-77 Emission factors CH_4 and N_2O for industry and construction vehicles with diesel oil engines by emission standards including the year of entry into force.

Gas	**Power class**	**PreEU-A**	**PreEU-B**	**EU-I**	**EU-II**	**EU-IIIA**	**EU-IIIB**	**EU-IV**
		<1996	1996	2002/03	2002/04	2006/08	2011/12	2014
	kW	g/kWh						
CH_4	<18	0.0547	0.0547	0.0384	0.0240	0.0142	0.0142	0.0142
CH_4	18–37	0.0578	0.0578	0.0221	0.0134	0.0089	0.0089	0.0089
CH_4	37–56	0.0319	0.0319	0.0156	0.0110	0.0079	0.0055	0.0058
CH_4	56–75	0.0319	0.0319	0.0156	0.0110	0.0079	0.0031	0.0031
CH_4	75–130	0.0218	0.0218	0.0108	0.0084	0.0067	0.0031	0.0031
CH_4	130–560	0.0218	0.0218	0.0103	0.0072	0.0053	0.0031	0.0031
CH_4	>560	0.0218	0.0218	0.0103	0.0072	0.0053	0.0031	0.0031
N_2O	0–3000	0.035	0.035	0.035	0.035	0.035	0.035	0.035

Table 3-78 Emission factors CH_4 and N_2O for industry and construction vehicles with gasoline engines by emission standards including the year of enforcement.

Gas	**Power class**	**PreEU-A**	**PreEU-B**	**PreEU-C**	**EU-I**	**EU-II**
		<1996	1996	2000	2004	2005/09
	ccm	g/kWh				
CH_4	<66	2.040	2.040	2.040	1.394	1.394
CH_4	66–100	1.360	1.360	1.360	1.088	1.088
CH_4	100–225	0.680	0.680	0.680	0.408	0.408
CH_4	>225	0.680	0.680	0.680	0.340	0.306
N_2O	0–3000	0.03	0.03	0.03	0.03	0.03

Table 3-79 Emission factors CH_4 and N_2O for industry and construction vehicles with liquefied petroleum gas engines (for all years).

Gas	without catalyst	with catalyst
	g/kWh	
CH_4	0.552	0.035
N_2O	0.05	0.05

Table 3-80 Implied emission factors 2022 for industry and construction vehicles.

1A2gvii Non-road vehicles and other machinery	CO_2	CH_4	N_2O	NO_x	NMVOC	SO_2	CO
	t/TJ	kg/TJ					
Gasoline	73.8	33.9	1.1	94	603	0.10	19'700
Diesel oil	73.3	0.43	3.3	185	19	0.31	93
Liquefied petroleum gas	65.5	0.67	2.3	96	8.7	NA	24
Biodiesel	73.3	0.37	2.8	158	16	0.31	79
Bioethanol	73.8	7.4	0.79	42	209	0.22	12'046

Activity data (1A2gvii)

Activity data for non-road (1A2gvii) are described in. chp. 3.2.4.6.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics of renewable energies (SFOE 2015a). Activity data are shown in Table 3-81 and in Annex A5.1.3. Detailed data can be downloaded from the non-road database (INFRAS 2015a). Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can also be downloaded by query from the online non-road database (INFRAS 2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels.

Table 3-81 Activity data for industry and construction vehicles.

1A2gvii Non-road vehicles and other machinery	Unit	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total fuel consumption	TJ	5'721	6'852	7'636	8'169	8'779	8'875	8'906	8'938	8'944	8'949	8'955	8'960	8'966	8'991	9'016
Gasoline	TJ	196	224	227	225	220	198	191	184	180	177	174	171	168	167	166
Diesel oil	TJ	5'359	6'380	7'106	7'626	8'254	8'341	8'370	8'399	8'380	8'361	8'342	8'323	8'304	8'296	8'288
Liquefied petroleum gas	TJ	165	248	294	290	269	243	235	226	215	203	192	180	168	163	157
Biodiesel	TJ	NO	NO	9.2	28	36	91	110	128	166	205	243	282	320	360	400
Bioethanol	TJ	NO	NO	NO	NO	0.0047	0.76	1.02	1.3	2.0	2.7	3.3	4.0	4.7	5.4	6.1

3.2.8.3. Uncertainties and time-series consistency for 1A2gvii (mobile)

The uncertainty of emission estimates for source category 1A2gvii (mobile) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.9. Uncertainties by fuel type are given in Table 3-38.

3.2.8.4. Category-specific QA/QC and verification for 1A2gvii (mobile)

The general QA/QC procedures are described in chp. 1.5. Furthermore, QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.10.

3.2.8.5. Category-specific recalculations for 1A2gvii (mobile)

There were no recalculations implemented in submission 2024.

3.2.8.6. Category-specific planned improvements for 1A2gvii (mobile)

No category-specific improvements are planned.

3.2.9. Source category 1A3 – Transport

3.2.9.1. Source category description for 1A3

Table 3-82 Key categories of 1A3 Transport. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	**IPCC category**	**Gas**	**Identification criteria**
1A3a	Domestic aviation; Kerosene fossil	CO2	T1
1A3b	Road transportation; Diesel oil	CO2	L1, L2, T1
1A3b	Road transportation; Diesel oil	N2O	T1
1A3b	Road transportation; Gasoline	CO2	L1, T1
1A3b	Road transportation; Gasoline	CH4	T1
1A3b	Road transportation; Gasoline	N2O	T1

Table 3-83 Specification of source category 1A3 Transport.

1A3	**Source category**	**Specification**
1A3aii	Domestic aviation	LTO and Cruise; Large (jet, turboprop) and small (piston) aircrafts, helicopters
1A3bi	Road Transportation	Passenger cars
1A3bii		Light duty trucks
1A3biii		Heavy duty trucks and buses
1A3biv		Motorcycles
1A3bv		Other
1A3c	Railways	Diesel locomotives
1A3d	Domestic navigation	Passenger ships, motor and sailing boats on the Swiss lakes and the river Rhine
1A3e	Other transportation - Pipeline compressors	Compressor station in Ruswil, Lucerne

For information on international bunker fuel emissions from international aviation and navigation, see chp. 3.2.2.

3.2.9.2. Methodological issues for 1A3

3.2.9.2.1. Domestic aviation (1A3a)

Methodology (1A3a)

The emissions of domestic aviation are modelled by a Tier 3A method (IPCC 2006, Volume 2, chp. 3 Mobile Combustion, Table 3.6.2 and figure 3.6.2) developed by FOCA (2006) and based on origin and destination of single movements by aircraft type according to detailed movement statistics. LTO emissions are modelled based on the individual engine type. The emissions of domestic aviation are modelled together with the international aviation reported in 1D1 (aviation bunker, see chp. 3.2.2.2.1).

FOCA is represented in the emissions technical working group (Committee on Aviation Environmental Protection CAEP, WG3) and in the modelling and database group (CAEP MDG) of the International Civil Aviation Organisation (ICAO). FOCA is directly involved in the development of ICAO guidance material for the calculation of aircraft emissions and in the update of the IPCC Guidelines (via the secretariat of ICAO CAEP). The Tier 3A method applied for the emission modelling is in line with the methods developed in the working groups mentioned. The modelling scheme for domestic aviation refers to aircraft basic data, activity data and emission factors that result in calculated emissions. Respective values are ultimately imported into the EMIS database as shown in Figure 3-24.

The Tier 3A method follows standard modelling procedures at the level of single aircraft movements based on detailed movement statistics. The primary key for all calculations is the aircraft tail number, which allows to calculate on the most precise level, namely on the level of the individual aircraft and engine type. Every aircraft is linked to the FOCA engine data base containing emission factors for more than 800 individual engine types with different power settings. Emissions in the landing/take-off (LTO) cycle are calculated with aircraft category dependent flight times and corresponding power settings. Cruise emissions are calculated based on the individual aircraft type with individual engine model (since 2021) and the trip distance for every flight. For piston-engine powered aircraft and helicopters, to the knowledge of FOCA, it has been the only provider of publicly available engine data and a full methodology. All piston engine data and study results have been published in 2007 (FOCA 2007a). The guidance on the determination of helicopter emissions has been published in 2009 (FOCA 2009a) and updated in 2015 (FOCA 2015a).

The movement database from Swiss airports registers the departure and destination airports of each flight. With this information, all flights from and to Swiss airports are differentiated into domestic and international flights prior to the emission calculation. The emissions of domestic flights are reported under 1A3a Domestic Aviation, the emissions of international flights are reported under 1D1 international aviation (international bunkers).

The emission factors used are either country-specific or taken from the ICAO engine emissions databank, from EMEP/EEA guidebook (EMEP/EEA 2019), Swedish Defence Research Agency (FOI) and Swiss FOCA measurements (precursors). Cruise emission factors are generally calculated from the values of the ICAO engine emissions databank, aircraft performance tables and from confidential airline data. Pollutant emission factors are adjusted to cruise conditions by using the Boeing Fuel Flow Method 2. For N_2O, the IPCC default emission factor of 2 kg/TJ is used (IPCC 2006). For the methane split of unburnt hydrocarbons, the 10 % methane share for the LTO, given in IPCC 2006 is used. For cruise emissions, no methane is reported.

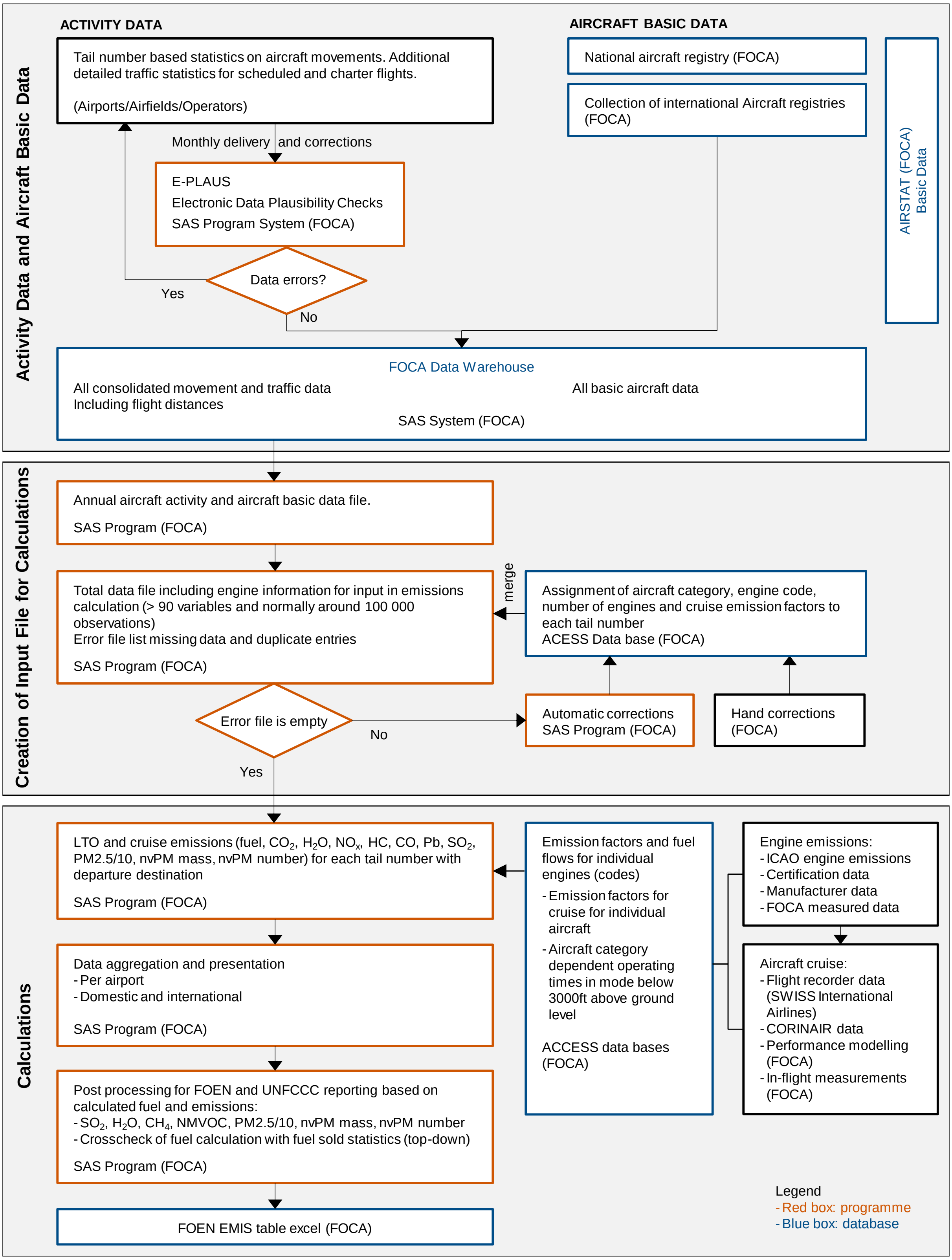

Figure 3-24 Modelling scheme (activity data, emission factors, emissions) for domestic aviation.

A complete emission modelling (LTO and cruise emissions for domestic and international flights) has been carried out by FOCA for 1990, 1995, 2000, 2002, 2004–2022. The results of the emission modelling have been transmitted from FOCA to FOEN in an aggregated form (FOCA 2006a, 2007–2023). FOEN calculated the implied emission factors 1990, 1995, 2000, 2002, 2004 and carried out a linear interpolation for the years in-between. The interpolated implied emission factors were multiplied with the annual fuel sold from Swiss overall energy statistics (SFOE in respective years), providing the missing emissions of domestic aviation for the years 1991–1994, 1996–1999, 2001 and 2003.

Details of emission factors and activity data follow below. Further tables containing more information are also given in Annex A5.1.1, more detailed descriptions of the emission modelling may be found in FOCA (2006).

Emission factors (1A3a)

Landing/take-off (LTO) cycle

The FOCA engine emissions database consists of more than 800 individual engine data sets. Jet engine factors for engines above 26.7 kN thrust (emission certificated) are identical to the ICAO engine emissions databank. Emission factors for lower thrust engines, piston engines and helicopters were taken from manufacturers or from own measurements. Emission factors for turboprops could be obtained in collaboration with the Swedish Defence Research Agency (FOI).

Cruise

The fuel flows of the whole Airbus fleet (which produces a great portion of the Swiss inventory) have been modelled on the basis of real operational aircraft data from flight data recorders (FDR) of Swiss International Airlines. GHG emission factors have been modelled on the basis of the ICAO engine databank and corrected to cruise conditions using FDR engine parameters and the Boeing Fuel Flow Method 2. For older aircraft types (pre-2003), part of the cruise emission factors were taken from the EMEP/EEA guidebook (EMEP/EEA 2019) and from former CROSSAIR (FOCA 1991). For new aircraft type entries, the FOCA models the cruise emission factors based on the aircraft type characteristics and the engine models fitted to the aircraft. The model uses proprietary aircraft information as well as public information from the ICAO engine databank. For those aircraft types, which dominate the fuel consumption in Switzerland, flight data recorder information has been used to calibrate emission factors. The factors are updated periodically to take account of flight operational improvements, as well. Calculation results for international aviation emissions are periodically compared to Eurocontrol results. For piston engine aircraft and helicopters, Swiss FOCA has produced its own data, which were taken under real flight conditions (2005 data, FOCA 2009a, FOCA 2015a).

In 2015 and 2016, the FOCA Helicopter Emissions Calculation Guidance has been updated and implemented in the emissions calculation for the 2015 and 2016 emission inventory (FOCA 2015a, 2016a). Since then, FOCA uses engine power specific emission factors for most helicopters, taking into account lower power requirement per engine, if engines are installed in a twin-engine configuration. On top of the few non-public manufacturer data sources, FOCA introduced 80 individual helicopter engine models replacing most of the generic engine assignments.

Gases

- CO_2: the emission factor for jet kerosene is country-specific and is based on measurements and analyses of fuel samples (see Table 3-13 and Table 3-84)

- CH_4, NMVOC (country-specific; CORINAIR): VOC emissions (see section “Precursors” below) of jet kerosene are split into CH_4 and NMVOC by a constant share of 0.1 (CH_4) and 0.9 (NMVOC) for LTO. For cruise flights, the VOC emissions do not contain CH_4. The implied emission factor for CH_4 for the reporting year is shown in Table 3-84.
- The N_2O emission factor for jet kerosene corresponds to the default value given by the 2006 IPCC Guidelines (IPCC 2006, Table 3.6.5), see Table 3-84. It is assumed that the emission factor for international cruise is sufficient for all kind of flight periods (LTO and cruise) and remains constant over the entire time period 1990–2022.

Precursors (further details see Switzerland’s Informative Inventory Report (FOEN 2024b))

- Assignment of emission factors for 1990 and 1995: The fleet that operated in and from Switzerland during those years has been analysed. The corresponding most frequent engines within an aircraft category (ICAO Code) have been assigned to every aircraft type.
- Assignment of emission factors for the year 2000, 2002 and 2004 to 2022: the actual engine of every single aircraft operating in and from Switzerland has been assigned. FOCA uses the aircraft tail number as the key variable which links activity data and individual aircraft engine information (see Annex A5.1.1 Table A – 10 Aircraft Engine Combinations).

FOCA determines the emission factors of different gases as given in Table 3-84.

Table 3-84 Implied emission factors of 1A3a in 2022. Emission factors that are highlighted in green are described in chp. 3.2.4.5.

1A3a/1D1 Civil aviation	**CO_2 fossil**	**CO_2 biogenic**	**CH_4**	**N_2O**	**NO_X**	**NMVOC**	**SO_2**	**CO**
	kg/TJ							
1A3a Domestic aviation								
1A3a Domestic aviation, LTO, Jet kerosene fossil	72'800	NA	15	2.0	218	139	19	3'944
1A3a Domestic aviation, CR, Jet kerosene fossil	72'800	NA	NA	2.0	246	84	22	656
1D1 International aviation (not part of national total)								
1D1 International aviation, LTO, Jet kerosene fossil	72'800	NA	2.6	2.0	326	23	23	269
1D1 International aviation, LTO, Jet kerosene biogenic	NA	72'800	2.4	2.0	345	21	23	254
1D1 International aviation, CR, Jet kerosene fossil	72'800	NA	NA	2.0	418	4.1	23	46
1D1 International aviation, CR, Jet kerosene biogenic	NA	72'800	NA	2.0	441	3.7	23	40

Activity data (1A3a)

The statistical basis has been extended after 1996. Therefore, the modelling details are not exactly the same for the years 1990/1995 as for the subsequent years. The source for the 1990 and 1995 modelling are the movement statistics, which record information for every movement on airline, number of seats, Swiss airport, arrival/departure, origin/destination, number of passengers, distance. From 1996 onwards, every movement in the FOCA statistics also contains the individual aircraft tail number (aircraft registration). This is the key variable to connect airport data and aircraft data. The FOCA activity data contain both, instrument flight rules (IFR) traffic and visual flight rules (VFR) traffic. As visual flight rules traffic dominates the domestic flight activity, a complete inclusion of visual flight rules traffic is important. The statistics may contain more than one million records with individual tail numbers. All annual aircraft movements recorded are split into domestic and international flights. There are 355’915 aircraft movements in the total of scheduled and charter traffic in 2022 (FSO 2023j). The number of aircraft movements in 2020 and 2021 was clearly lower than usual due to the COVID-19 pandemic (2020: 166’758, 2021: 191’219 movements), which also led to a strong reduction of fuel consumption from civil aviation (see Table 3-85). In 2022, the number of aircraft movements increased again, but is still below pre-pandemic levels (e.g. 2019: 469’667).

Handling of small aircraft and helicopters

- Airports and most of the airfields report individual aircraft data (aircraft registration). FOCA may therefore compute the inventory for small aircraft with a Tier 3A method, too. However, for 1990 and 1995, the emissions data for non-scheduled, non-charter and General Aviation (helicopters etc.) could not be calculated with a Tier 3A method. Its fuel consumption is estimated to be 10 % of the domestic fuel consumption. Data were taken from two FOCA studies (FOCA 1991, FOCA 1991a). For 2000–2007, all movements from airfields are known, which allows a more detailed modelling of the emissions (FOCA 2007a).
- Helicopter flights which do not take off from an official airport or airfield such as transport flights, flights for lumbering, animal transports, supply of alpine huts, heli-skiing and flight trainings in alpine regions cannot be recorded with the movement data base from airports and airfields. These emissions are taken into account using the statistics of the Swiss Helicopter Association (Unternehmensstatistik der Schweizer Helikopterunternehmen). These statistics are officially collected by FOCA and updated annually (see FOCA 2004 as illustrative example for all subsequent years). In this case, emissions are calculated based on operating hours of the helicopters, with emission factors taken from the helicopter study (see FOCA 2015a).
- Since 2007, the data of these helicopter statistics are included electronically in the data warehouse of the model and undergo first some plausibility checks (E-plaus software). In order to distinguish between single engine helicopters and twin-engine helicopters a fix split of 87 % for single engine helicopters and 13 % for twin engine helicopters has been applied until 2014 based on investigations in 2004 (FOCA 2004). Since 2015, the statistics allows to assign the individual helicopters to the helicopter companies. All emissions from helicopter flights without using an official airport or an official airfield are considered domestic emissions.

Fuel consumption

Table 3-85 summarises the activity data for 1A3a Civil aviation. It also includes international aviation, which belongs to the memo items, international bunkers/aviation (1D1, see also chp. 3.2.2). In order to split the fuel consumption for domestic and international flights, the FOCA calculates the fuel for each domestic and international flight bottom-up. A first validation of this calculation can be done top down for the sum of all flights: The total annual aviation fuel sold known from robust energy statistics in a country should correspond very closely (within a few percent) to the modelled total fuel consumption of domestic and international flights together. In 2021 and 2020, in contrast to the years before, the modelled total fuel consumption in Switzerland was clearly higher than the fuel sold value (2021: 9.8 %), so the model showed a clear overestimation. For domestic aviation, the statistical data did not show systematic changes, which could have caused differences to the modelling of pre 2020 years. However, for international aviation, which is dominated by large and scheduled aircraft in Switzerland, FOCA investigation revealed a much lower load factor in 2020 and 2021 due to the COVID-19 pandemic. The model fully accounts for the individual aircraft flying but calculates the fuel burn of normally loaded aircraft. In fact, many aircraft were flying lighter than usual, thus burning less fuel than usual on a given distance, which explains the 9.8 % difference observed in 2021. A small additional effect reported by a Swiss carrier were more direct routes in Europe due to the low traffic volume, especially in 2020. In 2022, this effect diminishes slightly as flight activity increased again, but there is still a 4.1% overestimation of the fuel consumption by the model. A cross comparison for the modelled difference for international aviation was done with Eurocontrol calculations for Switzerland’s international flights, where the same phenomenon (overestimation by the model) was observed by Eurocontrol. For domestic flights, FOCA takes every movement including the smallest aircraft into account and applies conservative emission factors. An indication of this is the fact that Eurocontrol calculations for Switzerland’s domestic flight fuel consumption is usually only around half the value reported by Switzerland. In summary, Switzerland reports the domestic fuel consumption according to the modelled value, whereas the international fuel consumption (bunker) is scaled downwards so that the sum of domestic and international fuel consumption becomes identical with the fuel sold, as reported in the Swiss overall energy statistics.

Since 2021, sustainable aviation fuels (SAF) are included in the energy statistics and attributed to international flights. The amount is still very small compared to the amount of fossil jet fuel.

Table 3-85 Fuel consumption of civil aviation in TJ separated for domestic/international and LTO/cruise. Domestic consumption and the corresponding emissions are reported under 1A3a, international consumption is reported under Memo items, international bunkers. Sustainable aviation fuels (SAF) are referred to as jet kerosene biogenic. (FOCA 2007, 2007a, 2008–2023).

1A3a/1D1 Civil aviation	**1990**	**1995**	**2000**	**2005**	**2010**
	Fuel consumption in TJ				
1A3a Domestic aviation	3'450	3'075	2'541	1'702	1'694
1A3a Domestic aviation, LTO, Jet kerosene fossil	1'050	935	773	518	464
1A3a Domestic aviation, CR, Jet kerosene fossil	2'401	2'139	1'768	1'184	1'230
1D1 International aviation (not part of national total)	41'884	49'918	63'726	47'775	58'334
1D1 International aviation, LTO, Jet kerosene fossil	4'277	5'097	6'507	4'878	5'643
1D1 International aviation, LTO, Jet kerosene biogenic	NO	NO	NO	NO	NO
1D1 International aviation, CR, Jet kerosene fossil	37'608	44'821	57'219	42'896	52'691
1D1 International aviation, CR, Jet kerosene biogenic	NO	NO	NO	NO	NO
Total 1A3a/1D1 Civil aviation	45'334	52'993	66'267	49'477	60'028
1990 = 100%	100%	117%	146%	109%	132%

1A3a/1D1 Civil aviation	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	Fuel consumption in TJ									
1A3a Domestic aviation	1'817	1'921	1'887	1'932	1'641	1'579	1'571	1'056	811	944
1A3a Domestic aviation, LTO, Jet kerosene fossil	494	525	387	421	384	346	321	170	183	227
1A3a Domestic aviation, CR, Jet kerosene fossil	1'323	1'396	1'500	1'511	1'257	1'234	1'250	886	628	717
1D1 International aviation (not part of national total)	64'709	65'006	67'333	70'603	72'824	77'214	78'196	28'194	31'872	57'499
1D1 International aviation, LTO, Jet kerosene fossil	6'208	6'142	6'459	6'529	6'728	6'953	6'963	2'395	2'718	5'129
1D1 International aviation, LTO, Jet kerosene biogenic	NO	NO	NO	NO	NO	NO	NO	NO	2.0	0.03
1D1 International aviation, CR, Jet kerosene fossil	58'501	58'864	60'874	64'073	66'096	70'261	71'233	25'799	29'129	52'369
1D1 International aviation, CR, Jet kerosene biogenic	NO	NO	NO	NO	NO	NO	NO	NO	24	0.33
Total Civil aviation	66'526	66'927	69'220	72'534	74'465	78'793	79'767	29'250	32'683	58'443
1990 = 100%	147%	148%	153%	160%	164%	174%	176%	65%	72%	129%

3.2.9.2.2. Road transportation (1A3b)

Methodology (1A3b)

Choice of method

- The CO_2 emissions are calculated by a Tier 2 method based on the decision tree Fig. 3.2.2 in chp. 3. Mobile Combustion in IPCC (2006).
- The CH_4 and the N_2O emissions are calculated by a Tier 3 method based on the decision tree Fig. 3.2.3 in chp. 3. Mobile Combustion in IPCC (2006).
- The use of urea in urea-based catalysts is reported in chp. 4.5.2.2 under Urea use in SCR catalysts of diesel engines (2D3d) as recommended in the reporting table’s footnotes.
- CO_2 emissions from the use of lubricants as an additive in 2-stroke motorcycles are reported in chp. 4.5.2.1 under 2D1 Non-energy products from fuels and solvent use / lubricant use. Non-CO_2 emissions are reported under 1A3biv.

Connections between road model, non-road model and Swiss overall energy statistics

For the source categories related to transport, INFRAS developed a territorial emission model for 1A3b Road transportation and a model for non-road vehicles and machinery (mobile sources categories 1A2gvii, 1A3c, 1A3d, 1A4aii, 1A4bii, 1A4cii, 1A5b excl. military aviation). The general method of the road transportation model is described in the following paragraphs and Annex A5.1.2 (INFRAS 2017c, INFRAS 2019a, Matzer et al. 2019, Notter et al. 2022).

Due to fluctuating fuel price differences in the vicinity of the national borders, gas stations sell varying amounts of fuels to foreign car owners. This amount of fuel is referred to as “fuel tourism”. Fuel tourism is not captured by the territorial road transportation model.

The Swiss overall energy statistics (SFOE 2023) provide information on the total amount of fuel sold, i.e. the sum of territorial consumption **and** fuel tourism. From the amount of fuel sold, the consumption modelled by the territorial road and non-road models – i.e. fuel used – is subtracted. The resulting difference represents the amount of fuel tourism plus statistical differences. The amount of fuel tourism is regularly estimated in ex-post analyses, latest update by SFOE (2023e). The results for fuel tourism clearly show that the difference between fuels sales and fuels determined by the traffic model tends to overestimate the “true” fuel tourism. It is concluded that the difference also contains potential underestimation of the mileage and other statistical biases. Therefore, the difference between fuel sold and fuel used in the traffic model is indicated in the NID as “fuel tourism and statistical differences”. The value for fuel tourism can be negative (in case of net fuel imports – e.g. the case for diesel oil in the years 2015–2022 since it was cheaper in the neighbouring countries) or positive (in case of net fuel exports – the case for gasoline in most years, since it is cheaper in Switzerland). It is assumed that no fuel tourism takes place with non-road vehicles and therefore the fuel tourism and the statistical difference is attributed to 1A3b Road transportation for gasoline, diesel oil, natural gas, bioethanol and biodiesel (see Figure 3-9, Figure 3-16 and Figure 3-20). The statistical difference for biogas is attributed to 1A4ai Other sectors (stationary) – commercial/institutional (see Figure 3-18) and the one from liquefied petroleum gas to 1A2gvii Other (boilers) (see Figure 3-13). In the reporting tables, activity data and emissions from fuel tourism and statistical difference are reported in the most appropriate categories. In the latest submission, the old CRF reporter (which was used for QS for the latest submission as the new CRT reporter was not available at that time) produced still an error due to negative values in some source categories for some years for CH_4. The negative values occurred because of the way the fuel tourism and statistical difference was integrated in the reporting tables (CRT Table1.A(a)s3). Therefore, the distribution of fuel tourism amongst the source categories 1A3bi, 1A3bii and 1A3biii had to be changed. The new distribution is not intuitive for diesel oil and gaseous fuels, but there was no other solution which did not lead to an error from the CRF reporter. The distribution of fuel tourism and statistical differences does not affect total fuels sold and has no effect on the total emissions reported. The distribution is conducted as follows:

- Emissions from gasoline: fuel tourism and statistical difference is proportionally distributed amongst source categories 1A3bi, 1A3bii and 1A3biii according to annual consumption data within these categories.
- Emissions from diesel oil: fuel tourism and statistical difference is distributed amongst source categories 1A3bi and 1A3biii. The distribution is conducted in proportion to annual consumption data within these two source categories, but due to negative CH_4 emission values, 25 % of the fuel tourism had to be reallocated from source category 1A3biii to category 1A3bi for all years.
- Emissions from gaseous fuels: fuel tourism and statistical difference is completely allocated to source category 1A3biii.
- Emissions from biomass: fuel tourism and statistical difference is proportionally distributed amongst source categories 1A3bi, 1A3bii and 1A3biii according to annual

consumption data within these categories. Due to negative CH_4 emission values 2 % of fuel tourism from 1A3bi and 8 % of fuel tourism from 1A3bii had to be reallocated to source category 1A3biii. Due to negative N_2O emission values 2 % of fuel tourism from 1A3bii had to be reallocated to source category 1A3biii.

Figure 3-25 shows how the models and the Swiss overall energy statistics are linked to determine the GHG emissions from road and non-road transportation:

- CO_2 emissions are calculated by using fuel sales and country-specific CO_2 emission factors.
- CH_4 and N_2O emissions are calculated in three steps (the same procedure also applies to precursor gases):
  - From fuel used and country-specific CH_4 and N_2O emission factors, the territorial emissions are calculated.
  - The differences between fuels sold and fuels used (territorial) are interpreted as fuel tourism and statistical differences. These amounts of gasoline and diesel oil are multiplied with implied CH_4 and N_2O emission factors, which are deduced from the territorial road transportation model (including weighted averages over all vehicle categories), to form the CH_4 and N_2O emissions resulting from fuel tourism and statistical differences.
  - The sum of CH_4 and N_2O emissions from the territorial model and CH_4 and N_2O from fuel tourism and statistical differences represents the total CH_4 and N_2O emissions as reported in 1A3b Road transportation.

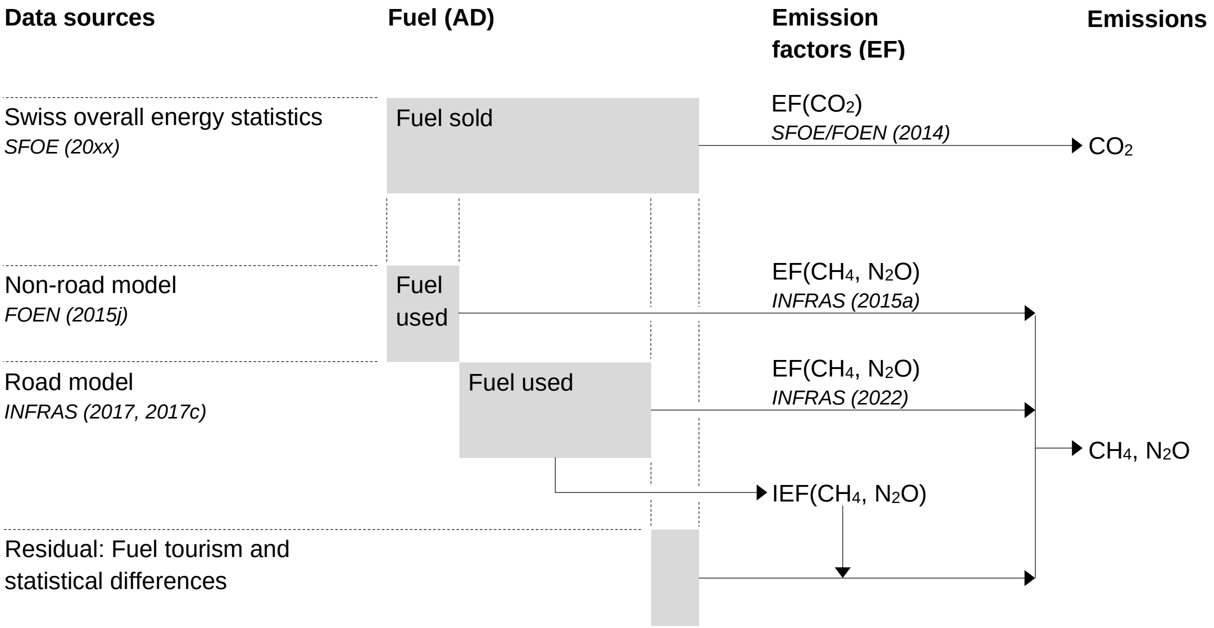

Figure 3-25 Connections between fuel sold and fuel used for road and non-road transportation. Fuel sold is provided by the Swiss overall energy statistics (minus Liechtenstein's gasoline and diesel oil consumption and bunker fuels for navigation). Fuel used results from the territorial road and non-road models. The residual fuel consists of fuel tourism and statistical differences. Its emissions are calculated by means of implied emission factors deduced from the territorial road model. The diagram holds separately for gasoline and diesel oil. SFOE (20xx) stands for the latest Swiss overall energy statistics.

Methodology of the territorial road transportation model

The emission computation is based on two sets of data:

- Emission factors: specific emissions in grams per activity data unit.
- Traffic activity data:
    - vehicle kilometres travelled (hot emissions, evaporative losses during operation)
    - number of starts/stops
    - vehicle stock (cold start, evaporative losses from gasoline passenger cars, light duty vehicles and motorcycles)
    - fuel consumption per vehicle category

Emissions are calculated as follows:

- Hot emissions: $E_{hot} = VKT \cdot EF_{hot}$
- Cold start excess emissions: $E_{start} = N_{start} \cdot EF_{start}$
- Evaporation soak and diurnal VOC emissions: $E_{evap,i} = N_{evap,i} \cdot EF_{evap,i}$,
- Evaporation running VOC losses: $E_{evap-RL} = VKT \cdot EF_{Evap-RL}$

with

- EF_{hot}, $\mathrm{EF}_{\mathrm{start}}$, $EF_{evap,i}$, $EF_{evap-RL}$: Emission factors for ordinary driving conditions (hot engine), cold start excess emissions, and evaporative (VOC) emissions (after stops, diurnal losses, and running losses)
- *VKT:* Vehicle km travelled
- N_{start}: Number of starts
- $N_{evap,i}$: Number of stops, or number of vehicles. *i* runs over two evaporation categories:
a) evaporation soak emissions, i.e. emissions after stopping when the engine is still hot; and
b) evaporation diurnal emissions, i.e. emissions due to daily air temperature differences. For a) the corresponding activity is the number of stops, for b) it is the number of vehicles multiplied with the number of days in the reporting period.

Emission factors are differentiated for all fuel types: Gasoline (4-stroke), gasoline (2-stroke), diesel oil, liquefied petroleum gas bioethanol, biodiesel, gas (CNG), biogas. In terms of vehicle categories, the emission factors are weighted according to the fleet composition in Switzerland (within HBEFA).

CO_2 emissions from lubricant use in 2-stroke engines are calculated from the gasoline consumption of 2-stroke motorcycles, assuming a lubricant content of 2 % in the gasoline. Note that the road transportation model distinguishes 2-stroke (including 2 % lubricant) and 4-stroke gasoline (without lubricant). It is assumed that the whole amount of lubricant is being oxidised. The resulting CO_2 emissions are reported in source category 2D1 Lubricant use. In contrast, CH_4 and N_2O emissions from lubricant use are reported in source category 1A3biv, since the emission factors are deduced from measurements on motorcycles including 2-stroke engines.

Cold start excess emissions for N_2O were originally not accounted for in the model described. During the in-country review in 2016, the ERT identified a potential underestimation. Switzerland therefore estimated N_2O cold start excess emissions for passenger cars and light duty vehicles by means of emission factors from the EMEP/EEA guidebook, as recommended by the ERT. The corresponding emission factors per Euro class are documented in the EMEP/EEA guidebook on p. 72 ff. (EMEP/EEA 2019).

Emission factors (1A3b)

CO_2

- The country-specific CO_2 emission factors are described in chp. 3.2.4.5.2. Values are shown in Table 3-13 (gasoline, diesel oil, biofuels) and in Table 3-14 (natural gas, biogas). The values for the reporting year are also shown in Table 3-86.
- The same emission factors are also applied for the calculation of the emissions resulting from fuel tourism and statistical differences.
- Emission factors for 2-stroke gasoline: For the gasoline part of the fuel, the CO_2 emission factor for gasoline according to Table 3-13 is applied. For the lubricant part of the fuel, the IPCC default CO_2 emission factor for lubricants is applied (see Table 4-38, IPCC 2006). The resulting emissions from the gasoline part are reported under 1A3biv, the emissions from the lubricant part, however, under source category 2D1 Lubricant use (see chp. 4.5.2.1).

CH_4

- Country-specific emission factors are applied. For details including data sources see below (*"Country-specific emission factors").* Emission factors are applied based on HBEFA 4.2 (INFRAS 2022).
- CH_4 emissions from fuel tourism and statistical difference: From the territorial model, implied emission factors for CH_4 are derived per fuel type corresponding to mean emission factors for Switzerland including all vehicle categories (see Figure 3-25). These factors are then applied to calculate the emissions resulting from fuel tourism. This approach has been verified by comparing implied emission factors with the neighbouring countries (see chp. 3.2.9.4).
- For biofuels, no country-specific emission factors for CH_4 are available. Therefore, the same emission factors as for fossil fuels have been used (e.g. emission factor for gasoline was used for bioethanol, and emission factor for diesel oil for biodiesel).

N_2O

- N_2O emissions from territorial traffic under hot operating condition: Country-specific emission factors are used, details see below (INFRAS 2022).
- Cold start N_2O emission factors for gasoline, diesel oil, natural gas and liquefied petroleum gas vehicles are based on the EMEP/EEA guidebook (EMEP/EEA 2019) (see Annex A5.1.2 for details).
- N_2O emissions from fuel tourism and statistical difference: The same approach as for CH_4 is applied (see paragraph above) by means of mean emission factors (country-specific).

- For biofuels no country-specific emission factors for N_2O are available. Therefore, the same emission factors as for fossil fuels have been used (e.g. emission factor for gasoline was used for bioethanol, and emission factor for diesel oil for biodiesel).

Country-specific emission factors

Emission factors for gases other than CO_2 are derived from “emission functions” which are determined from a compilation of measurements from various European countries with programmes using similar driving cycles (legislative as well as standardized real-world cycles, like “Common Artemis Driving Cycle” (CADC)). The method was developed in 1990–1995 and has been extended and updated in 2000, 2004, 2010, 2017, 2019 and latest 2022. These emission factors are compiled in the “Handbook of Emission Factors for Road Transport” (HBEFA, see INFRAS 2022). The latest version 4.2 is presented on the website (http://www.hbefa.net/) and documented in Notter et al. 2022. Further descriptions can also be found in the former publications INFRAS (2017c), INFRAS (2019a) and Matzer et al. (2019). The emission factors are differentiated by so-called “traffic situations”, which represent characteristic patterns of driving behaviour determined by road type, speed limit, area type (rural/urban), traffic density, and road gradient. They serve as a key to the disaggregation of the activity data. The underlying database contains dynamic fleet compositions simulating the release of new exhaust technologies and the fading out of old technologies. Further details are shown in Annex A5.1.2.

Implied emission factors for GHG and precursors

The following Table 3-86 presents implied emission factors for GHG and precursors for the reporting year in kg per TJ fuel consumption. More or less pronounced decreases of the emission factors have occurred in the last years due to new emission regulations and subsequent new exhaust technologies (optimized combustion, use of catalytic converters, particle filters, lower limits for sulphur content in diesel fuels). Early models of catalytic converters represented substantial sources of N_2O, leading to an emission increase of this gas until 1998. More recent converter technologies have overcome this problem resulting in a decrease of the (mean) emission factor.

Table 3-86 Implied emission factors in 2022 for road transportation. For more details see Annex A5.1.2. The implied emission factors in the reporting tables (CRT) are slightly different because of the distribution of fuel tourism and statistical differences in the reporting tables (see chapter 3.2.9.2.2).

1A3b Road Transportation Gasoline / Bioethanol	CO_2	CH_4	N_2O	NO_X	NMVOC	SO_2	CO
	kg/TJ						
1A3bi Passenger cars	73'800	3.8	0.51	31	46	0.22	555
1A3bii Light duty vehicles	73'800	9	2.3	87	114	0.22	2558
1A3biii Heavy duty vehicles	73'800	17	0.82	799	482	0.22	605
1A3biv Motorcycles	73'800	63	1.3	65	263	0.22	1755
1A3bv Other, gasoline evaporation	NO	NO	NO	NO	23	NO	NO
1A3bi-iii Fuel tourism and statistical differences	73'800	6.2	0.56	33	78	0.22	627

1A3b Road Transportation Diesel oil / Biodiesel	CO_2	CH_4	N_2O	NO_X	NMVOC	SO_2	CO
	kg/TJ						
1A3bi Passenger cars	73'300	4.0	3.6	214	3.4	0.31	44
1A3bii Light duty vehicles	73'300	2.1	2.8	246	1.6	0.31	49
1A3biii Heavy duty vehicles	73'300	0.06	4.0	108	2.4	0.31	45
1A3biv Motorcycles	NO	NO	NO	NO	NO	NO	NO
1A3bv Other, gasoline evaporation	NO	NO	NO	NO	NO	NO	NO
1A3bi-iii Fuel tourism and statistical differences	73'300	2.6	3.6	189	2.9	0.31	45

1A3b Road Transportation Natural gas / Biogas	CO_2	CH_4	N_2O	NO_X	NMVOC	SO_2	CO
	kg/TJ						
1A3bi Passenger cars	56'000	15	3.7	25	1.3	NA	165
1A3bii Light duty vehicles	56'000	6.7	16	13	0.59	NA	1187
1A3biii Heavy duty vehicles	56'000	19	NE	112	1.6	NA	54
1A3biv Motorcycles	NO	NO	NO	NO	NO	NO	NO
1A3bv Other, gasoline evaporation	NO	NO	NO	NO	NO	NO	NO
1A3bi-iii Fuel tourism and statistical differences	56'000	16	3.1	62	1.4	NA	204

1A3b Road Transportation Liquefied petroleum gas	CO_2	CH_4	N_2O	NO_X	NMVOC	SO_2	CO
	kg/TJ						
1A3bi Passenger cars	65'500	1.2	1.1	24	1.8	0.50	359
1A3bii Light duty vehicles	NO	NO	NO	NO	NO	NO	NO
1A3biii Heavy duty vehicles	NO	NO	NO	NO	NO	NO	NO
1A3biv Motorcycles	NO	NO	NO	NO	NO	NO	NO
1A3bv Other, gasoline evaporation	NO	NO	NO	NO	NO	NO	NO
1A3bi-iii Fuel tourism and statistical differences	NO	NO	NO	NO	NO	NO	NO

Activity data (1A3b)

Energy-related activity data (basis for modelling the CO_2 emissions)

The Swiss overall energy statistics (SFOE 2023) provides the amount of liquid fuels (gasoline, diesel oil) and gaseous fuels (CNG) sold in Switzerland for road transportation. From the amount of liquid fuels sold, Liechtenstein’s sales, Switzerland’s non-road consumption, bunker fuel emissions and fugitive emissions from transmission, storage and fuelling of gasoline (reported under 1B2av Distribution of oil products) are subtracted. Amounts of liquefied petroleum gas used for road transportation are very small and not provided in the Swiss overall energy statistics. Therefore, the liquefied petroleum gas consumption for road transportation is entirely based on the road transportation model.

The consumption of biofuels is based on the Swiss overall energy statistics (SFOE 2023), the Swiss renewable energy statistics (SFOE 2023a) and the Federal Office for Customs and Border Security (FOCBS 2023). The NCV of biogas is assumed to be equal to the NCV of natural gas since the raw biogas is treated to reach the same quality level including its energetic properties as natural gas (see NCV time series for natural gas and biogas in Table 3-11).

Table 3-87 shows the split of fuel sales into territorial road transportation model, the territorial non-road transportation model and fuel tourism including statistical differences.

- The relevant numbers for 1A3b Road transportation are given as two different contributions in the rows “on road fuel consumption (model)” and “fuel tourism and statistical differences”.
- Consumption of biofuels for road transportation (biodiesel, bioethanol and biogas) starts in Switzerland in 1997.

Table 3-87 Split of fuel sales between territorial “on-road consumption (model)”, “non-road consumption (models)” and “fuel tourism and statistical differences“ (residual value to sold amounts) for gasoline, diesel oil, natural gas (CNG), liquefied petroleum gas, and biofuels (vegetable/waste oil is included in the numbers of Biodiesel) in PJ. Numbers may not add to totals due to rounding.

Activity data for on-road and non-road categories	Source category	1990	1995	2000	2005	2010
		PJ				
Gasoline						
on-road consumption (model)	1A3b	137	135	147	136	120
fuel tourism and statistical differences	1A3b	16	14	19	13	12
non-road consumption (models)	1A2gvii; 1A3dii; 1A4aii,bii,cii; 1A5b	2.4	2.4	2.3	2.1	1.9
Gasoline sold in Switzerland		156	151	168	152	134
Diesel oil						
on-road consumption (model)	1A3b	38	41	47	61	82
fuel tourism and statistical differences	1A3b	-2.0	-5.9	-5.8	-2.0	0.56
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	11	12	14	14	15
Diesel oil sold in Switzerland		47	48	55	73	98
Natural gas						
on-road consumption (model)	1A3b	NO	NO	NO	0.053	0.54
fuel tourism and statistical differences	1A3b	NO	NO	NO	0.037	0.17
non-road consumption (models)		NO	NO	NO	NO	NO
Natural gas sold in on- and non-road categories in Switzerland		NO	NO	NO	0.090	0.71
Liquefied petroleum gas (LPG)						
on-road consumption (model)	1A3b	NO	NO	NO	NO	NO
non-road consumption (models)	1A2gvii	0.17	0.25	0.29	0.29	0.27
Liquefied petroleum gas sold in on- and non-road categories in Switzerland		0.17	0.25	0.29	0.29	0.27
Biodiesel						
on-road consumption (model)	1A3b	NO	NO	0.016	0.16	0.23
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	NO	NO	0.017	0.050	0.064
Biodiesel sold in Switzerland		NO	NO	0.034	0.22	0.30
Bioethanol						
on-road consumption (model)	1A3b	NO	NO	NO	0.019	0.055
non-road consumption (models)	1A2gvii; 1A3dii; 1A4bii; cii; 1A5b	NO	NO	NO	NO	0.000037
Bioethanol sold in Switzerland		NO	NO	NO	0.019	0.055
Biogas						
on-road consumption (model)	1A3b	NO	NO	NO	0.031	0.14
non-road consumption (models)		NO	NO	NO	NO	NO
Biogas sold in Switzerland		NO	NO	NO	0.031	0.14

Activity data for on-road and non-road categories	Source category	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
		PJ									
Gasoline											
on-road consumption (model)	1A3b	106	101	97	94	89	88	86	77	80	82
fuel tourism and statistical differences	1A3b	11	11	7	6.9	8.3	8.3	8.9	7.0	6.1	1.8
non-road consumption (models)	1A2gvii; 1A3dii; 1A4aii,bii,cii; 1A5b	1.8	1.7	1.7	1.7	1.6	1.6	1.6	1.6	1.6	1.5
Gasoline sold in Switzerland		119	114	106	102	99	98	97	86	88	85
Diesel oil											
on-road consumption (model)	1A3b	97	101	104	107	106	106	107	98	103	104
fuel tourism and statistical differences	1A3b	0.13	-1.0	-6.2	-8.0	-7.4	-5.1	-5.9	-3.7	-6.9	-8.1
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	15	15	15	15	15	15	15	15	15	14
Diesel oil sold in Switzerland		111	114	113	114	114	115	115	109	110	110
Natural gas											
on-road consumption (model)	1A3b	0.39	0.40	0.39	0.41	0.38	0.40	0.39	0.33	0.37	0.37
fuel tourism and statistical differences	1A3b	0.31	0.27	0.24	0.19	0.19	0.19	0.19	0.19	0.17	0.15
non-road consumption (models)		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Natural gas sold in on- and non-road categories in Switzerland		0.70	0.67	0.63	0.60	0.57	0.59	0.58	0.52	0.54	0.52
Liquefied petroleum gas (LPG)											
on-road consumption (model)	1A3b	0.015	0.015	0.018	0.020	0.020	0.019	0.019	0.020	0.021	0.022
non-road consumption (models)	1A2gvii	0.24	0.23	0.23	0.21	0.20	0.19	0.18	0.17	0.16	0.16
Liquefied petroleum gas sold in on- and non-road categories in Switzerland		0.26	0.25	0.24	0.23	0.22	0.21	0.20	0.19	0.18	0.18
Biodiesel											
on-road consumption (model)	1A3b	0.17	0.44	1.2	2.4	4.1	5.9	5.9	5.3	4.2	4.0
non-road consumption (models)	1A2gvii; 1A3c,dii; 1A4cii; 1A5b	0.16	0.19	0.23	0.29	0.36	0.43	0.49	0.56	0.63	0.70
Biodiesel sold in Switzerland		0.33	0.63	1.4	2.7	4.5	6.3	6.4	5.9	4.8	4.7
Bioethanol											
on-road consumption (model)	1A3b	0.078	0.16	0.58	0.79	0.97	1.2	1.3	1.3	1.7	1.9
non-road consumption (models)	1A2gvii; 1A3dii; 1A4bii; cii; 1A5b	0.0065	0.0086	0.011	0.017	0.023	0.029	0.035	0.041	0.046	0.052
Bioethanol sold in Switzerland		0.084	0.17	0.59	0.80	1.0	1.2	1.4	1.3	1.7	2.0
Biogas											
on-road consumption (model)	1A3b	0.12	0.11	0.13	0.12	0.12	0.11	0.12	0.12	0.13	0.12
non-road consumption (models)		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Biogas sold in Switzerland		0.12	0.11	0.13	0.12	0.12	0.11	0.12	0.12	0.13	0.12

Mileage-related activity data (basis for modelling of the non-CO_2 emissions by means of a traffic model)

The activity data are derived from different data sources:

- Vehicle stock: The federal vehicle registration database IVZ (run by the Federal Roads Office FEDRO) contains vehicle stock data including all parameters needed for the emission modelling (vehicle category, engine capacity, fuel type, total weight, vehicle age and exhaust technology). The data are not public, but the overall vehicle stock numbers are published by the Federal Statistical Office (FSO 2023e). With the help of a fleet turnover model, the vehicle categories are assigned emission standards based on age and thereby split up into “sub-segments”, which are used to link with the specific emission factors of the same categorisation (vehicle category, size class, fuel type, emission standard [“Euro classes”]).
- The specific mileage per vehicle category is an input from the Federal Statistical Office (FSO 2023e, 2023f). It is based on periodical surveys/Mikrozensus (ARE 2002, ARE/SFSO 2005, 2012, 2017). By means of the vehicle stock data (see paragraph above), the specific mileage per vehicle category can be derived (FSO 2023e, SFOE 2023e, INFRAS 2017).
- Numbers of starts/stops: Derived from vehicle stock and periodical surveys/Mikrozensus (ARE/SFSO 2005, 2012, 2017).

The total mileage of each vehicle category is differentiated by “traffic situations” (characteristic patterns of driving behaviour) and gradients, which serve as a key to select the appropriate emission factors, which are also available per traffic situation and gradient. The relative shares of the traffic situations and gradients are derived from a national road traffic model (operated by the Federal Office of Spatial Development, see ARE (2022)). The traffic model is based on an origin-destination matrix that is assigned to a network of about 600’000 road segments. The model is calibrated partly bottom-up and partly top-down: bottom-up by a number of traffic counts from the national traffic-counter network, and top-down by the total of the mileage per vehicle category. The assignment of traffic situations and gradients to the modelled mileage is described in INFRAS (2017). The traffic model in combination with consumption factors (per vehicle category, size class, fuel type, emissions standard and per traffic situation) allows to calculate the territorial road traffic consumption of gasoline and diesel oil.

Table 3-88 shows the time series of the mileage per vehicle category. The total mileage has constantly been increasing since 1995. This trend was halted in 2020 and 2021, as total mileages decreased compared to the years before due to the restrictions related to the COVID-19 pandemic. In 2022 total mileages increased again to pre-pandemic levels. The major part of vehicle kilometres was driven by passenger cars over the whole period. In the same period, on-road fuel consumption increased less strongly, indicating improved fuel efficiency. This effect is also reflected in Table 3-89 that shows the specific fuel consumption per vehicle-km. Average consumption and the specific consumption for most of the vehicle categories have decreased in the period 1990–2022.

Table 3-88 Mileages in millions of vehicle kilometres. PC: passenger cars, LDV: light duty vehicles, HDV: heavy duty vehicles).

Veh. category	**1990**	**1995**	**2000**	**2005**	**2010**
	million vehicle-km				
PC	42'649	41'324	45'613	48'040	52'066
LDV	2'600	2'746	2'957	3'228	3'502
HDV	1'992	2'107	2'273	2'120	2'226
Coaches	108	110	99	106	118
Urban Bus	174	192	200	229	244
2-Wheelers	2'025	1'563	1'700	1'785	1'852
Sum	49'548	48'043	52'841	55'507	60'009
(1990=100%)	100%	97%	107%	112%	121%

Veh. category	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	million vehicle-km									
PC	54'695	55'641	56'620	57'737	58'735	59'344	59'833	53'371	56'662	59'784
LDV	3'874	3'998	4'129	4'269	4'392	4'530	4'668	4'809	4'947	5'220
HDV	2'243	2'236	2'235	2'235	2'242	2'238	2'226	2'203	2'273	2'278
Coaches	125	128	131	134	136	139	142	131	138	177
Urban Bus	262	267	272	281	281	291	300	294	311	311
2-Wheelers	1'904	1'920	1'937	1'976	2'009	2'046	2'068	2'152	2'209	2'331
Sum	63'102	64'188	65'324	66'631	67'795	68'588	69'238	62'960	66'541	70'100
(1990=100%)	127%	130%	132%	134%	137%	138%	140%	127%	134%	141%

Table 3-89 Specific fuel consumption of road transport, excluding fuel tourism and statistical differences. Numbers include additional fuel consumption by cold starts.

Veh. Category	**Fuel**	**1990**	**1995**	**2000**	**2005**	**2010**
		MJ / veh-km				
PC	Gasoline	3.15	3.23	3.29	3.21	3.06
	Diesel oil	3.34	3.16	3.05	2.77	2.79
	Liquefied petroleum gas	NO	NO	NO	NO	NO
	CNG	NO	NO	NO	NO	2.04
LDV	Gasoline	3.85	3.75	3.65	3.62	3.54
	Diesel oil	4.54	4.51	4.33	3.98	3.77
	CNG	NO	NO	NO	NO	2.40
HDV	Gasoline	NO	NO	NO	NO	NO
	Diesel oil	11.3	11.6	11.6	12.2	11.9
	CNG	NO	NO	NO	10.4	13.1
Coach	Diesel oil	12.7	12.6	12.3	12.0	11.5
Urban Bus	Gasoline	NO	NO	NO	NO	NO
	Diesel oil	16.3	16.7	16.8	16.8	16.2
	CNG	NO	NO	NO	NO	16.7
2-Wheeler	Diesel oil	1.49	1.66	1.48	1.59	1.52
Average		3.53	3.66	3.68	3.55	3.38
(1990=100%)		100%	104%	104%	101%	96%

Veh. Category	**Fuel**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
		MJ / veh-km									
PC	Gasoline	2.86	2.79	2.72	2.65	2.51	2.45	2.41	2.37	2.32	2.24
	Diesel oil	2.74	2.72	2.68	2.64	2.55	2.52	2.52	2.54	2.56	2.53
	Liquefied petroleum gas	2.94	2.92	2.86	2.84	2.74	2.72	2.71	2.70	2.69	2.64
	CNG	1.88	1.89	1.81	1.84	1.71	1.75	1.70	1.61	1.62	1.64
LDV	Gasoline	3.40	3.35	3.29	3.22	3.04	2.94	2.90	2.85	2.77	2.60
	Diesel oil	3.71	3.69	3.66	3.61	3.41	3.32	3.28	3.24	3.23	3.18
	CNG	2.55	2.55	2.45	2.48	2.29	2.32	2.26	2.14	2.15	1.97
HDV	Gasoline	9.16	9.15	9.11	9.11	8.73	8.70	8.65	8.62	8.56	8.48
	Diesel oil	11.7	11.6	11.5	11.3	11.1	10.8	10.7	10.5	10.5	10.2
	CNG	12.4	12.5	12.1	12.5	11.9	10.5	10.3	8.93	9.60	9.75
Coach	Diesel oil	10.5	10.4	10.3	10.1	9.7	9.46	9.36	9.09	9.13	8.95
Urban Bus	Gasoline	NO	NO	NO	NO	NO	8.82	8.78	8.74	8.68	NO
	Diesel oil	16.0	15.9	15.6	15.4	14.2	14.0	13.9	13.9	13.8	14.0
	CNG	15.8	15.7	15.2	15.6	14.3	14.8	14.6	13.9	14.1	14.6
2-Wheeler	Diesel oil	1.51	1.55	1.59	1.55	1.60	1.62	1.62	1.60	1.55	1.47
Average		3.21	3.16	3.10	3.03	2.90	2.84	2.81	2.82	2.80	2.72
(1990=100%)		91%	90%	88%	86%	82%	81%	80%	80%	79%	77%

For modelling of evaporative emissions, the stock, the mileage and the number of stops of gasoline passenger cars, light duty vehicles and motorcycles are used. For modelling cold start excess emissions, also the numbers of starts of passenger cars and light duty vehicles are used as activity data. The corresponding numbers are summarised in Table 3-90. Vehicle stock figures correspond to registration data. The starts and stops per vehicle are based on specific surveys (ARE/SFSO 2005, 2012, 2017).

Table 3-90 Vehicle stock numbers (gasoline vehicles only – relevant for diurnal evaporation) and average number of starts per vehicle per day (gasoline, diesel oil, and CNG vehicles).

Veh. Category	**1990**	**1995**	**2000**	**2005**	**2010**
	stock in 1000 veh. (gasoline/bioeth.)				
PC	2'839	3'049	3'305	3'263	2'957
LDV	167	164	148	112	78
2-Wheelers	764	688	712	746	764
	starts per veh. per day				
PC	2.94	2.68	2.91	2.52	2.56
LDV	1.97	1.97	1.96	1.96	1.96

Veh. Category	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	stock in 1000 veh. (gasoline/bioeth.)									
PC	2'822	2'774	2'731	2'693	2'693	2'708	2'714	2'762	2'801	2'831
LDV	64	61	59	57	55	53	52	54	53	51
2-Wheelers	789	798	807	814	831	851	856	865	856	859
	starts per veh. per day									
PC	2.54	2.55	2.55	2.56	2.58	2.59	2.59	2.30	2.41	2.54
LDV	1.96	1.96	1.96	1.96	1.96	1.89	2.05	2.03	2.00	2.04

Further details are given in Annex A5.1.2.

3.2.9.2.3. Railways (1A3c)

Methodology (1A3c)

As mentioned in chp. 3.2.4.6.1, the emissions are calculated by the non-road transportation model. The following methods are used:

- Tier 2 for CO_2 (based on decision tree Fig. 3.4.1 in IPCC 2006)
- Tier 3 for CH_4, N_2O and precursors (based on decision tree Fig. 3.4.2 in IPCC 2006).

The entire Swiss railway system is electrified. Electric locomotives are used in passenger as well as freight railway traffic. Diesel locomotives are used for shunting purposes in marshalling yards and for construction activities only.

Emissions are calculated for the years 1990, 1995, 2000, 2005 etc. up to 2022 based on fuel used. For the years in-between, the emissions are interpolated linearly.

Emission factors (1A3c)

Only diesel oil is being used as fuel, therefore all emission factors refer to diesel oil.

- The CO_2 emission factor applied for the time series 1990–2022 for diesel oil is country-specific and is given in Table 3-13.
- The CH_4 and N_2O emission factors of diesel locomotives are shown in Table 3-91.
- The emission factors for precursors are country-specific and are given in FOEN (2015j). More details concerning the emission factor for SO_2 are shown in Table A – 16 (row diesel oil). NMVOC emissions are calculated as the difference between VOC and CH_4 emissions.
- Implied emission factors for the reporting year are shown in Table 3-92.

All emission factors (GHG, precursors) can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS (2015a)).

Table 3-91 CH_4 and N_2O emission factors for rail vehicles

Gas	**Power class**	**Rail vehicles with diesel oil engines**				
		PreEU <2000	UIC1 2000	UIC2 2003	EU3a 2006	EU3b 2012
	kW	g/kWh				
CH_4	<18	0.0547	0.0384	0.024	0.0142	0.0142
CH_4	18–37	0.0578	0.0221	0.0134	0.0089	0.0089
CH_4	37–56	0.0319	0.0156	0.011	0.0079	0.0055
CH_4	56–75	0.0319	0.0156	0.011	0.0079	0.0031
CH_4	75–130	0.0218	0.0108	0.0084	0.0067	0.0031
CH_4	>130	0.0218	0.0103	0.0072	0.0053	0.0031
N_2O	all	0.035	0.035	0.035	0.035	0.035

Table 3-92 Implied emission factors 2022 for rail vehicles. Emission factors that are highlighted in green are described in chp. 3.2.4.5.

1A3c Railways	**CO_2 fossil**	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_X**	**NMVOC**	**SO_2**	**CO**
	kg/TJ							
Diesel oil	73'300	NA	1.2	3.6	888	104	0.31	507
Biodiesel	NA	73'300	1.0	3.1	759	89	0.31	434

Activity data (1A3c)

Activity data for non-road, including 1A3c Railways, are described in chp. 3.2.4.6.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics of renewable energies (SFOE 2015a). Activity data are shown in Table 3-93 and in Annex A5.1.3.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS (2015a)).

Table 3-93 Activity data (diesel oil consumption) for railways.

1A3c Railways	Unit	1990	1995	2000	2005	2010
Diesel oil	TJ	390	441	455	472	492
Biodiesel	TJ	NO	NO	0.59	1.7	2.1
Total Railways	TJ	390	441	456	474	494
1990 = 100%		100%	113%	117%	121%	127%

1A3c Railways	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Diesel oil	TJ	431	410	390	388	387	385	383	382	380	378
Biodiesel	TJ	4.4	5.2	5.9	7.7	9.4	11.2	13	15	16	18
Total Railways	TJ	435	416	396	396	396	396	396	396	396	397
1990 = 100%		112%	107%	102%	102%	102%	102%	102%	102%	102%	102%

3.2.9.2.4. Domestic navigation (1A3d)

Methodology (1A3d)

Based on the decision tree Fig. 3.5.1 Box 1 of the 2006 IPCC Guidelines (IPCC 2006) the emissions of navigation are calculated by a Tier 2 method with the non-road transportation model described in chp. 3.2.4.6.1.

There are passenger ships, dredgers, fishing boats, motor and sailing boats on the lakes and rivers of Switzerland. The emissions are calculated for the years 1990, 1995, 2000, 2005 etc. up to 2022 based on fuel used. For the years in-between, the emissions are linearly interpolated.

On the river Rhine as well as on Lake Geneva and Lake Constance, some of the boats cross the border. Fuels bought in Switzerland but used for international navigation are therefore reported as bunker fuels (memo items, chp. 3.2.2.).

CO_2 emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO_2 emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported in source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, CH_4 and N_2O emissions from lubricant use are reported in source category 1A3d Domestic navigation, since the emission factors are deduced from measurements including 2-stroke engines.

Emission factors (1A3d)

- The CO_2 emission factor applied for the time series 1990–2022 for diesel oil, gasoline and gas oil are country-specific and are given in Table 3-13.
- The CH_4 and N_2O emission factors are country-specific and are shown below in Table 3-94 to Table 3-96 for all fuel types and emission standards.
- For SO_2 the emission factors are country-specific. See also Table A – 18 in Annex A5.1.4 rows diesel oil, gasoline, gas oil.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).
- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and CH_4 emissions.
- The implied emission factors for the reporting year are shown in Table 3-97.

All emission factors (GHG, precursors) can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS (2015a)).

Table 3-94 CH_4 and N_2O emission factors for ships with diesel engines.

Gas	Power class	Ships with diesel oil engines				
		Pre SAV (<1995)	SAV 1995	EU-I 2003	EU-II 2008	EU-IIIA 2009
	kW	g/kWh				
CH_4	<18	0.0547	0.0547	0.0384	0.0240	0.0142
CH_4	18–37	0.0578	0.0578	0.0221	0.0134	0.0089
CH_4	37–56	0.0319	0.0319	0.0156	0.0110	0.0079
CH_4	56–75	0.0319	0.0319	0.0156	0.0110	0.0079
CH_4	75–130	0.0218	0.0218	0.0108	0.0084	0.0067
CH_4	>130	0.0218	0.0218	0.0103	0.0072	0.0053
N_2O	all	0.035	0.035	0.035	0.035	0.035

Table 3-95 CH_4 and N_2O emission factors for ships with gasoline engines by emission standards including the year of enforcement.

Gas	Power class	Boats with 2-stroke gasoline engines			Boats with 4-stroke gasoline engines		
		Pre SAV <1995	SAV 1995	SAV/EU 2007	Pre SAV <1995	SAV 1995	SAV/EU 2007
	kW	g/kWh			g/kWh		
CH_4	<18	18.2	1.54	1.75	1.25	1.10	1.25
CH_4	18–37	18.2	0.84	0.91	1.00	0.60	0.65
CH_4	37–56	18.2	0.42	0.56	1.00	0.30	0.40
CH_4	56–75	18.2	0.42	0.56	1.00	0.20	0.30
CH_4	75–130	18.2	0.42	0.56	1.00	0.17	0.25
CH_4	130–560	18.2	0.42	0.56	1.00	0.10	0.25
N_2O	0–300	0.01	0.01	0.01	0.03	0.03	0.03

Table 3-96 CH_4 and N_2O emission factors for steamboats by the year of enforcement.

Gas	Steamboats		
	<2000	2000–2004	>2004
	g/kWh		
CH_4	0.0218	0.0103	0.0072
N_2O	0.035	0.035	0.035

Table 3-97 Implied emission factors 2022 for navigation. Emission factors that are highlighted in green are described in chp. 3.2.4.5.

1A3d Navigation	CO_2 fossil	CO_2 biog.	CH_4	N_2O	NO_X	NMVOC	SO_2	CO
	kg/TJ							
Gasoline	73'800	NA	23	1.9	545	418	0.22	8'801
Diesel oil	73'300	NA	1.3	3.4	732	206	0.31	492
Gas oil	73'700	NA	0.24	0.73	27	1.6	2.0	6.9
Biodiesel	NA	73'300	1.1	2.9	626	176	0.31	421
Bioethanol	NA	73'800	14	1.3	351	258	0.22	5'574

Activity data (1A3d)

Activity data for navigation (1A3d) are described in chp. 3.2.4.6.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics of renewable energies (SFOE 2015a). Activity data are shown in Table 3-98 and in Annex A5.1.3.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (INFRAS 2015a).

Table 3-98 Fuel consumption of (domestic) navigation.

1A3d Domestic navigation	Unit	1990	1995	2000	2005	2010
Gasoline	TJ	701	654	616	565	535
Diesel oil	TJ	738	724	792	800	868
Gas oil	TJ	110	139	147	150	159
Biodiesel	TJ	NO	NO	1.0	2.9	3.8
Bioethanol	TJ	NO	NO	NO	NO	0.013
Total Navigation	TJ	1'550	1'517	1'556	1'518	1'565
1990 = 100%		100%	98%	100%	98%	101%

1A3d Domestic navigation	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Gasoline	TJ	522	518	514	512	511	509	508	506	505	503
Diesel oil	TJ	874	876	878	873	867	862	857	851	847	842
Gas oil	TJ	154	153	151	150	149	148	147	146	145	144
Biodiesel	TJ	9.5	11.5	13	17	21	25	29	33	37	40
Bioethanol	TJ	2.3	3.1	3.9	6.3	8.6	11.0	13	16	18	20
Total Navigation	TJ	1'562	1'561	1'560	1'559	1'557	1'556	1'554	1'552	1'551	1'550
1990 = 100%		101%	101%	101%	101%	100%	100%	100%	100%	100%	100%

3.2.9.2.5. Other transportation (1A3e)

Methodology (1A3e)

The emissions are calculated with a Tier 2 method (the 2006 IPCC Guidelines (IPCC 2006) do not contain a decision tree to determine the Tier level specifically).

Source 1A3e includes only pipeline transportation (1A3ei) from a compressor station located in Ruswil. Emissions of CO_2, CH_4, N_2O, NO_x, CO, NMVOC and SO_2 are reported. The compressor station uses a centrifugal compressor according to Transitgas AG (the company operating the compressor station and the pipeline network).

Emission factors (1A3e)

- The CO_2 emission factor applied for the time series 1990–2022 for natural gas is country-specific and is given in Table 3-14.
- The CH_4 emission factor corresponds to the one used for gas turbines in Switzerland (SAEFL 2000) as suggested by expert judgement. The CH_4 emission factor is assumed to be 5 g/GJ up to 1995 and 2 g/GJ from 2000 onwards, with linear interpolation in between. This corresponds with the fact that a catalyst was fitted to the system, which reduced the CH_4 emissions of the gas turbine.
- For N_2O emission factors the IPCC 2006 default value (Table 3-17) is used as displayed in Table 3-99.
- The emission factors for precursors are mostly country-specific. The NO_x emission factor stems from the Factsheet Emission Factors Furnaces (FOEN 2015k). NMVOC and SO_x emission factors stem from section “Gasturbinen; Erdgas” in SAEFL (2000). More details

concerning the emission factor for SO_2 are shown in Table A – 16(row natural gas). The CO emission factor is a default factor from the EMEP/EEA guidebook (EMEP/EEA 2019).

- The emission factors for the reporting year are shown in Table 3-99.

Table 3-99 Emission factors of 1A3ei Pipeline transportation / compressor station located in Ruswil in 2022. Emission factors that are highlighted in green are described in chp. 3.2.4.5.

1A3e Other transportation	**CO_2 fossil**	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_X**	**NMVOC**	**SO_2**	**CO**
	kg/TJ							
Gas	56'000	NA	5.2	0.69	32	1.60	0.18	10.1
Biogas	NA	56'000	5.2	0.69	48	1.60	0.50	10.1

Activity data (1A3e)

The data on fuel consumption for the operation of the compressor station in Ruswil is based on the Swiss overall energy statistics (SFOE 2023; Table 17).

Table 3-100 Activity data of 1A3e.

1A3ei Pipeline transport	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Natural gas	TJ	560	310	340	1'070	830
Biogas	TJ	NO	NO	NO	NO	NO
1990 = 100%		100%	55%	61%	191%	148%

1A3ei Pipeline transport	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Natural gas	TJ	410	830	760	340	470	490	600	540	120	400
Biogas	TJ	NO	NO	NO	NO	NO	NO	NO	NO	23	30
1990 = 100%		73%	148%	136%	61%	84%	88%	107%	96%	26%	77%

3.2.9.3. Uncertainties and time-series consistency for 1A3

The uncertainty of emission estimates for source category 1A3 is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.9. Uncertainties by fuel type are given in Table 3-38.

Time series for 1A3 Transport are all considered consistent.

3.2.9.4. Category-specific QA/QC and verification for 1A3

General

The general QA/QC measures are described in chp. 1.5. Furthermore, QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.10.

Specific: Domestic aviation (1A3a)

Emissions

Total calculated emissions for domestic and international flights have been compared between different years. The development of total emissions with time is consistent with a fleet renewal of former Swissair in the early nineties, the technological improvements and changes in fleet composition.

Emission factors

- From total fuel consumption, total distance, number of passengers (without freight) per aircraft type, the fuel consumption per 100 passenger km has been calculated (backward calculation). The result of 2 to 10 kg fuel per 100 passenger km is in line with expectations for 1990 passenger fleets. Current modern fleets are in the order of 2.5 kg fuel per 100 passenger km. During the COVID-19 pandemic, the seat load factor was exceptionally low and therefore, a calculation of the fuel consumption per 100 passenger km is not representative.
- The implied emission factors were calculated for the reporting year and compared with previous years.

Activity data

- In an independent Tier 3B calculation, EUROCONTROL performed a fuel calculation for Switzerland's international flights, based on collected Instrument Flight Rules flight plan data and single movements. The results for the years 2004, 2005 and 2007 matched the FOCA calculations by more than 97.4 %. The FOCA results were generally 1 % to 2 % higher but included the total number of actual flight movements of all flights, including visual flight rules and non-scheduled flights such as helicopter movements in alpine regions.
- Comparison between total movement numbers in the calculation and in the corresponding published statistics. Example: In 1990 calculation, FOCA considered all flights for which there was a form 'Traffic report to the airport authorities' filled in (total heavy aircraft). The total number of movements in 1990 is 263'951 (without Basel). The published number of movements for scheduled and charter flights in 1990 is: 263'952 (without Basel).
- The bottom-up calculation of total fuel matches the total fuel sold within a few percent, except for 2020 and 2021, where the difference is larger due to the COVID-19 pandemic.
- Real-world fuel consumption was compared with modelled consumption for selected aircraft of four Swiss airlines. The difference between the two methods was smaller than 1 %.

Specific: Road transportation (1A3b)

Comparison between the 2006 IPCC Guideline's default (IPCC 2006) and Switzerland's emission factors:

- CO_2 (see also Table 3-39): IPCC default value for gasoline is 69.3 t/TJ and for diesel oil 74.1 t/TJ (IPCC 2006, Table 3.2.1). Switzerland's emission factors vary between 73.8 and 73.9 t/TJ for gasoline – 6 % higher than IPCC – and between 73.3 and 73.6 t/TJ for diesel oil – about 1 % below IPCC default value (IPCC 2006).
- CH_4: The IPCC default emission factor for gasoline motors with oxidation catalysts is 25 kg/TJ with an uncertainty range from 7.5 to 86 kg/TJ (IPCC 2006, Table 3.2.2). Switzerland's emission factor for gasoline passenger cars varied between 27.5 kg/TJ and 3.8 kg/TJ throughout the time series and is therefore in the lower part of and below IPCC's uncertainty range. For diesel oil, the IPCC default emission factors lie in the range of 1.6–9.5 kg/TJ (IPCC 2006), whereas Switzerland's range is on a lower level (0.8–4.0 kg/TJ).
- N_2O: The IPCC default emission factor for gasoline motors with oxidation catalysts lies in the uncertainty range 2.6–24 kg/TJ (IPCC 2006, Table 3.2.2). Switzerland's emission factor for gasoline passenger cars varied between 5.4 kg/TJ and 0.5 kg/TJ and is therefore in the lower part of and below IPCC's uncertainty range. For diesel oil the IPCC

default emission factors lies in the range of 1.3–12 kg/TJ (IPCC 2006), whereas Switzerland's range is lower (0.2–3.6 kg/TJ).

The international project for the update of the emission factors for road vehicles is overseen by a group of external national and international experts that guarantees an independent quality control. For the update of the modelling of Switzerland's road transport emissions, which has last been carried out comprehensively between 2019–2020 in the framework of the update of Switzerland's energy perspectives, several experts from the federal administration have accompanied the project (INFRAS 2019a). The results have undergone extensive plausibility checks and comparisons with earlier estimates. A light update of the emission factors took place in 2022 (Notter et al. 2022).

The emission factors CH_4 and N_2O used for the modelling of 1A3b Road Transportation are taken from version 4.2 of the Handbook Emission Factors for Road Transport (HBEFA) (INFRAS 2022), which is also applied in Germany, Austria, Norway, Sweden, and France. The Swiss emission factors for CH_4 and N_2O used in 1A3b Road transportation were additionally compared with those shown in the CRF from Germany and a good match was found. Possible small differences might result from a varying fleet composition.

Use of implied emission factors from the territorial model to calculate emissions for fuel tourism: This approach has been verified by comparing implied emission factors with the neighbouring countries. The differences turned out to be small between Switzerland, Austria, and Germany because all three countries used the same emission factors (INFRAS 2010), whereas there were some differences when comparing with France and Italy that use other emission factors for national greenhouse gas and air pollutant emissions reporting (COPERT, EEA 1997). Nevertheless, the use of the implied Swiss emission factors seemed to be the consistent approach. It must be noted, that this comparison was carried out with version 3.1 of the "Handbook of Emission Factors for Road Transport", whereas the current emissions are based on version 4.2. It is expected that an update of this comparison would result in similarly low differences with the neighbouring countries, since the underlying measurement data in the inventory models are the same (given the neighbouring countries also work with an eventually updated COPERT version).

The activity data for gasoline and diesel oil of the road transportation model (consumption without tank tourism and statistical difference) is verified due to the fact that more than 90 % of the gasoline and diesel oil sold 2022 in Switzerland, as reported by the Swiss overall energy statistic (SFOE 2023), is consumed by the road transportation model (see Table 3-87).

3.2.9.5. Category-specific recalculations for 1A3

The following recalculations were implemented in submission 2024. Major recalculations, which contribute significantly to the total differences in emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1A3b: Recalculation of activity data in sector 1A3b Road transportation due to newly available statistics for activity data (mileage) for the different vehicle categories for all years from 1990–2021.
- 1A3e: A new model for stationary engines and gas turbines was implemented (INFRAS 2022a). The new allocation of the engines and gas turbines surveyed to the various

source categories entails various changes in fuel consumption for fossil (diesel oil, gas oil, natural gas and liquefied gas in refineries) and biogenic (biodiesel, biogas and sewage gas) fuels in source categories 1A1a, 1A1b, 1A2d, 1A2gviii, 1A3e and 1A4ai/bi/ci. All emission factors for these engines and gas turbines were also revised in the model. This results in recalculations for all years 1990–2021.

3.2.9.6. Category-specific planned improvements for 1A3

No category-specific improvements are planned.

3.2.10. Source category 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

3.2.10.1. Source category description for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

Key categories 1A4

See key categories mentioned in chp. 3.2.7.1, Table 3-68.

Table 3-101 Specification of source category 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors (1A4aii, 1A4bii, 1A4cii).

1A4	Source category	Specification
1A4aii	Commercial/ institutional	Emission from non-road vehicles (professional gardening) and motorised equipment
1A4bii	Residential	Emissions from mobile machinery (hobby, gardening) and motorised equipment
1A4cii	Agriculture/forestry	Emisions from non-road vehicles and machinery in agriculture and forestry

3.2.10.2. Methodological issues for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

Methodology (1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors)

Based on the decision tree Fig. 3.3.1 in chp. “3. Mobile Combustion” in the 2006 IPCC Guidelines (IPCC 2006), the emissions of vehicles and machinery in 1A4 are calculated by a Tier 3 method with the non-road transportation model described in chp. 3.2.4.6.1.

CO_2 emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO_2 emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported under source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, CH_4 and N_2O emissions from lubricant use in 2-stroke engines are reported in the corresponding source category in 1A4 Other non-road machinery sources in residential, commercial, agriculture and forestry sectors, since the emission factors are based on measurements including 2-stroke engines.

Emission factors (1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors)

All emission factors (GHG, precursors) can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS (2015a)).

- The CO_2 emission factors applied for the time series 1990–2022 are country-specific and are given in Table 3-13.
- The CH_4 and N_2O emission factors are country-specific and are shown in Table 3-77 and Table 3-78 for diesel oil and gasoline engines for all emission standards.
- For SO_2 the emission factors are country-specific. See also Table A – 18 in Annex A5.1.4 for diesel oil, gasoline, gas oil.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).
- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and CH_4 emissions.
- Implied emission factors for the reporting year are shown in Table 3-102.

Table 3-102 Implied emission factors 2022 for 1A4 – Other non-road machinery sources in residential, commercial agriculture and forestry sectors (1A4aii – 1A4cii mobile). Emission factors that are highlighted in green are described in chp. 3.2.4.5.

1A4 Non-road machinery	**CO_2 fossil**	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_X**	**NMVOC**	**SO_2**	**CO**
	kg/TJ							
1A4aii Gardening professional								
Gasoline	73'800	NA	82	1.2	171	1'295	0.22	26'704
Bioethanol	NA	73'800	14	1.0	67	400	0.22	15'942
1A4bii Gardening								
Gasoline	73'800	NA	40	1.5	136	822	0.22	25'529
Bioethanol	NA	73'800	14	1.0	77	409	0.22	15'945
1A4cii Forestry and agriculture								
Gasoline	73'800	NA	80	1.2	176	1'372	0.22	24'792
Diesel oil	73'300	NA	0.93	3.0	330	38	0.31	190
Biodiesel	NA	73'300	0.80	2.5	282	33	0.31	163
Bioethanol	NA	73'800	18	0.93	74	508	0.22	15'176

Activity data (1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors)

In Non-road vehicles and other machinery in categories 1A4aii Commercial/institutional and 1A4bii Residential, only gasoline (and a small share of bioethanol) is being used as fuel. In category 1A4cii Agricultural/forestry/fishing, mainly diesel oil is consumed and only a small amount of gasoline (e.g. chainsaws) or biodiesel/bioethanol.

Activity data are described in chp. 3.2.4.6.1 (non-road transportation model) and are shown in Table 3-103 and in Annex A5.1.3.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS 2015a).

Table 3-103 Activity data for non-road vehicles and machinery in 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors.

1A4 Non-road machinery	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
1A4aii Gardening professional						
Gasoline	TJ	191	245	295	295	287
Bioethanol	TJ	NO	NO	NO	NO	0.0039
1A4bii Gardening						
Gasoline	TJ	142	155	165	166	163
Bioethanol	TJ	NO	NO	NO	NO	0.0034
1A4cii Forestry and agriculture						
Gasoline	TJ	1'160	1'070	963	824	689
Diesel oil	TJ	4'269	4'604	4'920	4'802	4'882
Biodiesel	TJ	NO	NO	6.4	17	21
Bioethanol	TJ	NO	NO	NO	NO	0.012
Total 1A4 non-road machinery	TJ	5'761	6'073	6'349	6'103	6'042
Relative values 1A4 (1990 = 100%)		100%	105%	110%	106%	105%

1A4 Non-road machinery	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
1A4aii Gardening professional											
Gasoline	TJ	266	260	253	251	250	248	247	245	243	241
Bioethanol	TJ	0.72	0.95	1.2	1.9	2.6	3.3	4.0	4.7	5.4	6.1
1A4bii Gardening											
Gasoline	TJ	159	158	156	155	154	153	152	151	150	149
Bioethanol	TJ	0.64	0.85	1.06	1.7	2.3	2.9	3.6	4.2	4.8	5.4
1A4cii Forestry and agriculture											
Gasoline	TJ	616	592	568	551	535	519	503	486	473	459
Diesel oil	TJ	4'864	4'859	4'853	4'835	4'817	4'800	4'782	4'764	4'742	4'721
Biodiesel	TJ	53	63	74	96	118	140	162	184	205	227
Bioethanol	TJ	1.96	2.6	3.3	4.8	6.4	8.0	9.6	11.1	12	13
Total 1A4 non-road machinery	TJ	5'962	5'936	5'909	5'898	5'886	5'874	5'862	5'851	5'836	5'822
Relative values 1A4 (1990 = 100%)		103%	103%	103%	102%	102%	102%	102%	102%	101%	101%

3.2.10.3. Uncertainties and time-series consistency for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

The uncertainty of emission estimates for source category 1A4 Other sectors (mobile) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.9. Uncertainties by fuel type are given in Table 3-38.

3.2.10.4. Category-specific QA/QC and verification for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

The general QA/QC procedures are described in chp. 1.5. Furthermore QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.10.

3.2.10.5. Category-specific recalculations for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

There were no recalculations implemented in the latest submission.

3.2.10.6. Category-specific planned improvements for 1A4 – Other non-road machinery sources in residential, commercial, agriculture and forestry sectors

No category-specific improvements are planned.

3.2.11. Source category 1A5b – Other (mobile)

3.2.11.1. Source category description for 1A5b (mobile)

Table 3-104 Key categories of 1A5b – Other (mobile). Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Source category 1A5b – Other (mobile) is not a key category.

All of the Swiss source categories of 1A5 refer to mobile sources of military activities (1A5b). Stationary activities (1A5a) are not occurring.

Table 3-105 Specification of Swiss source category 1A5 Other.

1A5	Source category	Specification
1A5bi	Military aviation	Emissions from military aircrafts
1A5bii	Military non-road vehicles and machines	Emissions from machines like power generators, tanks, bulldozers, boats etc.

3.2.11.2. Methodological issues for 1A5b Other (mobile)

3.2.11.2.1. Military aviation (1A5bi)

Methodology (1A5bi Other, military aviation)

To calculate the emissions from military aviation, a Tier 2 method is used for CO_2, while a Tier 1 method is used for CH_4 and N_2O.

Emission factors (1A5bi Other, military aviation)

- The CO_2 emission factor applied for the time series 1990–2022 for jet kerosene is country-specific and is given in Table 3-13.
- CH_4: Because there is no split in LTO and cruise flights in military aviation, the CH_4 emission factor of 1A3a Civil aviation (see chp. 3.2.9.2.1) cannot be applied. Therefore, the Tier 1 emission factor from IPCC 2006, table 3.6.5 is used.
- N_2O: As for 1A3a Civil aviation, the Tier 1 IPCC default value is used (IPCC 2006, table 3.6.5).
- NO_x, NMVOC, CO: average emission factors for military aircraft are calculated by the Federal Office of Civil Aviation (FOCA) based on collaborative measurement efforts of FOCA and the Federal Department of Defence, Civil Protection and Sport (DDPS) and the FOCA aircraft engine data bank. The fuel consumption per aircraft type in the year 2016–2017 is provided by DDPS (DDPS 2018b). The emission factors stay constant for the whole time series from 1990 onwards.
- SO_2: the emission factor is taken from the EMEP/EEA guidebook (EMEP/EEA 2019, Table 3.11, row “Switzerland/CCD” (where: CCD means: climb/cruise/descent)) and is assumed to be constant over the period 1990–2022.
- Implied emission factors for the reporting year are shown in Table 3-106.

Table 3-106 Implied emission factors 1A5bi military aviation in 2022. Emission factors that are highlighted in green are described in chp. 3.2.4.5.

1A5bi Other: Military aviation	CO_2 fossil	CH_4	N_2O	NO_X	NMVOC	SO_2	CO
	kg/TJ						
Jet kerosene	72'800	0.50	2.0	231	33	23	235

Activity data (1A5bi Other, military aviation)

Fuel consumption data for 1990–2022 is available on an annual basis (VTG 2011, VTG 2023). A very small fraction of fuel is consumed for training abroad and might be allocated under “International aviation” (assumed to be less than 3 % of total military aviation consumption). Since the exact numbers for the fuels used abroad is not known, it is not subtracted from the total consumption but included under national military aviation, as recommended by the 2006 IPCC Guidelines (IPCC 2006, chp. 3.6.1.4).

Table 3-107 Activity data (fuel consumption) for military aviation.

1A5bi Other: Military aviation	Unit	1990	1995	2000	2005	2010
Jet kerosene	TJ	2'733	1'955	1'794	1'624	1'592

1A5bi Other: Military aviation	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Jet kerosene	TJ	1'542	1'615	1'567	1'627	1'469	1'457	1'303	1'365	1'301	1'423

3.2.11.2.2. Military non-road vehicles (1A5bii Other, military machinery)

Methodology (1A5bii Other, military machinery)

Emissions are calculated as part of the non-road transportation model (chp. 3.2.4.6.1) corresponding to a Tier 3 according to the decision tree Fig. 3.3.1 in chp. 3. Mobile Combustion in IPCC (2006).

CO_2 emissions from lubricants of gasoline 2-stroke engines are calculated by using the IPCC default CO_2 emission factor for lubricants, 73.3 t/TJ (IPCC 2006). However, these emissions are reported under source category 2D1 Lubricant use (see chp. 4.5.2.1). In contrast, CH_4 and N_2O emissions from lubricant use in 2-stroke engines are reported in source category 1A5bii, since the emission factors are based on measurements including 2-stroke engines.

Emission factors (1A5bii Other, military machinery)

- The CO_2 emission factors applied for the time series 1990–2022 for diesel oil, gasoline and biofuels are country-specific as shown in Table 3-13.
- The CH_4 and N_2O emission factors are country-specific and are shown in Table 3-77 and Table 3-78 for diesel oil and gasoline engines for all emission standards.
- For SO_2 the emission factors are country-specific. See Table A – 18 in Annex A5.1.4, rows diesel oil, gasoline.
- The emission factors for precursors are country-specific and are given in FOEN (2015j).
- NMVOC is not modelled bottom-up. The NMVOC emissions are calculated as the difference between VOC and CH_4 emissions.
- Implied emission factors for the reporting year are shown in Table 3-108.

All emission factors (GHG, precursors) can be downloaded by query from the online non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS (2015a)).

Table 3-108 Implied emission factors 1A5bii military non-road vehicles 2022. Emission factors that are highlighted in green are described in chp. 3.2.4.5.

1A5bii Military non-road	CO_2 fossil	CO_2 biog.	CH_4	N_2O	NO_X	NMVOC	SO_2	CO
	kg/TJ							
Gasoline	73'800	NA	37	1.5	120	688	0.20	24'765
Diesel oil	73'300	NA	0.61	3.0	272	25	0.31	127
Biodiesel	NA	73'300	0.52	2.6	232	22	0.31	108
Bioethanol	NA	73'800	10	1.1	60	267	0.22	15'702

Activity data (1A5bii Other, military machinery)

Activity data for military non-road vehicles (1A5bii) are described in. chp. 3.2.4.6.1 (non-road transportation model). Values are taken from FOEN (2015j). Data on biofuels are provided by the statistics of renewable energies (SFOE 2015a). Activity data are shown in Table 3-109 and in Annex A5.1.3.

Underlying activity data (vehicle stock, operating hours) of mobile non-road sources can be downloaded by query from the public part of the non-road database INFRAS (2015a). They can be queried by vehicle type, fuel type, power class and emission standard either at aggregated or disaggregated levels (see INFRAS 2015a).

Table 3-109 Activity data (fuel consumption) for military non-road vehicles.

1A5bii Military non-road	Unit	1990	1995	2000	2005	2010
Total fuel consumption	TJ	239	248	252	257	275
Gasoline	TJ	19	19	19	19	18
Diesel oil	TJ	220	228	233	238	256
Biodiesel	TJ	NO	NO	0.30	0.86	1.1
Bioethanol	TJ	NO	NO	NO	NO	0.00038

1A5bii Military non-road	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total fuel consumption	TJ	275	275	275	274	273	272	271	270	269	269
Gasoline	TJ	17	17	17	17	16	16	16	16	16	16
Diesel oil	TJ	255	254	254	252	250	248	246	244	243	241
Biodiesel	TJ	2.8	3.3	3.9	5.0	6.1	7.2	8.3	9.4	10.5	12
Bioethanol	TJ	0.069	0.092	0.115	0.18	0.25	0.31	0.38	0.45	0.51	0.58

3.2.11.3. Uncertainties and time-series consistency for 1A5b Other (mobile)

The uncertainty of emission estimates for source category 1A5b Other (mobile) is described in the general uncertainty assessment of source category 1A Fuel combustion in chp. 3.2.4.9. Uncertainties by fuel type are given in Table 3-38.

3.2.11.4. Category-specific QA/QC and verification for 1A5b Other (mobile)

The general QA/QC measures are described in chp. 1.5. Furthermore, QA/QC procedures conducted for all 1A source categories are listed in chp. 3.2.4.10.

The activity data of military aviation (1A5b), jet kerosene consumption, is provided by the Federal Department of Defence, Civil Protection and Sport. For a compatibility check with the emission database of civil aviation, they are sent to the FOCA (office of the Federal Department of the Environment, Transport, Energy and Communications).

3.2.11.5. Category-specific recalculations for 1A5b Other (mobile)

There were no recalculations implemented in the latest submission.

3.2.11.6. Category-specific planned improvements for 1A5b Other (mobile)

No category-specific improvements are planned.

3.3. Source category 1B – Fugitive emissions from fuels

3.3.1. Source category description for 1B – Fugitive emissions from fuels

Table 3-110 Key categories of 1B Fugitive emissions from fuels. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Source category 1B Fugitive emissions from fuels is not a key category.

The only relevant source categories of fugitive emissions in Switzerland are:

- Oil (1B2a)
- Natural gas (1B2b)
- Venting and flaring (1B2c)

3.3.2. Source category 1B1 – Solid Fuels

Coal mining is not occurring in Switzerland, only coal handling. There are no greenhouse gas emissions from coal handling.

3.3.3. Source category fugitive emissions from 1B2a – Oil

3.3.3.1. Source category description for 1B2a

In Switzerland, oil production is not occurring. Fugitive emissions in the oil industry result exclusively from the refineries transforming crude oil into liquid fuels and the several gasoline stations and storage tanks for gasoline and jet kerosene. At the beginning of 2015, one of the two refineries ceased operation. Crude oil is imported by underground pipelines only. The extents of the two existing oil pipelines in Switzerland are approximately 40 km and 70 km, respectively.

Table 3-111 Specification of source category fugitive emissions from 1B2a Oil in Switzerland.

1B2	Source category	Specification
1B2aiii	Fugitive emissions oil: Transport	Emissions only stem from pipeline transport
1B2aiv	Fugitive emissions oil: Refining / storage	Emissions from oil refining process
1B2av	Fugitive emissions oil: Distribution of oil products	Distribution of oil products (from gasoline storage tanks and gasoline stations) (only precursor emissions NMVOC)

3.3.3.2. Methodological issues for 1B2a

Methodology (1B2a)

According to the decision tree for crude oil transport, refining and upgrading, Switzerland estimates 1B2a Fugitive emissions from oil based on a Tier 3 (for 1B2aiii Fugitive emissions oil: Transport) and a Tier 2 (for 1B2aiv Fugitive emissions oil: Refining / storage, 1B2av

Fugitive emissions oil: Distribution of oil products) approach (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.3 and for precursors EMEP/EEA 2019, Figure 3-1).

For source category 1B2a Fugitive emissions from oil, fugitive emissions of CH_4 are reported. They occur only in 1B2aiii Transport and 1B2aiv Refining/storage. Indirect CO_2 emissions resulting from CH_4 and NMVOC emissions in this source category are included in CRT Table 6 as documented in chp. 9. As no CO emissions occur in source category 1B2a, from this source category no indirect CO_2 emissions from CO are included in CRT Table 6 as documented in chp. 9.

Emission factors (1B2a)

Crude oil transportation (1B2aiii): In Switzerland crude oil is transported by underground pipelines only. According to experts from the pipeline operator, there are no emissions along the pipelines but only at the pig trap. There is one pig trap per pipeline and one pipeline per refinery. Based on expert estimates 0.5 m^3 air saturated with VOC are emitted per week and pig trap. This leads to CH_4 emissions of 1–2 kg per year. The CH_4 to NMVOC ratio is assumed to be 1:10.

For oil refining and storage (1B2aiv), country-specific emission factors for CH_4 and NMVOC are used. The emission factors for CH_4 are delineated from an emission estimation project in one of the refineries in 1992 called CRISTAL (Raffinerie de Cressier 1992). The emission factor from the other refinery is assumed to be twice as high, because the technology of the plant is older. Then a weighted mean based on the quantity of crude oil used in both refineries was calculated (for further details see the internal documentation of the EMIS database, EMIS 2024/1B2aiv). This emission factor is used for all the years until 1995. For the years 2007–2019, total NMVOC emissions from 1A1b, 1B2aiv and 1B2c correspond to those reported in the Swiss Pollutant Release and Transfer Register (PRTR) from the two refineries. Since 2019, the emission factor is kept constant. Therefore, emission factors in 1B2aiv are adapted to reach the total NMVOC emissions as reported in the Swiss Pollutant Release and Transfer Register. Between the years 1995 and 2007, the emission factors are interpolated linearly. The ratio between CH_4 and NMVOC stays at 1:10 for all the years.

The emission factors for SO_x emissions from Claus units in refineries are country-specific and based on measurements and data from industry and expert estimates.

For the distribution of oil products in gasoline stations (1B2av): The emission factors of NMVOC from 1B2av are country-specific and based on a bottom-up model (Luftkollektiv 2023) that sums up the different processes generating fugitive gasoline emissions, i.e. transport to the gasoline station, unloading to the tank at the gasoline station, opening the manhole, pressure equalisation, vapour recovery and finally refuelling of the vehicles. The bottom-up model developed was applied to the state of the years 1990, 2002, 2010 and 2030 and the respective emission factors were determined. In between, the emission factors are linearly interpolated.

For the distribution of oil products in gasoline and jet kerosene storage tank facilities (1B2av): Emission factors for storage tanks are estimated by Carbura based on two studies, one for gasoline storage tanks (Carbura 2022) and one for jet kerosene storage tanks (Carbura 2023). NMVOC emissions were estimated on the basis of information on tank volumes, tank equipment, throughput quantities and maintenance. For gasoline storage tanks, detailed information is available for all historical reporting years. For jet kerosene storage tanks, historical data is available since 2000. Due to lack of data for earlier years, the emission factor for 1990 is the same as the one calculated for 2000 and kept constant in between. It should be noted that the storage and handling of jet kerosene causes significantly lower NMVOC emissions than gasoline due to the significantly lower vapour pressure.

Table 3-112 Emission factors for fugitive emissions of source category 1B2a Oil in 2022.

1B2a Fugitive emissions attributed to oil	**Per amount of**	**Unit**	**CO_2**	**CH_4**	**N_2O**	**NO_x**	**NMVOC**	**SO_2**	**CO**
1B2ai Exploration		g/t	NO	NO	NO	NO	NO	NO	NO
1B2aii Production		g/t	NO	NO	NO	NO	NO	NO	NO
1B2aiii Transport of crude oil by pipelines	Number of refineries	g/No.	NA	1'000	NA	NA	10'000	NA	NA
1B2aiv Refining/Storage of crude oil	Crude oil imported	g/t	NA	7	NA	NA	75	5	NA
1B2av Distribution of oil products: Gasoline storage tank	Gasoline sold	g/GJ	NA	NA	NA	NA	1.2	NA	NA
1B2av Distribution of oil products: Gasoline station	Gasoline sold	g/GJ	NA	NA	NA	NA	22	NA	NA
1B2av Distribution of oil products: Kerosene storage tank	Jet kerosene imported	g/GJ	NA	NA	NA	NA	0.082	NA	NA

Activity data (1B2a)

As crude oil is transported per pipeline to the refineries in Switzerland, activity data for oil transport (1B2aiii) reflects the number of pipelines, which is equal to the number of refineries. Activity data for oil refining and storage (1B2aiv) is the amount of crude oil imported. This data is provided by Avenergy Suisse (Avenergy 2023) in their annual statistics and also reported in the Swiss overall energy statistics (SFOE 2023).

For oil distribution from storage tanks and gasoline stations (1B2av), gasoline sales based on the Swiss overall energy statistics (SFOE 2023), corrected for consumption of Liechtenstein, are used as activity data.

Table 3-113 Activity data for fugitive emissions from 1B2a Oil.

1B2a Oil products	**Amount of**	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
1B2aiii Transport of crude oil by pipelines	Number of refineries	No.	2	2	2	2	2
1B2aiv Refining/Storage	Crude oil imported	kt	3'127	4'657	4'649	4'877	4'546
1B2av Gasoline distribution	Gasoline sold	TJ	156'516	151'672	168'353	152'182	134'129
1B2av Jet kerosene distribution	Jet kerosene imported and produced	TJ	48'160	54'739	68'310	51'004	61'815

1B2a Oil products	**Amount of**	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	***1990 vs. 2022 (%)***
1B2aiii Transport of crude oil by pipelines	Number of refineries	No.	2	2	1	1	1	1	1	1	1	1	*-50%*
1B2aiv Refining/Storage	Crude oil imported	kt	4'935	4'975	2'836	3'006	2'889	3'076	2'789	2'857	2'339	3'102	*-1%*
1B2av Gasoline distribution	Gasoline sold	TJ	118'717	113'956	105'664	102'367	99'223	97'654	96'850	85'769	87'628	85'110	*-46%*
1B2av Jet kerosene distribution	Jet kerosene imported and produced	TJ	69'248	68'219	70'857	73'853	75'027	80'262	83'698	34'816	31'736	54'264	*13%*

3.3.3.3. Uncertainties and time-series consistency for 1B2a

Based on expert judgement, a preliminary uncertainty assessment of all sources in source category 1B2a results in medium confidence in the emissions estimate (see Table 1-8).

Time series for 1B2a Oil are all considered consistent.

3.3.3.4. Category-specific QA/QC and verification for 1B2a

The general QA/QC measures are described in chp. 1.5 and partly also in chp. 3.2.4.10. No further source-specific activities undertaken for fugitive emissions from oil (1B2a).

3.3.3.5. Category-specific recalculations for 1B2a

There were no recalculations implemented in the latest submission.

For recalculations relating to indirect CO_2 emissions resulting from NMVOC emissions, please refer to recalculations reported in chp. 3 on Energy in Switzerland’s Informative Inventory Report 2024 (FOEN 2024b).

3.3.3.6. Category-specific planned improvements for 1B2a

No category-specific improvements are planned.

3.3.4. Source category fugitive emissions from 1B2b – Natural gas

3.3.4.1. Source category description for 1B2b

In Switzerland, natural gas exploration activities (1B2bi) and natural gas processing activities (1B2biii) are not occurring. Emissions from natural gas production (1B2bii) only occurred during the years of operation of the only production plant in Switzerland from 1985 to 1994. The dominating emissions in source category 1B2b stem from natural gas transmission (1B2biv) and distribution (1B2bv). Emissions directly related to accidents affecting the gas pipeline system would be reported under source category 1B2bvi Other, but so far, no events with direct emissions have occurred (mudflows close to Guttannen in the year 2010 did not lead to any direct emissions, but to controlled venting of limited sections of the transit pipeline in the years 2010 and 2011; the respective emissions are therefore reported under source category 1B2biv Transmission).

Table 3-114 Specification of source category fugitive emissions from 1B2b Natural gas in Switzerland.

1B2	Source category	Specification
1B2bii	Fugitive emissions attributed to natural gas: Production	Emissions from natural gas production (1990-1994 only).
1B2biv	Fugitive emissions attributed to natural gas: Transmission	Emissions from natural gas transmission.
1B2bv	Fugitive emissions attributed to natural gas: Distribution	Emissions from natural gas distribution.

3.3.4.2. Methodological issues for 1B2b

Methodology (1B2b)

According to the decision tree for natural gas systems (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.1), Switzerland follows a Tier 1 approach for fugitive emissions attributed to 1B2bii Production and a Tier 2 approach for fugitive emissions attributed to 1B2biv Transmission as well as 1B2bv Distribution. As source category 1B2 is not a key category (see Table 3-110) and as the contribution from 1B2bii Production is small, the use of a Tier 1 method for this source category is justified.

An important basis of the methodology to estimate fugitive emissions from natural gas transmission (1B2biv) and distribution (1B2bv) are the country-specific gas properties which are continuously measured at the various import stations. The Swiss Gas and Water Industry Association (SGWA) reports annually weighted values for densities and net calorific values as well as concentrations of CO_2, CH_4 and NMVOC (see chp. 3.2.4.2 for more details and references). The same country-specific properties are used for fugitive emissions from natural gas production (1B2bii) as there are no other data available.

Those fugitive emissions from natural gas production (1B2bii) are calculated based on annual production data and default emission factors (IPCC Tier 1 approach), taking into account the country-specific gas properties as mentioned above. There has been no natural gas production in Switzerland since 1994, due to the closure of the only production site at that time.

For transmission (1B2biv) and distribution (1B2bv), a country-specific methodology – established by Quantis (2014) and fully revised by the Swiss Gas and Water Industry Association (SGWA 2023a) – is applied to derive country-specific losses for each emission source. The methodology assesses losses from transmission and distribution pipelines, including from the transit pipeline and its single compressor station. Calculations of losses from the gas network are based on the length and material of the gas pipelines, distinguishing various pressure levels. Also comprised are leakages from gas devices and network components (e.g. control units and gas meters as well as appliances in households, industry and natural gas fuelling stations), pipeline fittings, small-scale damages and maintenance work. To estimate emissions resulting from the permanent leakiness of the different gas appliances, the number and kind of end users and connected gas appliances are considered. The methodology by SGWA (2023a) provides the amount of gas lost in cubic meters per year which serves – after conversion to energy units (GJ per year) based on the country-specific net calorific values – as the activity data. Finally, emissions of CO_2, CH_4 and NMVOC are calculated by multiplying the losses (activity data) with the country-specific composition of the gas (emission factors).

Indirect CO_2 emissions resulting from CH_4 and NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9. As no CO emissions occur in source category 1B2b, from this source category no indirect CO_2 emissions from CO are included in CRT Table6 as documented in chp. 9.

Emission factors (1B2b)

For natural gas production (1B2bii), CO_2, CH_4 and NMVOC default emission factors are taken from the 2006 IPCC Guidelines (IPCC 2006, see EMIS 2024/1B2b Gasproduktion). The default emission factors are provided in grams per cubic meter of gas produced and – to match the units of the activity data – are converted to grams per energy unit (GJ) produced based on the country-specific gas properties as mentioned above.

For natural gas transmission (1B2biv) and distribution (1B2bv), the emission factors represent the composition of the gas lost and are based on the country-specific gas properties as mentioned above.

Table 3-115 Emission factors for fugitive emissions of source category 1B2b Natural gas in 2022 (related to the amount of gas produced for 1B2bii and to the amount of gas lost for 1B2biv and 1B2bv).

1B2b Natural gas	Per amount of	Unit	CO_2	CH_4	N_2O	NO_x	NMVOC	SO_2	CO
1B2bii Production	Natural gas	g/GJ	NO	NO	NO	NO	NO	NO	NO
1B2biv Transmission, losses	Natural gas	g/GJ	364	17'907	NA	NA	2'233	NA	NA
1B2bv Distribution, losses	Natural gas	g/GJ	364	17'907	NA	NA	2'233	NA	NA

Activity data (1B2b)

For natural gas production (1B2bii), activity data are the actual gas production data for the years 1990–1994 (SFOE 2023).

For gas transmission (1B2biv) and distribution (1B2bv), the activity data represent the amount of natural gas lost from the gas network. All the details are documented in SGWA (2023a) and EMIS 2024/1B2b Diffuse Emissionen.

The key points within 1B2biv Transmission are as follows:

- **Compressor Station:** Since 2016 the operator of the transit pipeline provides annual emissions data for specific areas (such as starting gas for turbines, compressor depressurization, control valves, gas meters, etc.). For the years before 2016 and for areas not covered by the operator's data, emission factors from Battelle (1989) are used. The calculations are performed by scaling with the actual compressor power (yearly average).
- **Transit pipeline:** Since 2016, the operator of the transit pipeline provides annual emissions data for losses from operation and maintenance of the transit pipeline. Before 2016, emission factors from Battelle (1989) are used. For pressure reducing and metering stations, emission factors from DVGW (2022) are applied. The calculations are performed by scaling with the pipeline length (gas statistics from SGWA).
- **Components of the transport network (excluding the transit pipeline):** Emission factors from DVGW (2022) for 2020 are converted to the structures of the Swiss gas network. The calculations are performed by scaling with the pipeline length (gas statistics from SGWA).
- **Network Maintenance of the transport network (excluding the transit pipeline):** For 1990, emission factors from Battelle (1989) are used with linear interpolation to the emissions factors for 2020 based on DVGW (2022). The calculations are performed by scaling with the pipeline length (without the share of the transit pipeline; gas statistics from SGWA).

The key points within 1B2bv Distribution are as follows:

- **Leakage:** The methodology is based on the actual number of leaks per kilometre for the years since 2017 (gas statistics from SGWA). For 1990, the number of leaks is derived from Battelle (1989). The various materials and pressure levels of the pipelines are distinguished. The losses per leak are based on measurements from DVGW (2022). The calculations are performed by scaling with the pipeline length (gas statistics from SGWA).
- **Damage by external influences (third-party damage):** The methodology is based on actual third-party damage per kilometre since 2017 (gas statistics from SGWA). For 1990, the amount of third-party damage per kilometre is derived from Battelle (1989). The losses per damage are determined based on DVGW (2022). The calculations are performed by scaling with the pipeline length (gas statistics from SGWA).
- **Permeation:** Permeation through polyethylene pipelines is estimated based on DVGW (2022), while permeation is considered to be negligible for other materials. The calculations are performed by scaling with the pipeline length (gas statistics from SGWA).

- **Components:** Emission factors from Battelle (1994) for 1990 and DVGW (2022) for 2020 are considered. The calculations are performed by scaling with the pipeline length (gas statistics from SGWA).
- **Network Maintenance:** Emission factors from Battelle (1994) for 1990 and DVGW (2022) for 2020 are considered. The calculations are performed by scaling with the pipeline length (gas statistics from SGWA).
- **Industrial Networks:** Emission factors are formed based on Battelle (1994), referring to the gas quantity used by industrial plants. The calculations are performed by scaling with the gas quantity used by industrial plants (until 2019 based on statistics from the Swiss Gas Industry Association, thereafter estimated based on the total gas quantity).
- **House Installations:** Emission factors are based on usability tests – for 1990 based on Battelle (1994), for 2020 based on measurement campaigns by the network operators. The calculations are performed by scaling with the number of end users (gas statistics from SGWA).
- **Gas Stoves:** Emission factors according to Battelle (1994) are used. The number of gas stoves is estimated based on the number of end users (as determined by a survey by SGWA).
- **Gas Stations:** Emission factors according to Battelle (1994) are used.
- **Liquefied natural gas:** Calculations are based on the number of transfer operations and the dead volume of the couplings. Additional losses are estimated to amount to one per cent of the total liquefied natural gas quantity used.

Table 3-116 Activity data (amount of gas produced for 1B2bii and amount of gas lost for 1B2biv and 1B2bv) for fugitive emissions from 1B2b Natural gas.

1B2b Natural Gas	Amount of	Unit	1990	1995	2000	2005	2010
1B2bii Production	Natural gas	GJ	130'000	NO	NO	NO	NO
1B2biv Transmission, losses	Natural gas	GJ	11'975	13'072	13'620	13'324	47'990
1B2bv Distribution, losses	Natural gas	GJ	161'643	168'601	155'978	138'860	119'407

1B2b Natural Gas	Amount of	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	1990 vs. 2022 (%)
1B2bii Production	Natural gas	GJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	-100%
1B2biv Transmission, losses	Natural gas	GJ	11'029	12'304	11'641	10'381	18'062	11'269	11'105	14'367	7'910	8'970	-25%
1B2bv Distribution, losses	Natural gas	GJ	103'515	98'328	94'441	90'580	88'134	82'119	78'760	74'659	76'401	75'485	-53%

3.3.4.3. Uncertainties and time-series consistency for 1B2b

All sources in source category 1B2b are attributed to the uncertainty category medium according to Table 1-8.

Time series for 1B2b Natural gas are all considered consistent.

3.3.4.4. Category-specific QA/QC and verification for 1B2b

The general QA/QC measures are described in chp. 1.5.

As suggested by the 2006 IPCC Guidelines (IPCC 2006), the gas industry – represented by the Swiss Gas and Water Industry Association – was actively involved in the reassessment of fugitive emissions from the natural gas system, resulting in the updated methodology used since the 2024 submission (SGWA 2023).

3.3.4.5. Category-specific recalculations for 1B2b

The following recalculations were implemented in the latest submission. Major recalculations which contribute significantly to the total differences in emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

Fugitive emissions from 1B2b – Natural gas: A new country-specific methodology has been established, completely revising the hitherto applied methodology by Quantis (2014). The main renewals are:

- Where applicable, outdated emission factors from Battelle (1989) are now replaced by emission factors from DVGW (2022) or actual measurements. This applies in particular to components, appliances, house installations, industrial networks, gas stoves, etc.
- The number of actual leakages and third-party damages are now used, combined with emissions per leakage according to DVGW (2022).
- Actual losses from the operation and maintenance of the transit pipeline based on annual data provided by the operator (for the years since 2016) are considered. Therewith, mitigation measures such as reducing the pressure within the pipelines before maintenance can now be reflected.
- For the compressor station, the actual average compressor power is now used instead of the installed power.
- Permeation through polyethylene pipelines is newly considered based on DVGW (2022).
- Emissions from the handling of liquefied natural gas is newly considered under 1B2bv Distribution.
- Emissions previously reported under 1B2bvi Other are now included under 1B2biv Transmission (relevant for the years 2010 and 2011).

The combined changes in emission factors and activity data for CH_4 and CO_2 lead to the following changes in emissions:

- CH_4 emissions 1990: -76 % (-10.100 kt CH_4)
- CH_4 emissions 2021: -79 % (-5.929 kt CH_4)
- CO_2 emissions 1990: -76 % (-0.293 kt CO_2)
- CO_2 emissions 2021: -79 % (-0.141 kt CO_2)

3.3.4.6. Category-specific planned improvements for 1B2b

No category-specific improvements are planned.

3.3.5. Source category 1B2c – Venting and flaring

3.3.5.1. Source category description for 1B2c

In Switzerland, oil production is not occurring, and only one production site for natural gas production was operational from 1985–1994. Therefore, emissions from flaring result primarily from the torches, which were operational at the two refineries (1B2ci Flaring). Since 2015, there is only one refinery in operation. In addition, CO_2 emissions from H_2 production in one of the two refineries are also reported under 1B2c.

Table 3-117 Specification of source category 1B2c Venting and flaring in Switzerland.

1B2	Source category	Specification
1B2ci	Fugitive emissions attributed to venting and flaring: Flaring oil	The combustion of excess gas at the oil refinery (flaring) only.
1B2ci	Fugitive emissions attributed to venting and flaring: H_2 production	Emissions from H_2 production (butane and natural gas).
1B2cii	Fugitive emissions attributed to venting and flaring: Flaring gas	Emissions from gas production (1990-1994 only).

3.3.5.2. Methodological issues for 1B2c

Methodology (1B2c)

For source category 1B2ci Flaring, Oil, emissions of CO_2 as well as CH_4, N_2O, NO_x, CO and NMVOC are considered. According to the decision tree for crude oil transport, refining and upgrading, Switzerland follows a Tier 3 method for CO_2 emissions and a Tier 2 method for all further pollutants attributed to 1B2ci Flaring, Oil in order to estimate fugitive emissions under 1B2c fugitive emissions from venting and flaring (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.3). For CO_2 emission calculations, country-specific CO_2 emission factors and activity data are available from the refining industry.

Emissions from gas production are calculated by a Tier 1 method according to 1B2c fugitive emissions from venting and flaring according to the decision tree for natural gas systems (IPCC 2006, Volume 2 Energy, chp. 4 Fugitive Emissions, Figure 4.2.1). For source category 1B2cii Flaring, Gas, emissions of CO_2 as well as CH_4, N_2O and NMVOC are considered.

One of the refining plants produces H_2. Until 2017, butane was used for the production of H_2, leading to process emissions of CO_2. During 2017, additionally to butane, the refinery started to use natural gas in its hydrogen production unit. Emissions are estimated based on plant-specific data (Tier 3 method).

Since the CO_2 emission factors assume an oxidation of 100 %, no indirect emissions need to be accounted for. Therefore, no indirect emissions from this source category are included in CRT Table6 as documented in chp. 9.

Emission factors (1B2c)

Emission factors concerning flaring of refinery gas during the refining process are documented in the internal emission database documentation (EMIS 2024/1B2c Raffinerie Abfackelung). The emission factor for CO_2 is based on a study from Frischknecht et al. (1996), the emission factor for N_2O is based on the expert estimate in the German NIR 2019 (UBA 2019), and those for the other greenhouse gases and precursors base on a study from USEPA (1995b) and data from the refining industry.

Since 2005 (with the exception of 2012), the refining industry provides annual data on the CO_2 emissions from flaring under the Federal Act on the Reduction of CO_2 Emissions (Swiss Confederation 2011) based on daily measurements of CO_2 emission factors of the flared gases. From these data, annual emission factors are derived. Since 2005, the evolution of the other emission factors (CH_4, N_2O, NO_x, CO and NMVOC) is assumed to vary proportionally to the CO_2 emission factor. Emission factors are considered confidential and are available to reviewers on request.

The emissions from flaring in the gas production facility are calculated based on default emission factors provided in the 2006 IPCC Guidelines.

CO_2 emission factors for H_2 production are confidential. Data are available to reviewers on request.

Table 3-118 Emission factors for 1B2c Venting and flaring in 2022.

1B2c Fugitive emissions attributed to venting and flaring	Per amount of	Unit	CO_2	CH_4	N_2O	NO_x	NMVOC	SO_2	CO
1B2ci H2 production refinery	Butane	g/GJ	NO	NA	NA	NA	NA	NA	NA
1B2ci H2 production refinery	Natural gas	g/GJ	C	NA	NA	NA	NA	NA	NA
1B2cii1 Flaring Oil	Crude oil imported	g/t	C	C	C	C	C	C	C
1B2cii2 Flaring gas	Natural gas produced	g/GJ	NO	NO	NO	NA	NO	NA	NA

Activity data (1B2c)

Before 2005, the amount of flared gas during the refining process is assumed to be proportional to the amount of crude oil processed in the refineries. Avenergy Suisse (formerly the Swiss petroleum association EV) provides data on the use of crude oil on an annual basis (Avenergy 2023). Between 2001 and 2004, one of the two refineries made major changes to their installations (new cracker, new flaring installation) and their standard operation process. Therefore, emissions from flaring decreased significantly thereafter. Since 2005, the industry provides data on the amount of gas flared.

For gas production, the amount flared is estimated based on the amount of gas produced.

For H_2 production in one of the refining plants, annual data on butane and natural gas consumption are provided by the industry since 2005, when the H_2 production unit was installed. Data are confidential and they are available to reviewers on request.

Table 3-119 Activity data for 1B2c Venting/flaring.

1B2c Venting and flaring	Amount of	Unit	1990	1995	2000	2005	2010
1B2ci: H2 production in refinery	Butane and natural gas	GJ	NO	NO	NO	C	C
1B2cii1 Flaring Oil	Crude oil imported	kt	C	C	C	C	C
1B2cii2 Flaring Gas	Natural gas produced	GJ	130'000	NO	NO	NO	NO

1B2c Venting and flaring	Amount of	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1B2cii1 Flaring Oil	Crude oil imported	kt	C	C	C	C	C	C	C	C	C	C
1B2ci: H2 production in refinery	Butane and natural gas	GJ	C	C	C	C	C	C	C	C	C	C
1B2cii2 Flaring Gas	Natural gas produced	GJ	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

3.3.5.3. Uncertainties and time-series consistency for 1B2c

A preliminary uncertainty assessment of all sources in source category 1B2 based on expert judgement results in medium confidence in the emissions estimate (see Table 1-8).

Consistency: Time series for 1B2c Venting and flaring are all considered consistent.

3.3.5.4. Category-specific QA/QC and verification for 1B2c

The general QA/QC measures are described in chp. 1.5 and partly also in chp. 3.2.4.9. No category-specific QA/QC activities were undertaken for venting and flaring (1B2c).

3.3.5.5. Category-specific recalculations for 1B2c

The following recalculations were implemented in submission 2024. Major recalculations which contribute significantly to the total differences in emissions of sector 1 Energy between the latest and the previous submissions are presented also in chp. 10.1.2.1.

- 1B2c: Recalculations for CO_2, CH_4 and N_2O in 1B2c Flaring oil due to the use of more precise values (more significant decimal places) for the emission factors of these gases for the years 2005-2021.

3.3.5.6. Category-specific planned improvements for 1B2c

No category-specific improvements are planned.

3.4. Source category 1C – CO_2 transport and storage

CO_2 transport and storage is not occurring in Switzerland.

4. Industrial processes and product use (IPPU)

Responsibilities for sector Industrial processes and product use (IPPU)	
Overall responsibility	Sabine Schenker (FOEN)
Method updates & authors	Sabine Schenker (FOEN), Cornelia Stettler (Carbotech; F-gases)
EMIS database operation	Myriam Guillevic (FOEN; F-gases), Sabine Schenker (FOEN)
Annual updates (NID text, tables, figures)	Dominik Eggli (Meteotest), Fabio Fasel (Meteotest), Beat Rihm (Meteotest), Cornelia Stettler (Carbotech; F-gases)
Quality control (NID annual updates)	Gavin Roberts (Carbotech; F-gases), Regine Röthlisberger (FOEN), Adrian Schilt (FOEN), Felix Weber (INFRAS)
Internal review	Stefan Reimann (Empa; F-gases), Regine Röthlisberger (FOEN), Sabine Schenker (FOEN), Adrian Schilt (FOEN; F-gases), Loïc Schmidely (FOEN, SF6)

4.1. Overview

This chapter provides information on the estimation of the GHG emissions from sector 2 Industrial processes and product use. The following source categories are reported:

- 2A Mineral industry
- 2B Chemical industry
- 2C Metal industry
- 2D Non-energy products from fuels and solvent use
- 2E Electronics industry
- 2F Product uses as substitutes for ozone-depleting substances (ODS)
- 2G Other product manufacture and use
- 2H Other

Emissions within this sector comprise GHG emissions as by-products from industrial processes and also emissions of F-gases during production, use and disposal. Emissions from fuel combustion in industry are reported in source category 1A2 under sector 1 Energy.

According to the 2006 IPCC Guidelines this sector provides also information on the GHG emissions from solvent and product use. CO_2 emissions from solvent and partly from product use are due to post-combustion of NMVOC in order to reduce NMVOC in exhaust gases. The disposal of solvents is reported in the energy sector (waste derived fuels, chp. 3.2.6).

Indirect CO_2 emissions resulting from fossil CH_4, CO and NMVOC emissions as well as indirect N_2O emissions resulting from NO_x and NH_3 emissions are included in CRT Table6 as documented in chp. 9. However, indirect CO_2 emissions are taken into account when calculating the key categories of sector 2 (see Figure 4-4). Since the CO_2 emissions from the cracker reported in source category 2B8b Ethylene, from 2C1 Secondary steel production, electric arc furnace and from 2C3 Primary aluminium production are based on carbon mass balances, their emissions of CO (from source categories 2C1 and 2C3) and NMVOC (from source categories 2B8b and 2C1) are not accounted for in the calculation of the indirect CO_2 emissions. Biogenic CO and NMVOC emissions occur in source category 2H2 Food and beverages and 2G4 tobacco consumption and are not reported as indirect CO_2 emissions.

For several industrial processes within source categories 2A Mineral industry, 2B Chemical industry, 2C Metal industry and 2G Other product manufacture and use, data and information on emission factors and activity data are classified as confidential (C), because they refer to a single enterprise. For reviewers, there is an additional version of chp. 4 Industrial processes and product use (IPPU) available, including all confidential data and information.

Figure 4-1 shows the evolution of greenhouse gas emissions in sector 2 between 1990 and 2022.

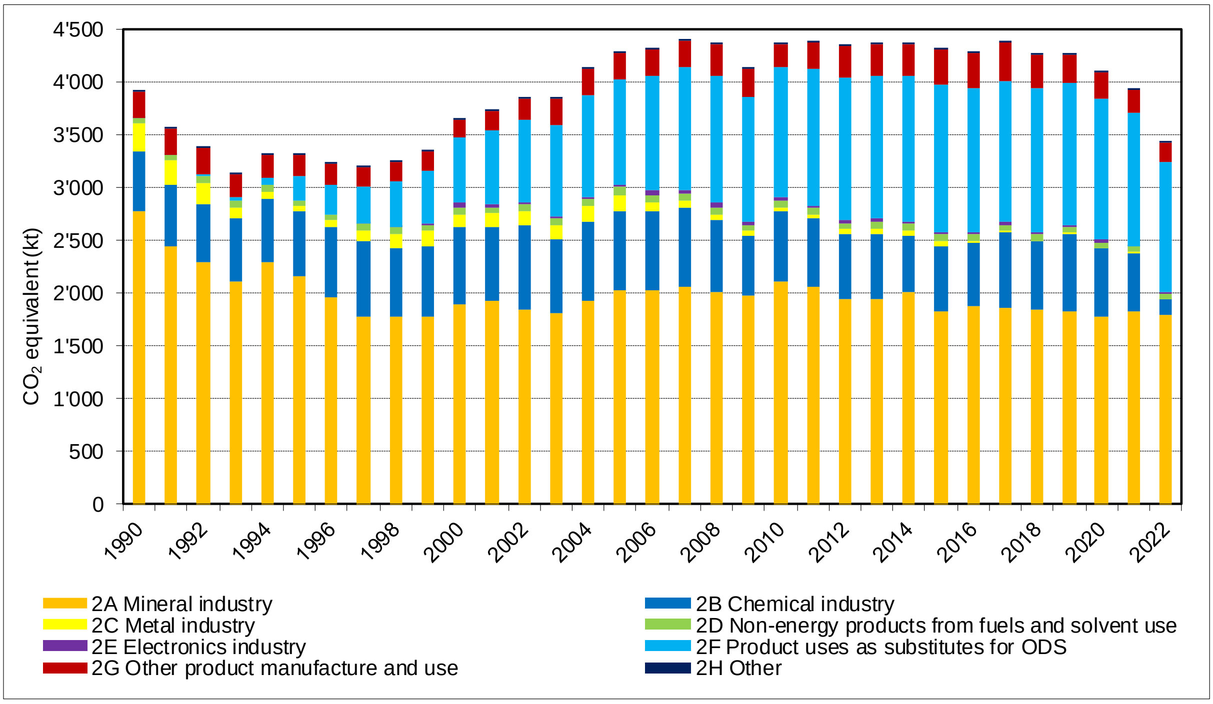

Figure 4-1 Switzerland's greenhouse gas emissions of sector 2 Industrial processes and product use.

2A Mineral industry remains the dominant source of sector 2, accounting for around 50 % of the GHG emissions in 2022 although absolute emissions have decreased since 1990. 2B Chemical industry shows no clear trend until 2021, but a strong decline in 2022, due to the installation of a catalytic converter in the niacin production plant late in the year 2021. In 2022, it accounts for a small share only. 2C Metal industry shows a strong decreasing trend and accounts only for a negligibly small share in 2022. 2D Non-energy products have also only a minor contribution in 2022.

2F Product uses as substitutes for ozone depleting substances (ODSs) is of considerable importance: The emissions have increased from 1990 to 2015 due to the replacement of CFCs and other ODSs by HFCs in many technical applications. However, the emissions are gradually decreasing over the past years due to restrictions of HFC use in mobile air-conditioning and stationary refrigeration. They account for one third of total GHG emissions in sector 2 in 2022. 2G Other product manufacture and use shows, after an increase between 2000 and 2017, a decrease in emissions since then. 2E Electronic industry and 2H Other are of little importance with regard to the overall GHG emissions of sector 2.

In Table 4-1, the development of GHG emissions in sector 2 Industrial processes and product use is given by gases. Dominant gases are CO_2 and F-gases in 2022 whereas N_2O

and CH_4 have only minor contributions. The relative trend of these gases referring to the base year 1990 is shown in Figure 4-2 and Figure 4-3.

Table 4-1 GHG emissions of sector 2 Industrial processes and product use by gases in CO_2 equivalent (kt).

Gas	**1990**	**1995**	**2000**	**2005**	**2010**
	CO_2 equivalent (kt)				
CO_2	3'122	2'396	2'188	2'350	2'346
CH_4	4.0	6.6	5.8	7.0	7.8
N_2O	541	575	646	667	572
F-gases	246	339	815	1'253	1'447
Sum	3'913	3'318	3'654	4'277	4'373

Gas	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	CO_2 equivalent (kt)									
CO_2	2'180	2'233	2'065	2'128	2'103	2'089	2'075	2'001	2'081	2'028
CH_4	5.9	6.4	6.3	7.9	7.9	8.4	7.8	7.2	6.8	7.7
N_2O	523	446	517	477	613	531	617	545	425	38
F-gases	1'650	1'680	1'735	1'670	1'661	1'645	1'568	1'540	1'426	1'355
Sum	4'359	4'366	4'323	4'282	4'385	4'273	4'268	4'094	3'939	3'428

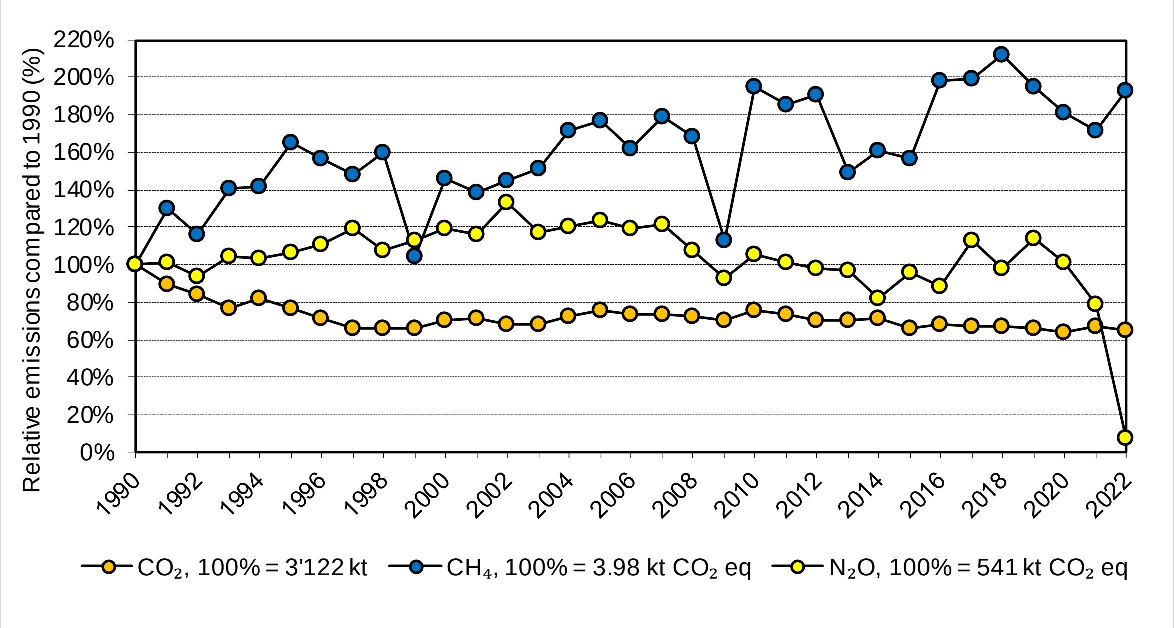

Figure 4-2 Relative trends of the greenhouse gas emissions (without F-gases, see Figure 4-3) of sector 2 Industrial processes and product use. The base year 1990 represents 100 %.

Figure 4-2 shows that the emissions of CO_2 decreased between 1990 and 1997 and since then, they have remained at a constant level. Emissions of N_2O have increased slowly between 1990 and 2002 and decreased afterwards until 2014. Since 2014 there has been an increasing trend again with even higher emissions in 2017, 2019 and 2020 than in 1990. Clearly visible is the drop in N_2O emissions starting in 2021 as explained above. Emissions of CH_4 have an increasing trend with considerable interannual fluctuations. However, absolute emissions are very small compared to CO_2 and N_2O.

Figure 4-3 shows a large increase in emissions of F-gases compared to the year 1990. Main contributions in the inventory 1990 result from the PFC emissions in the smeltering process of aluminium production (chp. 4.4.2.2) and from the use of SF_6 in electrical equipment and soundproof windows (chp. 4.8.2.1 and chp. 4.8.2.2). The increase between 1995 and 2012 is due to the increasing product uses of HFCs as substitutes for ODS (chp.4.7) in refrigeration and air conditioning. Since 2012, total F-gas emissions have remained at a constant level with a visible drop after 2018. The main driver are the restrictions of HFC use in mobile air-conditioning and the progressing limitation of HFCs with a high GWP for stationary refrigeration. The most relevant and main source of F-gases emissions in 2022 is the use of HFC in refrigeration and air conditioning.

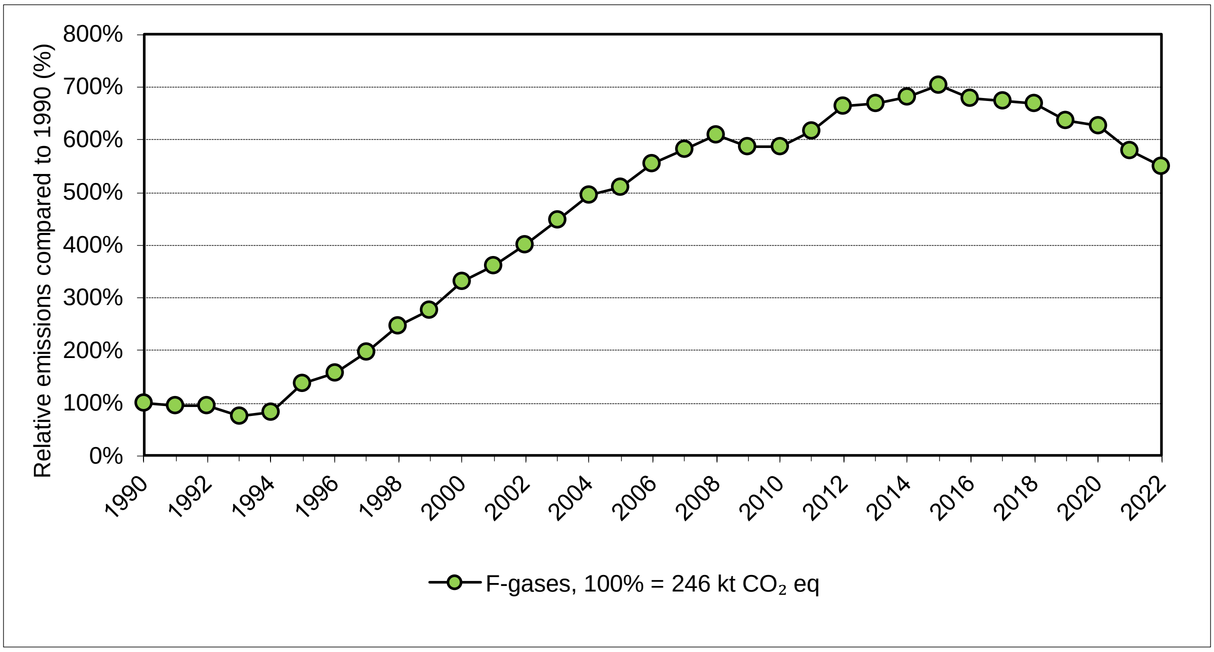

Figure 4-3 Relative trends in emissions of F-gases in sector 2 Industrial processes and product use. The base year 1990 represents 100 %.

There are a total of six key categories identified in sector 2 IPPU, thereof five key categories with direct greenhouse gas emissions and one category with indirect CO_2 emissions (see Figure 4-4).

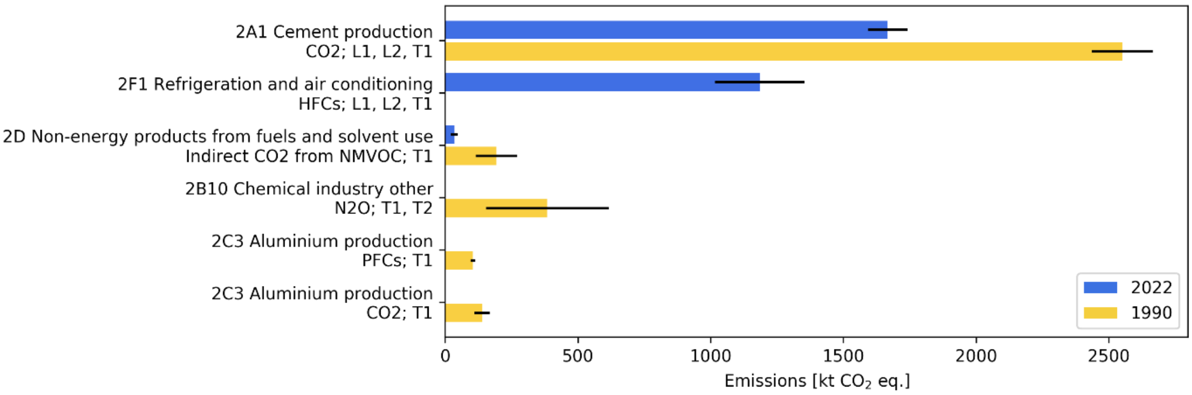

Figure 4-4 Key categories in the Swiss GHG inventory from sector 2 IPPU, including indirect CO$_2$ emissions, determined by the key category analyses, approaches 1 and 2. Categories are set out in order of decreasing emissions in 2022. L1: key category according to approach 1 level in 2022; L2: same for approach 2; T1: key category according to approach 1 trend 1990–2022; T2: same for approach 2. Black uncertainty bars represent the narrowest 95 % confidence interval obtained by Monte Carlo simulations (see chp. 1.6 for details).

4.2. Source category 2A – Mineral industry

4.2.1. Source category description

Table 4-2 Key categories of 2A Mineral industries. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	**IPCC category**	**Gas**	**Identification criteria**
2A1	Cement Production	CO2	L1, T1, L2

Table 4-3 Specification of source category 2A Mineral industry.

2A	**Source category**	**Specification**
2A1	Cement production	Geogenic CO_2 emissions from calcination process in cement production; Emissions of CO_2, NOx, CO, NMVOC and SO_2 from blasting operations
2A2	Lime production	Geogenic CO_2 emissions from calcination process in lime production; Emissions of CO_2, NOx, CO, NMVOC and SO_2 from blasting operations
2A3	Glass production	Geogenic CO_2 emissions from production of container and tableware glass, and glass wool
2A4	Other process uses of carbonates	Geogenic CO_2 emissions from production of fine ceramics, bricks and tiles and rockwool; Geogenic CO_2 emissions from use of carbonates for sulphur oxide removal in municipal solid waste incineration plants, a combined heat and power plant that burns all classes of wood waste and cellulose production (ceased in 2008); Geogenic CO_2 emissions from use of sodium bicarbonate; Emissions of CO_2, NOx, CO, NMVOC and SO_2 from blasting operations in plaster production

4.2.2. Methodological issues

4.2.2.1. Cement production (2A1)

In Switzerland, there are six plants producing clinker and cement. The Swiss plants are rather small and do not exceed a capacity of 3’000 tonnes of clinker per day. All of them use modern dry process technology.

Emissions of geogenic CO_2 occur during the production of clinker, which is an intermediate component in the cement manufacturing process. During the production of clinker, limestone, which is mainly calcium carbonate ($CaCO_3$), is heated (calcined) to produce lime (CaO) and CO_2 as by-product. The CaO reacts subsequently with minerals in the raw materials and yields clinker. During this reaction step no further CO_2 is emitted. Clinker is then mixed with other components such as gypsum to make cement.

Blasting operations in the limestone quarries are another source of emissions for both CO_2 and precursor greenhouse gases such as NO_x, CO, NMVOC and SO_2.

Indirect CO_2 emissions resulting from CO and NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9.

Methodology

Calcination process

The geogenic CO_2 emissions from the calcination process in cement production are determined in the years 1990–2004 and 2007 by a Tier 2 method and in the years 2005, 2006 and from 2008 onwards by a Tier 3 method according to the decision tree Fig. 2.1 of 2006 IPCC Guidelines (vol. 3, chp. 2.1 Cement production).

In Switzerland, no long wet or long dry kilns are used. Only modern preheater or precalciner kilns are used and also no so-called low-alkali cement is produced. Therefore, there is no land-filling of calcined cement dust (cement kiln dust, CKD) in Switzerland. In the cement plants all the filter dust is collected in high performance electrostatic precipitator or bag filters (having an efficiency of more than 99.999 %) and mostly being recycled to the kiln feed. In some cases, small portions of the CKD are added directly to the cement as filler. Due to the kiln technology used in Switzerland the degree of decarbonization of the CKD is almost equal to that of the kiln feed, meaning, that this CKD has not been decarbonised yet.

Blasting operations

Emissions resulting from blasting operations during the digging of limestone are calculated by a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2A1, Fig. 3.1) using country-specific emission factors. The CO_2 emissions from "blasting" are related only to the usage of explosives in the quarries and not to the fuel consumption of construction machinery such as bulldozers etc.

The CO_2 emission factor for the use of blasting agents amounts to 600 kg CO_2/t of blasting agent (EMIS 2024/2A1 Zementwerke übriger Betrieb). The amount of used explosives is reported to be 0.13 kg/t cement on average, based on measurement data of four Swiss cement plants in 2002. Since these covered more than 60 % of the production, the value is considered representative for cement plants in Switzerland.

Total emissions reported for the production of cement are the sum of emissions from calcination process and blasting operations. The share of CO_2 emissions from blasting operations in limestone quarries is well below one tenth of a percent of the geogenic CO_2 emissions from the calcination process.

Emission factors

Calcination process

The emission factor of CO_2 from calcination is provided per tonne of clinker. It accounts for geogenic emissions from the carbonate containing raw material, emissions from organic carbon content of the raw material and from cement kiln dust (CKD).

The emission factor is based on plant-specific measurements. For the time period from 1990–2021, the emission factor of the raw material is derived from measurements of CaO and MgO content of clinker in 2005, 2006, 2008–2011. The emissions from CKD not recycled to the kiln are estimated based on plant-specific data for 2013–2021. From 2022 onwards, the cement plants are required to provide detailed data to the ETS, including data on carbon content of the raw meal (carbonate and non-carbonate C) and CKD, which is used to calculate plant-specific emission factors.

While the plant-specific emission factors are assumed to be constant from 1990–2021, the share of each individual plant varies slightly over the years, so that the national average emission factor also shows some variations (see information below on activity data). However, variations are relatively small and do not exceed 0.4 %.

Table 4-4 CO_2 emission factor for calcination in 2A1 Cement Production 1990 to 2022.

2A1 Cement production	Unit	1990	1995	2000	2005	2010
Calcination, CO_2	kg/t clinker	530	530	530	530	530

2A1 Cement production	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Calcination, CO_2	kg/t clinker	530	530	531	530	530	530	531	530	530	528

Blasting operations

The emission factors are country-specific based on emission factors of civil explosives and information on the specific consumption of explosives in the quarries as documented in the Handbook on emission factors for stationary sources (SAEFL 2000) as documented in the EMIS database (EMIS 2024/2A1 Zementwerke übriger Betrieb). They are assumed to be constant over the entire time period and are given per tonne of clinker.

Table 4-5 Emission factors for CO_2, NO_x, CO, NMVOC and SO_2 from blasting operations in g/t clinker from source category 2A1 Cement Production in 2022.

2A1 Cement production	Unit	CO_2	NO_X	CO	NMVOC	SO_2
Blasting operations	g/t clinker	34	3.3	3.3	8.6	0.14

Activity data

Since 1990, data on annual clinker production are provided by the industry association cemsuisse as documented in the EMIS database (EMIS 2024/2A1_Zementwerke Rohmaterial). In order to use plant-specific emission factors, also activity data are required at plant level. For 2005, 2006, 2008–2011 and from 2013 onwards, clinker production data is available for each individual plant based on annual monitoring reports from the Swiss Emissions Trading Scheme (ETS). The average share of 2005 and 2006 is used to extrapolate the plant-specific production data from 1990–2004 and for 2007. The average of 2011 and 2013 is used to interpolate plant-specific production data for 2012.

Table 4-6 Activity data of clinker production.

2A1 Cement production	Unit	1990	1995	2000	2005	2010
Clinker production	kt	4'808	3'706	3'214	3'442	3'642

2A1 Cement production	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Clinker production	kt	3'415	3'502	3'195	3'296	3'279	3'239	3'227	3'129	3'227	3'155

4.2.2.2. Lime production (2A2)

During the production of lime, calcium carbonate ($CaCO_3$) is heated (calcined) yielding burnt lime (CaO) and CO_2 as by-product. In Switzerland, there is only one plant producing lime.

There is no industry in Switzerland producing lime for its own requirements, except for sugar production. A request to both sugar producing plants confirmed that indeed they produce lime from limestone in own shaft kilns. However, the CO_2 is re-captured in the sugar production process and thus no CO_2 emissions occur.

Blasting operations in quarries are another source of emissions for both CO_2 and precursor emissions such as NO_x, CO, NMVOC and SO_2.

Indirect CO_2 emissions resulting from CO and NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9.

Methodology

Calcination process

Since 2013, the geogenic CO_2 emissions from the calcination process in lime production are determined by a Tier 3 method using plant-specific emission factors according to the decision tree Fig. 2.2. of the IPCC Guidelines (IPCC 2006, vol. 3, chp. 2.2 Lime production). Between 1990 and 2012, a Tier 2 method is applied.

Blasting operations

Emissions resulting from blasting operations during the digging of limestone are calculated by a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2A2, Fig. 3.1) using country-specific emission factors. The CO_2 emissions from "blasting" are related only to the usage of explosives in the quarries and not to fuel consumption of e.g. bulldozers etc.

Total emissions reported for the production of lime are the sum of emissions from calcination process and blasting operations. CO_2 emissions from blasting operations in limestone quarries account only for a small share of the total emissions.

Emission factors

Calcination process

The emission factor for CO_2 from calcination of limestone depends both on the purity of the limestone and the degree of calcination (i.e. amount of CO_2 remaining in the lime produced). A plant-specific value has been calculated based on industry declaration and it is assumed to be constant for the years 1990–2012 (EMIS 2024/2A2 Kalkproduktion, Rohmaterial). The value is confidential and is available to reviewers on request. Since 2013, emission factors are derived from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

Table 4-7 CO_2 emission factor for calcination process in lime production in kg/t lime for 1990–2022 are documented in the confidential NID, which is available to reviewers on request.

Blasting operations

The emission factors are country-specific as documented in EMIS 2024/2A2 Kalkproduktion, übriger Betrieb. The values are confidential and they are available to reviewers on request.

Table 4-8 CO_2 emission factor for the calcination process in lime production in kg/t lime and emission factors for CO_2, NO_x, CO, NMVOC and SO_2 from blasting operations in g/t lime in 2022.

2A2 Lime production	**Unit**	**CO_2**	**NO_X**	**CO**	**NMVOC**	**SO_2**
Calcination	kg/t	C	NA	NA	NA	NA
Blasting operations	g/t	C	C	C	C	C

Activity data

Activity data on annual lime production are provided by the only existing plant in Switzerland, as documented in the EMIS database (EMIS 2024/2A2 Kalkproduktion, Rohmaterial and EMIS 2024/2A2 Kalkproduktion übriger Betrieb). Since 2009 they are based on plant-specific annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

Detailed activity data are not reported since they are considered confidential.

Table 4-9 In the confidential NID, the respective table with activity data on lime production are separately reported and available to reviewers.

4.2.2.3. Glass production (2A3)

Source category 2A3 Glass production comprises geogenic CO_2 emissions from the carbonate containing raw materials, i.e. soda ash, limestone and dolomite. In Switzerland, the following three glass types are produced: container glass, tableware glass and glass wool. Today, there is only one production plant remaining for container glass and tableware glass after the other plants closed in 2002 and 2006, respectively. Glass wool is produced in two plants.

Methodology

For determination of geogenic CO_2 emissions from glass production, a Tier 2 method according to the decision tree Fig. 2.3 of IPCC 2006 (vol. 3, chp. 2.4 Glass production) is used. For glass production in Switzerland this results in the following formula:

$$CO_2 \text{ Emissions} = M_{\text{Glass type}} \bullet EF_{\text{Glass type}} \bullet (1 - \text{cullet ratio})$$

The cullet ratio describes the share of recycled glass material which is used in the production. The melting of cullet causes no geogenic CO_2 emissions.

From 2005 onwards, the geogenic CO_2 emissions from container glass production is determined according to a Tier 3 method based on the amount of carbonate containing raw materials used, i.e. soda, dolomite and limestone and their effective carbonate content.

For the two plants producing glass wool, the amount of soda ash used as raw material is available from 2013 and 2021 onwards, respectively. Accordingly, the geogenic CO_2 emission factor corresponds to a Tier 3 method from 2021 onwards. For the years 2013 to

2020, the emission factor is thus based on a Tier 3 method of one plant and a Tier 2 method of the other one.

Emission factors

The emission factors for glass production in Switzerland are taken from IPCC 2006 (vol.3, chp. 2.4 Glass production, Table 2.6). For the production of container glass (1990–2004), tableware glass and glass wool (1990–2020) the values for glass type container, tableware and fibreglass are taken, respectively. As the emission factors are material properties, they remain constant over time.

From 2005 onwards, effective amounts of carbonate containing raw materials (soda ash, dolomite and limestone) are available from ETS monitoring reports for the container glass production and thus the corresponding default CO_2 emission factors are taken from IPCC 2006 (vol. 3, chp. 2.1, Table 2.1). As these emission factors are material properties, they remain constant over time. Whereas for the two plants producing glass wool, the amounts of soda ash are available from ETS monitoring reports from 2013 and 2021 onwards, respectively.

Table 4-10 Geogenic CO_2 emission factor for glass production in g/t glass and g/t carbonate containing raw material (IPCC 2006).

2A3 Glass production	**Unit**	**CO_2 geogenic**	
Glass (speciality tableware)	g/t	100'000	
		1990–2020	**2013–2022**
Glass wool (fibre glass insulation)	g/t	250'000	
Soda use	g/t soda		414'920
		1990–2004	**2005–2022**
Container glass	g/t	210'000	
Soda use	g/t soda		414'920
Dolomite use	g/t dolomite		477'320
Limestone use	g/t limestone		439'710

Table 4-11 In the confidential NID, a comparison of implied CO_2 emission factors based on Tier 2 and Tier 3 approaches is provided for container glass production in g/t glass for the time period 2005–2011.

Figure 4-5 In the confidential NID, a comparison of Tier 2 and Tier 3 methods for deriving emission factors of geogenic CO_2 from 2A3 Container glass production is provided for the years between 2005 and 2011.

Activity data and cullet ratios

Source category 2A3 Glass production is dominated by the emissions from the production of container glass and glass wool.

For glass wool production, activity data are based on data from the two glass wool production plants in Switzerland. Since 2008, activity data are based on plant-specific annual monitoring reports (EMIS 2024/2A3 Glaswolle Produktion Rohprodukt).

Activity data of tableware and container glass production are based on data from Swiss glass producers (EMIS 2024/2A3 Hohlglas Produktion, EMIS 2024/2A3 Glas übrige Produktion). For container glass, they are based on ETS monitoring reports from 2005 onward.

Detailed information on activity data for container glass production and tableware production is confidential as there is only one production plant for container glass and tableware glass, respectively. Data are available to the reviewers on request.

Table 4-12 Activity data of glass production in Switzerland and cullet ratio in % as well as consumption of carbonate containing raw materials in container glass production

2A3 Glass production	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Container glass																
Production	kt	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Cullet ratio	%	C	C	C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Soda use	kt	NA	NA	NA	C	C	C	C	C	C	C	C	C	C	C	C
Dolomite use	kt	NA	NA	NA	C	C	C	C	C	C	C	C	C	C	C	C
Limestone use	kt	NA	NA	NA	C	C	C	C	C	C	C	C	C	C	C	C
Glass (speciality tableware)																
Production	kt	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Cullet ratio	%	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Glass wool																
Production	kt	24	24	31	37	36	33	32	31	32	36	40	47	40	47	45
Cullet ratio	%	21	45	69	65	71	C	C	C	C	C	C	C	C	NA	NA
Soda use	kt	NA	NA	NA	NA	NA	C	C	C	C	C	C	C	C	C	C

4.2.2.4. Other process uses of carbonates (2A4)

Source category 2A4 Other process uses of carbonates comprises geogenic CO_2 emissions from production of fine ceramics (2A4a), bricks and tiles (2A4a) and rock wool (2A4d), from use of carbonates for sulphur oxide removal in municipal solid waste incineration plants (2A4d) and cellulose production (ceased in 2008) (2A4d), and from use of sodium bicarbonate (2A4d) as well as emissions of CO_2, NO_x, CO, NMVOC and SO_2 from blasting operations in plaster production (2A4d). The limestone use in cupola furnaces of iron foundries has been reallocated from source category 2A4d to 2C1.

Indirect CO_2 emissions resulting from CO and NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9.

Ceramics (2A4a)

Source category 2A4a Ceramics consists of the production of fine ceramics and brick and tile.

Fine ceramics (2A4a)

In Switzerland, the main production of fine ceramics is sanitary ware. The carbonate containing raw materials limestone and dolomite as well as small amounts of soda ash are used in product glazes only. All information on the fine ceramics production is documented in EMIS 2024/2A4a Feinkeramik Produktion.

Methodology

The geogenic CO_2 emissions from fine ceramics production are determined by a Tier 2 method according to the decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates).

For fine ceramics production in Switzerland, this results in the following formula:

$$CO_2 \text{ Emissions} = (M_{\text{Limestone}} \bullet EF_{\text{Limestone}}) + (M_{\text{Dolomite}} \bullet EF_{\text{Dolomite}}) + (M_{\text{Soda Ash}} \bullet EF_{\text{Soda Ash}})$$

Emission factors

The CO_2 emission factors of limestone, dolomite and soda ash are taken from IPCC 2006 (vol. 3, chp. 2.1, Table 2.1). As these emission factors are material properties, they remain constant over time.

Table 4-13 Geogenic CO_2 emission factors used for fine ceramics and the production of brick and tile in g/t carbonate containing raw material and g/t product, respectively.

2A4a Ceramics	**Unit**	**CO_2 geogenic**								
Fine ceramics		**1990–2022**								
Limestone use	g/t limestone	439'710								
Dolomite use	g/t dolomite	477'320								
Soda use	g/t soda	414'920								
		1990–2012	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Brick and tile production	g/t	117'000	103'000	112'000	113'000	107'000	107'000	103'000	113'000	106'000

Activity data

Activity data for carbonate containing raw materials (i.e. limestone, dolomite and soda ash) used in the glazes of the fine ceramics production are extrapolated values based on industry data from the largest production plant in Switzerland. Detailed activity data are considered confidential. They are available to the reviewers on request.

Brick and tile production (2A4a)

In Switzerland, there are about 20 plants producing bricks and tiles. The manufacturing process uses limestone containing clay as main raw material.

Methodology

The brickearth used in Switzerland for the production of bricks and tiles does not consist of pure and defined contents of clay minerals but its clay content is varying depending on the individual pit, comprising other minerals such as calcite, dolomite and quartz. Compared to other countries, the fraction of carbonate containing raw material is relatively high. Detailed data on the composition of carbonate containing raw materials from the Swiss brick and tile industry were not available before 2013. Therefore, for the period 1990 until 2012 data from a comparison of geogenic CO_2 emissions based on representative analyses of the carbonate content of the clay used for brick and tile production in a number of plants in Switzerland and the European Union are applied. This study was carried out by the Swiss association of brick and tile industry (Verband Schweizerische Ziegelindustrie, VSZ) in 2012 (see EMIS 2024/2A4a Ziegeleien).

Since 2013, the Swiss brick and tile production plants are legally obliged to report geogenic emissions from carbonate containing raw materials annually (Federal Act on the Reduction of CO_2 Emissions, Swiss Confederation 2011 and Ordinance for the Reduction of CO_2 Emissions, Swiss Confederation 2012). The emissions are estimated from analyses of the carbonate content of the raw materials and an assumed calcination factor of 100 %. This procedure corresponds to a Tier 3 method according to the decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates). Between 1990 and 2012 a Tier 2 method is applied.

Emission factors

According to the above-mentioned study, bricks emit a weighted average of 13.2 % of geogenic CO_2 (variation range 5.4–24 %) and roof tiles have a weighted average of 8.6 % (variation range 5.6–13 %). Based on the production shares of the largest Swiss brick producer, a production ratio for bricks to tiles of 2:1 was assumed for the whole period from 1990 to 2012. This resulted in an average geogenic CO_2 emission factor of 117 kg CO_2/t brick and tile, which was assumed constant for the time period 1990 to 2012.

Since 2013, a production weighted emission factor is derived based on the plant-specific monitoring data of the geogenic CO_2 emissions from the carbonate containing raw materials. For emission factors see Table 4-13.

Activity data

Activity data are based on production data from the Swiss association of brick and tile industry (VSZ) and are presented in Table 4-14 (EMIS 2024/2A4). Since 2011 they are based on plant-specific annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

Table 4-14 Activity data for the production of fine ceramics including the use of limestone, soda and dolomite in the glazes, brick and tile, rock wool and plaster as well as other use of carbonates (sodium bicarbonate).

2A4a Ceramics	Unit	1990	1995	2000	2005	2010
Fine ceramics production	kt	C	C	C	C	C
Limestone use	kt	C	C	C	C	C
Dolomite use	kt	C	C	C	C	C
Soda use	kt	C	C	C	C	C
Brick and tile production	kt	1'271	1'115	959	1'086	879
2A4d Other						
Rock wool production	kt	C	C	C	C	C
Carbonate use in waste incineration plants	kt	0.71	0.76	0.82	0.61	NO
Limestone use in cellulose production	kt	8.5	9.4	9.3	8.3	NO
Other use of carbonates	kt	5.9	5.4	7.0	7.3	6.9
Plaster production	kt	319	304	288	327	335

2A4a Ceramics	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Fine ceramics production	kt	C	C	C	C	C	C	C	C	C	C
Limestone use	kt	C	C	C	C	C	C	C	C	C	C
Dolomite use	kt	C	C	C	C	C	C	C	C	C	C
Soda use	kt	C	C	C	C	C	C	C	C	C	C
Brick and tile production	kt	785	765	726	660	622	581	554	531	484	521
2A4d Other											
Rock wool production	kt	C	C	C	C	C	C	C	C	C	C
Carbonate use in waste incineration plants	kt	2.7	1.9	6.5	6.6	6.8	7.2	7.0	7.0	8.3	9.2
Limestone use in cellulose production	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other use of carbonates	kt	6.1	7.5	6.7	6.8	6.5	7.4	7.8	7.9	8.7	9.0
Plaster production	kt	213	166	140	148	146	152	149	122	C	C

Other uses of soda ash (2A4b)

Soda ash is mainly used in the glass production, which is reported separately in source category 2A3 Glass production. A very small amount of soda ash is also applied in glazes of fine ceramics and is thus accounted for in source category 2A4a Ceramics (see Table 4-13). Based on a study investigating carbonate use in industry (INFRAS 2015), it is concluded that there are no known other uses of soda ash (2A4b) in Switzerland. No soda ash is used in flue gas or wastewater treatment. It was concluded that there is no other relevant emissive soda ash use and thus, reported as not occurring in the inventory so far.

During the in-depth review in 2019, the ERT raised the question about potential other uses of soda ash in Switzerland. Based on net imports of soda ash and the known uses in the production of glass (assuming for glass wool and speciality tableware glass the same soda ash content of carbonate raw materials as for container glass) and fine ceramics, an amount of about 11.6 kt resulted for 2017, of which it is not clear whether its use is emissive or not. In a conservative estimate, this would yield a maximum of about 4.8 kt of CO_2 emissions (default emission factor of 0.41492 t CO_2/t soda ash, IPCC 2006), which corresponds to 0.01 % of the national total (excluding LULUCF) in 2017. Considering the entire time series, the share of the national total was largest in 1990 (0.02 %) and has remained about constant (0.01 %) since 2003. In accordance with decision 18/CMA.1 (UNFCCC 2019), annex, paragraph 32, this is below the significance threshold and thus, the ERT recommended that Switzerland reports CO_2 emissions from source category 2A4b Other use of soda ash as not estimated (“NE”) in its inventory, which was implemented in the submission 2021.

Other (2A4d)

Rock wool production (2A4d)

In Switzerland, there is one single producer of rock wool. The plant uses carbonate containing raw materials like dolomite, basalt, cement and further additives as documented in the EMIS database (EMIS 2024/2A4d Steinwolle Produktion).

Methodology

Since 2013, rock wool manufacturers are legally obliged to report geogenic CO_2 emissions from carbonate containing raw material annually. For the years 2005–2011 and 2013 plant-specific data on raw material consumption and emission factors is available from monitoring reports of the Swiss ETS. From this information, data for the other years are interpolated for calculating an implied emission factor.

The geogenic CO_2 emissions from rock wool production are determined by a Tier 3 method according to IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates). Before 2004, a Tier 2 method was applied.

Emission factors

For rock wool production in Switzerland, the CO_2 emission factor is based on measurements of the oxides (CaO, MgO, Na_2O, K_2O, MnO) of the carbonate containing raw materials and the product for the years 2005 to 2011 as well as since 2013. Based on the difference in the oxide content in the raw material and the products, the total geogenic CO_2 emissions are determined. Consequently, the emission factor is specified as g/t rock wool. Since data on the carbonate content are missing for the years 1990 to 2004 and 2012 the mean value of the years 2005–2011 and 2013 is applied for these years.

The CO_2 emission factors are confidential. They are available to reviewers on request.

Table 4-15 Geogenic CO_2 emission factors used for rock wool production and other carbonate uses, CO_2 fossil, NO_x, CO, NMVOC and SO_2 emission factors for plaster production in g/t carbonate containing raw material and g/t product, respectively for 2022.

2A4d Other	Unit	CO_2 geogenic	CO_2 fossil	NO_x	CO	NMVOC	SO_2
Rock wool production	g/t	C	NA	NA	NA	NA	NA
Carbonate use in waste incineration plants	g/t	523'880	NA	NA	NA	NA	NA
Other carbonate uses	g/t	523'880	NA	NA	NA	NA	NA
Plaster production	g/t rocks	NA	C	C	C	C	C

Table 4-16 In the confidential NID, the respective table with geogenic CO_2 emission factors used for rock wool production is separately reported and available to reviewers.

Activity data

Activity data are based on industry data from the single rock wool production plant in Switzerland (monitoring reports of the Swiss ETS) and are therefore confidential. They are available to reviewers on request.

Other carbonate uses (2A4d)

In 2014, an assessment was carried out in order to identify sources of CO_2 emissions from carbonate use for sulphur oxide removal and acid neutralization, which were not considered in the Swiss greenhouse gas inventory so far (INFRAS 2015). The survey among selected potentially relevant industrial plants, industry associations, Swiss cantons and the Swiss customs administration (EZV) comprised the following substances: limestone ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), sodium bicarbonate ($NaHCO_3$) and soda ash (Na_2CO_3).

Besides applications of calcium hydroxide and sodium hydroxide in flue gas treatment also a few applications of limestone and sodium bicarbonate for sulphur oxide removal could be identified in Switzerland. Limestone had been used in the cellulose production up to 2008, when the plant was closed, and in one municipal solid waste incineration plant up to 2005. Since 2013, several waste incineration plants and one combined heat and power plant that burns all classes of wood waste (from 2021 onwards) are using sodium bicarbonate.

In cupola furnaces of iron foundries limestone is also used as flux. The resulting geogenic CO_2 emissions are reported in 2C1 Iron and steel production. Limestone is also used to neutralize acid wastewater in one chemical production plant. These emissions are reported in source category 2B10 Limestone pit.

Additionally, it is assumed, that all other applications of sodium bicarbonate result in a complete conversion to CO_2. Since there is no production of sodium bicarbonate in Switzerland, the annual emissions can be estimated based on the net import.

Methodology

The method for calculating the geogenic CO_2 emissions from the use of limestone and sodium bicarbonate in all the source categories mentioned above – except in waste incineration plants from 1994 onwards – corresponds to a Tier 2 method according to the decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates).

The method for calculating the geogenic CO_2 emissions from the use of limestone and sodium bicarbonate in waste incineration plants from 1994 onwards corresponds to a Tier 3 method according to the decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates).

Emission factors

The emission factors of limestone and sodium bicarbonate are based on the stoichiometry of $CaCO_3$ (IPCC 2006, vol. 3 chp. 2.1, table 2.1) and $NaHCO_3$ (CRC 2004), respectively, see Table 4-15. A conversion factor of 100 % is assumed for all applications of both carbonates.

Activity data

Activity data on limestone use in flue gas treatment in cellulose production are based on expert estimates on the specific consumption of limestone per tonne of cellulose as documented in the EMIS database (EMIS 2024/1A2d Zellulose Produktion).

The activity data of limestone and sodium bicarbonate use in waste incineration plants and a combined heat and power plant fuelled with all classes of wood waste are provided by the industry as documented in the EMIS database (EMIS 2024/1A1a Kehrichtverbrennungsanlagen).

The activity data of sodium bicarbonate correspond to difference between the net import of sodium bicarbonate and the amount of sodium bicarbonate used in waste incineration plants and a wood waste plant. The net import data are provided by the Swiss customs administration as documented in the EMIS database (EMIS 2024/2A4d Karbonatanwendung weitere). For activity data see Table 4-14.

Plaster production (2A4d)

Methodology

There were two plaster production sites in Switzerland. In August 2020, one of the two sites was closed. Therefore, data on plaster production are confidential from 2021 onwards.

The emissions stem mainly from blasting operations. They are determined by a country-specific method analogous to a Tier 2 method of the EMEP/EEA guidebook (EMEP/EEA 2019).

Emission factors

As there are no specific emission factors for gypsum mining, the emission factors for cement raw material mining are taken instead (with a rough estimate that 1.5 t of raw material are required for production of 1 t of cement). This method is documented in EMIS 2024/2A4d Gips-Produktion übriger Betrieb. For emission factors see Table 4-15. Emission factors for Plaster production are confidential but available to reviewers on request.

Activity data

The activity data of the annual amount of raw material processed in the plaster production are based on industry data and expert estimates as documented in EMIS 2024/2A4d Gips-Produktion übriger Betrieb (see Table 4-14). Activity data for Plaster production are confidential from 2021 onwards but available to reviewers on request.

4.2.3. Uncertainties and time-series consistency for 2A

For all source categories in 2A, emitting CO_2, an uncertainty of 2 % is assumed for activity data, since data at plant level are available and assumed to be fully representative. This is in agreement with the default range of 1 % to 3 % (IPCC 2006, vol. 3, chp. 2, p. 2.39).

For source category 2A1 Cement production, an uncertainty of 4 % is assumed for the CO_2 emission factor. This estimation comprises the measurement uncertainty for each plant and, since the emission factor is the mean over all plants weighted by the clinker production per plant, the uncertainty coming from the estimation of the clinker production per plant.

The uncertainty of the CO_2 emission factor is estimated to be 2 % for 2A2 Lime production, which is the mean value of the default range for Tier 3 (IPCC 2006, vol. 3, chp. 2, p. 2.31, suggested range of 1 % to 3 %).

For 2A3 Glass production, the uncertainty of the CO_2 emission factor is estimated to be 3 %, which is the upper value of the default range for Tier 3 (IPCC 2006, vol. 3, chp. 2, p. 2.31, suggested range of 1 % to 3 %).

For CO_2 emissions in source category 2A4 Other process uses of carbonates, most of the data are provided by industrial plants participating in the Swiss ETS, which requires that the uncertainty in the emissions does not exceed a given limit (1.5 % to 7.5 %, depending on the amount of emissions resulting from a given source) and from the Swiss Federal Customs Administration. For the emission factor, the chosen value of 3 % is also in agreement with the default range of 1 % to 5 % (IPCC 2006, vol. 3, chp. 2, p. 2.39).

Consistency: Time series for 2A Mineral industry are all considered consistent.

4.2.4. Category-specific QA/QC and verification for 2A

The general QA/QC measures are described in chp. 1.5.

For submission 2017, implied emission factors of 2A3 container glass production were assessed by both a Tier 2 and Tier 3 method for the years 2005–2011. This comparison provides an indication of the differences caused by the switch in the Tier level from Tier 2 (1990–2004) to Tier 3 (2005–2015).

4.2.5. Category-specific recalculations for 2A

The following recalculations were implemented in submission 2024. Major recalculations which contribute significantly to the total differences in GHG emissions of sector 2 IPPU between the latest and the previous submissions are also presented in chp. 10.1.2.2.

- 2A1: The geogenic CO_2 emission factor for 2A1 Cement production was revised for all years from 1990–2021 based on plant-specific measurements of the CaO and MgO content of clinker.
- 2A3: The incorrect activity data for 2021 of source category 2A3 Glass wool production was corrected, which also resulted in a revised CO_2 emission factor.
- 2A4: The activity data of source category 2A4d Carbonate use in waste incineration plants was revised for 2021 based on information from a new plant using sodium bicarbonate since 2021, which consequently yields revised activity data in source category 2A4d Other carbonate uses for 2021 as well. However, the total CO_2 emissions of 2A4d Other for 2021 remain the same.

4.2.6. Category-specific planned improvements for 2A

There are no category-specific planned improvements.

4.3. Source category 2B – Chemical industry

4.3.1. Source category description

Table 4-17 Key categories of 2B Chemical industry. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
2B10	Chemical industry other	N2O	T1, T2

Table 4-18 Specification of source category 2B Chemical industry.

2B	Source category	Specification
2B1	Ammonia production	Emissions of CO_2 and NMVOC are reported in 2B8b Ethylene production
2B2	Nitric acid production	Emissions of N_2O and NOx from the production of nitric acid (ceased in 2018)
2B5	Carbide production	Emissions of CO_2, CH_4, CO and SO_2 from the production of silicon carbide and graphite
2B8	Petrochemical and carbon black production	Emissions of CO_2 and NMVOC from ethylene production. In Switzerland there is only ethylene production under this source category
2B10	Other	Emissions of CO_2, CH_4, CO and NMVOC from acetic acid production; CO_2 emissions from limestone pit; CO_2, N_2O, NO_x and CO emissions from niacin production; NMVOC emissions from PVC production (ceased in 1996); SO_2 emissions from sulphuric acid production

4.3.2. Methodological issues

4.3.2.1. Ammonia production (2B1)

Ammonia (NH_3) is produced in one single plant in Switzerland by catalytic reaction of nitrogen and synthetic hydrogen (see Figure 4-6). Ammonia is not produced in an isolated reaction plant but is part of an integrated production chain (see Figure 4-6).

The starting production process is the thermal cracking of liquefied petroleum gas and light virgin naphtha yielding ethylene (ethene, C_2H_4), and a series of by-products such as e.g. synthetic hydrogen and methane, which are used as educts for further production steps. According to the Swiss ammonia producer it is not possible to split and allocate the emissions of the cracking process (CO_2 and NMVOC) to every single product such as, e.g., ethylene, acetylene (ethyne, C_2H_2), cyanic acid or ammonia. Therefore, all CO_2 and NMVOC emissions of the cracking process are allocated to the ethylene production and are reported under the category 2B8b Ethylene production. Thus, for source category 2B1 Ammonia production, CO_2 and NMVOC emissions are reported as included elsewhere (IE). All information on the ammonia production and the cracking process is documented in EMIS 2024/2B1 Ammoniak-Produktion and EMIS 2024/2B8b Ethen-Produktion, respectively.

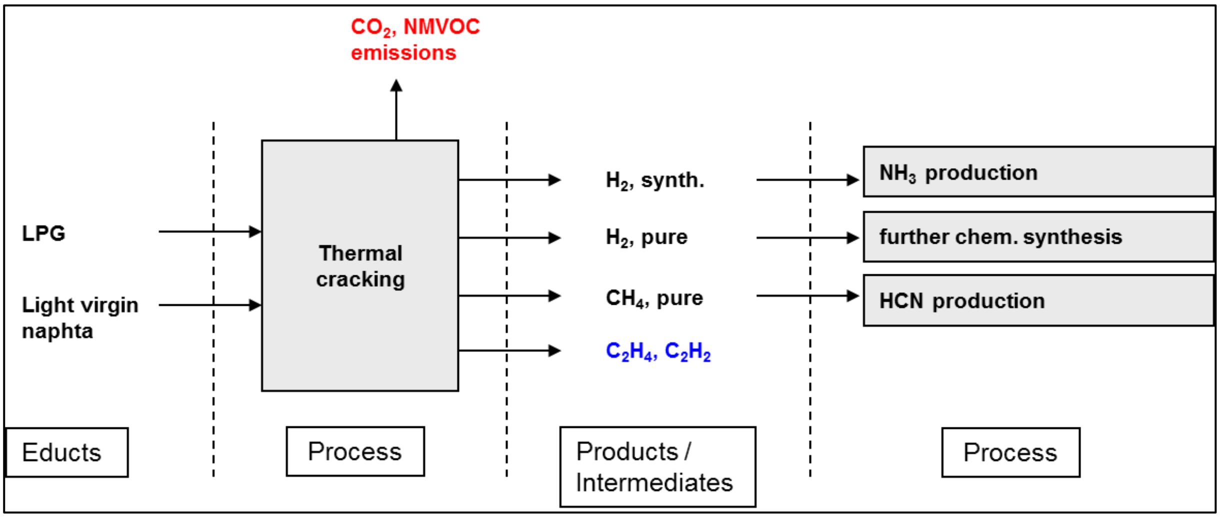

Figure 4-6 Process flow chart for the production of ethylene (C_2H_4) and acetylene (C_2H_2) by thermal cracking of liquefied petroleum gas (LPG) and light virgin naphtha. The intermediate product H_2, synth. is used as educt in the ammonia production in the same plant.

Table 4-19 Activity data for ammonia production in Switzerland are documented in the confidential NID, which is available to reviewers on request.

4.3.2.2. Nitric acid production (2B2)

In Switzerland, there was one single plant producing nitric acid (HNO_3) which stopped production in spring 2018. Nitric acid was produced by catalytic oxidation of ammonia (NH_3) with air. At temperatures of 800°C nitric monoxide (NO) is formed. During cooling, nitrogen monoxide reacted with excess oxygen to form nitrogen dioxide (NO_2). The nitrogen dioxide reacted with water to form 60 % nitric acid (HNO_3). Today, two types of processes are used for nitric acid production: single pressure or dual pressure plants. In Switzerland a dual pressure plant was installed.

During this process, nitrous oxide (N_2O) can be formed as an unintentional by-product. In addition, also some nitrogen oxide (NO_x) is produced. In the Swiss production plant abatement of NO_x was done by selective catalytic reduction (SCR, installed in 1988), which reduced NO_x to N_2 and O_2 (the SCR in this plant was also used for treatment of other flue gases and was not installed for the HNO_3 production specially). In 1990, an automatic control system for the dosing of ammonia to the SCR process was installed. A new catalyst installed in 2013 reduced the N_2O emissions.

No additional abatement technique is installed to destroy N_2O. A decomposition of N_2O occurs, to some extent, simultaneously in the NO_x reduction process.

Methodology

According to decision tree Fig. 3.2 of IPCC 2006 (vol. 3, chp. 3.3 Nitric acid production), the N_2O emissions from nitric acid production are determined by a Tier 2 method during the time period 1990–2012 and by a Tier 3 method between 2013 and the end of production in 2018 based on direct measurements. The NO_x emissions are calculated by a Tier 2 method according to the decision tree Fig. 3.1 in the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry) using a plant-specific emission factor.

Emission factors

The N_2O and NO_x emission factors for nitric acid production in Switzerland are based on measurements from the single nitric acid production plant.

The measurement of N_2O was carried out in 2009 according to the guideline VDI-Richtlinie 2469/Blatt 1 (Messen gasförmiger Emissionen – Messen von Distickstoffmonoxid – Manuelles gaschromatographisches Verfahren) and is the only plant-specific measurement of N_2O emissions. The test gas is sucked in via a heated titanium sensor and then treated with a solution of potassium permanganate and hydrogen peroxide in order to remove nitrogen oxides and further disturbing components. The N_2O concentration is then measured using a gas chromatograph with an electron capture detector. The measurement uncertainty is ±20 % (minimum ±0.5 mg/m^3). On repeated enquiries the plant confirmed that since a denitrification system and an automatic control system for the ammonia addition was installed in 1988 and 1990, respectively, no modifications were made in the production line until 2012. Therefore, a constant N_2O-emission factor is assumed for this time period. A new catalyst installed in 2013 reduced the N_2O emissions, which are measured online by NDIR photometry between 2013 and 2018.

The NO_x emission factor is the mean value based on three plant-specific measurements in 2007, 2009 and 2012. Since no modifications were made in the production line between 1990 and 2012, a constant emission factor is assumed for this time period. In 2013, the volume of the SCR-plant was doubled. This modification together with the new catalyst in the production line slightly reduced the NO_x emission factor. The values are documented in EMIS 2024/2B2 Salpetersäure Produktion.

Table 4-20 Emission factors for N_2O for nitric acid production in Switzerland in kg/t nitric acid for 1990–2022 are provided in the confidential NID, which is available to reviewers on request.

Activity data

Activity data on annual production of nitric acid (100 %) are provided annually by the Swiss production plant for the entire time period 1990–2018. Since 2013, activity data of the annual nitric acid production is taken from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS). The data are confidential but available to reviewers (see EMIS 2024/2B2 Salpetersäure Produktion).

Table 4-21 Activity data for the production of nitric acid (100 %) in Switzerland are documented in the confidential NID, which is available to reviewers on request.

4.3.2.3. Carbide production (2B5)

In Switzerland, there is one single plant producing carbide. The plant produces silicon carbide, which is used in abrasives, refractories, metallurgy and anti-skid flooring. Silicon carbide is produced together with graphite in a coupled process in an electric furnace at temperatures above 2000 ºC using the Acheson process. The starting materials are quartz sand (SiO_2), petroleum coke and anthracite (C) which yield silicon carbide (SiC) and carbon monoxide (CO). The CO is converted to CO_2 in excess oxygen and released to the atmosphere. Petroleum coke and anthracite – although to a lower portion – may contain volatile organic compounds, which can form methane (CH_4) as an unintended by-product. There are no abatement techniques installed which could capture the CO_2 or CH_4 emissions.

Indirect CO_2 emissions resulting from CH_4 and CO emissions in this source category are included in CRT Table6 as documented in chp. 9.

Methodology

According to decision tree Fig. 3.5 of IPCC 2006 (vol. 3, chp. 3.6 Carbide production), the CO_2 and CH_4 emissions from silicon carbide production are determined by a Tier 2 method. The CO and SO_2 emissions are calculated by a Tier 2 method according to the decision tree Fig. 3.1 in the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry) using plant-specific emission factors.

Emission factors

The CO_2, CH_4, CO and SO_2 emission factors are confidential and available to reviewers on request. The values are partly based on data from the single silicon carbide production plant and are documented in EMIS 2024/2B5 Graphit und Siliziumkarbid Produktion.

The CO_2, CO and SO_2 emission factors are based on data from the production plant. For CO_2 and CO, they are calculated based on the carbon mass balance of the production process and CO exhaust measurements from 2001 onwards. The SO_2 emission factor is derived from the sulphur content of the feedstocks, i.e. petroleum coke and anthracite. The CO_2 emission factors for the entire time series are listed in the following table.

Table 4-22 In the confidential NID, a respective table with emission factors of fossil CO_2 in kg/t silicon carbide are provided. Data are available to reviewers on request.

Table 4-23 Emission factors for CO_2, CH_4, CO and SO_2 for carbide production in kg/t silicon carbide in Switzerland for 2022 are provided in the confidential NID, which is available for reviewers upon request.

Activity data

Activity data on annual production of silicon carbide (and graphite) are provided annually from 1995 onwards by the production plant. For the time period 1990–1994 they are based on industry data.

The data are confidential but available to reviewers on request (see EMIS 2024/2B5 Graphit und Siliziumkarbid Produktion).

Table 4-24 In the confidential NID, the respective table with activity data on silicon carbide production in Switzerland is separately reported and available to reviewers.

4.3.2.4. Petrochemical and carbon black production (2B8)

Ethylene (2B8b)

Ethylene (ethene, C_2H_4) is produced by a single plant in Switzerland by thermal cracking of liquefied petroleum gas and virgin naphtha. Ethylene is not produced in an isolated process but is co-processed together with several other products such as H_2, CH_4, and C_2H_2 (see flow chart in Figure 4-6 in chp. 4.3.2.1). From the thermal cracking process, emissions of CO_2 and NMVOC are released. They are both allocated entirely to the production of ethylene, which is the first product within the integrated production chain. CH_4 emissions to the atmosphere do not occur since CH_4 is completely used as an educt in the downstream production of cyanic acid (HCN) in the same facility (again, see Figure 4-6 and for further information see EMIS 2024/2B8b Ethen-Produktion). Therefore, CH_4 emissions are reported as NA for ethylene production and only CO_2 and NMVOC emissions are reported.

The CO_2 emissions from the cracker reported in source category 2B8b Ethylene production are based on a mass balance considering all feedstocks, products and by-products. Therefore, the NMVOC emissions are not included in the calculation of the indirect CO_2 emissions from sector 2 IPPU in order to avoid double counting.

Methodology

According to decision trees Fig. 3.8 of IPCC 2006 (vol. 3, chp. 3.9 Petrochemical and carbon black production) and Fig. 3.1 of the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry), the CO_2 and NMVOC emissions, respectively, from ethylene production are determined by a Tier 2 method using plant-specific emission factors (EMIS 2024/2B8b Ethylene production).

Emission factors

The CO_2 and NMVOC emission factors for ethylene production are based on industry data from the single ethylene production plant in Switzerland. Annual emission data were only available from the year 2000 onwards. For the period 1990–1999 constant emission factors, i.e. the mean emission factors of the years 2000–2009 were assumed.

The emission factors for ethylene production are considered confidential; however, they are available to reviewers on request.

Table 4-25 Emission factors for CO_2 and NMVOC in ethylene production, NMVOC in acetic acid production, CO_2 in limestone pit, CO_2, N_2O, NO_x and CO in niacin production and SO_2 in sulphuric acid production for 2022 in kg/t product.

2B8 Petrochemical and carbon black production	Unit	CO_2	N_2O	NO_x	CO	NMVOC	SO_2
2B8b Ethylene	kg/t	C	NA	NA	NA	C	NA
2B10 Other							
Acetic acid production	kg/t	NA	NA	NA	NA	C	NA
Limestone pit	kg/t	C	NA	NA	NA	NA	NA
Niacin production	kg/t	C	C	C	C	NA	NA
Sulphuric acid production	kg/t	NA	NA	NA	NA	NA	C

Table 4-26 CO_2 fossil emission factors in 2B8b Ethylene are documented in the confidential NID, which is available to reviewers on request.

Activity data

Activity data on the annual production of ethylene are provided annually by the single ethylene production plant in Switzerland. Since 2013, activity data are taken from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS). The data are considered confidential but available to reviewers on request.

Table 4-27 Activity data for the production of ethylene, acetic acid, niacin, PVC and sulphuric acid as well as for limestone pit in Switzerland in kt.

	Unit	1990	1995	2000	2005	2010	2013–2022
2B8 Petrochemical and carbon black production							
2B8b Ethylene	kt	C	C	C	C	C	C
2B10 Other							
Acetic acid production	kt	30	27	24	8.4	20	C
Limestone pit	kt	C	C	C	C	C	C
Niacin production	kt	C	C	C	C	C	C
PVC production	kt	43	43	NO	NO	NO	NO
Sulphuric acid production	kt	C	C	C	C	C	C

4.3.2.5. Other (2B10)

Source category 2B10 Other comprises emissions from production of acetic acid, sulphuric acid, niacin and PVC (ceased in 1996) as well as from limestone pits.

Acetic acid production (2B10)

In Switzerland, there is only one plant producing acetic acid (CH_3COOH) remaining after the other one stopped its production by the end of 2012. The still existing plant emits NMVOC only whereas from the latter one also emissions of CO_2, CH_4 and CO occurred.

Indirect CO_2 emissions resulting from CH_4, CO and NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9.

Methodology

In order to determine emissions of CO_2 and CH_4 from acetic acid a country-specific method analogous to a Tier 2 method according to IPCC 2006 (vol. 3) is used. The CO and NMVOC emissions are calculated by a Tier 2 method according to the decision tree Fig. 3.1 in the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry).

Emission factors

The emission factors for CO_2, CH_4, CO and NMVOC from acetic acid production in Switzerland are plant-specific and based on data from industry and expert estimates documented in EMIS 2024/2B10 Essigsäure-Produktion.

In the plant which ceased production by the end of 2012 process emissions had been treated in a flue gas incineration. Thus, the reported emissions of CH_4, CO and NMVOC only occurred in case of malfunction, which resulted in strongly fluctuating plant-specific emission factors. In addition, the resulting implied emission factors based on the emissions of both plants are modulated by considerable production fluctuations of one of the plants from 2000 onwards.

The emission factors for acetic acid production are confidential but available to reviewers on request.

Table 4-28 In the confidential NID, the respective table with emission factors for CO_2 and CH_4 in acetic acid production are separately reported and available to reviewers.

Activity data

The annual amount of produced acetic acid is based on data from industry and from the Swiss industry association for the chemical, pharmaceutical and biotech industry (scienceindustries) documented in EMIS 2024/2B10 Essigsäure-Produktion (see Table 4-27).

The data for acetic acid production since 2013 are confidential, since there is only one manufacturer remaining. The data are available for reviewers on request.

Limestone pit (2B10)

In one chemical plant acids are neutralized in a so-called limestone pit yielding geogenic CO_2 emissions.

Methodology

According to decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates), the CO_2 emissions from the limestone pit are determined by Tier 2 method using plant-specific emission factors.

Emission factors

The CO_2 emission factor is considered confidential but available to reviewers on request.

Activity data

Activity data of annual consumption of calcium carbonate are provided by the chemical plant from 1999 onwards as documented in EMIS 2024/2B10 Kalksteingrube. For the years 2005–2011 and since 2013 they are based on monitoring reports of the Swiss ETS. Since no data are available of the limestone pit for the time period 1990–1998, the annual activity is derived from the average annual consumption between 1999 and 2015.

Activity data are considered confidential but available to reviewers on request.

Niacin production (2B10)

In Switzerland, there is one plant producing niacin that emits CO_2, N_2O, NO_x and CO. In the production process nitric acid is used as oxidizing agent. Since the nitric acid production plant was closed in spring 2018 the required nitric acid is directly produced within the niacin production plant using a so-called ammonia burner. In autumn 2021, a catalytic converter was installed to treat the non-absorbed gas components of the production plant (including ammonia burner). The nitrogen oxides are denitrified with ammonia, and nitrous oxide, hydrocyanic acid and carbon monoxide are decomposed to nitrogen, water and carbon dioxide.

Methodology

In order to determine emissions of CO_2 and N_2O from niacin production, a country-specific method analogous to a Tier 2 method according to IPCC 2006 (vol. 3) is used for the years 1990 to 2021. From 2022 onwards, a Tier 3 method based on continuous emissions monitoring (CEM) is applied. The NO_x and CO emissions are calculated by a Tier 2 method based on the decision tree Fig. 3.1 in chapter 2B Chemical industry in EMEP/EEA (2019) using plant-specific emission factors.

Emission factors

The emission factors of CO_2, N_2O, NO_x and CO are plant-specific based on measurement data from industry. From 2022 onwards, the plant is obliged to continuously monitor the emissions of CO_2 and N_2O and provides the hourly averages as part of the ETS monitoring. Accordingly, the emission factors have since been derived from this data. For CO_2 (1990–2021) and CO, they are based on measurements in 2018 and 2021 before and after the production process was modified (i.e. including the ammonia burner) and after the installation of the catalytic converter, respectively. For N_2O (1990–2021), the emission factor is derived from measurements in 2018 after the modification of the production process but with and without operating the ammonia burner and in 2021 (after catalytic converter installation). For NO_x, the emission factor is based on measurements in 2017 and 2018 (after process modification) and 2021 (after converter installation). Due to lack of emission measurements in previous years, constant emission factors are assumed between 1990 and 2017 as documented in the EMIS database (EMIS 2024/2B10 Niacin-Produktion) The emission factors are considered confidential but available to reviewers on request.

Table 4-29 In the confidential NID, the respective table with emission factors for CO_2 and N_2O emission factors for 2B10 Niacin production are separately reported and available to reviewers.

Activity data

Activity data of annual niacin production were provided by the Swiss production plant for the entire time period as documented in EMIS 2024/2B10 Niacin-Produktion. For the years 2005–2011 and since 2013 they are based on monitoring reports of the Swiss ETS.

Activity data are considered confidential but available to reviewers on request.

PVC and sulphuric acid production (2B10)

Sulphuric acid (H_2SO_4) is produced by one plant only in Switzerland. From this production process SO_2 is emitted. Until 1996, also PVC was produced in Switzerland releasing NMVOC emissions.

Indirect CO_2 emissions resulting from NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9.

Methodology

In order to determine NMVOC and SO_2 emissions from sulphuric acid and PVC production, respectively, a Tier 2 method according to the decision tree Fig. 3.1 in the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2B Chemical industry) with plant-specific emission factors is used.

Emission factors

The emission factor for SO_2 from sulphuric acid production in Switzerland is plant-specific and based on measurement data from industry and expert estimates documented in the EMIS database (EMIS 2024/2B10 Schwefelsäure-Produktion).

The SO_2 emission factor is confidential but available to reviewers on request.

For PVC production the NMVOC emission factor was based on industry information and expert estimates (EMIS 2024/2B10 PVC-Produktion).

Activity data

The annual amount of sulphuric acid and PVC produced is based on data from industry and expert estimates documented in EMIS 2024/2B10 Schwefelsäure-Produktion and EMIS 2024/2B10 PVC-Produktion (see Table 4-27). The activity data for sulphuric acid production are confidential but available to reviewers on request.

4.3.3. Uncertainties and time-series consistency for 2B

For all source categories in 2B, the activity data are based on plant level data and the corresponding uncertainties are therefore considered small and estimated to be 2 %.

For N_2O emissions from 2B2 Nitric acid production, the combined uncertainty is assumed to be 7.2 % (from 2013 – 2018) since the Swiss ETS requires that an uncertainty of 7.5 % is not exceeded for emission estimations based on continuous N_2O measurements. The uncertainty for the emission factor is derived using the activity data uncertainty of 2 %. For 1990 an uncertainty of 60 % is assumed for the emission factor, based on the uncertainty rating given in EMEP/EEA (2019) (part A, chp. 5, Table 2-2, rating B) since the calculated emissions are based on a single N_2O emission measurement in 2009.

For 2B5 Silicon carbide production, the uncertainty of the CO_2 and CH_4 emission factors is set at 10 %, which is the default value according to IPCC 2006 (vol. 3, chp. 3, p. 3.45).

For 2B8b Ethylene production, the uncertainty of the CO_2 emission factor is 10 % according to the default value for a Tier 2 methodology (IPCC 2006, vol. 3, chp. 3, p. 3.87).

The uncertainties for the CO_2 and N_2O emission factors from 2B10 Niacin production are assumed to be 60 % according to the uncertainty rating given in EMEP/EEA (2019) (part A, chp. 5, Table 2-2, rating B) since the calculated emissions are based on (spot) measurement data from industry in 2018 and 2021 only.

Consistency: Time series for 2B Chemical industry are all considered consistent.

4.3.4. Category-specific QA/QC and verification for 2B

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

4.3.5. Category-specific recalculations for 2B

There were no recalculations implemented in submission 2024.

4.3.6. Category-specific planned improvements for 2B

No category-specific improvements are planned.

4.4. Source category 2C – Metal industry

4.4.1. Source category description

Table 4-30 Key categories of 2C Metal industry. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	**IPCC category**	**Gas**	**Identification criteria**
2C3	Aluminium production	CO2	T1
2C3	Aluminium production	PFCs	T1

Table 4-31 Specification of source category 2C Metal industry.

2C	**Source category**	**Specification**
2C1	Iron and steel production	Emissions of CO_2, NOx, CO, NMVOC and SO_2 from the production of iron and steel; Geogenic CO_2 emissions from use of limestone in iron-foundries (cupola furnaces)
2C2	Ferroalloys production	Production is not occuring in Switzerland
2C3	Aluminium production	Emissions of PFC, CO_2, NOx, CO, NMVOC, and SO_2 from the production of primary aluminium (ceased in 2006); Emissions from use of SF_6 in aluminium foundries
2C4	Magnesium production	Emissions from use of SF_6 in magnesium foundries
2C7	Other	Emissions of CO and NMVOC from non-ferrous metal foundries; Emissions of CO_2, NOx, CO and SO_2 from battery recycling

4.4.2. Methodological issues

4.4.2.1. Iron and steel production (2C1)

There is no primary iron and steel production in Switzerland. Only secondary steel production occurs, which is steel production from recycled steel scrap. After closing down of two steel plants in 1994, there remain two plants in Switzerland. Both plants use electric arc furnaces (EAF) with a carbon electrode for melting the steel scrap. During the melting process CO_2 emissions occur mainly from scrap, electrodes and carburization coal whereas the produced steel, filter dust and slag act as carbon sinks. Emissions of precursors such as NO_x, CO, NMVOC and SO_2 occur as well.

In Switzerland, no production of pig iron occurs but iron is processed in foundries only. Today, there exist about 14 iron foundries in Switzerland. About 75 % of the iron is processed in induction furnaces and 25 % in cupola furnaces. From induction furnaces only precursors are emitted. In cupola furnaces also CO_2 emissions from other bituminous coal and limestone occur. Other bituminous coal acts first of all as fuel but also as carburization material and reductant. Therefore, it was decided to report those CO_2 emissions in source category 1A2a. This ensures consistency with the reported use of other bituminous coal as fuel in the Swiss overall energy statistics (SFOE 2023). In cupola furnaces of iron foundries, limestone is also used as flux as documented in the EMIS database (EMIS 2024/1A2a 2C1 Eisengiessereien Kupolöfen). The resulting geogenic CO_2 emissions are reported in 2C1.

The CO_2 emissions from 2C1 Secondary steel production, electric arc furnace are based on a carbon mass balance considering all carbon sources and sinks of the process. Therefore, the emissions of CO and NMVOC are not included in the calculation of the indirect CO_2 emissions from sector 2 IPPU in order to avoid a double counting.

Methodology

For determination of CO_2 emission from EAF in secondary steel production a mixture of a Tier 2 (before 2005 and for 2012) and a Tier 3 method (2005–2011 and since 2013) according to decision tree Fig. 4.7 of IPCC 2006 (vol. 3, chp. 4.2 Iron & steel and metallurgical coke production) is used. For the years 2005–2011 and from 2013 onwards plant-specific data on the carbon mass balance is available from monitoring reports of the Swiss ETS, since under the Ordinance for the Reduction of CO_2 Emissions (Swiss Confederation 2012) the plants are required to report their emissions annually (Tier 3). From this information, data for the other years are interpolated for calculating an implied emission factor. In Switzerland, no CH_4 emissions occur in the EAF process.

The method for calculating geogenic CO_2 emissions from limestone use in cupola furnaces of iron foundries corresponds to a Tier 2 method according to the decision tree Fig. 2.4 of IPCC 2006 (vol. 3, chp. 2.5 Other process uses of carbonates).

Emissions of all precursors are determined by a Tier 2 method based on the decision tree Fig. 3.1 in chapter 2C1 in the EMEP/EEA guidebook (EMEP/EEA 2019) using country-specific emission factors (EMIS 2024/2C1).

Emission factors

The emission factors for EAF in secondary steel production in Switzerland are country-specific and are based on measurements from industry and expert estimates documented in the EMIS database (EMIS 2024/2C1 Stahl-Produktion Elektroschmelzöfen).

The electrode consumption in the two Swiss plants differs. For the calculations all carbon sources (graphite electrodes, steel scrap, alloy coal, etc.) and carbon sinks (steel, filter dust and slag) for the years 2005–2011 and from 2013 onwards were taken into account. Based on these carbon mass balances, a mean plant-specific CO_2 emission factor results. The reported CO_2 emission factor for Swiss steel industry is the production-weighted average (Table 4-32). As direct CO_2 emissions cover all carbon sources (carbon mass balance) from this source category, no indirect emissions are included in CRT Table6 as documented in chp. 9.

The plant-specific data are confidential but available to reviewers on request.

Table 4-32 CO_2 emission factor of electric arc furnaces in 2C1 Steel production in kg/t.

2C1 Steel production	Unit	1990	1995	2000	2005	2010
CO_2	kg/t	8.3	8.0	7.7	8.8	7.6

2C1 Steel production	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CO_2	kg/t	7.4	7.5	6.4	6.2	6.6	6.2	5.8	5.6	5.5	6.7

Emission factors for all precursors emitted from steel production are based on air pollution control measurements of the steel plants. For submission 2016, emission factors of NO_x, CO, NMVOC, and SO_2 have been revised based on air pollution control measurements at the electric arc furnaces of the two plants in 1999, 2005 and 2010 and in 1998, 2009 and 2014, respectively.

The emission factor of geogenic CO_2 from limestone use in cupola furnaces of iron foundries is based on the stoichiometry of $CaCO_3$ (IPCC 2006, vol. 3 chp. 2.1, table 2.1), see Table 4-33. A conversion factor of 100 % is assumed. The emission factors of the precursors from induction furnaces of iron foundries are provided by the Swiss foundry association (GVS).

Table 4-33 Emission factors for CO_2, NO_x, CO and NMVOC in iron production, for CO_2, NO_x, CO, NMVOC and SO_2 in steel production, for CO and NMVOC in non-ferrous metal production and for CO_2, NO_x, CO and SO_2 in battery recycling for 2022.

2C Metal industry	Unit	CO_2	NO_x	CO	NMVOC	SO_2
2C1 Iron production	kg/t	NA	0.01	4.1	4.0	NA
2C1 Limestone use in iron foundries (cupola furnaces)	kg/t	439.71	NA	NA	NA	NA
2C1 Steel production	kg/t	6.7	0.14	0.7	0.1	0.014
2C7a Non-ferrous metals	kg/t	NA	NA	0.24	0.05	NA
2C7c Battery recycling	kg/t	C	C	C	C	C

Activity data

Activity data on annual production of iron and steel are provided annually by the Swiss foundry association (Giesserei-Verband Schweiz, GVS) and the steel plants, respectively.

Since 2009, activity data of the annual steel production is taken from annual monitoring reports from the Swiss Emissions Trading Scheme (ETS).

The amount of limestone used as flux in iron foundries (cupola furnaces) is estimated by GVS to be in the range of 30–50 % of the coal consumed. Therefore, an average share of 40 % is assumed to calculate the activity data of limestone use (EMIS 2024/1A2a_2C1 Eisengiessereien Kupolöfen).

Table 4-34 Production of iron, steel, aluminium and non-ferrous metals as well as amount of batteries recycled in Switzerland in kt.

2C Metal industry	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
2C1 Iron production	kt	170	130	120	67	53	45	43	37	34	35	34	24	20	22	23
2C1 Limestone use in iron foundries (cupola furnaces)	kt	6.2	4.1	3.8	2.3	0.98	0.86	0.82	0.70	0.65	0.67	0.65	0.45	0.38	0.41	0.44
2C1 Steel production	kt	1'108	716	1'022	1'159	1'218	1'231	1'315	1'296	1'238	1'270	1'291	1'130	1'125	1'294	1'208
2C3 Aluminium production	kt	87	21	36	45	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2C7a Non-ferrous metals	kt	60	56	53	33	20	6.4	9.5	8.9	9.0	8.0	6.8	6.4	5.1	7.5	7.9
2C7c Battery recycling	kt	NO	C	C	C	C	C	C	C	C	C	C	C	C	C	C

4.4.2.2. Aluminium production (2C3)

Methodology

The last production site for primary aluminium in Switzerland closed down in April 2006. According to IPCC 2006 (vol. 3, chp. 4.4, fig. 4.11), CO_2 emissions are calculated by a Tier 2 method using a country-specific emission factor. For PFC emissions, a more specific Tier 3 method with facility-specific data according to the Guidelines (IPCC 2006) was used. Operating smelter emissions have been monitored periodically by the industry for selected years.

FOEN import statistics indicate in the year 2003 part of the SF_6 imports to be related to the aluminium industry, referring to cleaning processes in foundries. The 2006 IPCC Guidelines mention use of SF_6 in aluminium production for magnesium alloys on a low scale but do not provide further information for evaluation. Accordingly, the same evaluation methodology as for magnesium foundries with an emission factor based on a Tier 2 method is applied.

Emission factors

The emission factor for CO_2 of 1.6 tonnes per tonne of aluminium is country-specific. It is based on measurements and data from industry and expert estimates, as documented in the EMIS database (EMIS 2024/2C3 Aluminium Produktion). CO_2 emissions from aluminium production stem from the oxidation of the anode in the electrolysis process. In Switzerland, only prebake anode technology was used. For the anode consumption, a constant mean value of 0.43 tonnes per tonne of aluminium was applied. It is assumed that the anode consisted completely of carbon and that it was fully oxidized during the process. Therefore, no indirect CO_2 emissions resulting from CO emissions from primary aluminium production are included in CRT Table6 as documented in chp. 9. However, the NMVOC emissions solely originate from the production of the electrodes at the plants. Accordingly, the respective indirect CO_2 emissions resulting from NMVOC in this source category are included in CRT Table6 as documented in chp. 9.

Before the close down of the only Swiss primary aluminium factory in 2006, PFC emission factors of operating smelters have been monitored periodically. Measurements made in 1990, 1999 and 2000 reported emission factors of 0.17, 0.06 and 0.04 kg per tonne, respectively, for those three years (Alcan 2003). This was reported to be lower than the European averages, by factors of 4.0, 4.7 and 4.0, respectively. For other years no measurements have been made in Switzerland; thus, European Union (EU) average emission factors have been used, multiplied by a factor of 0.25 (Alcan 2002).

Figure 4-7 shows the resulting development of the emission factor for PFC over time. The European average has decreased by over 75 % from 0.68 kg PFC per tonne of aluminium to 0.16 kg PFC per tonne of aluminium between 1990 and 2000 (European Aluminium 2019).

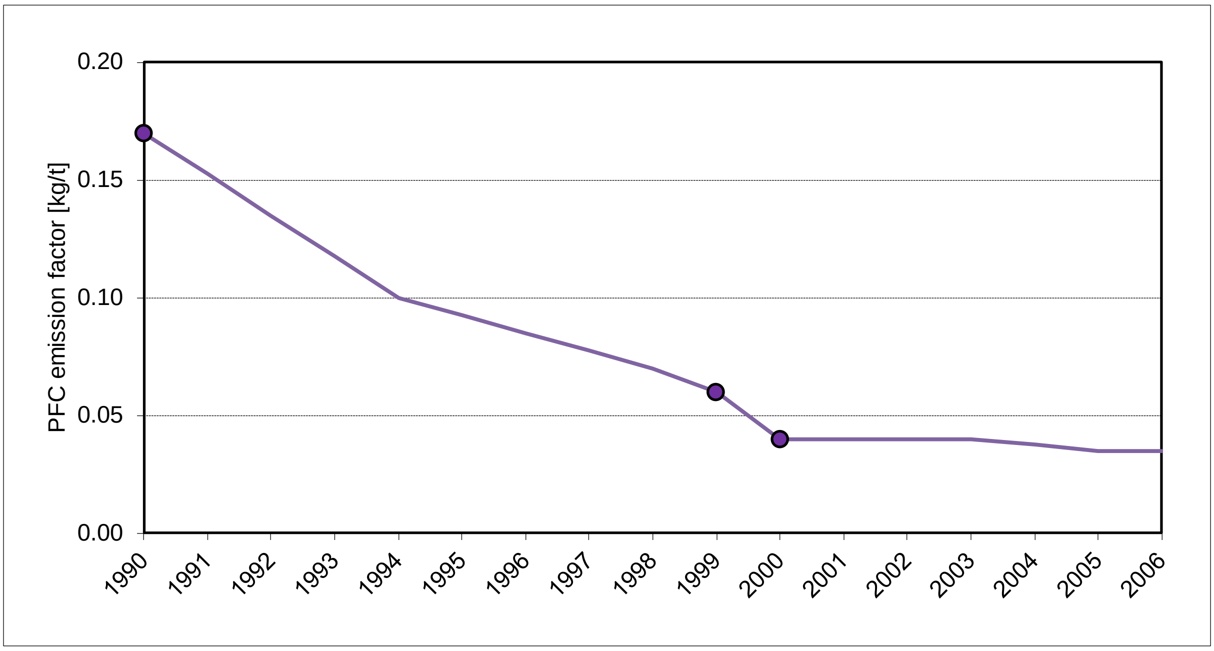

Figure 4-7 Extrapolation of PFC emission factor based on measurements in 1990, 1999 and 2000. The path for the reduction between measurements and the stagnation after the last measurements reflects the observed development of average emission factors in the European Union.

There is no documentation of the measurements. Due to the close down in 2006 it is not possible to redo any measurements or to collect any information about the process details retroactively. Measurement results and development of emission factors are assumed to be plausible because the factory used point feed prebake (PFPB) technology which is known for the lowest emissions per tonne of aluminium. The resulting emission factors for Switzerland are within the uncertainty range according to the 2006 IPCC Guidelines (variations by a factor of 10 using same technologies). The comparison with data from IAI (2005) on global PFC emissions from aluminium production showed that the monitored emissions from the smelter in Switzerland were lower by a factor of about 4.

Table 4-35 PFC emission factors for aluminium production in Switzerland. Aluminium production in Switzerland ceased in 2006.

Gas	Unit	1990	1995	2000	2005	2006	2007–2022
CF_4	kg/t	0.15	0.083	0.036	0.032	0.032	NO
C_2F_6	kg/t	0.017	0.0093	0.0040	0.0035	0.0035	NO

There are no measurements of SF_6 emissions available from aluminium foundries to identify the fraction of SF_6 destroyed or transformed in the cleaning process. For SF_6 used in aluminium foundries (2C3) it is therefore assumed that the total imported amount is emitted, in accordance with the default emission factor (1’000 kg per tonne of imported substance) of the IPCC Guidelines (IPCC 2006).

Activity data

In 2006, the last primary aluminium production site in Switzerland was closed. Activity data on aluminium production from 1997 to 2006 are based on annual data published by the Swiss Aluminium Association. For earlier years, data were provided directly by the aluminium industry. Activity data for aluminium production in Switzerland are given in Table 4-34.

Activity data on SF_6 used in aluminium foundries (2C3) is derived from import data from FOEN statistics. Import companies indicated in the year 2003 a portion of SF_6 imports for foundries to be used for aluminium cleaning. For the activity data of any particular year, the mean value of the imports in the present and the previous year is used to account for possible time lag between import and consumption (e.g. for 2004 the mean value of 2003 and 2004 import data are used). In 2011, a study was carried out among members of the Swiss Foundry Association (GVS), confirming that SF_6 is not used any more in aluminium foundries. As no details on the imported amount are available for the time period 2003–2011, a steady decrease of the import amount of SF_6 is assumed from 2003 until the final elimination of SF_6 for aluminium cleaning in 2011. This assumption is based on the above-mentioned survey and on information obtained on applications within the category ‘others’ from FOEN import statistics.

4.4.2.3. Magnesium production (2C4)

Use of SF_6 in magnesium foundries (2C4)

SF_6 was used in Swiss magnesium foundries in the time period 1997 to 2016. There have been two magnesium foundries known to be using SF_6. In 2007 one of them closed down. A survey carried out 2011 among members of the Swiss Foundry Association (GVS) confirmed that only one company was using SF_6.

The import of SF_6 for magnesium foundries has been prohibited in Switzerland since 2017.

Methodology

SF_6 was used in magnesium foundries in the cleaning process as inert gas to fill casting forms. The Swiss Foundry Association (GVS) has not provided information on emission factors and hence a Tier 2 method is used.

Emission factors

There are no measurements of SF_6 emissions available to identify the fraction of SF_6 destroyed or transformed in the process. For SF_6 used in magnesium foundries (2C4) it is therefore assumed that the total imported amount is emitted, in accordance with the default emission factor (1’000 kg per tonne of imported substance) of the 2006 IPCC Guidelines (IPCC 2006).

Activity data

Activity data on SF_6 used in magnesium foundries (2C4) are based on import data from FOEN statistics. For the activity data of any particular year, the mean value of the imports in the present and the previous year is used to account for possible time lag between import and consumption (e.g. for 2016 the mean value of 2015 and 2016 import data are used). The import of SF_6 ceased in 2016. Part of the import of the preceding year were considered for the phase-out 2016.

One of the magnesium foundries reported on the SF_6 consumption between 2008 to 2015 to the Swissmem statistics. The information is in accordance with import data obtained from FOEN statistics.

4.4.2.4. Other (2C7)

Battery recycling and non-ferrous metal foundries (2C7)

There is one battery recycling plant in Switzerland which started operation in 1992. The recycling is done by applying the Sumitomo process. The batteries are first pyrolised at temperatures of 700°C in a reducing atmosphere in a shaft kiln. The gas with the carbonised components then goes to a post-combustion step where it is completely oxidised at temperatures of 1000°C. The flue gas is then directed to a flue gas treatment installation. The metal fraction from the pyrolysis goes to a melting furnace where it is reduced by addition of coal and magnesium oxide. As reducing agent coke and Carburit is used.

In Switzerland, there are one large company and several small plants operating non-ferrous metal foundries producing mainly copper alloys. During the melting process emissions of CO and NMVOC occur.

Indirect CO_2 emissions resulting from CO and NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9.

Methodology

To determine emissions of CO_2, NO_x, CO and SO_2 from battery recycling and of CO and NMVOC from non-ferrous metal foundries, Tier 2 methods according to the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2C7c and 2C7a) with country-specific emission factors are used.

Emission factors

The emission factors of CO_2, NO_x, SO_2, CO from battery recycling between 1992 and 2002 are based on measurements in 2003 as well as mass balances of the single recycling site and are assumed constant. Since 2003 they are based on air pollution control measurements from 2003 and 2012 and are assumed constant during this time period. Emission factors of NMVOC are also based on air pollution control measurements from 2003 and 2012 and are assumed constant for the entire time period (EMIS 2024/2C7 Batterie-Recycling).

Emission factors of CO and NMVOC from non-ferrous metal foundries in Switzerland are country-specific and based on measurements from industry and expert estimates documented in the EMIS database (EMIS 2024/2C7 Buntmetallgiessereien Elektroöfen) (see Table 4-33). Emission factors are confidential. They are available to reviewers on request.

Activity data

The annual amount of recycled batteries and produced non-ferrous metals in Switzerland is reported by industry (including monitoring reports of the Swiss ETS from 2006 onwards for the large non-ferrous metal company) and the foundry association as documented in the EMIS database (EMIS 2024/2C7 Batterie-Recycling and EMIS 2024/2C7 Buntmetallgiessereien Elektroöfen). Activity data are confidential. They are available to reviewers on request.

4.4.3. Uncertainties and time-series consistency for 2C

Production data of the steel industry have a high confidence and its uncertainty is estimated at 2 %. The uncertainty for the CO_2 emission factor is estimated at 50 %, due to the high uncertainty of the carbon content of the electric arc furnace slag. Since the geogenic CO_2 emissions from the limestone use in cupola furnaces (iron foundries) are comparatively small their contribution to the uncertainty calculation was neglected.

For source category 2C3 Aluminium production (1990–2006), the uncertainty of the activity data is estimated to be 5 %. The uncertainty of the CO_2 emission factor is estimated to be 20 %. For PFCs, the uncertainty of the emission factor is estimated -79 % to +112 % (Carbotech, 2023a).

For the emissions of SF_6 from the use in 2C4 Magnesium production (1990–2016), the combined uncertainty is estimated at 27.7 % (Carbotech, 2023a).

For CO_2 emissions from source category 2C7 Other, the uncertainty of the activity data is set at 2 % because plant level data are available. The uncertainty of the CO_2 emission factor is estimated to be 20 % (expert estimate based on the observed variability in the available data).

Consistency: Time series for 2C Metal industry are all considered consistent.

4.4.4. Category-specific QA/QC and verification for 2C

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

4.4.5. Category-specific recalculations for 2C

There were no recalculations implemented in submission 2024.

4.4.6. Category-specific planned improvements for 2C

No category-specific improvements are planned.

4.5. Source category 2D – Non-energy products from fuels and solvent use

4.5.1. Source category description

Table 4-36 Key categories of 2D Non-energy products from fuels and solvent use. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Direct emissions of Source category 2D Non-energy products from fuels and solvent use are not a key category. Indirect emissions are documented in chp. 9.

Table 4-37 Specification of source category 2D Non-energy products from fuels and solvent use in Switzerland.

2D	Source category	Specification
2D1	Lubricant use	Emissions of CO_2 from primary usage of lubricants in machinery and vehicles and from fully oxidised lubricants blended into gasoline for 2-stroke engines
2D2	Paraffin wax use	Emissions of CO_2 from primary usage of paraffin waxes
2D3a	Solvent use	Emissions of NMVOC from coating applications, degreasing, dry cleaning and chemical products as well as emissions of CO_2 resulting from post-combustion of NMVOC in exhaust gases of these sources
2D3b	Road paving with asphalt	Emissions of NMVOC from road paving with asphalt
2D3c	Asphalt roofing	Emissions of CO and NMVOC from asphalt roofing
2D3d	Urea use in SCR catalysts of diesel engines	Emissions of CO_2 from urea use in SCR catalysts of diesel engines

4.5.2. Methodological issues

4.5.2.1. Lubricant use (2D1) and Paraffin wax use (2D2)

Lubricants are mostly used in industrial and transportation applications. They can be subdivided into motor oils, industrial oils and greases, which differ in terms of physical characteristics, commercial applications and environmental fate. Lubricants in engines of road and non-road vehicles are primarily used for their lubricating properties and associated GHG emissions are therefore considered as non-combustion emissions reported in 2D1 Lubricant use. Only lubricants blended into gasoline for 2-stroke engines are assumed to be fully oxidised.

The source category 2D2 Paraffin wax use includes products such as petroleum jelly, paraffin waxes and other waxes, including mixtures of saturated hydrocarbons, solid at ambient temperature. Paraffin waxes are separated from crude oil during the production of light (distillate) lubricating oils. Emissions from the use of waxes occur primarily when the waxes or derivatives of paraffins are combusted during use (e.g. candles).

Methodology

CO_2 emissions from the use of lubricants in 2-stroke engines (road and non-road vehicles) are calculated by a Tier 1 method and default emission factor according to the decision trees in IPCC 2006, vol. 2, chp. 3, Figure 3.2.2 and Figure 3.2.3) assuming that the lubricants are fully oxidised (as described in chp. 3.2.9.2.2). CH_4 and N_2O emissions from lubricant use in 2-stroke engines are reported in sector 1 Energy since these emissions are included in the CH_4 and N_2O emission factors of the respective 2-stroke engines (1A2gvii, 1A3biv, 1A3dii, 1A4aii, 1A4bii, 1A4cii and 1A5b).

CO_2 emissions from oxidation of all other lubricants and paraffin wax are calculated by a Tier 1 method according to the 2006 IPCC Guidelines applying the IPCC default oxidation fraction of 0.2 (IPCC 2006, vol. 3, chp. 5.2 and 5.3).

Emission factors

The CO_2 emission factor for lubricants used in 2-stroke vehicles is based on the default emission factor and the net calorific value from IPCC 2006 (vol. 2, chp. 2 Stationary combustion, Table 2.2 and chp.1, Table 1.2, respectively), see Table 4-38 and EMIS 2024/2 D 1_Schmiermittel-Verbrauch B2T. Non-CO_2 emissions from lubricant use in 2-stroke engines are included in the road and the non-road transportation model, since the emission factors are deduced from measurements on motorcycles including 2-stroke engines (see chp. 3.2.9.2.2).

The emission factors of CO_2 from all other lubricant and paraffin wax use in Switzerland are based on default IPCC values for NCV, carbon content and oxidation fraction documented in vol. 2, chp.1 and vol. 3, chp. 5.2 and 5.3, respectively, of IPCC 2006, see also EMIS 2024/2D1 Lubricant use and EMIS 2024/2D2 Paraffin wax use.

Table 4-38 CO_2 emission factor of 2D1 Lubricant use and 2D2 Paraffin wax use for 2022.

	Unit	CO_2
2D1 Lubricant use		
in two-stroke engines	kg/t	2'947
unspecified	kg/t	590
2D2 Paraffin wax use	kg/t	590

Activity data

The annual amount of lubricant and paraffin wax used in Switzerland is derived from Avenergy Suisse (formerly Swiss petroleum association) (Avenergy 2023). The consumption of lubricants of Liechtenstein, which forms a customs union with Switzerland, is subtracted from the consumption reported by Avenergy Suisse. The resulting amount is further differentiated between application in 2-stroke engines and unspecified use. The amount of lubricants corresponds to 2 % of total gasoline consumption of all 2-stroke engines based on the road and non-road transportation models (INFRAS 2022, INFRAS 2015a).

Table 4-39 Use of lubricants and paraffin waxes.

	Unit	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2D1 Lubricant use																
in two-stroke engines	kt	0.61	0.42	0.49	0.36	0.29	0.26	0.23	0.21	0.24	0.22	0.23	0.22	0.20	0.21	0.22
unspecified	kt	79	61	62	72	55	53	53	51	51	50	45	44	40	42	43
2D2 Paraffin wax use	kt	11	10	12	10	5.0	3.8	4.5	3.8	3.4	4.0	4.2	3.4	3.3	3.9	4.3

4.5.2.2. Other (2D3)

Solvent use (2D3a)

Since the 2006 IPCC Guidelines (IPCC 2006, vol. 3, chp. 5.5) refer to the EMEP/EEA guidebook regarding methodologies for estimating NMVOC emissions from solvent use, the respective NFR codes are indicated as reference as well. Within 2D3a Solvent use, the NMVOC emissions from coating applications (2D3d NFR), degreasing (2D3e NFR), dry cleaning (2D3f NFR) as well as production and processing of chemical products (2D3g NFR) are reported. Paint application on wood, paint application in construction, industrial and non-industrial paint application, production of fine chemicals and other industrial cleaning account for the largest share of NMVOC emissions from 2D3a in 2022. Indirect CO_2 emissions resulting from NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9.

Methodology

For the determination of NMVOC emissions from solvent use in coating applications (2D3d NFR), degreasing (2D3e NFR), dry cleaning (2D3f NFR) as well as production and processing of chemical products (2D3g NFR) a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019) is used. For coating applications, the emissions are based on the consumption of paints, lacquers, glazes, thinners etc. and their solvent content, for degreasing and dry cleaning on the solvent consumption and for production and processing of chemical products on the products manufactured or processed. Switzerland's Informative Inventory Report (FOEN 2024b, chp. 4.5.2.4–4.5.2.7) contains a detailed description of the country-specific emission factors and activity data of these four NFR source categories.

Post-combustion of NMVOC from solvent use (2D3a)

Due to the obligations of the Ordinance on Air Pollution Control (Swiss Confederation 1985) and Ordinance on the Incentive Tax on Volatile Organic Compounds (Swiss Confederation 1997) several industrial plants use facilities and equipment to reduce NMVOC in exhaust gases and room ventilation output. Often this implies the feeding of air with high NMVOC content into the burning chamber of boilers or other facilities to incinerate NMVOC. These CO_2 emissions from post-combustion of NMVOC are estimated based on industry data and expert estimates (Carbotech 2022a).

Methodology

The CO_2 emissions from post-combustion of NMVOC are calculated by a Tier 2 method using country-specific emission factors. Emissions are calculated based on the amount of NMVOC (and their carbon content) destroyed in the respective combustion facility of industrial plants (Carbotech 2022a). Post-combustion facilities are applied in source categories 2D3a Solvent use (industrial paint applications (2D3d NFR), metal degreasing (2D3e NFR) and chemical products, manufacture and processing (2D3g NFR)) and 2G4 Other. In 2018, the source category allocation of all post-combustion plants was verified. For the ten largest facilities (within 2D3a and 2G4), which are responsible for about 70 % of the emissions, the NMVOC quantities and respective carbon contents based on the composition of the solvents were updated annually whereas all the others every five years. For the submission 2022 (FOEN 2022), a complete update of all facilities was carried out by means of a survey of all cantonal air pollution control authorities, in addition, with VOC balances. If no information of the solvent composition is available, mean source category-specific values were applied for the carbon content.

Source categories coating applications (2D3d NFR) and degreasing (2D3e NFR) comprise nine facilities each, whereas chemical products, manufacture and processing (2D3g NFR) comprise about 80 facilities. Not all facilities have been in use for the entire period 1990–2022. There was a significant increase in total number of facilities from 32 in the year 1990 to 115 in 2002. Since then, the number fluctuates around 120.

The amounts of NMVOC eliminated by post-combustion are also declared in the respective VOC balances of the industrial plants and are thus not included as NMVOC emissions. When deriving the NMVOC emission factors for these source categories, the amount of NMVOC destroyed in post-combustion facilities is taken into account, i.e. the NMVOC emission factor is reduced accordingly.

Emission factors

CO_2 emission factors are derived based on the composition of the solvents (carbon content) destroyed in each post-combustion installation. For the ten most important installations (within 2D3a and 2G4), amount and composition of solvents destroyed were updated annually whereas for all others at least every five years. In between, the values were kept constant (see Table 4-40). For installations with no information on the solvent composition, mean industry-specific values are applied. The emission factors given in Table 4-40 are (source category specific) implied emission factors that depend both on carbon content and respective amount of the destroyed NMVOC. Thus, the implied emission factors of source categories with large post-combustion facilities may vary significantly over the years, due to changes in solvent compositions and amounts, starting-up or shutting down of facilities, etc.

Table 4-40 CO_2 emission factors for post-combustion of NMVOC in 2D3a Solvent use.

2D3a Solvent use	**Unit**	**CO_2**														
Post-combustion of NMVOC		**1990**	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Coating applications (2D3d NFR)	t/t NMVOC	2.78	2.75	2.72	2.78	2.78	2.79	2.78	2.27	2.25	2.24	2.25	2.25	2.05	2.05	2.05
Degreasing (2D3e NFR)	t/t NMVOC	NO	2.63	2.63	2.64	2.65	2.64	2.40	2.37	2.35	2.35	2.34	2.34	2.34	2.34	2.34
Chemical products, manufacture and processing (2D3g NFR)	t/t NMVOC	2.02	1.71	1.96	1.97	2.23	2.33	2.36	2.33	2.31	2.26	2.20	2.14	2.09	2.09	2.09

Activity data

Activity data are the amounts of NMVOC destroyed in post-combustion installations and are provided by the industry, VOC balances and cantonal air pollution control authorities. For the ten most important installations (within 2D3a and 2G4), they were updated annually whereas for all others at least every five years.

Table 4-41 Activity data of NMVOC post-combustion in 2D3a Solvent use.

2D3a Solvent use	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Post-combustion of NMVOC																
Coating applications (2D3d NFR)	t NMVOC	443	662	756	986	1'104	1'076	1'048	1'083	1'113	1'126	1'076	1'064	1'061	1'061	1'061
Degreasing (2D3e NFR)	t NMVOC	NO	749	749	576	898	972	665	663	855	817	976	922	882	882	882
Chemical products, manufacture and processing (2D3g NFR)	t NMVOC	1'199	4'501	5'677	8'237	5'490	5'038	5'078	4'574	5'232	5'345	5'406	5'267	5'587	5'587	5'587

Road paving with asphalt (2D3b)

Methodology

Asphalt road surfaces are composed of compacted aggregate and asphalt binder. From road surfacing operations only NMVOC emissions occur. Based on the decision tree Fig. 3.1 in chapter 2D3b in the EMEP/EEA guidebook (EMEP/EEA 2019), the NMVOC emissions from 2D3b Road paving with asphalt are determined by a Tier 2 method based on country-specific emission factors as documented in EMIS 2024/2D3b NFR.

Emission factors

The emission factor for NMVOC emissions from 2D3b Road paving with asphalt comprises NMVOC emissions from the use of prime coatings and from the bitumen content in asphalt products (about 5 %). The NMVOC content in the bitumen has decreased considerably between 1990 and 2010. The values are based on industry data from 1990, 1998, 2007, 2010 and 2013. All other years are interpolated and complemented with expert estimates documented in the EMIS database.

Table 4-42 Emission factors of 2D3b Road paving with asphalt, 2D3c Asphalt roofing and 2D3d Urea use in SCR catalysts (AdBlue) for 2022.

	Unit	**CO$_2$**	**CO**	**NMVOC**
2D3b Road paving	kg/t asphalt concrete	NA	NA	0.54
2D3c Asphalt roofing	kg/t asphalt sealing sheeting	NA	0.0059	4.8
2D3d Urea use in SCR catalysts	t/t urea solution	0.240	NA	NA

Activity data

Activity data on the amount of asphalt products (so-called mixed goods) used for road paving is based on annual data from the association of asphalt production industry (SMI) for 1990 and from 1998 onwards and expert estimates for the years between.

Table 4-43 Activity data for road paving with asphalt, asphalt roofing and urea use in SCR catalysts.

	Unit	1990	1995	2000	2005	2010
2D3b Road paving with asphalt						
Asphalt concrete	kt	5'500	4'800	5'170	4'780	5'250
2D3c Asphalt roofing						
Asphalt sealing sheeting	kt	54	56	58	51	68
2D3d Urea use in SCR catalysts						
AdBlue	kt	NO	NO	NO	0.26	20

	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2D3b Road paving with asphalt											
Asphalt concrete	kt	4'770	5'260	4'850	4'710	5'260	5'180	5'210	4'910	4'960	4'970
2D3c Asphalt roofing											
Asphalt sealing sheeting	kt	75	75	75	76	76	76	77	77	77	77
2D3d Urea use in SCR catalysts											
AdBlue	kt	26	27	29	31	33	35	36	36	38	39

Asphalt roofing (2D3c)

Methodology

This source category comprises emissions from production and use of asphalt roofing materials (saturated felt, roofing and siding shingles, roll roofing and sidings). These products are used in roofing and other building applications. From 2D3c Asphalt roofing only precursors such as CO and NMVOC arise. CO is emitted during the production process of asphalt roofing materials whereas NMVOC emissions are released during the entire production and laying processes (primers included). Based on the decision tree Fig. 3.1 in chapter 2D3c in the EMEP/EEA guidebook (EMEP/EEA 2019), the emissions of NMVOC from Asphalt roofing are determined by a Tier 2 method based on country-specific emission factors as documented in the EMIS database (EMIS 2024/2D3c Dachpappen Produktion und Verlegung). Emissions of CO are determined based on a Tier 1 method using the default emission factor for the production process from the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2D3c, Table 3.1).

Indirect CO_2 emissions resulting from CO and NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9.

Emission factors

The NMVOC emission factors from asphalt roofing are based on information from the industry association, literature and expert estimates as documented in the EMIS database. Tier 1 emission factor of CO for the production process is taken from the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 2D3c, Table 3.1) (see Table 4-42).

Activity data

Activity data are based on data from industry and expert estimates as documented in the EMIS database (see Table 4-43).

Urea use in SCR catalysts of diesel engines (2D3d)

This source category encompasses CO_2 emissions from the use of urea containing AdBlue in diesel engines with SCR-catalysts in road transportation (Euro V/VI and Euro 5/6).

Methodology

In accordance with the 2006 IPCC Guidelines, the consumption of AdBlue is reported following a methodology suggested in the EMEP/EEA guidebook (EMEP/EEA 2016; part B, chp. 1.A.3.b.i-iv, page 48). A specific percentage of the fuel consumption of SCR-vehicles in road transportation according to their Euro class is applied for AdBlue consumption estimates. Emissions are calculated according to following formula:

CO_2 Emissions = EF • FC • Share of SCR vehicles mileage • Specific urea share

“FC” relates to the fuel consumption in tonnes of the entire vehicle category. “Share of SCR vehicles mileage” implies the mileage share of SCR-vehicles in the entire vehicle category and “Specific urea share” comprises the percentage of fuel consumption, which relates to AdBlue (urea solution) consumption.

Emission factors

The emission factor for CO_2 emissions from urea use in SCR-catalysts in vehicles is a default value from the EMEP/EEA guidebook (EMEP/EEA 2019, chp. 1.A.3.b.i-iv, page 46) considering the molecular mass conversion of urea into CO_2 during the reaction with water and the content of 32.5 % of the aqueous AdBlue urea solution (see Table 4-42).

Activity data

Activity data on AdBlue consumption as well as annual mileage are provided by INFRAS (INFRAS 2017, INFRAS 2022) on a yearly basis as documented in EMIS 2024/2D3d NFR Urea (AdBlue) Einsatz Strassenverkehr. For activity data see Table 4-43.

4.5.3. Uncertainties and time-series consistency for 2D

The uncertainty of total CO_2 emissions from the entire source category 2D – Non-energy products from fuels and solvent use is estimated to be 14 % (expert estimate). This is the combined uncertainty according to uncertainty propagation assuming 10 % uncertainty of activity data and 10 % uncertainty for emission factors.

Consistency: Time series for 2D Non-energy products from fuels and solvent use are all considered consistent.

4.5.4. Category-specific QA/QC and verification for 2D

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

4.5.5. Category-specific recalculations for 2D

The following recalculations were implemented in submission 2024. Major recalculations which contribute significantly to the total differences in direct and indirect CO_2 emissions of sector 2 IPPU between the latest and the previous submissions are presented also in chp. 10.1.2.2.

- 2D1: The activity data of lubricant use in 2-stroke engines and thus also of unspecified lubricant use have changed from 2001 onwards due to recalculated gasoline consumption in 1A3biv 2-stroke motorcycles.
- 2D3d Urea (AdBlue) Use in Road Transportation: Due to recalculations in activity data in 1A3b Road transportation for diesel oil, the activity data for urea use changed for all years since 2005, too.

4.5.6. Category-specific planned improvements for 2D

There are no planned improvements.

4.6. Source category 2E – Electronics industry

4.6.1. Source category description

Table 4-44 Key categories of 2E Electronics industry. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Source category 2E Electronics industry is not a key category.

Source category 2E Electronics industry comprises HFC, PFC, NF_3 and SF_6 emissions from consumption of the applications listed in Table 4-45.

Table 4-45 Specification of source category 2E Electronics industry in Switzerland.

2E	Source category	Specification
2E1	Integrated Circuit or Semiconductor	Etching and cleaning processes in the production of IC and semiconductors (similar cleaning services for printed wiring boards included in the evaluation)
2E2	TFT flat panel display	No production of TFT flat panel displays in Switzerland, activities contained in the production of displays for watches
2E3	Photovoltaics	Emissions from photovoltaic manufacturing
2E4	Heat transfer fluids	No application in Switzerland assumed*
2E5	Other	Test activities (for example related to printed wiring boards), research activities

* Heat transfer fluids subject of research, for example ORC systems. Alternative products available with low GWP as for example Novec 649 and 7000

4.6.2. Methodological issues

Emission calculations are based on import data from FOEN statistics for etching and cleaning processes of the electronics industry, covering different source categories as listed in Table 4-45 (until 2010 import declarations for electronic industry under solvents). Process-specific transformation and emission rates are used. A survey within the electronics industry was carried out for the submission in 2015 to distribute the imported substances to the different source categories of electronic industry and to obtain information on waste air treatment. Information was obtained on the type of substance used in different source categories, but no information on emission factors and type of efficiency of exhaust treatment. More information are available from Carbotech (2024).

Methodology

A Tier 2a approach with specific parameters for each gas is used for emission calculations. IPCC default values for the gas-specific transformation rate of different processes and general values for the exhaust treatment efficiency are applied according to the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019). The Tier 2a method is for semiconductor sub-sector with revised emission factors, also accounting for additional precursors and by-products.

For the inventory report 2011 (FOEN 2011) interviews were conducted with the industry to get in-depth information on allocation of imported PFC volumes to different applications and to obtain process-specific information from consumers. Until 2010, most PFC imports declared as 2F5 Solvents or 2F6 Other were related to the electronics industry (2E). Since 2011, PFC import declarations have been improved and information is provided for the source category 2E separately. A survey was carried out for the submission in 2015 to determine contributions of different source categories 2E1–2E5 in Table 4-45 (Carbotech 2024). As a result, the peak of NF_3 imports (and corresponding emissions) between 2009 and 2011 was found to be related to photovoltaic manufacture.

Emission factors

Default emission factors according to the 2019 Refinement to the 2006 IPCC Guidelines are used for production and waste-air treatment (IPCC 2019). An exhaust treatment is assumed probable for most applications, in agreement with the requirements of the Chemical Risk Reduction Ordinance (Swiss Confederation 2005) to minimize emissions and in particular with the 5 % threshold for semiconductor production. Based on information available to the FOEN from several companies, a compliance with these requirements of close to 100 % can be expected (Wöhrnschimmel and Schmidely 2023).Therefore, for the purposes of calculating emissions, full compliance was assumed from 2021 onwards. In former years, a compliance of >60 % had been assumed, based on declarations from companies confirming the presence of exhaust treatment in a survey.

Activity data

Activity data are based on FOEN import statistics and industry information.

4.6.3. Uncertainties and time-series consistency for 2E

The uncertainty for the emissions from the use of HFC, PFC, SF_6, and NF_3 in 2E Electronics industry was estimated based on a Monte Carlo simulation. The obtained distribution types and numeric values for the emission uncertainties are reported in Annex A2.1. More information is available from Carbotech (2024).

Consistency: Time series for 2E Electronics industry are all considered consistent.

4.6.4. Category-specific QA/QC and verification for 2E

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

4.6.5. Category-specific recalculations for 2E

No recalculations were implemented in submission 2024.

4.6.6. Category-specific planned improvements for 2E

No category-specific improvements are planned.

4.7. Source category 2F – Product uses as substitutes for ozone depleting substances

4.7.1. Source Category Description

Table 4-46 Key categories of 2F Product uses as substitutes for ozone depleting substances. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
2F1	Refrigeration and air conditioning	HFCs	L1, L2, T1

Source category 2F Product uses as substitutes for ozone depleting substances comprises HFC and PFC emissions from consumption of the applications listed in Table 4-47.

Table 4-47 Specification of source category 2F Product uses as substitutes for ozone depleting substances in Switzerland.

2F	Source category	Specification
2F1	Refrigeration and air conditioning	Emissions from refrigeration and air conditioning (inclusive heat pumps and tumble dryers)
2F2	Foam blowing agents	Emissions from foam blowing, incl. polyurethan spray
2F4	Aerosols	Emissions from use as aerosols, incl. metered dose inhalers
2F5	Solvents	Emissions from use as solvents

Figure 4-8 shows HFC and PFC emissions from different applications in source category 2F. In 2022, stationary and mobile refrigeration and air conditioning equipment accounted by far for the highest emissions with a share of 96 % of the total emissions in source category 2F. Emissions are dominated by HFCs and only a minor contribution comes from PFCs (less than 1 %).

From 2015 onwards there is a decline in emissions as a result of the regulations from the Chemical Risk Reduction Ordinance (Swiss Confederation 2005). The regulations contain restrictions of F-gas import, limitation of HFCs with a high GWP for stationary refrigeration and a registration of equipment with more than 3 kg of refrigerants. Regarding the prefilled imported equipment, there is an effect of the EU F-gas regulation and the planned phase-out due to the Kigali Amendment. The results of the EU regulations are a complete replacement of HFCs in imported equipment for mobile air-conditioning and a lower HFC content in stationary refrigeration and air-conditioning equipment. Overall, this results in a decline of HFC emissions with a certain delay replacing the current stock of HFC in equipment. New substances such as hydrofluoroolefins (HFOs), HFO blends and hydrocarbons are replacing formerly used refrigerants with higher GWP and are also being used to substitute HFCs and PFCs in other applications such as foams, solvents and aerosols.

Additional factors for the decline are effects of monitoring of equipment, education and training. Some retailers maintain a monitoring program of refrigerant stock and emissions confirming improvements over time.

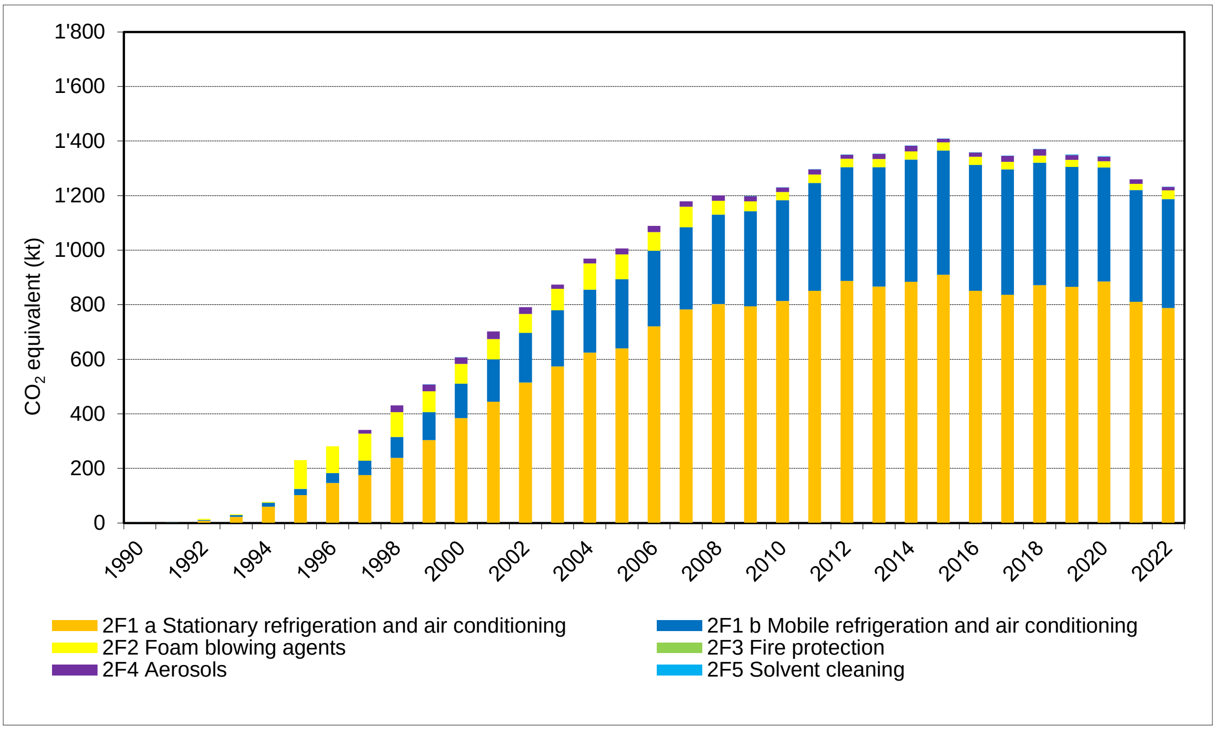

Figure 4-8 Development of emissions under source category 2F Product uses as substitutes for ozone depleting substances. HFC and small amounts of PFC are used as substitutes for ozone depleting substances. Most relevant today are emissions from the refrigerant stock in refrigeration and air conditioning equipment (2F1).

4.7.2. Methodological issues

The data models used for source category 2F are complex and therefore a comprehensive documentation of all relevant model parameters is not possible within the NID. Most relevant is the contribution of 2F1 refrigeration and air conditioning. Calculations are carried out for different applications separately.

2F1a Stationary refrigeration and air conditioning

- Domestic refrigeration
- Commercial refrigeration
- Industrial refrigeration
- Stationary air conditioning, heat pumps and tumble dryers

2F1b Mobile refrigeration and air conditioning

- Mobile air conditioning in different vehicle types
- Transport refrigeration for different vehicle types

Annex A5.2 shows an illustrative example of the model structure and parameters used for calculating emissions from mobile air conditioning in cars. The most important assumptions for the data model are documented in Table 4-48. More information of the individual data and models is available from Carbotech (2024) as well as related background documents. This information is considered confidential, but it will be made available for consultation by reviewers on request.

4.7.2.1. Refrigeration and air conditioning (2F1)

Methodology

The inventory under source category 2F1 includes different applications and equipment types. For each individual emission, models are used for calculating actual emissions as per the 2006 IPCC Guideline’s Tier 2a approach (emission factor approach). In order to obtain the most reliable data for the calculations, two different approaches are applied to get the stock data needed for the model calculations. For the following applications a bottom-up approach is applied relying on statistics, product information and expert estimations:

- Domestic refrigeration
- Mobile air conditioning for different vehicle types (example illustrated in Annex A5.2)
- Transport refrigeration for different vehicles types
- Stationary air conditioning (direct and indirect systems)
- Heat pumps
- Tumble dryers

On the other hand, a top-down approach is applied for the calculation of the stock in commercial and industrial equipment starting with the total imported amount of refrigerant. To determine the portion used for commercial and industrial refrigeration, the refrigerant consumption of other applications is subtracted from the import amount. Consumption for the production and maintenance is based on the bottom-up calculations of stock as given in the example of mobile air conditioning in Annex A5.2. A comparison to neighbouring countries shows higher stock and emissions from mobile air-conditioning in Switzerland. Model parameters were checked and a higher rate of air-conditioning of >95 % in vehicles is assumed plausible and is confirmed by companies dismantling vehicles.

Commercial and industrial refrigeration were evaluated together in former years. To obtain separate models, the total bulk refrigerant used for commercial and industrial applications is split based on the typical use of refrigerant blends and the available information on commercial and industrial equipment (Carbotech 2024). Parameters for commercial and industrial applications are given in Table 4-48. Furthermore, HFC-245fa, included under commercial and industrial refrigeration, was found to be used for organic rankine cycles (ORC).

The combination of bottom-up with top-down calculations leads to more comprehensive results than using just a single approach. Noteworthy, in the hypothetical but possible case of incomplete bottom-up evaluations, the remaining imported refrigerant would be attributed to the production and maintenance of industrial and commercial refrigeration equipment. This might be the reason why the resulting refrigerant stock of commercial and industrial refrigeration, which serves as the residual, tends to be higher than in neighbouring countries.

The import data as reported to FOEN are adjusted for imported substances to be used in Liechtenstein. This is to eliminate double counting with the inventory data of Liechtenstein. The split factor is based on the proportion of employees in the industrial and service sector (share of import for Liechtenstein <1 %). The adjustment does not affect the bottom-up calculations and leads to an adjustment of commercial and industrial refrigeration mainly.

Figure 4-9 shows the required data for the model calculation of refrigeration and air conditioning.

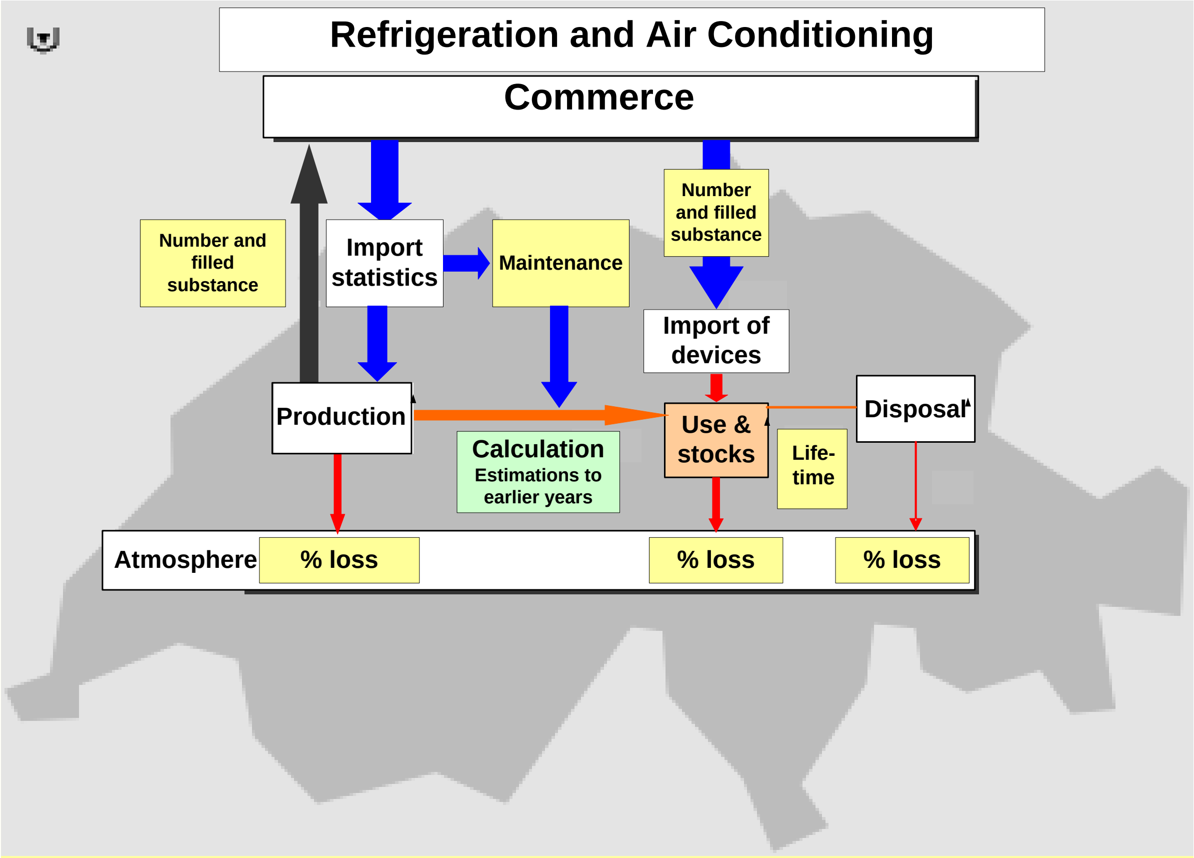

Figure 4-9 Required data for the model to calculate emissions from refrigeration and air conditioning in Switzerland.

Since 2008, operators handling equipment containing more than 3 kg of HFCs have been obligated to provide information to FOEN on the date of operation start, type of equipment, type and amount of refrigerant and date of disposal. This data source provides valuable information and is applied to improve the estimates used for modelling emissions under source category 2F and for the split of commercial and industrial equipment. However, it does not allow to directly draw the stock data or emission factors for the national inventory.

Emission factors

Emission factors related to manufacturing, product life and disposal as well as average product lifetime are established on the basis of expert judgement and literature. Direct monitoring of the product life emission factors is only done at the company level for internal use and has been used partly for the verification of the quality (confidential data from retailers and other industries). The product life factors and further parameters (i.e. re-filling frequency, handling losses and reuse of refrigerant) are used to allocate imported F-gases to new products and maintenance activities.

Table 4-48 displays the detailed model parameters used for the present submission and values used in the early period of HFC use (1990 to 1995). For product life emission factors of some equipment types, a dynamic model is applied, which implies that emissions decreased linearly between 1995 and 2015 due to improved production technologies and the continuous sensitisation of service technicians. The start/end values are based on expert statements (Carbotech 2024, UBA 2005, UBA 2007, Schwarz 2001, Schwarz and Wartmann 2005). Constant emission factors were assumed from 2015 onwards. The charge at the end of life for different applications has been analysed considering the technical minimal charge of the equipment and the expected frequency of the maintenance (UBA/Ökorecherche 2012). Disposal losses are calculated based on expert assumptions on the portion of broken equipment (100 % loss) and on assumptions on disposal losses for professional recovery on site or waste treatment by specialized companies.

Table 4-48 Typical values of lifetime, charge and emission factors used in the model calculations for 1990 to 2022 for refrigeration and air conditioning equipment. Changes of model parameters within this time period are indicated giving the initial value considered in the early time period of F-gas use around 1995 and the value used for modelling for 2022 (decrease between 1995 and 2015, steady values from 2015 onwards). The reduction of charge and losses is the result of improvement of technology and handling of equipment.

	Product life time	HFC Stock 2022	Composition of stock HFC/PFC	Initial charge of new product	Manufacturing emission factor	Product life emission factor	Disposal loss emission factor ***)	Charge at end of life *)	Export of retiring equipment **)
	[a]	[t]	Main products	[kg]	[% of initial charge]	[% per annum]	[% of remaining charge]	[% of initial charge of new product]	[% of retiring equipment]
Domestic refrigeration	16	1	HFC134a	0.1	NO	0.5	19 ****)	92.0	<3
Commercial refrigeration	8	1'820	R404a, R407C, R449a, R410a, R507, R422d, R448a	NR	0.5	1995: 12.5 2022: 7.8	24	80-90	NE
Industrial refrigeration	15	480	HFC134a, R410a, R407c, R404a, R422d, R507	NR	0.5	1995: 10 2022: 5	15	75-90	NE
Transport refrigeration: trucks/vans	10	55	R404a, R134a	1.8-7.8	1.5	15.0	28	86.0	90
Transport refrigeration: wagons	16			NR	NO	10.0	28	100.0	NE
Stationary air conditioning: direct cooling systems	15	2'415	R410a, HFC134a, R407c, R404a, HFC32, R517a	NR	1995: 3 2022: 1	1995:10 2022:4	28	74-89	NE
Stationary air conditioning: indirect cooling systems	15			NR	1.0	1995: 6 2022: 4	19	85-89	NE
Stationary air conditioning: heat pumps	15			1995: 4.7-7.5 2022: 2.8-4.5	1995: 3 2022: 1	2.0	19	86.0	NE
Stationary air conditioning: tumble dryers	15		HFC134a, R407c	0.4	0.5	2.0	19	74.0	NE
Mobile air conditioning: cars	15	2'420	HFC134a	1995: 0.84 2022: 0.55	NO	8.5	50	58.0	1995: 31-72 2022: 48
Mobile air conditioning: truck/van cabins	12			1.1	NO	1995: 10 2022: 8.5	50	69-73	90 trucks / 50 vans
Mobile air conditioning: buses	12			7.5	NO	1995: 20 2022:15	45	78.0	50
Mobile air conditioning: trains	16			20	NO	5.5	20	100.0	50

*) Calculated value taking into account annual loss and portion refilled over the whole product life where applicable.
**) Allocation of disposal losses to export country (export for reselling and secondhand use)
***) Calculated value taking into account share of total refrigerant loss and emission factor of professional disposal. Disposal losses occur from 2000 onwards (introduction of HFCs and PFCs starting 1991 and 8 to 16 years lifetime of equipment). The value of 50 % for mobile air conditioning is based on UBA 2005 and expert assumptions on share of total refrigerant loss, e.g. due to road accident.
****) Takes into account HFC-134a content in foams, based on information from the recycling organisation SENS.
NR = Not relevant as only aggregate data is used
NO = Not occurring (only import of charged units)
NE = Not estimated

Activity data

Activity data are taken from industry information and national statistics such as for admission of new cars, buses, vans and trucks. Stock data is modelled dynamically. Due to the large number of sub-models used for modelling the total emissions for source category 2F1, no table on time series of activity data is provided here. For illustration, Annex A5.2 shows the detailed calculation model for car air conditioning including the time series for the activity data for this particular sub-model. Mobile air conditioning accounts for approx. 32 % of the total emissions (CO_2 eq) of source category 2F1 Refrigeration and air conditioning in the inventory 2022.

For the NIR 2012 (FOEN 2012) a cross check has been performed for results from model calculation and FOEN statistics on disposal and recycling of HFCs. This has indicated a significant gap with higher disposal values in model calculations compared to the FOEN disposal statistics. Some of the gap is explained by the onsite reuse and recycling of refrigerants, which is not reflected in the FOEN statistics and by other factors as e.g. unrecorded exports of refrigeration equipment for second-hand use. Export rates used in model calculations are given in Table 4-48.

The registered refrigerant import is assumed to cover the consumption of Switzerland and Liechtenstein. To avoid double counting with the inventory data of Liechtenstein, the activity data for the equipment type commercial and industrial refrigeration is reduced by 0.9 %, based on the share of imports of substances to be used in Liechtenstein. The reduction factor is based on the proportion of employees in the industrial and service sector in these two countries. For other equipment types no scope for double counting with the inventory of Liechtenstein was identified and therefore no correction factor is applied.

4.7.2.2. Foam blowing agents (2F2)

Methodology

In Switzerland no production of open cell foam based on HFCs is reported by the industry. Therefore, only closed cell PU and XPS foams, PU spray applications and further closed cell applications as sandwich elements are relevant under source category 2F2.

The emission model (Tier 2a) for foam blowing has been developed top down, based on import statistics for products, industry information and expert assumptions for market volumes and emission factors. Emissions from further not specified applications of foam production have been calculated (Tier 1a) as residual balance between FOEN import statistics and consumption in PU spray, PU and XPS foams.

Desktop research on HFC-245fa use in neighbouring countries was carried out for the inventory 2019 to identify the relevance of HFC-245fa emissions from the import of foam products. HFC-245fa has not been used for foam blowing in Switzerland, but measurements at the Jungfraujoch site by Empa (see chp. 4.7.4 and Annex A6.1) indicate emissions probably related to the import of foam products. Due to the low relevance, lacking data and the decreasing use in neighbouring countries since 2005 (partly through bans) the model calculations were not extended with HFC-245fa (Carbotech 2024).

Emission factors

For the emission factors and the lifetimes of XPS and PU foams, expert estimates and default values according to the 2006 IPCC Guidelines (IPCC 2006, Volume 3, p. 7.37) are used. For PU sprays, expert estimates and specific default values according to the 2006 IPCC Guidelines (IPCC 2006, Volume 3, p. 7.37) are used. Unknown applications are evaluated following the Gamlen model recommended in the 2006 IPCC Guidelines (IPCC 2006). First-year losses are allocated to the country of production.

Table 4-49 Typical values on lifetime, charge and emission factors used in model calculations for foam blowing.

Product	**Product lifetime**	**Charge of new product**	**Manufacturing emission factor**	**Product life emission factor**	**Charge at end of life**
Foam type	years	% of product weight	% of initial charge	% per annum	% charge of new product
PU foam	50	4.5	NR	NR	Calculated charge minus emissions over lifetime (so far not relevant, products still in use)
XPS foam HFC-134a	50	6.5	NR	NR / 0.7**	
XPS foam HFC-152a				100 / 0**	
PU spray all HFC	50	13.6 / 0 *	<1%	95 / 2.5 **	
Unknown use:					
HFC 134a, HFC 227ea, HFC 365 mfc	20	NR	10	10 / 4.5 **	
HFC 152a			100	100 / 0 **	

* The first value represents the charge of HFC 1995 (start of HFC use as substitutes for ozone depleting substances). The HFC amount was reduced continuously between 1995 and 2008. Since 2009, the production of PU spray in Switzerland has been HFC-free.

** Data for 1st year / following years (HFC-152a all emissions allocated to production)

NR Not relevant (PU foam: no substances according to this protocol have been used; XPS foam: emissions occur outside Switzerland; unknown use: calculations are based on the remaining propellant import amount).

Activity data

HFCs have been used until 2008 in the Swiss production of PU spray. The export rate of PU spray from Swiss production was about 96.5 % of the total production volume in the time period of the HFC use. About one third of the PU spray sold in Switzerland originates from local production, the rest is imported. For PU rigid foams no HFCs are used as foam blowing agent (only pentane and CO_2). There has been no production of XPS in Switzerland with HFCs. XPS foams were 100 % imported until 2010. In 2011 a new production facility was started which, however, does not use HFCs.

The HFC import not related to the main applications above has been allocated to further unknown applications (possible use in the production of sandwich elements and pipe insulation mentioned by an import company of foam blowing agents has not been confirmed). The import amount shows a decreasing trend and choice of HFC with lower GWP values.

Without additional measurements, the release of F-gases from the disposal of PU and XPS foam product stock is assumed to occur approximately from 2050 onwards, thus resulting in an emission peak in the future. For the HFC blowing agents with unknown applications, emissions from disposal start in 2022 due to the assumed product lifetime of only 20 years.

Detailed activity data for this source category are considered confidential, but are available to reviewers on request.

4.7.2.3. Fire protection (2F3)

No emissions occur in source category 2F3 within Switzerland. The application of HFCs, PFCs and SF_6 in fire extinguishers is prohibited by law.

4.7.2.4. Aerosols (2F4)

Methodology

The Tier 2a emission model for Aerosol / metered dose inhalers is based on a top-down approach using import statistics for HFCs until 2020 (end of Swiss production). The consumption was extrapolated for the time period 2021 to 2022 considering the development of HFC use of former years and the reported consumption of inhalers containing HFC in Switzerland (Carbotech, 2024).

Emission factors

A manufacturing emission factor of 1 % is applied. The model then assumes prompt emissions, i.e. 50 % of the remaining substance is emitted in the first year and the rest in the second year, in line with the 2006 IPCC Guidelines (IPCC 2006).

Activity data

In most aerosol applications, HFCs have been replaced already in the past years. According to the information of companies filling aerosol bottles for use in households, e.g. cosmetics, cloth care and paint, no HFC is being used anymore. For special technical applications – especially metered dose inhalers (MDI) – HFC is still in use. Compared to the total amount of aerosol applied, the HFC use for MDI is considered to be irrelevant.

Activity data are based on import statistics until 2020 and extrapolations for the time period 2021 to 2022 considering the trend of HFC use and literature values on the consumption of inhalers containing HFC in Switzerland. Exports and imports of filled products are not known, but are assumed to be in a similar range until 2020. No exports are assumed after 2020, as the filling of aerosol bottles in Switzerland ended in 2020.

4.7.2.5. Solvents (2F5)

Methodology

HFCs and PFCs have been used as solvents until 2020. Emissions are calculated with a Tier 1a method according to the 2006 IPCC Guidelines on the basis of a top-down approach using import statistics and industry information on the allocation of the imported HFC and PFC amounts for different applications.

The import data as reported to FOEN cover imported substances to be used in Switzerland and Liechtenstein, and are therefore split in proportion of inhabitants of the two countries to avoid double counting.

Emission factors

In line with the 2006 IPCC Guidelines prompt emissions are assumed, i.e. half of the initial amount is emitted in the first year, the other half in the second year.

Activity data

Activity data are based on import statistics. Imports before 2011 were included under solvents. Therefore, the model for allocation of imported PFC volumes was adjusted accordingly for substances related to the electronics industry. Since 2011 imports for semiconductors manufacturing and further etching processes of electronics industry have been registered as separate category in FOEN import statistics.

To avoid double counting with the inventory data of Liechtenstein, the import data reported to FOEN which is assigned to source category 2F5 in the inventory of Switzerland is reduced by 0.5 %. The reduction factor is based on the proportion of inhabitants in these two countries.

The HFC import amount has been decreasing with alternatives of hydrofluorether HFE for the main applications. A complete replacement with HFC-free options is expected for the future.

4.7.2.6. Other applications (2F6)

There are no further applications of substitutes for ozone depleting substances in Switzerland.

4.7.3. Uncertainties and time-series consistency for 2F

For refrigeration equipment, air conditioning equipment as well as for foam blowing, a Monte Carlo analysis according to IPCC Good Practice Guidance (IPCC 2000) for the evaluation of uncertainties of model calculations according to Tier 1 and 2 has been carried out. The Monte Carlo analysis was performed on the inventory data of the latest GHG inventory (submission 2024), using the Cristal Ball Add-in for Excel. For the purpose of the Monte Carlo analysis, the uncertainty of all relevant parameters (e.g. initial appliance charge, product life emission factor, portion of products with HFC or HFC-blends, product lifetime, import and export volumes, etc.) used in the emission models for the applications as per Table 4-50 below has been characterised using the following statistical distributions:

- Triangular distribution (defined by the three parameters: minimum, maximum and most likely value)
- Uniform distribution (same probability for the whole spectrum)
- Normal or lognormal distribution (defined by mean and standard deviation, and, if necessary, additional minimum and maximum cut-off values).

The analysis was carried out with 10’000 cycles. Details on the distributions of parameters used (i.e. type of distribution, minimum, maximum, most likely value) are available from background documents at FOEN (Carbotech 2024).

For the submission 2006 the uncertainty for the import statistic data had been estimated for the first time. Discussions with the persons responsible for data collection in the years 1997–2015 led to the estimations of standard deviation and minimal and maximal values given in Table 4-50. A normal distribution is used in the Monte Carlo analysis and the standard deviation, minimal and maximal values applied to define the probability ranges.

Table 4-50 Estimated uncertainty for the data of the imported substances.

Year	Std. Dev.	Minimal	Maximal	Remarks
Up to 1999	20%	50%	50%	Data can be incomplete or possible double declaration
2000 – 2003	20%	20%	20%	Data can be incomplete or possible double declaration
2004 –	10%	20%	20%	Data can be incomplete or possible double declaration

The probability range of parameters applied in the model calculation is defined based on the variation given in expert interviews and the literature. Table 4-51 illustrate the definition of ranges for the example of commercial refrigeration.

Table 4-51 Assumptions on probability ranges for the example of commercial refrigeration and mobile air conditioning applied in Monte Carlo analysis.

Parameter applied for commercial refrigeration	Likeliest	Minimal	Maximal	Uncertainty range, distribution
Initial charge of product	NR	NR	NR	Not relevant, calculated value
Manufacturing emission factor	0.5%	0.3%	0.8%	Normal distribution, StdDev20%, Min -50%, Max +50%
Prefilled import	25%	25%	25%	Calculated value, based on result of initial charge
Product life emission factor	7.8%	3.9%	11.7%	Normal distribution, StdDev20%, Min -50%, Max +50%
Recharge of product life emissions	80%	60%	100%	Normal distribution, StdDev15%, Min -25%, Max +25%
Product lifetime in years*	8	6	10	Normal distribution, StdDev10%, Min -20%, Max +20%
Charge at end of life	NR	NR	NR	Not relevant, calculated value
Disposal loss emission factor (professional disposal)	10%	5%	15%	Normal distribution, StdDev20%, Min -50%, Max +50%
Professional disposal quote	85%	77%	94%	Normal distribution, StdDev5%, Min -10%, Max +10%

Parameter applied for mobile AC / car	Likeliest	Minimal	Maximal	Uncertainty range, distribution
Initial charge of new product in kg	0.55	0.41	0.69	Lognormal distribution, StdDev15%, Min -25%, Max +25%
Manufacturing emission factor	NR	NR	NR	Not relevant, prefilled import of equipment
Prefilled import	100%	100%	100%	No Swiss production of equipment
Product life emission factor (excluding service losses)	8.5%	6.8%	10.2%	Lognormal distribution, StdDev20%, Min -50%, Max +50%
Recharge of product life emissions	80%	60%	100%	Normal distribution, StdDev15%, Min -25%, Max +25%
Product lifetime in years	15	12	18	Normal distribution, StdDev10%, Min -20%, Max +20%
Charge at end of life	NR	NR	NR	Not relevant, calculated value
Disposal loss emission factor (professional disposal)	10%	5%	15%	Normal distribution, StdDev20%, Min -50%, Max +50%
Professional disposal	60%	45%	75%	Normal distribution, StdDev5%, Min -25%, Max +25%

Table 4-52 summarises the results for the application-specific emission models. The “value 2022” represents the reported emissions in kt CO_2 eq for the specific application for the year 2022. The uncertainty values stem from the Monte Carlo analysis. Detailed data are available from background documents at FOEN (Carbotech 2024).

The uncertainty of the resulting total emissions from source category 2F Product uses as substitutes for ODS is about 20 %. Higher values result for the contributions of sub-categories and for single applications evaluated under 2F1. The calculated refrigerant amount for commercial and industrial refrigeration depends on the consumption of further refrigerant applications. Higher consumption for those applications lead to lower consumption in commercial and industrial applications and vice versa.

Relevant parameters for the building of stock in foam are the PU foam import and export rate of past years and the PU spray first year emission factor. The data base for PU sprays has been significantly improved with effect from the 2007 submission (FOEN 2007). This is attributed to improved models which have been elaborated by the main producer and its blowing agent import firm. However, the following three factors lead to a small amount remaining in the stock with a relative high uncertainty: high import and export rate of PU spray, lacking information on import of PU spray and on propellant used in import products and high uncertainty regarding the emission factor of the first year.

Table 4-52 Summary of results for model parameter “emissions” from Monte Carlo analysis for 2022 data on selected emission sources.

Application	Value 2022 kt CO2-eq.	Average kt CO2-eq.	Median kt CO2-eq.	min. kt CO2-eq.	max. kt CO2-eq.	Uncertainty %
2F1 Refrigeration and air conditioning	1'187	1'221	1218	923	1'657	15
2F2 Foam blowing agents	32	57	50	8	336	285
2F4 Aerosols	13	13	13	4	23	43
Total 2F Product use as substitutes	1'232	1'290	1'281	935	2'016	16

Consistency: Time series for 2F are all considered consistent.

4.7.4. Category-specific QA/QC and verification for 2F

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

The assumptions of decreasing emission factors for the different equipment types under source category 2F1 Refrigeration and air conditioning have been cross-checked with the inventories of Austria and Germany and have been found to be in line with the assumptions made for these inventories.

The FOEN supports a monitoring campaign at the high-altitude research station Jungfraujoch, where various greenhouse gases are measured continuously. The location of the research station normally provides analyses of tropospheric background concentrations. However, under special meteorological conditions, an estimate of Swiss emissions can be derived from the measurements. For five HFCs (HFC-134a, HFC-125, HFC-152a, HFC-143a, HFC-32) and for SF_6 a comparison of the inventory data with the inferred emissions is presented in Annex A6.1. Estimated emissions based on measurements at Jungfraujoch agree fairly well with the emission estimates of HFC-134a, HFC-125, HFC-143a, HFC-32 and of SF_6 of the Swiss greenhouse gas inventory. Larger differences result for less relevant contributions of HFC-152a. The allocations of first year emissions of foam blowing agents to the country of production might be the reason for the observed differences.

4.7.5. Category-specific recalculations for 2F

Recalculations reported in submission 2024:

- 2F1: Changes in portion of different refrigerants used for stationary refrigeration; changes in time period required for the complete elimination of HFC/PFC blends. Correction in the disposal amount, remaining charge at end of life. For further details see Carbotech (2024).
- 2F4: Aerosol in asthma spray, revision of activity data based on literature of asthma spray use in Switzerland (inhalers).

4.7.6. Category-specific planned improvements for 2F

Changes are expected and will be analysed in this area due to the revision of the Chemical Risk Reduction Ordinance and CO_2 compensation programmes (share of products with HFC, recycling of HFC, replacement of HFC).

4.8. Source category 2G – Other product manufacture and use

4.8.1. Source category description

Table 4-53 Key categories of 2G Other product manufacture and use. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Source category 2G Other product manufacture and use is not a key category.

Table 4-54 Specification of source category 2G Other product manufacture and use.

2G	Source category	Specification
2G1	Electrical equipment	Emissions of SF_6 from use in electrical equipment
2G2	SF_6 and PFCs from other product use	Emissions of SF_6 and PFC not accounted in other source categories (i.e. for particle accelerators, soundproof windows, leakage detection, medicinal products, research and laboratory use)
2G3	N_2O from product uses	Emissions of N_2O from the use of N_2O in hospitals; Emissions of N_2O from the use of aerosol cans
2G4	Other	Emissions of NMVOC from domestic solvent use, printing, other solvent and product use as well as emissions of CO_2 resulting from post-combustion of NMVOC in exhaust gases of these sources; Emissions of CO_2, NO_x, CO, NMVOC and SO_2 from use of fireworks; Emissions of N_2O from the production of rock wool; Emissions of NO_x, CO and NMVOC from use of tobacco; Emissions of HFC not accounted elsewhere

4.8.2. Methodological issues

4.8.2.1. Electrical equipment (2G1)

Methodology

Under an agreement with FOEN, the industry association Swissmem is reporting actual emissions of SF_6 on the basis of a mass-balance approach (Tier 3a). The mass balance includes mainly data for the production, installation, operation and disposal of electrical equipment, but included in past years also small amounts of SF_6 for other applications (i.e. research, magnesium foundry). Swissmem is collecting data from its members and is cross-checking the reported SF_6 consumption data with data from importers of SF_6. Installations in operation with electrical equipment containing SF_6 are periodically inspected for leakage, and losses are refilled (topping up). The refilled quantities and any SF_6 charge required during repair are reported as emissions at the time of filling. A product lifetime of 35 years is assumed.

Emission factors

Emission factors for source category 2G1 are based on industry information and are calculated values based on the mass-balance data. The discontinuity in emission factor from 2005 to 2006 data is due to the inspection intervals, optimised data collection and technical optimisation of equipment. The trend for reduced emission factors can be linked to the existing agreement of Swissmem and FOEN on the reduction of SF_6 emissions.

Activity data

Activity data are based on industry information. The wide annual fluctuation of SF_6 emissions from electrical equipment is related to the annual fluctuation of market volumes for such equipment as well as variations in inspection intervals and equipment break-down requiring topping up of SF_6 charge in the equipment. Import declarations obtained for FOEN import statistics are cross-checked regularly in order to eliminate double counting between Swissmem data and other import declarations.

4.8.2.2. SF_6 and PFCs from other product use (2G2)

Methodology

The emissions reported under 2G2 are related to the use of SF_6 for industrial particle accelerators (2G2b), the use of SF_6 for soundproof windows (2G2c) and other PFC and SF_6 use (2G2e). 2G2e summarizes medicinal products, research/analytics and further applications that are not specified (including the unallocated difference in SF_6 emissions based on the FOEN import statistics and the Swissmem mass balance).

Under an agreement with FOEN, the industry association Swissmem is reporting actual emissions of SF_6 from industrial particle accelerators on the basis of a mass-balance approach (Tier 3a).

For 2G2c soundproof windows and 2G2e Other a Tier 2 approach is applied for SF_6. Therefore, the unallocated amount of SF_6 under 2G2e has been modelled assuming applications similar to those in 2G1.

Further evaluations of applications under 2G2e are based on FOEN import statistics and industry data, including applications with direct emissions and applications with banks. No further details are provided due to confidentiality. They are available in the confidential NID for reviewers on request.

Emission factors

For the unallocated amount of SF_6, the emission factor is assumed to be 4 % for manufacturing and 1 % per year during the product life for the remaining amount. The remaining charge is completely emitted at the time of disposal after a lifetime of 40 years. Because of the long lifetime, the disposal emissions are not yet relevant for the results.

For soundproof windows an emission rate of 1 % per year is assumed, including the contribution from broken windows. For the manufacturing an emission factor of 33 % is assumed. However, since 2008, there is no production of windows with SF_6 in Switzerland.

Activity data

Activity data are based on import statistics, Swissmen balances and industry information. For the unallocated amount of SF_6 an export rate of 80 % is assumed similar to electrical equipment 2G1.

No further details are provided due to confidentiality. They are available in the confidential NID for reviewers on request.

4.8.2.3. N_2O from product uses (2G3)

Methodology

Emissions of N_2O from the source category 2G3 occur from the anaesthesia use in hospitals (2G3a Medical applications) and from the use of aerosol cans in households and restaurants (2G3b Other). For both categories a Tier 2 method based on country-specific emission factors for the production/consumption of N_2O is used (IPCC 2006, vol. 3 chp. 8.4).

Emission factors

For source category 2G3a Medical applications the emission factor is calculated based on the amount of N_2O sold for anaesthesia purpose in Switzerland divided by the number of inhabitants. The amount of N_2O sold is derived from annual sales data from the main suppliers from 2005 onwards (EMIS 2024/2G3a Lachgasanwendung Spitäler).

Source category 2G3b Other includes N_2O emissions from whipped-cream makers using gas capsules for private households and restaurants. The emission factor is calculated based on sales data and N_2O content of gas capsules sold in Switzerland divided by the number of inhabitants (EMIS 2024/2G3b Lachgasanwendung Haushalt).

Table 4-55 N_2O emission factors for the source categories 2G3a Medical applications and 2G3b Other.

2G3a Use of N_2O for anaesthesia	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
N_2O	g/inhabitant	43	30	16	13	6.8	3.5	3.8	3.3	2.5	2.3	2.2	2.1	2.0	2.0	1.9
2G3b N_2O from aerosol cans																
N_2O	g/inhabitant	9.0	10	11	11	12	11	11	11	10	10	10	10	10	10	10

Activity data

As the emission factors are expressed in g N_2O per capita, the corresponding activity data for the source categories 2G3a Medical applications and 2G3b Other are the Swiss population (FSO 2023c).

Table 4-56 Activity data for the source categories 2G3a Use of N_2O for anaesthesia and 2G3b N_2O from aerosol cans.

2G3 N_2O from product uses	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
2G3a, 2G3b	inhabitants	6'712'000	7'041'000	7'184'000	7'437'000	7'825'000	8'089'000	8'189'000	8'282'000	8'373'000	8'452'000	8'514'000	8'575'000	8'638'000	8'705'000	8'739'000

4.8.2.4. Other (2G4)

Other solvent use (2G4)

Since the IPCC Guidelines (IPCC 2006, vol. 3, chp. 5.5) refer to the EMEP/EEA guidebook regarding methodologies for estimating NMVOC emissions from solvent use, the respective NFR codes are indicated as reference as well. Within 2G4 Other solvent use, the NMVOC emissions from domestic solvent use (2D3a NFR), printing (2D3h NFR), other solvent use (2D3i NFR) as well as other product use (2G NFR) are reported. Domestic solvent use comprises mainly the use of cleaning agents, detergents, cosmetics and toiletries in private households whereas the other three NFR source categories consist of solvent applications in various production processes and services and the use of solvent-based products in various industrial processes, services and commerce. Domestic solvent use is by far the largest NMVOC emission source of 2G4 Other solvent use. Indirect CO_2 emissions resulting from NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9.

Methodology

For the determination of NMVOC emissions from domestic solvent use (2D3a NFR), printing (2D3h NFR), other solvent use (2D3i NFR) and other product use (2G NFR) a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019) is used. For domestic solvent use, the emissions are based on the products consumed and their solvent content and are calculated in proportion to the Swiss population. For package printing and other printing industry the emissions are based on the ink consumption, for other solvent use mainly on the number of employees and for other product use on the number of employees and products applied or manufactured. Switzerland’s Informative Inventory Report (FOEN 2024b, chp. 4.5.2.1, 4.5.2.8, 4.5.2.9 and 4.6.2.1) contains a detailed description of the country-specific emission factors and activity data of these four NFR source categories.

Post-combustion of NMVOC from other solvent use (2G4)

Due to the obligations of the Ordinance on Air Pollution Control (Swiss Confederation 1985) and Ordinance on the Incentive Tax on Volatile Organic Compounds (Swiss Confederation 1997) several industrial plants use facilities and equipment to reduce NMVOC in exhaust gases and room ventilation output. Often this implies the feeding of air with high NMVOC content into the burning chamber of boilers or other facilities to incinerate NMVOC. These CO_2 emissions from post-combustion of NMVOC are estimated based on industry data and expert estimates (Carbotech 2022a).

Methodology

The CO_2 emissions from post-combustion of NMVOC are calculated by a Tier 2 method using country-specific emission factors. Emissions are calculated based on the amount of NMVOC (and their carbon content) destroyed in the respective combustion facility of more than 100 industrial plants (Carbotech 2022a).

Post-combustion facilities are applied in source categories 2D3a Solvent use (see chp. 4.5.2.2) and 2G4 Other solvent use comprising printing (2D3h NFR), other solvent use (2D3i NFR) and other product use (2G NFR). In 2018, the source category allocation of all post-combustion plants has been verified. For the ten largest facilities (within 2D3a and 2G4), which are responsible for about 70 % of the emissions, the NMVOC quantities and respective carbon contents based on the composition of the solvents were updated annually whereas all the others every five years. For the submission 2022, a complete update of all facilities was carried out by means of a survey of all cantonal air pollution control authorities, in addition, with VOC balances. If no information of the solvent composition was available, mean source category-specific values were applied for the carbon content.

Not all facilities have been in use for the entire period 1990–2022. There was a significant increase in total number of facilities from 32 in the year 1990 to 115 in 2002. Since then, the number fluctuates around 120.

These amounts of NMVOC eliminated by post-combustion are also declared in the respective VOC balances of the industrial plants and are thus not included as NMVOC emissions. When deriving the NMVOC emission factors for these source categories, the amount of NMVOC destroyed in post-combustion facilities is taken into account, i.e. the NMVOC emission factor is reduced accordingly.

Emission factors

CO_2 emission factors are derived based on the composition of the solvents (carbon content) destroyed in each post-combustion installation. For the ten most important installations (within 2D3a and 2G4), amount and composition of solvents destroyed were updated annually whereas for all others at least every five years. In between the values were kept constant (see Table 4-57). For installations with no information on the solvent composition, mean industry-specific values are applied. The emission factors given in Table 4-57 are (source category specific) implied emission factors that depend both on carbon content and respective amount of the destroyed NMVOC. Thus, the implied emission factors of source categories with large post-combustion facilities may vary significantly over the years, due to changes in solvent compositions and amounts, starting-up or shutting down of facilities, etc.

Table 4-57 CO_2 emission factors for post-combustion of NMVOC in 2G4 Other.

2G4 Other	**Unit**	**CO_2**														
Post-combustion of NMVOC		**1990**	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Printing (2D3h NFR)	t/t NMVOC	2.25	2.20	2.17	2.14	2.14	2.14	2.15	2.09	2.10	2.10	2.09	2.10	2.00	2.00	2.00
Other solvent use (2D3i NFR)	t/t NMVOC	1.97	1.96	1.96	1.94	1.95	2.00	2.05	2.27	2.27	2.27	2.27	2.27	2.49	2.49	2.49
Other product use (2G NFR)	t/t NMVOC	1.30	1.60	1.64	1.71	1.90	1.77	1.74	1.67	1.71	1.69	1.75	1.79	1.83	1.83	1.83

Activity data

Activity data are the amounts of NMVOC destroyed in post-combustion installations and are provided by the industry, VOC balances and cantonal air pollution control authorities. For the ten most important installations (within 2D3a and 2G4), they were updated annually whereas for all others at least every five years.

Table 4-58 Activity data of NMVOC post-combustion in 2G4 Other.

2G4 Other	Unit	1990	1995	2000	2005	2010
Post-combustion of NMVOC						
Printing (2D3h NFR)	t NMVOC	2'188	9'357	11'276	13'036	13'414
Other solvent use (2D3i NFR)	t NMVOC	288	474	530	395	554
Other product use (2G NFR)	t NMVOC	412	1'034	1'217	939	688

2G4 Other	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Post-combustion of NMVOC											
Printing (2D3h NFR)	t NMVOC	14'424	13'752	14'112	14'477	15'661	15'292	15'423	14'732	14'732	14'732
Other solvent use (2D3i NFR)	t NMVOC	583	364	368	360	352	344	336	58	58	58
Other product use (2G NFR)	t NMVOC	996	1'046	1'086	1'097	1'255	1'224	1'237	1'154	1'154	1'154

Other product use (2G4)

In addition to NMVOC emissions from the use of solvent-based products in industrial processes, services and commerce, emissions of CO_2, NO_x, CO and SO_2 as well as of NO_x, CO and NMVOC from the use of fireworks and tobacco, respectively, are reported in source category 2G4 Other product use (2G NFR).

Since the emissions of CO and NMVOC from tobacco use are of biogenic origin, they are not considered for calculation of indirect CO_2 emissions. Thus, indirect CO_2 emissions resulting from CO emissions from use of fireworks only are included in CRT Table6 as documented in chp. 9.

Methodology

The emissions are determined by a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019) using country-specific emission factors. For tobacco use a description of the country-specific emission factors and activity data is given in Switzerland's Informative Inventory Report (FOEN 2024b, chp. 4.6.2).

Emission factors

The emission factors for CO_2, NO_x, CO and SO_2 from the use of fireworks are documented in FOEN (2014p) and are displayed in Table 4-59.

Table 4-59 Emission factors for CO_2, N_2O, NO_x, CO, SO_2 for source category 2G4 Use of fireworks and 2G4 Rock wool production in 2022.

2G4 Other	Unit	CO_2	N_2O	NO_x	CO	SO_2
Other product use (2G NFR)						
Fireworks	kg/t	43	NA	0.26	7.4	4.1
Rock wool production	g/t	NA	C	NA	NA	NA

Activity data

Activity data for the use of fireworks are annual sales figures based on import statistics (until 2009, EMIS 2024/2G4 Feuerwerke) and the statistics of the Swiss federal office for police (FEDPOL 2023).

Table 4-60 Activity data for source category 2G4 Use of Fireworks and Rock wool production.

2G4 Other	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Other product use (2G NFR)						
Fireworks	kt	0.84	1.0	1.5	1.4	1.7
Rock wool production	kt	C	C	C	C	C

2G4 Other		**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Other product use (2G NFR)											
Fireworks	kt	2.3	1.8	1.6	1.2	1.7	1.8	1.0	1.0	1.5	1.9
Rock wool production	kt	C	C	C	C	C	C	C	C	C	C

Rock wool production (2G4)

In connection with the updating of allocations under the 3rd commitment period of the Swiss Emissions Trading Scheme (ETS), it became apparent that nitrous oxide is also emitted during rock wool production. It seems that nitrous oxide is produced in the curing process due to the high temperatures. The binder used in the production process is assumed to be the source of the nitrogen. Small amounts of nitrous oxide are apparently also released from the cupola furnace process. These process emissions are now reported in the annual monitoring report of the Swiss Emission Trading System.

Methodology

The N_2O emissions from rock wool production are determined by an approach analogous to a Tier 2 method using a country-specific emission factor.

Emission factor

The N_2O emission factor is based on analyses and estimates of nitrous oxide emissions in various European rock wool plants. It is assumed that the emission factor is constant over the entire period. The data (Table 4-59) are confidential but available to reviewers.

Activity data

Activity data on annual production of rock wool are provided annually by the Swiss production plant for the entire time period. Since 2013, activity data are taken from annual ETS monitoring reports. The data (Table 4-60) are confidential but available to reviewers (see EMIS 2024/2G4 Steinwolle-Imprägnierung).

HFC not accounted in other source categories (2G4)

Emissions of HFC not accounted for in any other source categories are reported under 2G4 Other. For confidentiality reasons, no further details are provided here. Information is documented in the confidential NID.

Methodology

A Tier 2 approach is applied for HFCs with prompt emissive applications based on import statistics.

Emission factors

Prompt emissions of HFC are calculated following the IPCC Guidelines assuming a total loss of product within two years (50 % loss in the first and 50 % in the second year) (IPCC 2006).

Activity data

HFC activity data under 2G4 are based on FOEN import statistic and company data.

4.8.3. Uncertainties and time-series consistency for 2G

The uncertainty of total CO_2 emissions from the entire source category 2G4 is obtained assuming 10 % uncertainty for the activity data (expert estimate) and 20 % uncertainty for the emission factor (expert estimate).

The uncertainty of N_2O emissions from source category 2G3 is estimated at 80 % (expert estimate, see Table 1-8).

For N_2O in source category 2G4 Rock wool production, the uncertainty of the activity data is estimated to be 1 % and the uncertainty of the emission factor 40 % (expert estimate).

The uncertainty of SF_6, HFC and PFC emissions in source category 2G is estimated based on a Monte Carlo analysis and reported in Table A – 2 of Annex A2.1. Further details are available from background documents, confidential/internal excel calculations and the respective report (Carbotech 2024).

Time series is consistent, with exception of the source category 2G2 Electrical equipment where from the year 2000 onwards the data are based on a Tier 3a approach instead of model calculations according to Tier 2 as applied for data before the year 2000. Due to lack of basic information it is not possible to provide a consistent time series for category 2G2 Electrical equipment retroactively.

4.8.4. Category-specific QA/QC and verification for 2G

The general QA/QC measures are described in chp. 1.5.

For SF_6, measurements at Jungfraujoch are used to estimate Swiss emissions for verification purposes (see chp. 4.7.4 and Annex A6.1). Estimated emissions based on measurements at Jungfraujoch agree within uncertainties with the emissions from the inventory.

4.8.5. Category-specific recalculations for 2G

The following recalculations were implemented in submission 2024. Major recalculations which contribute significantly to the total differences emissions of sector 2 IPPU between the latest and the previous submissions are presented also in chp. 10.1.2.2.

- 2G4: The activity data of source category 2G4 Other product use, fireworks, has been updated for the year 2021 due newly available statistics data. This results in an emission increase of +30 %.
- 2G4: Other (confidential), SF_6, HFC-134a.

4.8.6. Category-specific planned improvements for 2G

No category-specific improvements are planned.

4.9. Source category 2H – Other

4.9.1. Source category description

Table 4-61 Key categories of 2H Other. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Source category 2H Other is not a key category.

Table 4-62 Specification of source category 2H Other in Switzerland.

2H	Source category	Specification
2H1	Pulp and paper	Emissions from NMVOC from pulp and paper including chipboard, fibreboard and cellulose production (ceased in 2008)
2H2	Food and beverages industry	Emissions of CO and NMVOC from production of food and drink
2H3	Other	Emissions of CO_2, NOx, CO, NMVOC and SO_2 from blasting and shooting

4.9.2. Methodological Issues

4.9.2.1. Pulp and paper (2H1)

Methodology

In 2022, the production of chipboard and fibreboard are the relevant industrial processes in the source category 2H1 Pulp and paper. In Switzerland, chipboard and fibreboard were produced in one and two plants, respectively, until 2019. Since 2020 only one plant is left. The cellulose production was closed down in 2008 and is not occurring anymore in Switzerland. The NMVOC emissions are calculated by a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019) using country-specific emission factors.

Indirect CO_2 emissions resulting from NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9.

Emission factors

The emission factor for NMVOC emissions from pulp and paper production in Switzerland is country-specific and based on measurements and data from industry and expert estimates documented in EMIS 2024/2H1. The implied emission factor given in Table 4-63 is production-weighted and related to chipboard and fibreboard production. It is confidential but available to reviewers on request.

Table 4-63 Emission factors for CO and NMVOC in pulp and paper production and food and beverages industry, CO_2, NO_x, CO, NMVOC and SO_2 from blasting and shooting for 2022.

2H Other	Unit	CO_2	NO_x	CO	NMVOC	SO_2
2H1 Pulp and paper	g/t	NA	NA	NE	C	NE
2H2 Food and beverage industry (exc. beer, wine, spirits)	g/t	NA	NA	250	2'180	NA
2H2 Food and beverage industry (beer, wine, spirits)	g/m^3	NA	NA	NA	330	NA
2H3 Blasting and shooting	kg/t	400	35	310	60	0.5

Activity data

The annual amount of pulp and paper produced in Switzerland is based on data from industry and expert estimates documented in EMIS 2024/2H1. Due to the production structure in Switzerland, i.e. one production site for cellulose (ceased in 2008), one for chipboard and two for fibreboard (one ceased in 2019), only the sum of the production volume of 2H1 Pulp and paper industry is provided, and since 2020 activity data are confidential. Detailed data can be accessed by reviewers on request.

Table 4-64 Pulp and paper production, food and beverages production and amount of explosives used.

2H Other	Unit	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2H1 Pulp and paper	kt	604	593	641	693	602	510	516	519	503	507	502	460	C	C	C
2H2 Food and beverage industry (exc. beer, wine, spirits)	kt	2'249	2'114	2'300	2'134	2'397	2'413	2'533	2'473	2'471	2'492	2'455	2'479	2'421	2'478	2'465
2H2 Food and beverage industry (beer, wine, spirits)	m3	538'458	482'064	479'352	452'392	464'064	446'622	443'806	444'195	433'285	435'426	457'265	464'866	437'731	430'891	458'157
2H3 Blasting and shooting; blasting agent and powder	kt	2.6	1.3	1.9	0.79	2.4	2.2	2.1	2.1	0.67	0.73	0.81	0.67	0.63	0.61	0.65

4.9.2.2. Food and beverages industry (2H2)

Methodology

Production of beverages comprises wine, beer and spirits and food industry comprises production of bread, sugar, smoked meat, roasting of coffee and the milling industry. The CO and NMVOC emissions from food and beverages industry are calculated by a Tier 2 method according to the EMEP/EEA guidebook (EMEP/EEA 2019) using country-specific emission factors. Since these CO and NMVOC emissions are of biogenic origin, they are not considered for calculation of indirect CO_2 emissions.

Emission factors

The emission factors for CO and NMVOC emissions from food and beverages industry are country-specific and based on measurements and data from industry and expert estimates as documented in the EMIS database (EMIS 2024/2H2). The implied emission factors are production-weighted (Table 4-63).

Activity data

The annual amount of food and beverages produced is based on data from industry and the farmers’ association (SBV) and expert estimates as documented in EMIS 2024/2H2 (Table 4-64).

4.9.2.3. Other (2H3)

Methodology

For determination of emissions of CO_2, NO_x, CO, NMVOC and SO_2 from blasting and shooting, an analogous Tier 2 method with country-specific emission factors is used as documented in the EMIS database (EMIS 2024/2H3 Sprengen und Schiessen).

Indirect CO_2 emissions resulting from CO and NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9.

Emission factors

The emission factors for CO_2, NO_x, CO, NMVOC and SO_2 from blasting and shooting activities are country-specific and based on measurements and data from industry and expert estimates (see Table 4-63).

Activity data

The annual amount of used explosives is based on the Federal statistics on explosives (FEDPOL 2023) (Table 4-64).

4.9.3. Uncertainties and time-series consistency for 2H

The uncertainty for CO_2 emissions from 2H3 Other is estimated to be 8 % (expert judgement) since activity data are taken from customs statistics.

Consistency: Time series for 2H Other are all considered consistent.

4.9.4. Category-specific QA/QC and verification for 2H

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

4.9.5. Category-specific recalculations for 2H

There were no recalculations implemented in submission 2024.

4.9.6. Category-specific planned improvements for 2H

No category-specific improvements are planned.

5. Agriculture

Responsibilities for sector Agriculture	
Overall responsibility, author	Daniel Bretscher (Agroscope)
Sector experts (including QC)	Christoph Ammann (Agroscope), Thomas Kupper (HAFL), Chloé Wüst-Galley (Agroscope; QC)
EMIS database operation	Sabine Schenker (FOEN)
Technical contributors (including QC)	Dominik Eggli (Meteotest), Fabio Fasel (Meteotest)
Annual updates (NID text, tables, figures)	Daniel Bretscher (Agroscope)
Internal review	Michael Bock (FOEN)

5.1. Overview

This chapter provides information on the estimation of the greenhouse gas emissions from the sector Agriculture. The following categories are reported:

- 3A Enteric fermentation, CH_4 emissions from domestic livestock.
- 3B Manure management, emissions of CH_4, N_2O and NO_x
- 3D Agricultural soils, emissions of N_2O, NO_x and NMVOC
- 3G Liming, emissions of CO_2
- 3H Urea application; emissions of CO_2

No emissions are reported for 3C Rice cultivation as in Switzerland only a small area is cultivated with upland rice. The categories 3E Prescribed burning of savannahs and 3F Field burning of agricultural residues do not occur in Switzerland and are therefore not reported.

CO_2 emissions from soils are reported under 4 Land use, land-use change and forestry (LULUCF). CO_2 emissions from energy use in agriculture are reported under 1A4c Agriculture/forestry/fishing.

Because CH_4 and NMVOC emissions from the Agriculture sector are of biogenic origin (CO emissions do not occur), from this sector no indirect CO_2 emissions are included in CRT Table 6 as documented in chp. 9.

Total greenhouse gas emissions from the Agriculture sector in 2022 were 5'888 kt CO_2 equivalent which is a contribution of 14.1 % to the total of Swiss greenhouse gas emissions (excluding indirect CO_2, excluding LULUCF, Table 2-5, Table 5-1). Main agricultural sources of greenhouse gases were 3A Enteric fermentation, emitting 61 % of all agricultural greenhouse gases, followed by 3D Agricultural soils with 22 % and 3B Manure management with 16 % (Figure 5-1). EG Liming and 3H Urea application contributed 0.6 % and 0.2 % respectively.

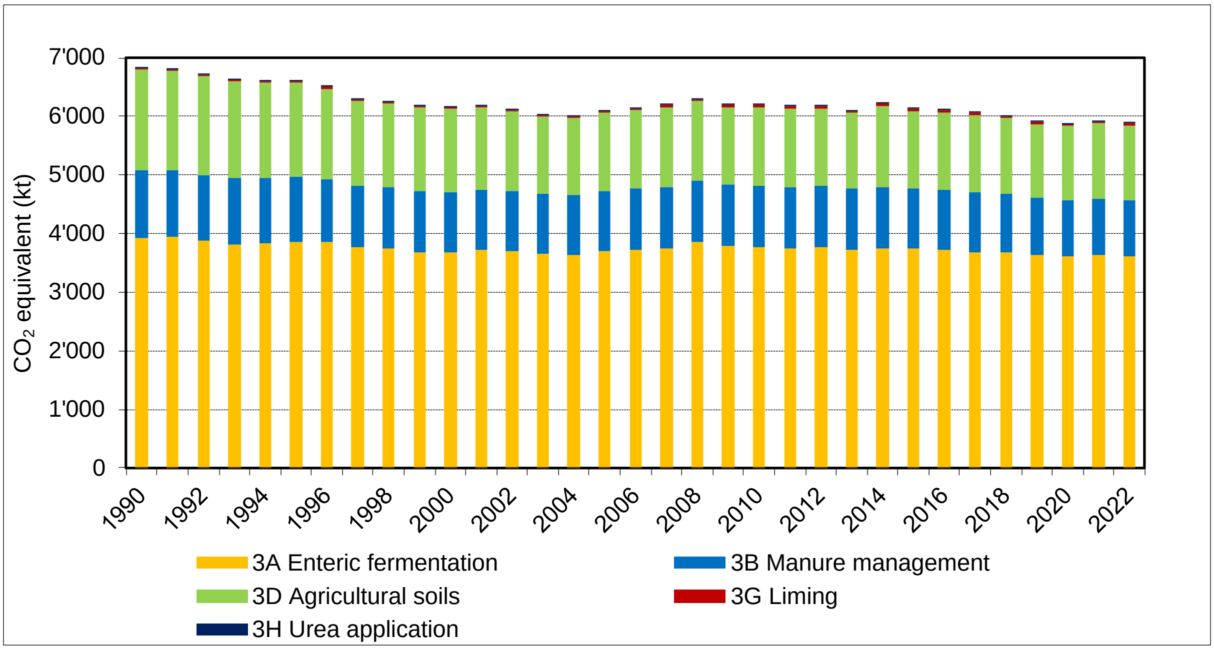

Figure 5-1 Greenhouse gas emissions of the agricultural sector in CO_2 equivalent (kt).

Table 5-1 Greenhouse gas emissions of the agricultural sector in CO_2 equivalent (kt).

Gas	1990	1995	2000	2005	2010
	CO_2 equivalent (kt)				
CO_2	49	42	39	42	44
CH_4	4'707	4'607	4'362	4'375	4'449
N_2O	2'097	1'966	1'763	1'682	1'711
Sum	6'852	6'615	6'164	6'100	6'205

Gas	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	CO_2 equivalent (kt)									
CO_2	42	46	45	47	48	46	45	45	46	44
CH_4	4'404	4'435	4'420	4'388	4'346	4'335	4'264	4'232	4'248	4'233
N_2O	1'654	1'751	1'670	1'687	1'680	1'632	1'603	1'606	1'631	1'611
Sum	6'100	6'231	6'135	6'122	6'074	6'014	5'913	5'883	5'925	5'888

CH_4 and N_2O emissions generally declined from 1990 until 2004 (Figure 5-2). Subsequently CH_4 emissions increased slightly until 2008 and decreased again afterwards. N_2O emissions remained more or less on a constant level since 2004 with a decreasing trend in the last years. This general development can be explained by the development of the cattle population and the input of mineral fertilisers. Use of mineral fertiliser declined due to the introduction of the “Proof of Ecological Performance (PEP)” in the early 1990s (Agroscope 2019a, Leifeld and Fuhrer 2005), while the cattle population was influenced by the market situation, the milk quotation system (suspended in 2009) and the general agricultural policy- and subsidy-system (OECD 2022). Most emission factors did not change significantly over the inventory years. CO_2 emissions display high year to year variability due to variability of urea application, which depends among others on the relative price levels of different industrial fertilisers.

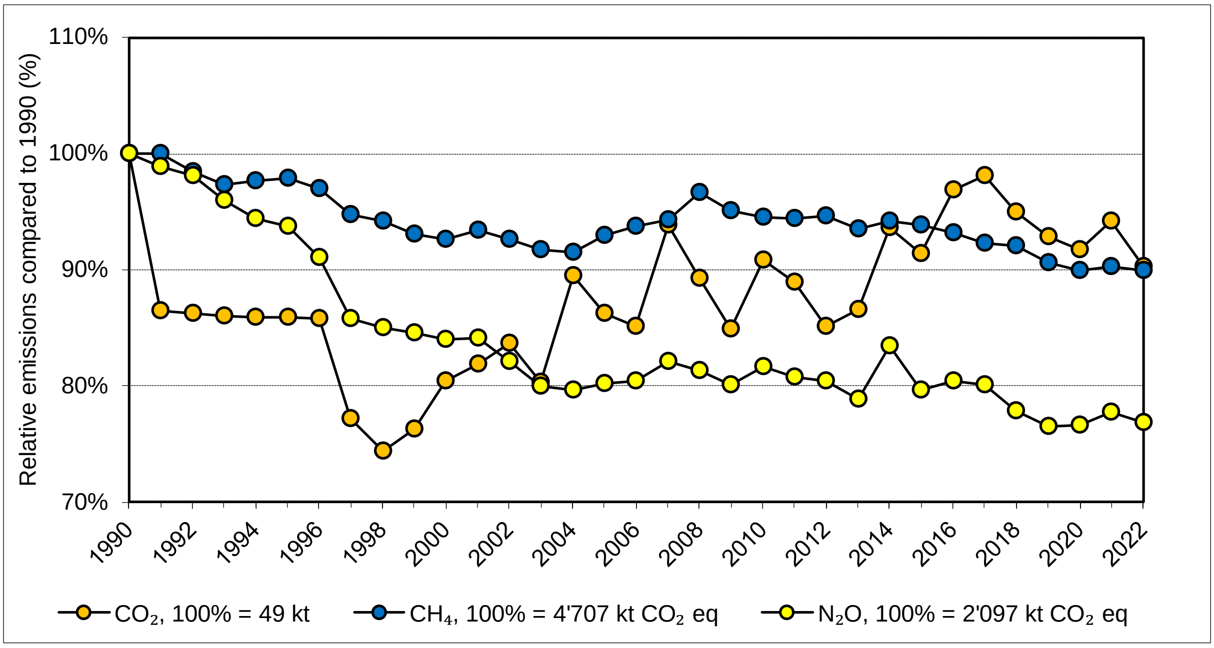

Figure 5-2 Relative trends of the greenhouse gas emissions of sector 3 Agriculture. The base year 1990 represents 100 %.

Among the key categories of the Swiss inventory, six are from the agricultural sector (Figure 5-3).

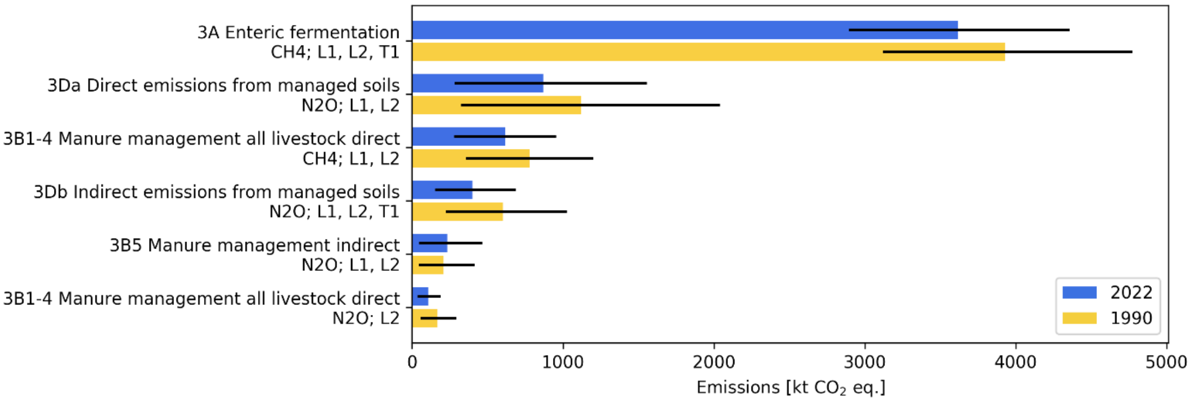

Figure 5-3. Key categories in the Swiss GHG inventory from sector 3 Agriculture determined by the key category analyses, approaches 1 and 2. Categories are set out in order of decreasing emissions in 2022. L1: key category according to approach 1 level in 2022; L2: same for approach 2; T1: key category according to approach 1 trend 1990–2022; T2: same for approach 2. Black uncertainty bars represent the narrowest 95 % confidence interval obtained by Monte Carlo simulations (see chp. 1.6 for details).

5.2. Source category 3A – Enteric fermentation

5.2.1. Source category description

Table 5-2 Key categories of 3A Enteric fermentation. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	**IPCC category**	**Gas**	**Identification criteria**
3A	Enteric fermentation	CH4	L1, L2, T1

This emission source comprises the domestic livestock population broken down into 3 cattle categories (mature dairy cattle, other mature cattle, growing cattle), sheep, swine, buffalo, camels, deer, goats, horses, mules and asses, poultry, rabbits and livestock not covered by the agricultural census (livestock NCAC) (Table 5-3).

Emissions from 3A Enteric fermentation declined from 1990 until 2004, mainly due to a reduction in the number of cattle. However, between 2004 and 2008 cattle livestock numbers and subsequently CH_4 emissions increased, whereas since 2008 they were decreasing again.

Cattle contribute over 90 % to the overall emissions from 3A Enteric fermentation and the contribution of mature dairy cattle is around 60 %.

Emissions from fur-bearing animals are not occurring in Switzerland as provisions for the husbandry of wild animals are very strict according to the Swiss Animal Welfare Act (Swiss Confederation 2003). This is true for the whole inventory time period as the first version of the law dates back to 1978. Consequently, fur farming is not economically viable in Switzerland. In addition, fur animals (other than rabbits) are not included in national livestock data.

Table 5-3 Specification of source category 3A Enteric fermentation.

3A	Source	Specification
3A1	Cattle	Mature Dairy Cattle
		Other Mature Cattle
		Growing Cattle (Fattening Calves[1], Pre-Weaned Calves, Breeding Cattle 1st year (Breeding Calves + Breeding Cattle 4-12 months), Breeding Cattle > 1 year, Fattening Cattle (Fattening Calves 0-4 months[2], Fattening Cattle 4-12 months))
3A2	Sheep	Lambs < 1 year
		Mature Sheep
3A3	Swine	
3A4a	Buffalo	Bisons < 3 years[3]
		Bisons > 3 years[3]
3A4b	Camels	Llamas < 2 years
		Llamas > 2 years
		Alpacas < 2 years
		Alpacas > 2 years
3A4c	Deer	Fallow Deer
		Red Deer
3A4d	Goats	
3A4e	Horses	Horses < 3 years
		Horses > 3 years
3A4f	Mules and Asses	Mules
		Asses
3A4g	Poultry	
3A4h i	Rabbits	
3A4h ii	Livestock NCAC	Sheep
		Goats
		Horses < 3 years
		Horses > 3 years
		Mules
		Asses

[1] Fattening for veal with a milk based diet (slaughtere at ap. 100 days). See chp. 5.2.2.3.

[2] Fattening for beef meat (slaughtered at ap. 400 days). See chp. 5.2.2.3.

[3] Bisons (Bos bison and/or Bos bonasus). Water buffalos (Bubalus bubalis) are included under cattle. See chp. 5.2.2.3.

5.2.2. Methodological issues

5.2.2.1. Methodology

For mature dairy cattle a detailed Tier 3 model approach is applied, predicting gross energy intake by the means of a feeding model that takes into account animal performance and diet bio-chemical composition. A country-specific methane conversion rate (Y_m) was derived from a series of studies representing Swiss specific feeding conditions.

Emission estimation for all other cattle categories follows a Tier 2 approach. This means that detailed country-specific data on nutrient requirements and feed intake were used. CH_4 conversion rates were taken from the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019).

Methods for all other animal categories are based on a Tier 2 approach, estimating country-specific energy intake rates. Methane conversion rates were taken from the 2019 Refinement (IPCC 2019), the 2006 IPCC Guidelines (IPCC 2006) or from published peer reviewed literature.

The calculation of CH_4 emissions is done by Agroscope, the Swiss centre of excellence for agricultural research (Agroscope 2024).

5.2.2.2. Emission factors

All emission factors for 3A Enteric fermentation are country-specific, based on IPCC equation 10.21 (IPCC 2019):

$$EF = \frac{GE * (Y_m \div 100) * 365\, days / y}{55.65\, MJ / kg\, CH_4}$$

EF = annual CH_4 emission factor (kg/head/year)

GE = gross energy intake (MJ/head/day)

Y_m = methane conversion rate, which is the fraction of gross energy in feed converted to methane (%)

55.65 MJ/kg = energy content of methane.

5.2.2.2.1. *Gross energy intake (GE)*

For calculating the gross energy intake (GE), country-specific methods based on available data on requirements of net energy, digestible energy and metabolizable energy were used. The different energy levels used for energy conversion from energy required for maintenance and production to GE intake are illustrated in Figure 5-4. The respective conversion factors are given in Table 5-4.

For the **cattle categories** detailed estimations for energy requirements are necessary. As the Swiss Farmers Union (SBV) does not provide these estimates on a detailed cattle sub-category level, requirements for each cattle category were calculated individually following the feeding recommendations for Switzerland provided in RAP (1999) and Morel et al. (2017). These RAP recommendations are also used by the Swiss farmers as the basis for their cattle feeding regimes and for filling in application forms for direct payments; they are therefore highly appropriate.

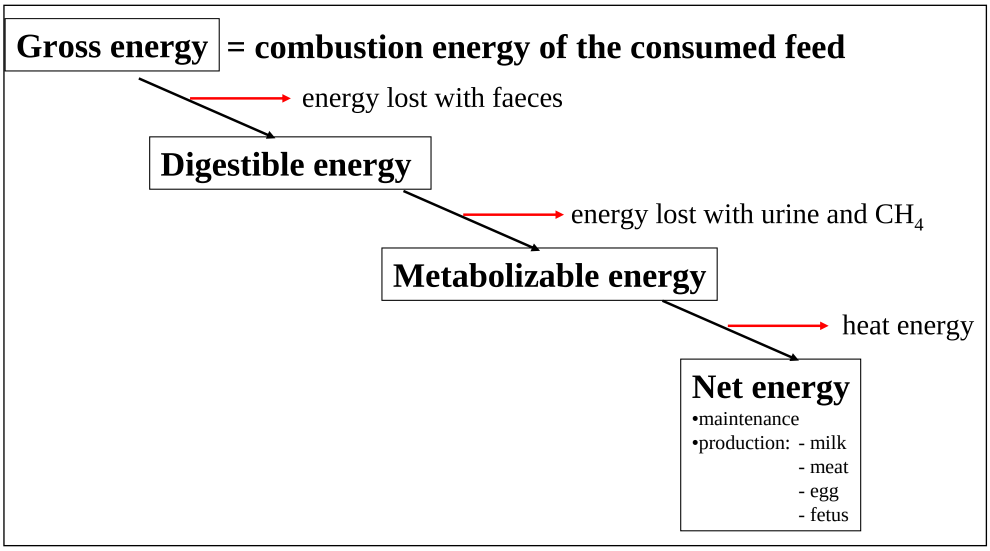

Figure 5-4 Levels of feed energy conversion (Soliva 2006).

Table 5-4 Conversion factors used for calculation of energy requirements of individual livestock categories (Soliva 2006). GE: Gross energy; DE: Digestible energy; ME: Metabolisable energy; NEL: Net energy for lactation; NEV: Net energy for growth. Blue: annually changing parameters, value for 2022.

Livestock Category		**Conversion Factors**	
Mature Dairy Cattle		NEL to GE	0.341
Other Mature Cattle		NEL to GE	0.263
Growing Cattle	*Fattening Calves*	*ME to GE*	*0.939*
	Pre-Weaned Calves	*NEL to GE*	*0.299*
	Breeding Calves	*NEL to GE*	*0.358*
	Breeding Cattle (4-12 months)	*NEL to GE*	*0.319*
	Breeding Cattle (> 1 year)	*NEL to GE*	*0.313*
	Fattening Calves (0-4 months)	*NEV to GE*	*0.355*
	Fattening Cattle (4-12 months)	*NEV to GE*	*0.397*
Sheep	*Fattening Sheep*	*NEV to GE*	*0.350*
	Milksheep	*NEL to GE*	*0.287*
Swine		DE to GE	0.682
Buffalo		NA	NA
Camels and Llamas		NA	NA
Deer		NA	NA
Goats		NEL to GE	0.283
Horses		DE to GE	0.700
Mules and Asses		DE to GE	0.700
Poultry		ME to GE	0.700
Rabbits		NA	NA
Livestock NCAC		NA	NA

For **mature dairy cattle** a detailed feeding model from the Agroscope department for Livestock Sciences was used to predict gross energy intake (Agroscope 2014c).

Energy and protein requirements were estimated based on animal performance (body weight, milk production, pregnancy) following the standard feeding recommendations for Switzerland (RAP 1999). Live weight was estimated based on statistics of carcass weight according to Burren et al. (2021). Live weight increased more or less linearly from 637 kg in 1990 to 679 kg in 2022. Statistics of annual milk production are provided by the Swiss Farmers Union (SBV 2023, Table 5-5). Milk production includes marketed milk, milk consumed by calves on farms and milk sold outside the commercial industry (MISTA 2023). It should be noted that daily milk yield refers to milk production during the whole year (365 days) and not during lactation only (305 days). During the dry months additional energy requirements for pregnancy were accounted for.

To cover total animal energy and protein requirements, typical Swiss specific basic feed rations were defined as model inputs. The average basic feed ration in summer consisted of 92 % fresh grass and 8 % maize cubes. In winter the feed ration consisted of 10 % maize silage, 13 % grass silage, 72 % hay and 5 % fodder beet. Concentrates are automatically supplemented in the model according to additional energy and protein requirements not covered by the basic feed ration. Concentrates consisted of a varying mixture of barley grains, wheat grains, maize grains, maize gluten, soybean meal and rapeseed meal according to specific animal requirements.

As suggested by Menzi et al. (2016) all calculations of feed intake and excretions rates for mature dairy cattle are based on the average between the model results of one first lactation (primiparous) and two subsequent lactations. The feed requirements for the additional weight gain during the first lactation is included in the equations to estimate feed intake as these equations are directly derived from feeding experiments.

Average bio-chemical composition and properties of the total feed ration (e.g. energy content, protein content, digestibility) were derived accounting for one first and two subsequent lactations as mentioned above, and weighing the respective values of the individual feed ingredients given in the Swiss Feed Database (Agroscope 2014b). Finally, gross energy intake was estimated based on the total feed intake and the gross energy content of the total ration that was 18.26 MJ/kg on average for the years 1990–2022.

In the year 2003 yearly milk yield surpassed 6000 kg per head. To achieve yearly milk yields higher than 6000 kg, cows have to be fed with an increasing share of feed concentrates that have a substantially higher net energy (NE) density than the basic feed ration. The model reproduces this behaviour. Due to the increasing ratio of net energy to gross energy the increase of gross energy intake is slower after the year 2003 although milk yield increases more or less at the same rate (Table 5-6).

A more exhaustive model description is contained in Agroscope (2019a).

Table 5-5 Average daily milk production in Switzerland (yearly milk production divided by 365).

Milk Production Cattle		**1990**	**1995**	**2000**	**2005**	**2010**	**2015**
Population Size Mature Dairy Cattle	head	783'100	739'641	669'410	620'708	589'024	583'277
Lactation Period	day	305	305	305	305	305	305
Milk Yield Mature Dairy Cattle	kg/head/day	13.21	14.13	15.57	17.15	18.76	19.32
Milk Yield Other Mature Cattle	kg/head/day	6.85	6.85	6.85	6.85	6.85	6.85

Milk Production Cattle		**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Population Size Mature Dairy Cattle	head	575'766	569'185	564'190	554'588	546'479	545'533	542'927
Lactation Period	day	305	305	305	305	305	305	305
Milk Yield Mature Dairy Cattle	kg/head/day	19.30	19.11	19.53	19.30	19.43	19.77	19.38
Milk Yield Other Mature Cattle	kg/head/day	6.85	6.85	6.85	6.85	6.85	6.85	6.85

For **other mature cattle** and **growing cattle,** data on energy intake were based on the feeding requirements according to RAP (1999) and Morel et al. (2017). In the calculation of the NE data, the animal’s weight, daily growth rate, daily feed intake (dry matter), daily feed energy intake, and energy required for milk production and pregnancy for the respective sub-categories were considered (for more detailed data see Annex A5.3). The method is described in detail in Soliva (2006) but has been revised slightly here. A distinction is made between NE for lactation (NEL) and NE for growth (NEV) (Table 5-4). For some of the growing cattle categories NEL is used instead of NEV, even if NEV would seem appropriate. However, cattle-raising is often coupled with dairy cattle activities and therefore the same energy unit (NEL) is used in these cases. Exceptions are the fattening calves (milk-fed calves), whose requirement for energy is expressed as metabolizable energy (ME).

Table 5-6 Gross energy intake per head of different livestock groups. Sub-categories not contained in the reporting tables (CRT) are displayed in italic. The entire time series at a livestock sub-category level is provided in a separate spreadsheet (Agroscope 2024a).

Gross Energy Intake		**1990-2015**					
		1990	**1995**	**2000**	**2005**	**2010**	**2015**
		MJ/head/day					
Cattle							
Mature Dairy Cattle		255.2	265.0	279.2	294.1	302.4	305.7
Other Mature Cattle		250.6	250.6	250.6	250.6	250.6	250.6
Growing Cattle (weighted average)		103.3	103.9	103.6	101.0	99.8	99.7
	Fattening Calves	*47.1*	*47.1*	*47.1*	*47.1*	*47.1*	*47.1*
	Pre-Weaned Calves	*60.1*	*60.1*	*60.1*	*60.1*	*60.1*	*60.1*
	Breeding Calves	*44.0*	*44.0*	*44.0*	*44.0*	*44.0*	*44.0*
	Breeding Cattle (4-12 months)	*90.1*	*90.1*	*90.1*	*90.1*	*90.1*	*90.1*
	Breeding Cattle (> 1 year)	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*
	Fattening Calves (0-4 months)	*56.9*	*56.9*	*56.9*	*56.9*	*56.9*	*56.9*
	Fattening Cattle (4-12 months)	*126.3*	*126.3*	*126.3*	*126.3*	*126.3*	*126.3*
Sheep		21.2	24.0	22.4	22.8	22.6	22.5
Swine		25.7	26.5	25.1	24.5	24.7	25.4
Buffalo (weighted average)		NA	136.6	146.9	140.6	136.9	134.5
Camels (weighted average)		NA	NA	34.8	31.7	31.0	31.6
Deer (weighted average) 1)		50.5	55.3	56.4	55.4	56.5	58.0
Goats		25.0	27.9	25.7	25.4	25.1	25.5
Horses (weighted average)		107.3	106.9	107.4	107.7	107.9	108.3
Mules and Asses (weighted average)		39.2	39.7	39.5	39.4	40.2	39.6
Poultry 2)		1.2	1.2	1.3	1.1	1.0	1.1
Rabbits		1.2	1.2	1.2	1.2	1.2	1.2
Livestock NCAC (weighted average)		90.2	72.0	32.9	34.3	37.8	39.3

Gross Energy Intake		**2016-2022**						
		2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
		MJ/head/day						
Cattle								
Mature Dairy Cattle		306.3	305.7	308.6	308.1	309.6	311.5	308.5
Other Mature Cattle		250.6	250.6	250.6	250.6	250.6	250.6	250.6
Growing Cattle (weighted average)		99.2	99.0	98.6	98.4	98.0	97.9	97.7
	Fattening Calves	*47.1*	*47.1*	*47.1*	*47.1*	*47.1*	*47.1*	*47.1*
	Pre-Weaned Calves	*60.1*	*60.1*	*60.1*	*60.1*	*60.1*	*60.1*	*60.1*
	Breeding Calves	*44.0*	*44.0*	*44.0*	*44.0*	*44.0*	*44.0*	*44.0*
	Breeding Cattle (4-12 months)	*90.1*	*90.1*	*90.1*	*90.1*	*90.1*	*90.1*	*90.1*
	Breeding Cattle (> 1 year)	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*
	Fattening Calves (0-4 months)	*56.9*	*56.9*	*56.9*	*56.9*	*56.9*	*56.9*	*56.9*
	Fattening Cattle (4-12 months)	*126.3*	*126.3*	*126.3*	*126.3*	*126.3*	*126.3*	*126.3*
Sheep		22.9	23.0	23.3	23.4	23.0	23.0	23.0
Swine		25.8	25.5	25.2	25.5	25.8	25.8	25.8
Buffalo (weighted average)		134.4	133.1	162.8	159.8	159.1	158.4	158.4
Camels (weighted average)		31.2	31.2	31.0	31.2	31.4	31.3	31.2
Deer (weighted average) 1)		58.5	58.8	59.3	59.6	59.6	59.7	60.2
Goats		25.1	25.2	25.1	25.2	25.0	25.0	25.0
Horses (weighted average)		108.4	108.4	108.5	108.5	108.5	108.5	108.5
Mules and Asses (weighted average)		39.6	39.5	38.4	38.4	38.4	38.5	38.5
Poultry 2)		1.0	1.1	1.1	1.0	1.1	1.1	1.1
Rabbits		1.2	1.2	1.2	1.2	1.2	1.2	1.2
Livestock NCAC (weighted average)		40.3	40.4	36.9	37.5	37.5	37.6	37.6

1) Deer: Gross energy intake per animal place (mother with offspring)

2) Poultry data is not gross energy intake (GE) but metabolizable energy intake (ME)

The gross energy intake for other mature cattle is significantly higher than would be suggested by the IPCC (IPCC 2019), since the category “other mature cattle” in Switzerland only includes mature cows that produce offspring for meat (so-called “suckler cows” or “mother cows”). Milk production of other mature cattle is 2'500 kg per head and year (305 days of lactation) and has not changed over the inventory time period (Morel et al. 2017).

The gross energy intake of growing cattle was calculated separately for all sub-categories displayed in Table 5-6 (in italics) and subsequently averaged (weighted average). No methane is generated from milk. Nevertheless, energy intake from milk or milk products is considered when estimating methane emission factors from enteric fermentation of calves. However, the methane conversion rate is adjusted accordingly as explained under chp. 5.2.2.2.2. The energy intake values for all 7 sub-categories are constant over time. Since the composition of the growing cattle category changed over time (e.g. more pre-weaned calves, fewer fattening calves, see Table 5-8), the average gross energy intake for growing cattle also changes slightly. To calculate an annual emission factor, the categories breeding calves and breeding cattle 4-12 months were combined in the category breeding cattle 1st year (not shown in Table 5-6 and Table 5-8). Accordingly, the respective animals have two separate gross energy intake values, i.e. 44.0 MJ/head/day for the first 4 months and 90.1 MJ/head/day for the last 8 months. The same procedure is applied for fattening calves 0–4 months (56.9 MJ/head/day) and fattening cattle 4–12 months (126.3 MJ/head/day) summing up to the category fattening cattle.

Energy requirements and gross energy intake of **sheep**, **swine**, **goats** and **poultry** were obtained from the respective estimates of the Swiss Farmers Union (SBV 2023, Giuliani 2023). These estimates are not officially published anymore in the statistical yearbooks (e.g. SBV 2023) but are still available from background data and are based on the same method as used for energy requirement statistics in earlier years (e.g. SBV 2007).

Gross energy intake for **horses**, **mules and asses** were estimated by Stricker (2012), mainly based on Meyer and Coenen (2002).

Table 5-7 Dry matter and gross energy requirements for buffalo, camels and deer according to Richner and Sinaj (2017).

		DM Intake	**GE Intake**
		kg DM/head/day	MJ/head/day
Buffalo	Bisons < 3 years	4.93	90.99
	Bisons > 3 years	10.68	197.14
Camels	Llamas < 2 years	1.34	24.77
	Llamas > 2 years	2.33	42.97
	Alpacas < 2 years	0.82	15.16
	Alpacas > 2 years	1.51	27.80
Deer [1)]	Fallow Deer	2.74	50.55
	Red Deer	5.48	101.10

[1)] Requirements for deer are assessed per animal place i.e. mother with offspring.

For **buffalo**, **camels** and **deer**, energy intake was derived from data on dry matter intake provided in Richner and Sinaj (2017) (Table 5-7). According to the IPCC Guidelines an energy density of 18.45 MJ*kg^{-1} was used to convert dry matter to gross energy (IPCC 2019).

Energy intake of **rabbits** was estimated by Menzi (2014) based on Schlegel and Menzi (2013).

Finally for **livestock NCAC** the same energy intakes as the respective animal categories in the official census were used.

Final compilation of livestock gross energy intake was conducted in Agroscope (2024). Resulting estimates are provided in Table 5-6 (main categories) and in a separate spreadsheet (Agroscope 2024a, all years and all sub-categories).

5.2.2.2.2. Methane conversion rate (Y_m)

For the methane conversion rate (Y_m), few country-specific data exist. Accordingly, for most animal categories default or literature values were used. Due to its great importance a country-specific Y_m was used for **mature dairy cattle**. A value of 6.9 % was derived from a series of measurements conducted under Swiss specific feeding and husbandry conditions at the Federal Institute of Technology in Zurich (based on data compiled in Zeitz et al. (2012) and additional measurements described in Estermann et al. (2001), Külling et al. (2002) and Staerfl et al. (2012)).

For all **other cattle categories**, **goats** and **buffalo** default values recommended by the IPCC for developed countries in Western Europe were used (IPCC 2019: Tables 10.12, 10.13). For all juvenile cattle consuming milk or milk products (i.e. calves) the methane conversion rate is weighted, assuming a Y_m of zero for milk energy and a Y_m of 6.3 % for all other energy.

For mature sheep an Y_m of 6.5 % was used as suggested for sheep with a dry matter intake higher than 0.8 kg*day^{-1} (IPCC 2019). For lambs <1 year the Y_m values of 4.5 % from the 2006 IPCC Guidelines was adopted (IPCC 2006). Overall Y_m for **sheep** was subsequently weighted according to the population structure. For **camels** and **deers** the same methane conversion rate as for sheep was applied, assuming the same relationship between adult and juvenile animals.

For **swine** a methane conversion rate of 0.6 % was used. This value was suggested by Crutzen et al. (1986) and was confirmed by the compilation of references in Minonzio et al. (1998). For **Horses**, **mules and asses** an Y_m of 2.45 % was used, which corresponds to a methane energy loss of 3.5 % of digestible energy (Vermorel et al. 1997, Minonzio et al. 1998) and a feed digestibility of 70 % (Stricker 2012). For **poultry** a country-specific value (0.16 % of metabolizable energy) was used. This value was evaluated in an in vivo trial with broilers (Hadorn and Wenk 1996). For **rabbits** an Y_m of 0.6 % was applied as suggested in the national GHG inventory of Italy (ISPRA 2020). Finally, as for gross energy intake, the same methane conversion rates as for the respective animals in the official census were used for **livestock NCAC**.

5.2.2.3. Activity data

Livestock population data were obtained from statistics published by the Swiss Farmers Union (SBV 2023) and the Federal Statistical Office (FSO 2023a) (Table 5-8). In 2011 activity data for the time series 1990–2010 were revised and harmonised during a joint effort of the Agroscope Reckenholz-Tänikon Research Station (ART) and the Swiss College of Agriculture (SHL) (ART/SHL 2012).

The category other mature cattle only includes mature cows used to produce offspring for meat.

Emission estimation for growing cattle was conducted at a more disaggregated level than the one displayed in the reporting tables (CRT). The livestock category growing cattle in the reporting tables includes the sub-categories fattening calves, pre-weaned calves, breeding calves, breeding cattle 4–12 months, breeding cattle >1 year, fattening calves 0–4 months and fattening cattle 4–12 months. The two sub-categories of fattening calves are distinguished by their weight at slaughter and their feeding regime. The first sub-category (“fattening calves”) refers to animals raised for veal with a milk-based diet (slaughtered at approximately 100 days) whereas the second sub-category (“fattening calves 0-4 months”) refers to animals fattened for beef meat (slaughtered at app. 400 days). Although not growing cattle in the proper sense, bulls are contained in the categories breeding cattle (>1 year) and fattening cattle (4–12 months) according to their purposes. This disaggregation of the category growing cattle enhances the accuracy of the emission estimation procedure from livestock activities (also refer to chp. 5.3.2.1).

Emission estimation for buffalo, camels, horses, mules and asses and deers was also conducted on a more disaggregated level than displayed in the reporting tables (CRT). Additional data on a livestock sub-category level are contained in in a separate spreadsheet (Agroscope 2024a). The livestock category “buffalo” in the Swiss GHG Inventory contains only bisons (*Bos bison* and/or *Bos bonasus*). Water buffalos (*bubalus bubalis*) are included under cattle. The category “camels” contains only llamas and alpacas.

For the categories "Fattening Pigs over 25 kg" (subcategory of swine) and "Broilers" (subcategory of poultry) adjustments were made in order to correctly consider animal turnover rates (Kupper et al. 2022, FSO 2023b). The values for these subcategories are thus higher here than in the official statistics.

Additional corrections of livestock population statistics implied to ensure time series consistency are described under chp. 5.2.3.

Additionally to official statistical data, population data of livestock not covered by the agricultural census of the Federal Statistical Office were assessed. The respective category “Livestock NCAC” (livestock not covered by agricultural census) consists of sheep, goats, horses and mules and asses held for non-agricultural purposes (e.g. horses for sports and leisure) and/or livestock held by private persons or enterprises that do not fulfil the criteria of an agricultural enterprise. Data for the respective horses, mules and asses were derived from background data of the gross nutrient balance of the Federal Statistical Office (FSO 2023b). For sheep and goats, data from individual cantons having full livestock census were used to estimate the relative share for the whole of Switzerland. The respective estimates were conducted in the course of the elaboration of the gross nutrient balance of the Federal Statistical Office (FSO 2023b).

Table 5-8 Activity data for calculating methane emissions from 3A Enteric fermentation (ART/SHL 2012, SBV 2023, FSO 2023a, FSO 2023b). The complete time series on a livestock sub-category level are provided in a separate spreadsheet (Agroscope 2024a).

Population Size		**1990-2015**					
		1990	**1995**	**2000**	**2005**	**2010**	**2015**
		1'000 head					
Cattle		1'855	1'748	1'588	1'555	1'591	1'554
Mature Dairy Cattle		783	740	669	621	589	583
Other Mature Cattle		12	23	45	78	111	118
Growing Cattle		1'060	986	874	856	891	853
	Fattening Calves	*112*	*102*	*103*	*106*	*114*	*103*
	Pre-Weaned Calves	*10*	*18*	*36*	*62*	*86*	*91*
	Breeding Cattle 1st Year	*346*	*295*	*236*	*222*	*222*	*210*
	Breeding Calves	*214*	*166*	*76*	*75*	*75*	*71*
	Breeding Cattle (4-12 months)	*132*	*129*	*161*	*147*	*146*	*139*
	Breeding Cattle (> 1 year)	*404*	*378*	*352*	*318*	*326*	*308*
	Breeding Cattle 2nd Year	*253*	*239*	*222*	*205*	*215*	*209*
	Breeding Cattle 3rd Year	*151*	*139*	*130*	*113*	*111*	*99*
	Fattening Cattle	*188*	*193*	*147*	*147*	*144*	*142*
	Fattening Calves (0-4 months)	*88*	*82*	*43*	*35*	*34*	*34*
	Fattening Cattle (4-12 months)	*100*	*110*	*105*	*112*	*110*	*108*
Sheep		395	387	421	446	434	395
Swine		1'965	1'739	1'670	1'744	1'750	1'605
Buffalo		0	0	0	0	1	1
Camels		0	0	1	3	6	6
Deer [1)]		0	1	3	4	6	6
Goats		68	53	62	74	83	84
Horses		28	41	50	55	62	55
Mules and Asses		6	8	12	16	20	20
Poultry		7'310	6'656	7'160	8'911	10'629	12'541
Rabbits		61	41	28	25	35	25
Livestock NCAC		16	19	88	89	95	120

Population Size		**2016-2022**						
		2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
		1'000 head						
Cattle		1'555	1'545	1'543	1'525	1'515	1'514	1'525
Mature Dairy Cattle		576	569	564	555	546	546	543
Other Mature Cattle		121	123	125	128	131	135	138
Growing Cattle		859	852	854	842	837	833	845
	Fattening Calves	*107*	*108*	*111*	*110*	*110*	*110*	*112*
	Pre-Weaned Calves	*93*	*96*	*97*	*99*	*102*	*105*	*107*
	Breeding Cattle 1st Year	*211*	*209*	*208*	*201*	*199*	*199*	*203*
	Breeding Calves	*72*	*71*	*71*	*68*	*68*	*68*	*69*
	Breeding Cattle (4-12 months)	*139*	*138*	*137*	*133*	*131*	*131*	*134*
	Breeding Cattle (> 1 year)	*306*	*305*	*302*	*295*	*290*	*290*	*293*
	Breeding Cattle 2nd Year	*209*	*208*	*207*	*204*	*203*	*203*	*204*
	Breeding Cattle 3rd Year	*97*	*98*	*94*	*91*	*87*	*88*	*88*
	Fattening Cattle	*141*	*134*	*136*	*136*	*136*	*130*	*130*
	Fattening Calves (0-4 months)	*33*	*32*	*32*	*32*	*32*	*31*	*31*
	Fattening Cattle (4-12 months)	*107*	*102*	*104*	*104*	*104*	*99*	*99*
Sheep		397	398	403	400	398	398	403
Swine		1'553	1'546	1'501	1'447	1'449	1'470	1'475
Buffalo		1	1	1	0	0	0	0
Camels		6	7	7	7	6	6	7
Deer [1)]		6	6	6	7	7	7	7
Goats		85	88	91	92	90	91	92
Horses		56	56	46	47	47	47	48
Mules and Asses		20	21	34	34	33	33	33
Poultry		13'180	13'207	13'984	14'417	15'213	15'622	15'975
Rabbits		25	22	22	21	19	17	16
Livestock NCAC		113	110	108	103	102	103	101

[1)] Deer: numbers correspond to animal places i.e. mother with offspring.

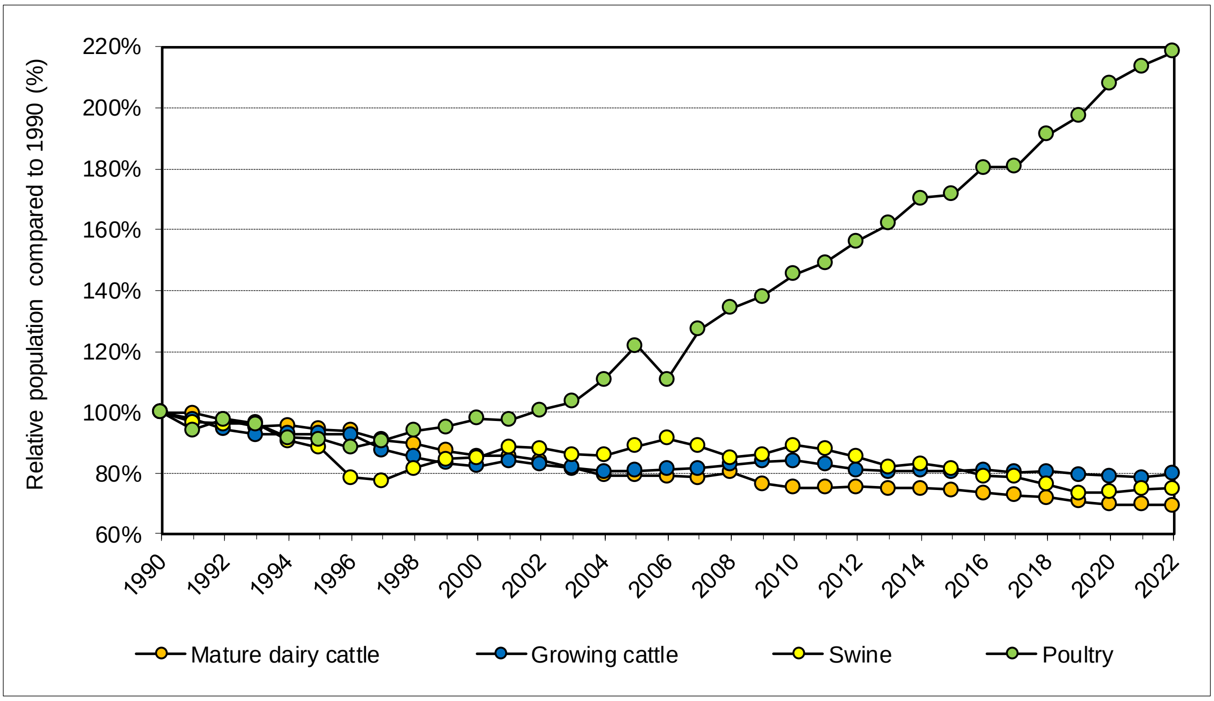

Figure 5-5 Relative development of the populations of main animal categories. The category with the strongest increase, i.e. other mature cattle, is not displayed, as it increases to over 1000 % of the 1990 value by 2022.

Livestock populations in Switzerland are primarily influenced by the general agricultural policy, i.e. the subsidy system, the milk quotation system and the development of the economic framework conditions. Relative development of the populations of main animal categories are shown in Figure 5-5. The number of cattle declined slightly until the year 2004. However, cattle livestock numbers increased between 2004 and 2008, mainly due to an increase of the number of growing cattle. Since 2008 the cattle population was slowly decreasing again, possibly due to the suspension of the milk quotation system in 2009.

After a decrease until 1996, the number of swine increased until 2006 – a process that has been observed in many other European countries (SBV 2004: p. 69). Since then, the number of swine is generally showing a slight decreasing trend with some short-term fluctuations. The number of poultry shows a rapid increase between 1990 and 2022 with a distinct dip only between 2005 and 2006, a consequence of changed human consumption patterns as a result of the avian flu in 2006.

The number of sheep was more or less constant while the number of goats is increasing after a decline between 1990 and 1995.

5.2.3. Uncertainties and time-series consistency for 3A

For the uncertainty analysis the input data from ART (2008a) were used and were updated with the latest activity and emission data as well as with default uncertainties of the 2019 Refinement (IPCC 2019). The detailed input uncertainty values for category 3A are reported in Annex A2.1. The resulting, combined uncertainty for emissions is [-19 %; +21 %] according to approach 1 (uncertainty propagation, Annex A2.2) and [-20 %; +20 %] according to approach 2 (Monte Carlo simulations, Annex A2.3).

The time series 1990–2022 are all considered consistent, although the following issues should be considered:

- Between 1998 and 1999 the questionnaire for the collection of livestock data was modified. In some animal categories this led to minor ruptures in the time series. Consequences for overall emissions are, however, of minor importance. An analysis conducted in 2012 revealed, that while the average annual change for the years 1990–2011 over all animal categories (excluding other mature cattle) was 3.3 % points, the annual change for the years 1998–1999 was 3.8 % points (ART/SHL 2012).
- Since 2009 the population statistics of growing cattle are derived from the animal traffic database (ATD 2023). Aggregation was adapted to the format necessary for the AGRAMMON-model and the GHG inventory by the School of Agricultural, Forest and Food Science (HAFL, Kupper et al. 2022). Data in the animal traffic database are considered more complete than the data from the survey of the FSO because the animal traffic database includes also animals held outside agricultural enterprises.
- Since 2015 the census date for sheep and goats is the 1st of January instead of May as before. This is especially relevant for juveniles as they are usually only born in spring. Accordingly, a rupture in the official time series can be observed. This has been corrected in the GHG Inventory based on background data of the gross nutrient balance of the Federal Statistical Office (FSO 2023b).
- Since 2018 the population statistics of bisons is assessed in the animal traffic database. The age limit between young and adult bisons changed from 3 years (1095 days) to 900 days. This causes a rupture in the time series. This has been corrected in the GHG Inventory based on background data of the gross nutrient balance of the Federal Statistical Office (FSO 2023b).
- Since 2018 the population statistics of horses, mules and asses are assessed in the animal traffic database (ATD 2023). The age limit between young and adult animals changed from 3 years (1095 days) to 900 days. Furthermore, allocation of different breeds to the categories horses, mules and asses changed. Additionally the animal traffic database comprises now all animals, i.e. equids covered by the official agricultural census of the Federal Statistical Office and equids held by private persons or enterprises that do not fulfil the criteria of an agricultural enterprise. To assure time series consistency population statistics of equids were reconditioned by the Federal Statistical Office (FSO 2023b). Nevertheless, small ruptures may still occur particularly due to the assessment of equids not covered by agricultural census. However, influence on the overall emissions is small.
- Gross energy intake and implied emission factors of some of the aggregated animal categories reveal some fluctuations during the inventory period due to varying shares of the sub-categories.
- Gross energy intake as well as the implied emission factor for mature dairy cattle increase, mainly as a result of higher milk production and live weight (Table 5-5).

5.2.4. Category-specific QA/QC and verification for 3A

General QA/QC measures are described in NID chp. 1.5.

All further category-specific QA/QC activities are described in a separate document (Agroscope 2019a). General information on agricultural structures and policies is provided and eventual differences between national and standard values (IPCC 2006, 2019) are being analysed and discussed. Furthermore, comparisons with data from other countries were conducted and discussed where possible. Agroscope (2019a) is periodically updated with the most recent inventory data.

A mutual peer review was conducted with the German GHG inventory group (Fuß et al. 2021). The respective recommendations were implemented as far as possible during the submissions 2022 and 2023.

Livestock data were compared with the livestock data provided by the FAO and checked for plausibility. In all cases the new recalculated data according to ART/SHL (2012) are considered more reliable than the FAO data. Small inconsistencies (usually in the order of ±2 %) are due to updates of provisional data that are not considered by the FAO. For horses, mules and asses disagreements might be due to the different accounting of agricultural and non-agricultural horses. The Swiss inventory system accounts for all animals and differentiates between animals captured by the official agricultural census and livestock not covered by agricultural census. Moreover, the numbers of mules and asses is higher in the Swiss GHG inventory because unlike the FAO, Switzerland accounts also for ponies and lesser horses. For the categories "Fattening Pigs over 25 kg" (subcategory of swine) and "Broilers" (subcategory of poultry) adjustments were made in the GHG inventory in order to correctly consider animal turnover rates (Kupper et al. 2022; FSO 2023b). The values for these subcategories are thus higher than in the official statistics. The total numbers of poultry in the GHG inventory and the FAO data also show minor discrepancies due to different accounting of turkeys, geese, ducks and quails.

Seasonal fluctuation of the cattle population was analysed for the years 2005–2007 based on detailed information from the Swiss Farmers Union (SBV 2007a). Seasonal fluctuations are usually in the order of ±3 % with census data (April) always slightly above the annual mean. Data from the animal traffic database (i.e. cattle populations for the years 2009–2022) refer to annual mean population.

IPCC tables with data for estimating emission factors for cattle (such as weight, weight gain, milk production) were filled in, checked for consistency and confidence and compared with IPCC (2006, 2019) default values (refer to Annex A5.3).

Country-specific energy-intake rates for all cattle categories were compared to intake rates estimated with the IPCC (2006) Tier 2 default methodology (see Agroscope (2019a) for details). Both approaches are comparable in the assessment of net energy requirements. However, the IPCC approach resulted in higher estimates of GE-intake. Further analyses suggest that the IPCC conversion rates of net energy into gross energy are unrealistic for conditions in Switzerland. Given the experimentally verified high feed quality standards in Switzerland, the results of the country-specific inventory method are thus much more plausible than the estimates using the unaltered IPCC (2006) default method. Moreover, a discrepancy of approximatively 5.9 % was found when comparing the overall GE-intake of the cattle population with the respective estimate of the Swiss Farmers Union (Giuliani 2019). As found for the comparison with the IPCC approach, different assumptions on net energy densities of the feed might explain the divergence.

For mature dairy cattle the implied methane emission factor was confirmed by a long-term field study, where methane emissions from a herd of twenty dairy cows were measured over a full grazing season with the eddy covariance method (Felber et al. 2015).

During the past years a couple of studies were conducted to verify methane emissions at the regional scale, comparing bottom-up estimates with atmospheric measurements. While virtually all these measurements are subject to great uncertainties, the overall picture support the bottom-up approach in the Swiss GHG inventory or at least does not indicate the omission of a significant methane source. Hiller et al. (2014a) found that methane emissions might be underestimated by the inventory method when they measured atmospheric CH_4 concentrations over the Reuss-valley with an airplane. However, the methodological approach applied by Hiller et al. (2014a) still relies on a number of rather uncertain basic assumptions and is therefore not beyond doubts. Additionally, it should be noted, that methane emission estimates from the Agriculture sector in the Swiss GHG inventory were revised since, and currently lie approximately 10 % above the estimates used by Hiller et al. (2014a) in their study. Stieger (2013) and Stieger et al. (2015) reported a very good agreement of bottom-up estimates and flux measurements with a tethered balloon system. Bamberger et al. (2014) conducted regional CH_4 measurements with a measurement device mounted on a car. Measurement precision and duration was not sufficient to validate bottom-up inventory estimates. Nonetheless, they concluded that a locally relevant emission source considered negligible in the emission inventory would have been identified. Finally, Henne et al. (2015, 2016, 2017) found a very good agreement between inventory estimates of CH_4 emissions and independent atmospheric measurements over Switzerland. For the years 2017–2023 a different atmospheric transport model version has been used resulting in higher CH_4 emission estimates for the inversion, which will be investigated further (see Annex A6.2).

5.2.5. Category-specific recalculations for 3A

General information on recalculations is provided in chp. 10.

Recalculations with an overall impact of >0.5 kt CO_2 equivalent are assessed quantitatively. All other recalculations are only described qualitatively.

- CH_4 emissions from enteric fermentation of sheep, goats, swine and poultry were recalculated for the years 2019 and 2021. Emission factors were revised due to updated data on net energy requirements from the Swiss Farmers Union (Giualiani et al. 2023). Overall emissions decreased by -1.5 and -0.7 and -0.7 kt CO_2 equivalents for the years 2019, 2020 and 2021.

5.2.6. Category-specific planned improvements for 3A

No category-specific improvements are planned.

5.3. Source category 3B – Manure management

5.3.1. Source category description

Table 5-9 Key categories of 3B Manure management. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	**IPCC category**	**Gas**	**Identification criteria**
3B1-4	Manure management all livestock direct	CH4	L1, L2
3B1-4	Manure management all livestock direct	N2O	L2
3B5	Manure management indirect	N2O	L1, L2

The emission source is the domestic livestock population broken down into 3 cattle categories (mature dairy cattle, other mature cattle, growing cattle), sheep, swine, buffalo, camels, deer, goats, horses, mules and asses, poultry, rabbits and livestock not covered by agricultural census (Livestock NCAC) (Table 5-10). Six (CH_4) respectively five (N_2O) different manure management systems are considered as well as indirect N_2O emissions from 3B Manure management (Table 5-11). Additionally, NO_x and NMVOC emissions from manure management are estimated. In the reporting tables all NO_x emissions are reported under 3D Agricultural soils.

The total emissions from 3B Manure management closely follow the development of the cattle population. Emissions declined from 1990 until 2004, increased until 2008 and subsequently declined slowly until 2015 and somewhat faster until 2020.

Significant contributors to CH_4 emissions from 3B Manure management are cattle with approximatively 65 % and swine with approximatively 31 % on average over the period 1990–2021. Cattle and swine contribute significantly to N_2O emissions with 69 % and 19 %, respectively, on average over the period 1990–2022.

Leaching of NO_3^- from manure management systems is not occurring in Switzerland and is thus not included in the estimates. This assessment is principally based on expert judgement from Thomas Kupper from the “School for Agricultural, Forest and Food Sciences (HAFL)” (Kupper 2014) and based on his personal expertise and on the following literature: Sagoo et al. (2007), Petersen et al. (1998), Webb (2001), Monteny et al. (2006), Oenema et al. (2007) and Chadwick (2005).

Emissions from fur-bearing animals are not occurring in Switzerland as provisions for the husbandry of wild animals are very strict according to the Swiss Animal Welfare Act (Swiss Confederation 2003). See also chp. 5.2.1.

Table 5-10 Specification of source category 3B Manure management by livestock categories.

3B	Source	Specification
3B1	Cattle	Mature Dairy Cattle
		Other Mature Cattle
		Growing Cattle (Fattening Calves[1], Pre-Weaned Calves, Breeding Cattle 1st year (Breeding Calves + Breeding Cattle 4-12 months), Breeding Cattle > 1 year (Breeding Cattle 2nd year + Breeding Cattle 3rd year), Fattening Cattle (Fattening Calves 0-4 months[2] + Fattening Cattle 4-12 months))
3B2	Sheep	Lambs < 1 year
		Mature Sheep
		Fattening Sheep
		Milk Sheep
3B3	Swine	Piglets
		Fattening Pig over 25 kg
		Dry Sows
		Nursing Sows
		Boars
3B4a	Buffalo	Bisons < 3 years[3]
		Bisons > 3 years[3]
3B4b	Camels	Llamas < 2 years
		Llamas > 2 years
		Alpacas < 2 years
		Alpacas > 2 years
3B4c	Deer	Fallow Deer
		Red Deer
3B4d	Goats	Goat Places
3B4e	Horses	Horses < 3 years
		Horses > 3 years
3B4f	Mules and Asses	Mules
		Asses
3B4g	Poultry	Growers
		Layers
		Broilers
		Turkey
		Other Poultry
3B4h i	Rabbits	
3B4h ii	Livestock NCAC	Sheep
		Goats
		Horses < 3 years
		Horses > 3 years
		Mules
		Asses

1) Fattening for veal with a milk based diet (slaughtere at ap. 100 days). See chp. 5.2.2.3.

2) Fattening for beef meat (slaughtered at ap. 400 days). See chp. 5.2.2.3.

3) Bisons (Bos bison and/or Bos bonasus). Water buffalos (Bubalus bubalis) are included under cattle. See chp. 5.2.2.3.

Table 5-11 Specification of source category 3B Manure management by manure management systems.

3B	Source	Specification CH_4		Specification N_2O	
3B6a	Direct Emissions	Liquid systems		Liquid systems --> Pit storage below animal confinement	
3B6b		Solid storage and dry lot		Solid storage and dry lot	
3B6c / 3D		Pasture, range and paddock		NA[1]	
3B6d		Digesters (anaerobic digestion)		Digesters (anaerobic digestion)	
3B6e		Other	Deep litter	Other	Deep litter
			Poultry system		Poultry system
3B5a	Indirect Emissions	NA		Atmospherical deposition	
3B5b		NA		Leaching and run-off	

1) Reported under 3D Agricultural Soils

5.3.2. Methodological issues

5.3.2.1. Methodology

The calculation is based on methods described in the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (CH_4: IPCC 2019 equation 10.23; N_2O: IPCC 2019 equation 10.25).

CH_4 emissions from 3B Manure management were generally estimated using a Tier 2 methodology. For cattle a more detailed Tier 3 method was applied, estimating volatile solids (VS) excretion based on gross energy intake estimates as used for enteric fermentation. VS excretion from sheep, goats, buffalo, camels, horses, mules and asses and deer was equally estimated based on gross energy intake. For swine, poultry and rabbits default parameters were used. Methane conversion factors (MCF) are from IPCC (2019; solid storage, pasture range and paddock, poultry manure), country-specific (deep litter) or were modelled according to Mangino et al. (2001) (liquid systems, anaerobic digesters).

N_2O emissions from 3B Manure management were estimated using a country-specific Tier 3 methodology. Activity data were adjusted to the particular situation of Switzerland in coordination with the Swiss ammonia model AGRAMMON (Kupper et al. 2022). Detailed country-specific data on nitrogen excretion rates, manure management system distribution and nitrogen volatilisation were applied. Emission factors for direct N_2O emissions (EF_3) are based on IPCC (2019) and Kupper 2017 whereas the emission factor for indirect emissions from atmospheric deposition is country-specific (Bühlmann et al. 2015, Bühlmann 2014).

The N_2O emissions from pasture, range and paddock are reported under 3D Agricultural soils, source category 3Da3 Urine and dung deposited by grazing animals.

For calculation of CH_4 and N_2O emissions, slightly different livestock sub-categories were used (Table 5-12). The livestock categories reported in the reporting tables (CRT) are the same, but the respective sub-categories as a basis for the calculation are different. The categorisation for the estimation of CH_4 emissions had to be adapted to data availability for energy requirements, while the categorisation for the estimation of N_2O emissions is determined by the respective categorisation of the Swiss ammonia inventory (AGRAMMON, Kupper et al. 2022, Richner and Sinaj 2017). Nevertheless, there is no inconsistency in the total number of animals as they are the same both for CH_4 and N_2O emissions. Note that although not growing cattle in the proper sense, bulls are contained in the categories breeding cattle >1 year, breeding cattle 3rd year and/or fattening cattle according to their purposes.

The calculation of CH_4 and N_2O emissions is done by Agroscope, the Swiss centre of excellence for agricultural research (Agroscope 2024).

Table 5-12 Livestock categories for estimating CH_4 and N_2O emissions from 3B Manure management.

3B	**CH_4**		**N_2O**	
Cattle	Mature Dairy Cattle		Mature Dairy Cattle	
	Other Mature Cattle		Other Mature Cattle	
	Growing Cattle	Fattening Calves[1] Pre-Weaned Calves Breeding Cattle 1st year (Breeding Calves + Breeding Cattle 4-12 months) Breeding Cattle > 1 year Fattening Cattle (Fattening Calves 0-4 months[2] + Fattening Cattle 4-12 months)	Growing Cattle	Fattening Calves[1] Pre-Weaned Calves Breeding Cattle 1st year Breeding Cattle 2nd year Breeding Cattle 3rd year Fattening Cattle
Sheep	Lambs < 1 year Mature Sheep		Fattening Sheep Milk Sheep	
Swine	Swine		Piglets Fattening Pig over 25 kg Dry Sows Nursing Sows Boars	
Buffalo	Bisons < 3 years[3] Bisons > 3 years[3]		Bisons < 3 years[3] Bisons > 3 years[3]	
Camels	Llamas < 2 years Llamas > 2 years Alpacas < 2 years Alpacas > 2 years		Llamas < 2 years Llamas > 2 years Alpacas < 2 years Alpacas > 2 years	
Deer	Fallow Deer Red Deer		Fallow Deer Red Deer	
Goats	Goats		Goat places	
Horses	Horses < 3 years Horses > 3 years		Horses < 3 years Horses > 3 years	
Mules and Asses	Mules Asses		Mules Asses	
Poultry	Poultry		Growers Layers Broilers Turkey Other Poultry	
Rabbits	Rabbits		Rabbits	
Livestock NCAC	Sheep Goats Horses < 3 years Horses > 3 years Mules Asses		Sheep Goats Horses < 3 years Horses > 3 years Mules Asses	

1) Fattening for veal with a milk based diet (slaughtere at ap. 100 days). See chp. 5.2.2.3.

2) Fattening for beef meat (slaughtered at ap. 400 days). See chp. 5.2.2.3.

3) Bisons (Bos bison and/or Bos bonasus). Water buffalos (Bubalus bubalis) are included under cattle. See chp. 5.2.2.3.

5.3.2.2. Emission factors CH_4

Calculation of CH_4 emissions from 3B Manure management is based on methods described in the 2019 Refinement (IPCC 2019, equation 10.23):

$$EF_T = VS_T \bullet 365\,days/year \bullet B_{0T} \bullet 0.67\,kg/m^3 \bullet \sum_S MCF_S \bullet MS_{TS}$$

EF_T = annual CH_4 emission factor for livestock category *T* (kg/head/year)

VS_T = daily volatile solids (VS) excreted for livestock category *T* (kg/head/day)

B_{0T} = maximum CH_4 producing capacity for manure produced by livestock category *T* (m^3/kg)

0.67 kg/m^3 = conversion factor of m^3 CH_4 to kilograms CH_4

MCF_S = CH_4 conversion factors for each manure management system *S* (%)

MS_{TS} = fraction of livestock category *T*'s manure handled using manure management system *S* (dimensionless)

5.3.2.2.1. Volatile solids excretion (VS)

The daily excretions of volatile solids (VS) for **all cattle sub-categories** were estimated based on equation 10.24 in the 2019 Refinement (IPCC 2019):

$$VS = \left[GE * \left(1 - \frac{DE\%}{100}\right)\right] * \left[\frac{1 - ASH}{EDF}\right]$$

VS = volatile solids excretion per day on a dry-organic matter basis (kg/day)

GE = gross energy intake (MJ/head/day)

DE = digestibility of the feed (%)

ASH = ash content of manure calculated as a fraction of the dry matter feed intake

EDF = energy density of feed, conversion factor for dietary GE per kg of dry matter (MJ/kg)

IPCC equation 10.24 originally contains an additional term to take account for the urinary energy (IPCC 2019). However, Dämmgen et al. (2011) highlight that the organic matter in urine does not account for any CH_4 formation and the term was hence omitted.

Gross energy intake was calculated according to the method described in chp. 5.2.2.2.1. In the case of **mature dairy cattle** the same model was used as for the estimation of CH_4 emissions from 3A Enteric fermentation. Content of net energy, gross energy and ash in feed dry matter as well as feed digestibility were also estimated using the Agroscope feeding model (Agroscope 2014c). The digestibility of feed is of crucial importance for the calculation of volatile solids. The modelled values for dairy cattle are in the range of the values provided in table 10.2 of the 2019 Refinement (IPCC 2019) and were compared to measurements from feeding trials in Switzerland. The comparison revealed that modelled values are on average slightly higher than measurements. Accordingly, an adjustment was made in order to take account of digestibility depression at high feeding levels that are usually above maintenance (Ramin and Huhtanen 2012). High feeding levels may lead to an increase in rumen passage rate and subsequently to lower feed digestibility (Nousiainen et al. 2009). The correction decreased the feed digestibility on average by 2.6 percent points. Resulting feed digestibility was 72.2 % on average, gross energy content (EDF) was 18.26 MJ/kg and ash content was 9.0 % each with very small fluctuations along the time series.

For **calves and other growing cattle** IPCC default values were taken for the feed digestibility (IPCC 2019, table 10A.2). For the energy density of the feed (EDF) the IPCC (2019) default value, i.e. 18.45 MJ/kg was adopted. Furthermore, an ash content of 8.0 % was used for all these categories.

For **sheep, goats, buffalo**, **camels, horses, mules and asses** and **deer** VS excretion was estimated based on equation 10.24 in IPCC 2019 with default values for feed digestibility of 65 % (sheep, goats, buffalo, camels and deer, IPCC 2019) and 70 % (horses, mules and asses, Stricker 2012). The energy density of the feed (EDF) was 18.45 MJ/kg. The ash content of manure was 8.0 % for sheep, goats, buffalo, camels and deer and 4.0 % for horses and mules and asses (IPCC 2006).

For VS excretion of the livestock categories **swine** and **poultry**, default values from IPCC were taken (IPCC 2006: Tables 10A-7, 10A-8, 10A-9). For **rabbits** the default value of IPCC 2019 was adopted.

Finally for **livestock NCAC** the same VS excretion rates as for the respective animal categories in the official census were used.

5.3.2.2.2. Maximum CH_4 producing capacity (B_0)

For the methane producing capacity (B_0) default values were used (IPCC 2019). For deer and rabbits no default values were available. Consequently, the same value as for sheep was applied for deer and the value of IPCC 2006 was applied for rabbits. For all grazing animals a B_0 of 0.19 was adopted as suggested in table 10.16 of the 2019 Refinement (IPCC 2019).

5.3.2.2.3. Methane conversion factor (MCF)

For estimating CH_4 emissions from manure management, six different manure management systems are distinguished. Switzerland has an average annual temperature below 15°C (MeteoSwiss 2022) and was therefore allocated to the cool climate region without differentiation.

In the case of **solid manure** and **pasture range and paddock** the default MCF values from table 10.17 of the 2019 Refinement (IPCC 2019) was used (Table 5-13).

Liquid/slurry systems are responsible for the major part of methane emissions from Manure management (87 % on average). Accordingly a more detailed model was used to determine the respective MCF. For this purpose the model developed by Mangino et al. (2001), that is also the basis of the model used in the IPCC Guidelines, was adapted to the specific conditions of Switzerland. On a monthly time step, loading of a virtual liquid/slurry manure system was simulated according to the VS excretion of the total livestock herd and the manure management system distribution (MS) in the respective inventory year. Thereby it was assumed that excretion on pasture, range and paddock takes only place during summer months, i.e. from April to September. Subsequently, monthly manure degradation was forecast using the temperature-dependent van't Hoff-Arrhenius equation with the parametrization as suggested by Mangino et al. (2001). Monthly mean air temperatures for the Swiss central plateau during the 1991–2020 time period were obtained from the Federal Office of Meteorology and Climatology (MeteoSwiss 2022). Minimum temperature in the liquid/slurry system was allowed to drop to 1°C instead of 5°C as proposed in the original model (see e.g. Vergé et al. 2007, Van der Zaag et al. 2013). Any carry-over effect of undergraded manure from one month to the next was neglected (see e.g. Park et al. 2006, Van der Zaag et al. 2013). Finally, an annual methane conversion factor was calculated by dividing the total VS degraded by the total load of VS.

Several authors have found that the simulated MCF-values according to the model described above are unrealistically high (Park et al. 2006, Van der Zaag et al. 2013). Consequently they propose to use a management and design practice factor (MDP factor) to bring the modelled factors into accordance with measurements. Accordingly, a MDP factor of 0.8 was applied here as suggested by Mangino et al. (2001). The resulting MCF-values for liquid/slurry systems range from 13.7 % to 14.8 %. The variation of the MCF along the time series is due to varying shares of manure dropped on pasture, range and paddock. The higher the share of manure dropped on pasture, range and paddock, the lower is the overall MCF for liquid/slurry systems (as livestock is only grazing during summer, the relative share of low methane conversion factors during the cold winter month increases when summer grazing time increases).

Anaerobic digestion of animal manure is increasing in Switzerland since the 1990s but is still not widespread (8.2 % of all volatile solids in 2022). Emissions from the digestion plant itself are reported under source category 5B2 (Anaerobic digestion at biogas facilities) and described in chp. 7.3.2.2. However, emissions from manure storage before alimentation into the digester are reported in source category 3B Manure management. The amount of manure digested anaerobically was estimated based on total energy production (SFOE 2023a) and eight monitoring protocols of agricultural biogas plants (Genossenschaft Ökostrom Schweiz 2014, GES Biogas GmbH 2014). According to the data in the monitoring protocols the total amount of manure entering the plant originated mainly from cattle manure stored as liquid/slurry (57 %) and solid storage (23 %) and from swine manure stored as liquid/slurry (20 %). It is assumed that 22.5 % of the liquid/slurry manure is coming from the farm where the biogas plant is located and is hence directly fed into the digester on a daily basis without being stored (Koehli 2014). The respective MCF was thus set to zero. As solid manure usually has a low MCF and is stored for only a short period before being fed into the digester, the respective MCF was also set to zero. The MCF for the remaining liquid/slurry manure that is delivered from neighbouring farms to the biogas plant was estimated with the methodology described in the “Standard method for compensating projects of the type “agricultural biogas plants”” (FOEN 2014n). This method is based on the “Approved small scale baseline and monitoring methodology AMS-III.D./Version 19.0. Methane recovery in animal manure management systems” and relies thus on a generally accepted foundation (UNFCCC 2013c).

According to this methodology the MCF value for conventional liquid/slurry systems given in Table 5-13 is reduced according to the duration of pre-storage before the manure is delivered to the digester:

$$MCF_{PSAD} = MCF_{LS} * \left(\frac{14.49 * \left(e^{-k*AI_j} - 1 \right)}{AI_j} + 1 \right)$$

MCF_{PSAD} = CH_4 conversion factor for pre-storage of liquid manure before delivery to biogas plants (%)

MCF_{LS} = CH_4 conversion factor for liquid/slurry systems (%)

k = degradation rate constant (0.069)

AI_j = average pre-storage time period (day)

The average pre-storage time was estimated to be 12 days (Koehli 2014). The resulting weighted average MCF-value for anaerobic digestion varies between 2.6 % and 2.8 %. Variation is due to the variation of the underlying MCF of liquid/slurry systems.

Fattening calves, sheep, camels, deer and goats are kept in **deep litter systems**. A MCF of 10 % was adopted, which is the mean value between the IPCC default values for cattle and swine deep bedding <1 month and >1 month at 10°C in IPCC (2006). The choice of a MCF of 10 % for deep litter is supported by the specific feeding and manure management regime in Switzerland (especially cold winter temperatures) and confirmed by a number of studies representative for the country-specific management conditions (Amon et al. 2001, Külling et al. 2002, Külling et al. 2003, Moller et al. 2004, Hindrichsen et al. 2006, Park et al. 2006 and Sommer et al. 2007, Zeitz et al. 2012). For further details see FOEN 2011 (chp. 16.5 attachment E).

For all poultry categories a MCF value of 1.5 % was used according to the default value for **poultry manure systems** in the 2019 Refinement (IPCC 2019).

Table 5-13 Manure management systems and methane conversion factors (MCFs). Blue: annually changing parameters, value for 2022.

Manure management system		Description	MCF (%)
Pasture		Manure is allowed to lie as it is, and is not managed (distributed, etc.).	0.5
Solid storage		Dung and urine are excreted in a barn. The solids (with and without litter) are collected and stored in bulk for a long time (months) before disposal.	2.0
Liquid/slurry systems		Combined storage of dung and urine under animal confinements for longer than 1 month.	13.8
Digesters		Storage before alimentation into anaerobic digester. Storage system can be liquid/slurry or solid storage.	2.6
Other	Deep litter	Dung and urine is excreted in a barn with lots of litter and is not removed for a long time (months).	10.0
	Poultry system	Manure is excreted on the floor with or without bedding.	1.5

5.3.2.2.4. Manure management system distribution (MS)

The fraction of animal manure handled using different manure management systems (MS) as well as the percentages of urine and dung deposited on pasture, range and paddock was separately assessed for each livestock category (Table 5-14). The fractions are determined by the livestock husbandry system (e.g. tie stall or loose housing system) as defined in Richner and Sinaj (2017). Estimation is conducted within the Swiss ammonium model AGRAMMON based on expert judgement and values from the literature (1990, 1995) and on extensive farm surveys (2002, 2007, 2010, 2015 and 2019) (Kupper et al. 2022). The data clearly reproduce the shift towards an increased use of pasture, range and paddocks and a decrease in solid storage. The changes of the manure management system distribution reflect the shift to a more animal-friendly livestock husbandry in the course of the agricultural policy reforms during the 1990s and the early 20th century. One of the most important voluntary programmes in this context is called “RAUS” and implies at least 156 days of pasture per year (Swiss Confederation, 2008). Accordingly, the share of mature dairy cattle (and other animals) going to pastures increased substantially and so did the length of stay on the pasture. In the year 2007 78 % of the dairy cattle were held on farms participating in the RAUS programme. The average number of pasture days (including all farms) in that year was 178, and it was 173 in 2010. It can thus be assumed, that already in the early years of the new millennium most farms accomplished the transition to RAUS and that a new management standard was reached at this point of time, which did not change significantly afterwards.

Data for manure management system distribution for cattle are different for VS and nitrogen. This is because cattle stables often have simultaneously both liquid and solid manure storage systems. As volatile solids are excreted mainly in dung and nitrogen mainly in urine, the proportion of VS stored as solid manure is higher compared to the proportion of N. For cattle categories the MS-distribution for nitrogen as provided by Kupper et al. (2022) was thus adjusted using data on stable systems and manure accumulation from Richner and Sinaj (2017) as well as data on frequency of stable systems on farms from (Kupper et al. 2022)(for a more detailed description of the approach see chp. A5.3.4). More or less the same result could be gained by adjusting the distribution of nitrogen by the VS/N-ratio. Data provided in Table 5-14 refer to the distribution of nitrogen while data provided in CRT Table3.B(a) refer to the distribution of VS.

The amount of manure digested anaerobically was estimated based on total energy production (SFOE 2023a) and eight monitoring protocols of agricultural biogas plants (Genossenschaft Ökostrom Schweiz 2014, GES Biogas GmbH 2014) as described under 5.3.2.2.3.

5.3.2.3. Activity data CH_4

Activity data of all livestock categories covered by the official census were obtained from SBV (2023) and the FSO (2023a). In 2011 the respective data for the time series 1990–2010 were revised and harmonised during a joint effort of the Agroscope Reckenholz Tänikon Research Station (ART) and the Swiss College of Agriculture (SHL) (ART/SHL 2012). Additionally to official statistical data, population data of livestock not covered by the agricultural census of the Federal Statistical Office were assessed based on background data of the gross nutrient balance of the Federal Statistical Office (FSO 2023b). For further details and additional data on a livestock sub-category level refer to chp. 5.2.2.3, Table 5-8 as well as Agroscope (2024b).

Table 5-14 Manure management system distribution for nitrogen (MS) according to the AGRAMMON model. Detailed data on livestock sub-category levels for the distribution of nitrogen and volatile solids are provided in a separate spreadsheet (Agroscope 2024a).

MS Distribution	1990					1995					2002					2007				
	%					%					%					%				
	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)
Mature Dairy Cattle	65.7	25.6	8.3	0.5	0.0	67.5	22.5	9.6	0.4	0.0	65.4	17.1	16.9	0.6	0.0	68.1	13.1	17.3	1.5	0.0
Other Mature Cattle	41.1	28.8	29.6	0.5	0.0	38.6	31.4	29.6	0.4	0.0	43.3	19.5	36.7	0.6	0.0	53.7	17.0	27.8	1.5	0.0
Growing Cattle (weighted average)	49.5	29.9	15.8	0.5	4.4	50.0	29.2	15.9	0.4	4.4	45.2	22.3	27.1	0.6	4.8	48.6	20.3	25.2	1.5	4.4
Fattening Calves	*15.9*	*0.0*	*0.0*	*0.5*	*83.6*	*15.6*	*0.0*	*0.0*	*0.4*	*83.9*	*14.9*	*0.0*	*0.7*	*0.6*	*83.9*	*25.1*	*0.0*	*0.4*	*1.5*	*73.0*
Pre-Weaned Calves	*41.1*	*28.8*	*29.6*	*0.5*	*0.0*	*38.6*	*31.4*	*29.6*	*0.4*	*0.0*	*40.2*	*23.8*	*35.5*	*0.6*	*0.0*	*52.7*	*16.7*	*29.2*	*1.5*	*0.0*
Breeding Cattle 1st Year	*39.1*	*46.3*	*14.1*	*0.5*	*0.0*	*40.1*	*45.3*	*14.2*	*0.4*	*0.0*	*37.3*	*34.7*	*27.4*	*0.6*	*0.0*	*44.8*	*28.9*	*24.8*	*1.5*	*0.0*
Breeding Cattle 2nd Year	*47.1*	*27.0*	*25.4*	*0.5*	*0.0*	*48.7*	*25.2*	*25.7*	*0.4*	*0.0*	*41.3*	*21.0*	*37.1*	*0.6*	*0.0*	*44.5*	*18.7*	*35.3*	*1.5*	*0.0*
Breeding Cattle 3rd Year	*52.3*	*27.1*	*20.0*	*0.5*	*0.0*	*52.9*	*26.3*	*20.4*	*0.4*	*0.0*	*45.6*	*19.6*	*34.2*	*0.6*	*0.0*	*48.8*	*17.1*	*32.6*	*1.5*	*0.0*
Fattening Cattle	*72.1*	*22.3*	*0.0*	*0.5*	*5.1*	*68.0*	*26.3*	*0.0*	*0.4*	*5.3*	*72.5*	*20.5*	*4.0*	*0.6*	*2.4*	*64.8*	*24.2*	*6.8*	*1.5*	*2.6*
Sheep (weighted average)	0.0	0.0	30.1	0.0	69.9	0.0	0.0	30.3	0.0	69.7	0.0	0.0	48.7	0.0	51.3	0.0	0.0	45.4	0.0	54.6
Swine (weighted average)	98.9	0.0	0.0	1.1	0.0	99.0	0.0	0.0	1.0	0.0	97.4	1.0	0.3	1.3	0.0	95.3	0.2	0.9	3.7	0.0
Buffalo (weighted average)	NA	NA	NA	NA	NA	0.0	70.8	29.2	0.0	0.0	0.0	64.2	35.8	0.0	0.0	0.0	63.8	36.2	0.0	0.0
Camels (weighted average)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.0	0.0	47.2	0.0	52.8	0.0	0.0	45.4	0.0	54.6
Deer (weighted average)	0.0	0.0	35.7	0.0	64.3	0.0	0.0	35.7	0.0	64.3	0.0	0.0	47.2	0.0	52.8	0.0	0.0	45.4	0.0	54.6
Goats	0.0	0.0	13.6	0.0	86.4	0.0	0.0	13.6	0.0	86.4	0.0	0.0	28.5	0.0	71.5	0.0	0.0	27.3	0.0	72.7
Horses (weighted average)	0.0	87.2	12.8	0.0	0.0	0.0	87.2	12.8	0.0	0.0	0.0	76.5	23.5	0.0	0.0	0.0	76.0	24.0	0.0	0.0
Mules and Asses (weighted average)	0.0	87.2	12.8	0.0	0.0	0.0	87.2	12.8	0.0	0.0	0.0	84.0	16.0	0.0	0.0	0.0	76.7	23.3	0.0	0.0
Poultry (weighted average)	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.5	0.0	99.5	0.0	0.0	2.7	0.0	97.3	0.0	0.0	3.2	0.0	96.8
Rabbits	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Livestock NCAC (weighted average)	0.0	87.2	12.8	0.0	0.0	0.0	76.3	12.9	0.0	10.8	0.0	37.2	34.2	0.0	28.6	0.0	40.0	32.5	0.0	27.5

MS Distribution	2010					2015					2019				
	%					%					%				
	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Digesters	Other (Deep litter, Poultry manure)
Mature Dairy Cattle	68.6	12.0	17.2	2.2	0.0	69.5	9.9	16.5	4.1	0.0	67.9	8.9	16.7	6.4	0.0
Other Mature Cattle	53.7	14.7	29.3	2.2	0.0	54.4	12.3	29.2	4.1	0.0	49.5	13.1	31.0	6.4	0.0
Growing Cattle (weighted average)	48.5	19.5	24.8	2.2	5.1	50.7	16.6	24.1	4.1	4.5	49.3	15.6	24.3	6.4	4.4
Fattening Calves	*25.4*	*0.0*	*1.0*	*2.2*	*71.5*	*33.3*	*0.0*	*1.2*	*4.1*	*61.3*	*37.2*	*0.0*	*1.7*	*6.4*	*54.7*
Pre-Weaned Calves	*44.5*	*20.8*	*32.5*	*2.2*	*0.0*	*43.2*	*20.3*	*32.4*	*4.1*	*0.0*	*40.0*	*20.8*	*32.7*	*6.4*	*0.0*
Breeding Cattle 1st Year	*47.9*	*25.8*	*24.2*	*2.2*	*0.0*	*48.4*	*24.1*	*23.4*	*4.1*	*0.0*	*49.2*	*21.1*	*23.3*	*6.4*	*0.0*
Breeding Cattle 2nd Year	*46.2*	*16.8*	*34.8*	*2.2*	*0.0*	*45.5*	*15.4*	*35.0*	*4.1*	*0.0*	*47.1*	*12.7*	*33.8*	*6.4*	*0.0*
Breeding Cattle 3rd Year	*50.7*	*15.3*	*31.8*	*2.2*	*0.0*	*52.5*	*13.2*	*30.2*	*4.1*	*0.0*	*50.2*	*12.7*	*30.7*	*6.4*	*0.0*
Fattening Cattle	*60.2*	*28.3*	*5.9*	*2.2*	*3.3*	*68.2*	*19.0*	*6.3*	*4.1*	*2.4*	*60.4*	*21.3*	*9.2*	*6.4*	*2.7*
Sheep (weighted average)	0.0	0.0	38.8	0.0	61.2	0.0	0.0	45.3	0.0	54.7	0.0	0.0	42.9	0.0	57.1
Swine (weighted average)	94.2	0.2	0.3	5.3	0.0	89.2	0.1	0.1	10.7	0.0	81.6	0.0	0.1	18.3	0.0
Buffalo (weighted average)	0.0	65.0	35.0	0.0	0.0	0.0	64.4	35.6	0.0	0.0	0.0	65.6	34.4	0.0	0.0
Camels (weighted average)	0.0	0.0	38.4	0.0	61.6	0.0	0.0	45.4	0.0	54.6	0.0	0.0	43.7	0.0	56.3
Deer (weighted average)	0.0	0.0	38.4	0.0	61.6	0.0	0.0	45.4	0.0	54.6	0.0	0.0	43.7	0.0	56.3
Goats	0.0	0.0	28.1	0.0	71.9	0.0	0.0	28.3	0.0	71.7	0.0	0.0	33.7	0.0	66.3
Horses (weighted average)	0.0	76.1	23.9	0.0	0.0	0.0	78.4	21.6	0.0	0.0	0.0	76.6	23.4	0.0	0.0
Mules and Asses (weighted average)	0.0	76.9	23.1	0.0	0.0	0.0	77.9	22.1	0.0	0.0	0.0	80.4	19.6	0.0	0.0
Poultry (weighted average)	0.0	0.0	2.8	0.0	97.2	0.0	0.0	3.0	0.0	97.0	0.0	0.0	3.4	0.0	96.6
Rabbits	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0
Livestock NCAC (weighted average)	0.0	42.8	29.5	0.0	27.7	0.0	45.1	30.3	0.0	24.6	0.0	43.6	30.6	0.0	25.7

5.3.2.4. Emission factors N_2O

Estimation of direct N_2O emissions from manure management relies basically on the same animal waste management systems as the estimation of CH_4 emissions (compare chp. 5.3.2.2). For liquid/slurry storage systems an emission factor of 0.002 kg N_2O-N/kg N as suggested for “Pit storage below animal confinements” was considered appropriate (IPCC 2019, Kupper 2017).The emission factors poultry manure is based on default values given in table 10.21 of IPCC 2019 whereas emissions factors for solid storage and anaerobic digesters are from the respective table in the 2006 IPCC Guidelines (see also Kupper 2017) (Table 5-15).

Table 5-15 Emission factors for calculating N_2O emissions from manure management. Blue: annually changing parameters, value for 2022.

Animal waste management system	**Emission factor**
	kg N_2O-N / kg N
Liquid/Slurry: Pit storage below animal confinement	0.002
Solid storage	0.005
Anaerobic digester	0.000
Cattle and swine deep bedding: no mixing	0.010
Poultry manure	0.001
Indirect emissions due to volatilisation	0.026

The emission factor for indirect N_2O emissions after volatilisation of NH_3 and NO_x from manure management systems was reassessed during a literature review by Bühlmann et al. 2015 and Bühlmann 2014. Due to the fragmented land use in Switzerland, where agricultural land use alternates with natural and semi-natural ecosystems over short distances, the share of volatilised nitrogen that is re-deposited in (semi-)natural habitats is on average higher than 55 %. Thus, the assumption made in the 2006 IPCC Guidelines that “a substantial fraction of the indirect emissions will in fact originate from managed land”, cannot be applied to Switzerland. Accordingly, the overall emission factor for indirect emissions was estimated by calculating an area-weighted mean of the indirect emission factor for managed land (i.e. 0.01 based on IPCC 2019) and the indirect emission factor for (semi-)natural land (as provided in Bühlmann 2014 chp. 5.2.1) (Table 5-16). Due to slightly changing land use over the inventory time period, the resulting emission factor shows some small temporal variation around a mean value of 2.57 % (see also chp. 9.2.2). Note that the emission factor in cell R37 of CRF Table3.B(b) refers to kg N_2O/kg N instead of kg N_2O-N/kg N (see also Annex 7). At the time of finalisation of the NID (April 2024), the CRT reporter was not yet available. Therefore, possible corrections within the CRT reporter cannot be discussed here.

Table 5-16 Data for estimating emission factors for indirect N_2O emissions from atmospheric deposition according to Bühlmann (2014).

EF_4 atmospheric deposition		**1990-2015**					
	Unit	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**
Share of deposition on agricultural land	%	0.573	0.574	0.575	0.569	0.543	0.543
Share of deposition in semi-natural ecosystems	%	0.427	0.426	0.425	0.431	0.457	0.457
EF_4 for agricultural land	kg N_2O-N / total kg N-deposited	0.010	0.010	0.010	0.010	0.010	0.010
EF_4 for semi-natural ecosystems	kg N_2O / kg N-deposited	0.030	0.030	0.030	0.031	0.033	0.033
EF_4 weighted	kg N_2O-N / kg N-deposited	0.0248	0.0248	0.0248	0.0257	0.0264	0.0264

EF_4 atmospheric deposition		**2016-2022**						
	Unit	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Share of deposition on agricultural land	%	0.543	0.543	0.543	0.543	0.543	0.543	0.543
Share of deposition in semi-natural ecosystems	%	0.457	0.457	0.457	0.457	0.457	0.457	0.457
EF_4 for agricultural land	kg N_2O-N / total kg N-deposited	0.010	0.010	0.010	0.010	0.010	0.010	0.01
EF_4 for semi-natural ecosystems	kg N_2O / kg N-deposited	0.033	0.033	0.033	0.033	0.033	0.033	0.033
EF_4 weighted	kg N_2O-N / kg N-deposited	0.0264	0.0264	0.0264	0.0264	0.0264	0.0264	0.0264

5.3.2.5. Activity data N_2O

Activity data for N_2O emissions from 3B Manure management were estimated according to equation 10.25 of the IPCC 2019:

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T \left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)} \right) \right] \bullet EF_{3(S)} \right] \bullet \frac{44}{28}$$

$N_2O_{D(mm)}$ = direct N_2O emissions from manure management (kg N_2O/year)

$N_{(T)}$ = number of head of livestock species/category *T* (head)

$Nex_{(T)}$ = annual average N excretion per head of species/category *T* (kg N/head/year)

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S*

$EF_{3(S)}$ = emission factor for direct N_2O emissions from manure management system *S* (kg N_2O-N/kg N)

44/28 = conversion of $(N_2O\text{-}N)_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions

5.3.2.5.1. Livestock population

Activity data of all livestock categories covered by the official census were obtained from SBV (2023) and the FSO (2023a). In 2011 the respective dataset for the time series 1990–2010 was revised and harmonised during a joint effort of the Agroscope Reckenholz Tänikon Research Station (ART) and the Swiss College of Agriculture (SHL) in 2011 (ART/SHL 2012). Additionally to official statistical data, population data of livestock not covered by the agricultural census of the Federal Statistical Office were assessed based on background data of the gross nutrient balance of the Federal Statistical Office (FSO 2023b) and based on data of the Swiss animal traffic database (ATD 2023). For further details and additional data on a livestock sub-category level refer to chp. 5.2.2.3, Table 5-8 as well as Agroscope (2024b).

5.3.2.5.2. Nitrogen excretion (N_{ex})

Data on nitrogen excretion per animal category (kg N/head/year) are country-specific and were obtained from Kupper et al. (2022) (Table 5-17). These values are based on the “Principles of Fertilisation in Arable and Forage Crop Production” (Richner and Sinaj 2017). As compared to the methods in IPCC 2019, the age structure of the animals and the different use of the animals (e.g. fattening and breeding) are considered in more detail. Generally, nitrogen excretion rates were determined by estimating nitrogen intake and then subtracting nitrogen retention in body tissue and products (milk, offspring). Most calculations are based on feeding requirements that were assessed in feeding trials at the Agroscope research station in Posieux as published e.g. in RAP (1999, ruminants) and Agroscope (2016c, swine). Additional data on feed ration composition and properties and nitrogen retention and excretion is available from the background literature listed for the specific animal categories below. Standard nitrogen excretion rates are modified within the AGRAMMON model in order to account for changing agricultural structures and production techniques over the years (e.g. milk yield, use of feed concentrates, protein reduced animal feed etc.; Kupper et al. (2022)). This more disaggregated approach leads to considerably lower calculated nitrogen excretion rates compared to IPCC (2019) mainly because lower N_{ex}-rates of young animals are considered explicitly.

The nitrogen excretion rates are given on an annual basis, considering replacement of animals (growing cattle, swine, poultry, rabbits) and including excretions from corresponding offspring and other associated animals (sheep, deer, goats, swine, rabbits) (ART/SHL 2012).

Nitrogen excretion rates of **mature dairy cattle** were adopted from the most recent version of the AGRAMMON model (Kupper et al. 2022). Regional data of animal performance and feed ration composition were used to adjust standard nitrogen excretion rates from Richner and Sinaj (2017). The calculations are based on the same feeding model as used for the estimation of gross energy intake and the excretion of volatile solids (Agroscope 2014c; chp. 5.2.2.2.1, 5.3.2.2.1) and are further described in Menzi et al. (2016). Nitrogen excretion is calculated as the nitrogen intake minus the nitrogen excretion in the milk minus the nitrogen in the calve assuming no change in body weight of the cow. Accordingly, nitrogen excretion of mature dairy cattle is dependent on feed composition (use of feed concentrates, corn silage, corn cubes, and hay in summer and winter rations), feed properties (N-content and digestibility of the individual feed components) and milk production. Estimated values of crude protein contents of animal feeds in the Swiss Feed Database are based on an extensive measurement program particularly also for roughages (Agroscope 2014b). Nitrogen content of the feed is estimated as crude protein content divided by 6.25. Protein content in the milk was set to 0.033 g*kg milk^{-1}. Nitrogen content in the milk is estimated as protein content divided by 6.38. After the year 2006 the yearly increase of nitrogen excretion slowed down due to an increased use of energy dense feedstuff (concentrates) and a slower increase of the milk yield compared to earlier years.

For the category **other mature cattle** as well as all **growing cattle** categories the nitrogen excretion rates of the AGRAMMON model (Kupper et al. 2022) were adopted which are again based on the standard values of Richner and Sinaj (2017). The assessment of these standard values is based on the Swiss feeding recommendations (RAP et al. 1999, Morel et al. 2017, Schlegel et al. 2020, Rediger et al. 2019) which are elaborated based on a great number of feeding trials at the Agroscope research station in Posieux. Nitrogen excretion rates of some sub-categories are fluctuating along the time series due to changes in feeding and management practices.

Sheep in Switzerland are fed mainly on roughage from extensive pasture and meadows (Richner and Sinaj 2017) and are estimated to excrete approximately 8.1 kg N per head and year. This is somewhat lower than IPCC default (IPCC 2006, 2019). However, nitrogen excretion is averaged over the whole population, of which roughly 40 % are lambs and other immature animals. **Swine** show a significant decrease in nitrogen excretion rates until 2007, which can be explained by the increasing use of protein-reduced fodder (Kupper et al. 2022, Bracher and Spring 2011, Sollberger et al. 2013). Changing production techniques and increasing use of protein-reduced fodder are also drivers of nitrogen excretion rates for **poultry**.

Table 5-17 Nitrogen excretion rates of Swiss livestock. The complete time series on a livestock sub-category level are provided in a separate spreadsheet (Agroscope 2024a).

Nitrogen Excretion		**1990-2015**					
		1990	**1995**	**2000**	**2005**	**2010**	**2015**
		kg N/head/year					
Mature Dairy Cattle		100.4	101.5	104.1	107.4	110.1	111.1
Other Mature Cattle		85.0	85.0	85.0	85.0	85.0	85.0
Growing Cattle (weighted average)		33.0	33.1	33.1	32.6	32.7	33.1
	Fattening Calves	*13.0*	*13.0*	*13.0*	*14.2*	*16.0*	*18.0*
	Pre-Weaned Calves	*22.0*	*22.0*	*22.0*	*22.0*	*22.0*	*22.0*
	Breeding Cattle 1st Year	*25.0*	*25.0*	*25.0*	*25.0*	*25.0*	*25.0*
	Breeding Cattle 2nd Year	*40.0*	*40.0*	*40.0*	*40.0*	*40.0*	*40.0*
	Breeding Cattle 3rd Year	*55.0*	*55.0*	*55.0*	*55.0*	*55.0*	*55.0*
	Fattening Cattle	*33.0*	*33.0*	*33.0*	*34.2*	*36.0*	*38.0*
Sheep (weighted average)		7.5	7.6	8.0	8.1	8.5	8.4
Swine (weighted average)		14.3	14.0	11.0	9.6	9.2	9.1
Buffalo (weighted average)		NA	37.2	41.1	38.7	37.3	36.4
Camels (weighted average)		NA	NA	14.1	12.8	12.6	12.7
Deer (weighted average) 1)		20.0	21.9	22.3	21.9	22.4	23.0
Goats		11.2	11.1	11.3	11.1	11.2	11.4
Horses (weighted average)		43.6	43.5	43.6	43.7	43.7	43.8
Mules and Asses (weighted average)		16.0	16.0	16.0	16.0	16.0	16.0
Poultry (weighted average)		0.5	0.5	0.5	0.5	0.5	0.5
Rabbits		1.0	1.0	1.0	1.0	1.0	1.0
Livestock NCAC (weighted average)		36.5	29.4	12.5	13.0	14.7	15.8

Nitrogen Excretion		**2016-2022**						
		2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
		kg N/head/year						
Mature Dairy Cattle		111.1	111.2	111.3	111.4	111.4	111.4	111.4
Other Mature Cattle		85.0	85.0	85.0	85.0	85.0	85.0	85.0
Growing Cattle (weighted average)		33.0	32.9	32.8	32.7	32.6	32.5	32.5
	Fattening Calves	*18.0*	*18.0*	*18.0*	*18.0*	*18.0*	*18.0*	*18.0*
	Pre-Weaned Calves	*22.0*	*22.0*	*22.0*	*22.0*	*22.0*	*22.0*	*22.0*
	Breeding Cattle 1st Year	*25.0*	*25.0*	*25.0*	*25.0*	*25.0*	*25.0*	*25.0*
	Breeding Cattle 2nd Year	*40.0*	*40.0*	*40.0*	*40.0*	*40.0*	*40.0*	*40.0*
	Breeding Cattle 3rd Year	*55.0*	*55.0*	*55.0*	*55.0*	*55.0*	*55.0*	*55.0*
	Fattening Cattle	*38.0*	*38.0*	*38.0*	*38.0*	*38.0*	*38.0*	*38.0*
Sheep (weighted average)		8.4	8.5	8.5	8.5	8.5	8.5	8.5
Swine (weighted average)		9.1	9.1	9.1	9.1	9.1	9.1	9.1
Buffalo (weighted average)		36.4	35.9	47.1	45.9	45.7	45.4	45.4
Camels (weighted average)		12.6	12.6	12.5	12.6	12.6	12.6	12.6
Deer (weighted average) 1)		23.1	23.3	23.4	23.6	23.6	23.6	23.8
Goats		11.4	11.4	11.4	11.4	11.4	11.4	11.4
Horses (weighted average)		43.8	43.9	43.9	43.9	43.9	43.9	43.9
Mules and Asses (weighted average)		16.0	16.0	16.0	16.0	16.0	16.0	16.0
Poultry (weighted average)		0.5	0.5	0.5	0.5	0.5	0.5	0.5
Rabbits		1.0	1.0	1.0	1.0	1.0	1.0	1.0
Livestock NCAC (weighted average)		16.1	16.1	14.7	14.9	15.0	15.0	15.0

1) Deer: Excretion per animal place

5.3.2.5.3. Manure management system distribution (MS)

The split of nitrogen flows into the different animal waste management systems and its temporal dynamics are based on the respective analysis in the AGRAMMON model (Kupper et al. 2022) and on data provided in Richner and Sinaj (2017). For cattle, the distribution of animal excreta to the various manure management systems is different with regard to estimating CH_4 emissions from 3B Manure management compared to estimating N_2O emissions from 3B Manure management (for further information refer to chp. 5.3.2.2.4 and chp. A5.3.4). This is because cattle stables often have simultaneously both liquid and solid manure storage systems. As volatile solids are excreted mainly in dung and nitrogen mainly in urine, the proportion of VS stored as solid manure is higher compared to the proportion of N. Data provided in Table 5-14 refer to the distribution of nitrogen while data provided in CRT Table3.B(a) refer to the distribution of VS. A detailed table of the distribution of VS is provided in a separate spreadsheet (Agroscope 2024a).

5.3.2.5.4. Volatilisation of NH_3, NO_x and N_2 from manure management systems

For indirect N_2O emissions from manure management the deposition of volatilised NH_3 and NO_x is considered. Losses of ammonia from stables and manure storage systems to the atmosphere are calculated according to the Swiss ammonia model AGRAMMON (Kupper et al. 2022). Specific loss-rates for all major livestock categories are estimated based on agricultural structures and techniques (e.g. stable type, manure management system, measures to reduce NH_3 emissions). Accordingly, the overall fraction of reactive nitrogen (NH_3, NO_x) volatilised underlies certain temporal dynamics that can be explained by changes in agricultural management practices (e.g. the transition to more animal friendly housing systems). It ranges from 14.5 to 20.4 %.

For the volatilisation of NO_x values from van Bruggen et al. (2014) were used. Accordingly, it is estimated that 0.2 %, 0.5 %, 1.0 % and 0.1 % of the total nitrogen in liquid/slurry, solid storage, deep litter and poultry manure systems are lost to the atmosphere, respectively. In this context the management systems “anaerobic digestion” is treated as liquid/slurry system.

For the estimation of the amount of animal manure applied to soils, the volatilisation of dinitrogen (N_2) during manure management is also considered. It is estimated that 0.020 %, 0.025 %, 0.050 % and 0.025 % of the total nitrogen in liquid/slurry, solid storage, deep litter and poultry manure systems are lost to the atmosphere, respectively (van Bruggen et al. 2014).

Note that volatilisation from pasture, range and paddock manure is included under 3Db (Indirect N_2O emissions from managed soils). A graphical overview of the nitrogen flow system is given in Figure 5-6 and respective numbers are provided in Table 5-21.

5.3.2.6. NMVOC emissions from manure management

The NMVOC emissions from animal husbandry are calculated by a Tier 1 approach according to the EMEP/EEA guidebook using country-specific and default emission factors (EMEP/EEA 2019, chp. 3B Manure management, Table 3.4) for cattle and all other livestock categories, respectively. A comprehensive literature study by Bühler and Kupper (2018) has shown that the data base of NMVOC emissions from animal husbandry is very scarce and that the derived emission factors differ widely. The studies on which the emission factors in EMEP/EEA (2016) (unchanged in EMEP/EEA 2019) are based show several inconsistencies that could affect significantly the emission factors. It remains also unknown, how the emissions from the studies performed in the United States were adapted to European agricultural feeding conditions and how the corresponding emission factors were derived.

Therefore, a study was conducted between 2018 and 2021 in order to measure NMVOC emissions from dairy cattle with and without silage feeding in an experimental housing system during summer, winter and the transitional season and to derive emission factors that are representative for cattle husbandry in Switzerland (Schrade et al. 2024). Switzerland's Informative Inventory Report (FOEN 2022b, chp. 5.2.2.) contains a detailed description of these country-specific emission factors for cattle.

5.3.3. Uncertainties and time-series consistency for 3B

For the uncertainty analysis the input data from ART (2008a) were used and were updated with current activity and emission data as well as with default uncertainties from the 2019 Refinement (IPCC 2019). The detailed input uncertainty values for category 3B are reported in Annex A2.1. The resulting, combined uncertainty for emissions according to approach 1 (uncertainty propagation) are reported in Annex A2.2 and in Annex A2.3 for results obtained by approach 2 (Monte Carlo simulations). The 95 % confidence intervals obtained by Monte Carlo simulations are slightly narrower and, for non-symmetric distributions, slightly shifted towards the lower edge.

Table 5-18 Uncertainties for 3B Manure management. Approach 1: intervals are exactly from 2.5 % to 97.5 % of the distribution; Approach 2: the narrowest interval representing 95 % of the distribution is given.

Source category	Gas	Activity data uncertainty 2022		Emission factor uncertainty 2022		Emission combined uncertainty 2022	
		(-)%	(+)%	(-)%	(+)%	(-)%	(+)%
Uncertainty propagation (approach 1)							
3B1-4 Manure management all livestock direct	CH4	6.5	6.5	55	55	55	55
3B1-4 Manure management all livestock direct	N2O	24	24	58	82	63	86
3B5 Manure management indirect	N2O	47	62	63	94	79	113
Monte Carlo simulations (approach 2)							
3B1-4 Manure management all livestock direct	CH4	6.5	6.4	54	55	55	55
3B1-4 Manure management all livestock direct	N2O	24	24	64	72	66	77
3B5 Manure management indirect	N2O	51	56	71	81	80	100

The time series 1990–2022 are all considered consistent, although the following issues should be considered:

- For time series consistency of livestock population data and gross energy intake see chp. 5.2.3.
- The MCF for liquid/slurry systems varies according to the development of the grazing management over the years as described under chp. 5.3.2.2.3.
- Input data from the AGRAMMON-model are available for the years 1990 and 1995 (expert judgement and literature) as well as for 2002, 2007, 2010, 2015 and 2019 (extensive surveys on approximately 3000 farms). Values in-between the assessment years were interpolated linearly. For 2020 to 2022 the same value as in 2019 was applied.
- The emission factor for indirect N_2O emissions after volatilisation of NH_3 and NO_x from manure management systems varies according to varying land use as described in chp. 5.3.2.4.

5.3.4. Category-specific QA/QC and verification for 3B

General QA/QC measures are described in NID chp. 1.5.

All further category-specific QA/QC activities are described in a separate document (Agroscope 2019a). General information on agricultural structures and policies is provided and eventual differences between national and standard values (IPCC 2006, 2019) are being analysed and discussed. Furthermore, comparisons with data from other countries were conducted and discussed where possible. Agroscope (2019a) is periodically updated with the most recent inventory data.

A mutual peer review was conducted with the German GHG inventory group (Fuß et al. 2021). The respective recommendations were implemented as far as possible during the submissions 2022 and 2023.

For quality assurance of livestock population data and livestock energy intake consult chp. 5.2.4.

5.3.4.1. QA/QC and verification – CH_4

IPCC tables with data for estimating emission factors of all livestock categories (such as weight, feed digestibility, maximum CH_4 producing capacity (B_0) or daily excretion of volatile solids) were filled in, checked for consistency and confidence and compared with IPCC (2006) default values (refer to Annex A5.3).

VS excretion rates of swine and poultry are based on IPCC default values (IPCC 2006). For swine, estimates using equation 10.24 from IPCC (2019) would yield very similar results. As for some of the parameters used in equation 10.24 (e.g. feed digestibility) no reliable country-specific data were available, it was decided to still use the default values.

Factors for methane conversion (MCF) and manure management system distribution (MS) were analysed considering the national agricultural context. The estimated MCF-values for liquid/slurry systems in Switzerland are somewhat lower than IPCC (2019) default. However, a relatively low MCF is supported by the fact that more than 80 % of all liquid/slurry storage tanks are covered and approximately one third of the remaining tanks have a surface crust (Kupper et al. 2022). Furthermore, a series of laboratory measurements of MCF-values by the group of animal nutrition from the Swiss Federal Institute of Technology in Zurich yielded consistently low MCF-values (Zeitz et al. 2012).

During the past years studies were conducted to verify methane emissions at the regional scale comparing bottom-up estimates with atmospheric measurements (Bamberger et al. 2014, Henne et al. 2015, Henne et al. 2016, Henne et al. 2017, Hiller et al. 2014, Hiller et al. 2014a, Stieger 2013, Stieger et al. 2015). For further information on these studies see chp. 5.2.4. and Annex A6.2.

5.3.4.2. QA/QC and verification – N_2O

Estimation of N_2O emissions is mainly based on the Swiss ammonium emission model AGRAMMON that is documented in Kupper et al. (2022).

All relevant data needed for the calculation of N_2O emissions such as nitrogen excretion rates, manure management system distribution and N_2O emission factors were checked for consistency and were compared to the corresponding values of other countries and to the IPCC (2006, 2019) default value if available (Agroscope 2019a).

As one of the most important parameters, nitrogen excretion rates were analysed in more detail. In order to validate the total nitrogen excretion of the whole livestock population a cross check was conducted comparing the bottom-up inventory estimates with an independent top-down approach. Thereby, the total amount of nitrogen contained in animal livestock products such as meat, milk or eggs (output) was subtracted from the total amount of nitrogen in animal feedstuff produced in or imported to the country (input). Under the condition that the nitrogen pool in the animal population remains constant, the result should be equal to the amount of nitrogen excreted in the manure (see e.g. Spiess 2011). There was good agreement (average discrepancy of ±2 %) for the years 1990–2005. However, for later years the top-down estimates were on average 10 % higher than the bottom-up estimates. Reasons for this observation are not yet clear and this finding will be subject to further analysis.

N_{ex}-values for the most important animal categories (mature dairy cattle and swine, being responsible for 65 % of total nitrogen excretion) were compared to the values of the alternative gross energy approach suggested in equation 10.32 in IPCC 2019. For swine, the IPCC approach estimated on average 16 % lower N_{ex} values for the years 1990–2004. This is probably due to an underestimation of the feed protein content in this model calculation and the inventory estimates are considered more realistic. After the year 2005 inventory estimates were lower than the IPCC approach using equation 10.32, which can be explained by the increased use of nitrogen reduced feed. Further QA/QC checks of the N_{ex} values are elaborated in Agroscope (2019a).

Henne et al. (2019) conducted a top-down assessment of Swiss N_2O emissions using atmospheric measurements and an inverse modelling framework. With recent updates in the present NID, inverse estimates and NID estimates agree very closely for two different atmospheric transport model versions used in the inversion (see also Annex A6.2).

5.3.5. Category-specific recalculations for 3B

General information on recalculations is provided in chp. 10.

Recalculations with an overall impact of >0.5 kt CO_2 equivalent are assessed quantitatively. All other recalculations are only described qualitatively.

- Recalculation of livestock population data and gross energy intake (influencing VS-excretion rates) is reported under chp. 5.2.5.
- CH_4 emissions from manure management in liquid systems and anaerobic digesters were recalculated for 1990–2021. The MCF-value for liquid systems (EF) was revised due to updated model projections based on slightly recalculated AGRAMMON data. The impact on overall emissions is negligible (< ±0.2 kt CO_2-equivalent).

5.3.6. Category-specific planned improvements for 3B

No category-specific improvements are planned.

5.4. Source category 3C – Rice cultivation

Rice cultivation is of minor importance in Switzerland. The agricultural land used for rice cultivation and the annual harvest of rice are not estimated by the Swiss Farmers Union (SBV 2023). Only one farm in the south of Switzerland is cultivating upland rice since 1997. CH_4 emissions are assumed to be zero. The area of upland rice is reported from 1997 onward in CRT Table3.C (EMIS 2024/4C “Reisanbau”).

5.5. Source category 3D – Agricultural soils

5.5.1. Source category description

Table 5-19 Key categories of 3D Agricultural soils. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	**IPCC category**	**Gas**	**Identification criteria**
3D1	Direct emissions from managed soils	N2O	L1, L2
3D2	Indirect emissions from managed soils	N2O	L1, L2, T1

The source category 3D includes direct and indirect N_2O emissions from managed soils (Table 5-20). Direct emissions are further subdivided in emissions from a. Inorganic N fertilisers, b. Organic N fertilisers, c. Urine and dung deposited by grazing animals, d. Crop residues, e. Mineralisation/immobilisation associated with loss/gain of soil organic matter, f. Cultivation of organic soils (i.e. histosols) and g. Other (i.e. Domestic use of synthetic fertilisers). Indirect N_2O emissions are further subdivided in a. Atmospheric deposition and b. Nitrogen leaching and run-off. All indirect N_2O emissions after deposition of NO_x and NH_3 or after leaching of NO_3^- are reported under source category 3D.2 Indirect N_2O Emissions from managed soils. This includes indirect N_2O emissions after NO_3^- leaching from N mineralisation in Cropland remaining cropland and Grassland remaining grassland. To avoid double counting the respective emissions are not reported under source category 4(III) Direct and indirect N_2O emissions from nitrogen (N) mineralization/immobilization and not included in CRT Table6 (see also chp. 9).

Table 5-20 Specification of source category 3D Agricultural soils.

3D	Source	Specification
3D.1	Direct N_2O emissions from managed soils	a. Inorganic N fertilisers b. Organic N fertilisers (i. animal manure applied to soils, ii. sewage sludge applied to soils, iii. other organic fertilisers applied to soils) c. Urine and dung deposited by grazing animals d. Crop residues (incl. residues from meadows and pasture) e. Mineralisation/immobilisation associated with loss/gain of soil organic matter f. Cultivation of organic soils (i.e. histosols) g. Other (domestic use of synthetic fertilisers)
3D.2	Indirect N_2O emissions from managed soils	a. Atmospheric deposition b. Nitrogen leaching and run-off

Furthermore, NO_x emissions from managed soils as well as NMVOC emissions are estimated.

Direct and indirect N_2O emissions from managed soils have decreased since 1990 in almost all major sub-categories. Only N_2O emissions from 3D.1.c (Urine and dung deposited by grazing animals) increased due to a higher share of manure excreted on pasture, range and paddock. NO_x emissions have declined by 26 % since 1990. The general trends can be explained by a reduction in the number of cattle and a reduced input of mineral fertilisers due to the introduction of the “Proof of Ecological Performance (PEP)” requiring a balanced fertiliser management (Agroscope 2019a, Leifeld and Fuhrer 2005). Major changes occurred mainly in the 1990s while most emissions were more or less stable after the year 2000.

The most significant N_2O emission sources are animal manure applied to soils (29 %, mean 1990–2022), nitrogen input from atmospheric deposition (21 %, mean 1990–2022), inorganic nitrogen fertilisers (16 %, mean 1990–2022) and nitrogen from fertilizers and other agricultural inputs that is lost through leaching and run-off (14 %, mean 1990–2022).

5.5.2. Methodological issues

5.5.2.1. Methodology

For the calculation of most N_2O emissions from 3D Agricultural soils a Tier 1 method was applied that is based on the IULIA model from Schmid et al. (2000). IULIA is an IPCC-derived method for the calculation of N_2O emissions from agriculture that basically uses the default emission factors (IPCC 2019), but adjusts the activity data to the particular situation of Switzerland. For the estimation of N_2O emissions from animal manure applied to soils as well as for the estimation of indirect N_2O emissions a more detailed Tier 3 approach was used. IULIA is continuously updated. New values for nitrogen excretion rates, manure management system distribution and ammonium emission factors from the Swiss ammonium model AGRAMMON were adopted (Kupper et al. 2022). Furthermore, the updated version of the "Principles of Fertilisation in Arable and Forage Crop Production" (GRUD; Richner and Sinaj 2017) was used instead of obsolete data from Flisch et al. (2009), FAL/RAC (2001) and Walther et al. (1994). More recently, the N-flow model was extended to include all gaseous N-species (including N_2) and new NO_x emission factors were implemented (Kupper 2017).

Emission factors for N_2O are all based on IPCC (2019) default with the exception of the emission factor for indirect N_2O emissions from atmospheric deposition of N volatilised from managed soils (EF_4) which is country-specific.

The modelling of the N_2O emissions is done by Agroscope, the Swiss centre of excellence for agricultural research (Agroscope 2024) and is consistent with source category 3B N_2O emissions from manure management. The model structure is displayed in Figure 5-6 and the corresponding amounts of nitrogen are given in Table 5-21.

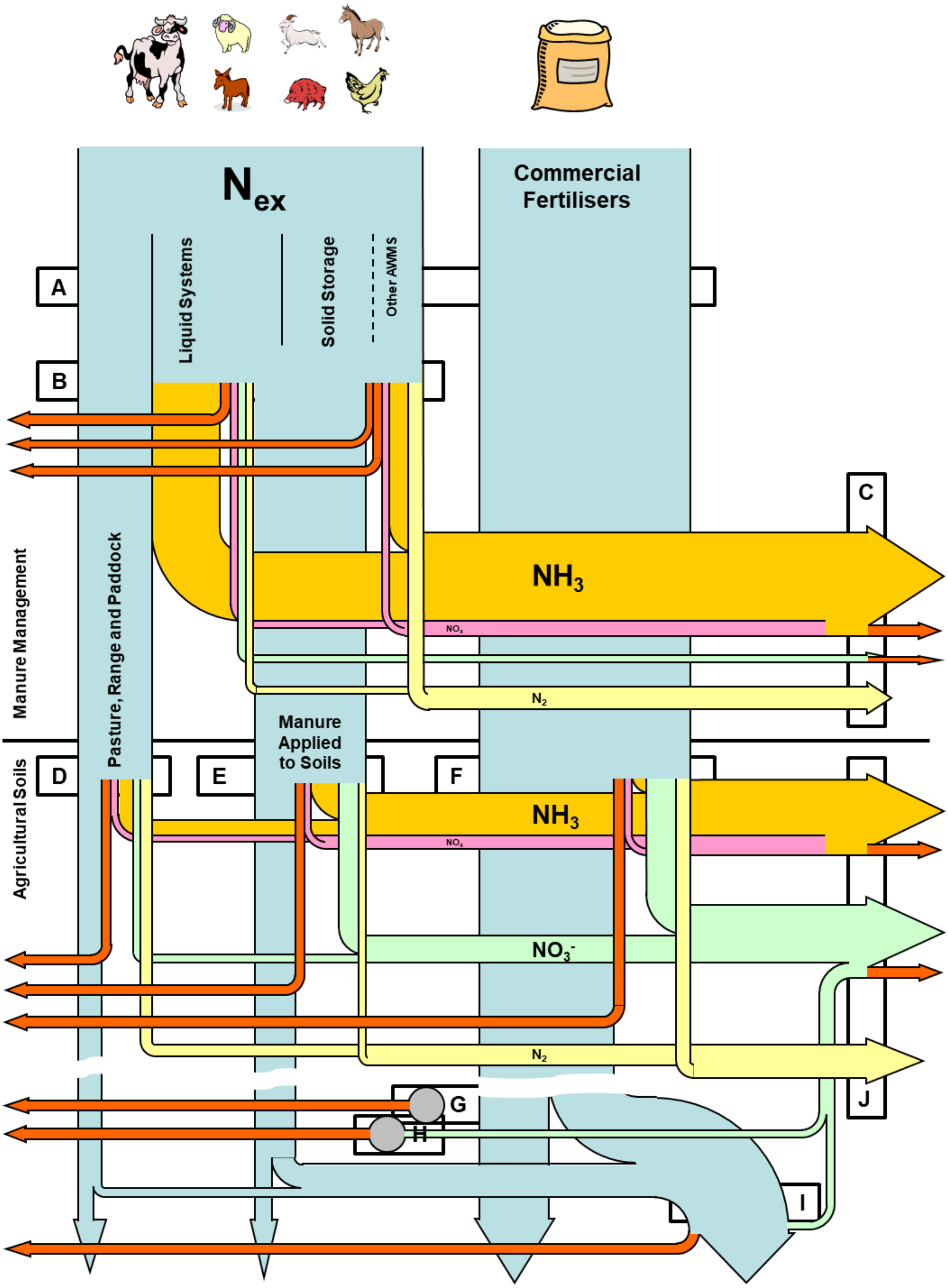

Figure 5-6 Diagram depicting the methodology of the approach to calculate the N_2O emissions in agriculture (red arrows). Black frames and the respective letters refer to the nitrogen flows in Table 5-21. Note that the figure shows explicitly the methodology of the approach and not necessarily the physical nitrogen flows. Commercial fertilisers refer to the sum of urea, other mineral fertilisers, sewage sludge, other organic fertilisers and domestic use of fertilisers. Blue: nitrogen; orange: ammonia (NH_3); pink: nitrogen oxides (NO_x); green: nitrate (NO_3^-); yellow: dinitrogen (N_2).

Table 5-21 Nitrogen flows of the N-flow-model for Swiss agriculture. Letters refer to the letters in Figure 5-6. Processes refer to the nitrogen flows in the black frames in Figure 5-6 from left to right or from top to bottom.

	Process	Amount of N			CRT table
		1990	2022		
		tN			
A	1 Pasture, range and paddock	13'546	23'679	= B	3.D.1.c
	2 Liquid/slurry systems	97'247	69'944		3.B(b)
	3 Solid storage	32'566	13'545		3.B(b)
	4 Other AWMS	9'081	22'240		3.B(b)
	5 Commercial fertiliser	77'448	47'294	= F	3.D.1.a,b(ii.iii),g
B	1 Pasture, range and paddock	13'546	23'679	= A1 + A2 + A3 + A4	3.D.1.c
	2 NH_3 volatilisation housing	11'623	14'028		3.B(b)5
	3 N_2O emission liquid/slurry	194	140		3.B(b)
	4 NO_x volatilisation liquid/slurry and digester	196	161		3.B(b)5
	5 Leaching manure management	0	0		3.B(b)5
	6 N_2 volatilisation liquid/slurry and digester	1'963	1'611		3.B(b)5
	7 Manure applied to soils	115'222	81'935		3.D.1.b.i
	8 N_2O emission solid storage	163	68		3.B(b)
	9 N_2O emission other AWMS	46	51		3.B(b)
	10 NO_x volatilisation solid storage and deep litter	209	119		3.B(b)5
	11 NH_3 volatilisation storage	8'154	6'877		3.B(b)5
	12 N_2 volatilisation solid storage and deep litter	1'125	739		3.B(b)5
C	1 NH_3 deposition manure management	19'776	20'905	= B2+B11	3.B(b)5
	2 NO_x deposition manure management	406	280	= B4+B10	
	3 Leaching manure management	0	0	= B5	
D	1 Plant available N PR&P and N2 volatilisation	9'972	17'998	= B1	
	2 N_2O emission PR&P	78	133		3.D.1.c
	3 NO_x volatilisation PR&P	75	130		
	4 NH_3 volatilisation PR&P	630	1'193		
	5 Leaching and run-off PR&P	2'791	4'224		
E	1 Plant available N animal manure and N_2 vol.	61'204	49'168	= B7	
	2 N_2O emission application animal manure	1'152	819		3.D.1.b.i
	3 NO_x volatilisation application animal manure	634	451		
	4 NH_3 volatilisation application animal manure	28'487	16'880		
	5 Leaching and run-off application animal manure	23'745	14'617		
F	1 Plant available N com. fertiliser and N_2 vol.	55'361	35'489	= A5	
	2 N_2O emission application com. fertiliser	774	461		3.D.1.a,b(ii.iii),g
	3 NO_x volatilisation application com. fertiliser	426	260		
	4 NH_3 volatilisation application com. fertiliser	4'926	2'777		
	5 Leaching and run-off application com. fertiliser	15'961	8'308		
G	1 Cultivation of organic soils (ha)	*20'391*	*19'566*		3.D.1.f
H	1 Mineralisation/immobilisation soil organic matter	7'202	14'678		3.D.1.e
I	1 N in crop residues pasture, range and paddock	26'440	20'548		3.D.1.d
	2 N in crop residues arable crops	11'953	11'091		
J	1 NH_3 deposition fertiliser appl. and PR&P	34'044	20'850	= D4+E4+F4	3.D.2.a
	2 NO_x deposition fertiliser appl. and PR&P	1'134	841	= D3+E3+F3	
	4 Leaching and run-off fertiliser appl. and PR&P	42'497	27'149	= D5+E5+F5	3.D.2.b
	5 Leaching and run-off mineralisation SOM	1'484	2'619		
	6 Leaching and run-off crop residues	7'912	5'644		

5.5.2.2. Direct N_2O emissions from managed soils (3D.1)

Calculation of Direct N_2O emissions from managed soils is based on IPCC 2006 equation 11.1 including six terms for activity data and three different emission factors:

$$N_2O_{Direct} - N = (F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \bullet EF_1 + F_{OS} \bullet EF_2 + F_{PRP} \bullet EF_3$$

N_2O_{Direct}-N = annual direct N_2O–N emissions produced from managed soils (kg N_2O–N/year)

F_{SN} = annual amount of synthetic fertiliser N applied to soils (kg N/year)

F_{ON} = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (kg N/year)

F_{CR} = annual amount of N in crop residues, including N-fixing crops, returned to soils (kg N/year)

F_{SOM} = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes of land use or management (kg N/year)

F_{OS} = annual area of managed/drained organic soils (ha)

F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock (kg N/year)

EF_1 = emission factor for N_2O emissions from N inputs (kg N_2O–N/kg N input)

EF_2 = emission factor for N_2O emissions from drained/managed organic soils (kg N_2O–N/ha)

EF_3 = emission factor for N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals (kg N_2O–N/kg N input)

5.5.2.2.1. Emission factors

Emission factors for calculating 3D.1 Direct N_2O emissions from managed soils are based on default values as provided in the 2019 Refinement (Table 5-22). For EF_1 the aggregated default value of 1 % is used (IPCC 2019). A rationale for the appropriateness is provided in chp. 5.5.4. Since the year 2007 mineral fertilisers with nitrification inhibitors are used in Switzerland. The use of nitrification inhibitors reduces direct N_2O emissions from these fertilisers by 65 %. This reduction factor is ultimately based on Pfab et al. (2012) but also supported by studies of Weiske et al. (2001) and a meta-analysis by Akiyama et al. (2009) as described in First Climate (2017). The applied amounts are still small and the weighted emission factor (EF_1) reported is thus only slightly below 1.0 %. The amount of fertilisers with nitrification inhibitors is classified as confidential (C). An additional table is available to reviewers on request, including all confidential data and information (Table 5-23). Due to the lack of data no other source specific emission factors were applied for EF_1. The N_2O emission factor for cultivated organic soils (EF_2) is the area weighted mean of the IPCC default emission factors for N_2O emissions from cultivated organic soils under cropland (drained 13.0 kg N_2O-N/ha/year, IPCC 2014a) and grassland (deep-drained, nutrient rich 8.2 kg N_2O-N/ha/year; IPCC 2014a). The emission factor for urine and dung deposited by grazing animals was calculated as the weighted mean between the emission factor for cattle, poultry and pigs in wet climates ($EF_{3PRP,CPP}$ = 0.006 kg N_2O–N/kg N) and the emission factor for sheep and “other animals” ($EF_{3PRP,SO}$ = 0.003 kg N_2O–N/kg N) according to the shares of nitrogen excreted by the respective animals (IPCC 2019).

Table 5-22 Emission factors for calculating direct N_2O emissions from managed soils (based on IPCC 2019 and IPCC 2014a). Blue: annually changing parameters, value for 2022.

Emission source	Emission factor
EF_1 Inorganic N fertilisers (kg N_2O-N/kg)	0.0097
EF_1 Organic N fertilisers (kg N_2O-N/kg)	0.01
EF_1 Crop residue (kg N_2O-N/kg)	0.01
EF_1 Mineralisation/immobilisation soil organic matter (kg N_2O-N/kg)	0.01
EF_1 Other (domestic synthetic fertilisers) (kg N_2O-N/kg)	0.01
EF_2 Cultivation of organic soils (kg N_2O-N/ha)	10.8
EF_3 Urine and dung deposited by grazing animals (kg N_2O-N/kg)	0.0056

Table 5-23 In the confidential NID, the amount of mineral fertilisers with and without nitrification inhibitors and corresponding emission factors are separately reported and available to reviewers.

5.5.2.2.2. Activity data

Activity data for calculation of 3D.1 Direct soil emissions include a. Inorganic N fertilisers, b. Organic N fertilisers, c. Urine and dung deposited by grazing animals, d. Crop residues, e. Nitrogen from mineralisation/immobilisation associated with loss/gain of soil organic matter f. Area of organic soils (i.e. histosols) and g. Other (i.e. Domestic use of inorganic fertilisers).

Emissions from **inorganic nitrogen fertilisers** include urea and other mineral fertilisers (mainly ammonium-nitrate). The amount of nitrogen input due to these fertilisers is obtained from Agricura (2022). Fertiliser statistics are based on sales statistics of the compulsory stockpiling of fertilisers (“Pflichtlagerhalter”) and small importers. Agricura conducts plausibility checks with import-data received by the Federal Office for Customs and Border Security (FOCBS). The estimates contain fertilisers used in Liechtenstein which are subtracted for the Swiss GHG inventory. Furthermore, it is estimated that 4 % of the mineral fertilisers are used for non-agricultural purposes (i.e. domestic use of inorganic fertilisers; Kupper et al. 2022). These fertilisers are used in public green areas, sports grounds and home gardens. In the reporting tables (CRT) they are reported under 3D.1.g **Other (Domestic inorganic fertilisers)** while emission calculation is conducted together with 3D.1.a. In some occasions, as for instance for the estimation of indirect N_2O emissions from managed soils, the sum of urea, other mineral fertilisers, sewage sludge, other organic fertilisers and domestic use of fertilisers is referred to as “**commercial fertilisers**” (see also Figure 5-6 and Table 5-21).

Organic nitrogen fertilisers include animal manure, sewage sludge and other organic fertilisers. The amount of nitrogen in **animal manure applied to soils** is calculated according to the methods described in chp. 5.3.2.5. As suggested in chp. 10.5.4. and equation 10.34 of IPCC 2019, all nitrogen excreted on pasture, range and paddock as well as all nitrogen volatilised prior to final application to managed soils is subtracted from the total excreted manure (for the estimation of the respective N–volatilisation during manure management see chp. 5.3.2.5, compare also Figure 5-6). $Frac_{GASM}$ in CRT Table3.D represents the amount of nitrogen volatilised as NH_3, NO_x, N_2O and N_2 from housing and manure storage divided by the manure excreted in the stable (liquid/slurry, solid storage, digesters, deep litter and poultry manure). The nitrogen input from manure applied to soils under 3D.1.b.i in CRT Table3.D can thus be calculated with the numbers given in CRT Table3.B(b) and Table3.D. Nitrogen from bedding material was not accounted for under animal manure applied to soils. The respective nitrogen is included in the nitrogen returned to soils as crop residues.

The amount of **sewage sludge** applied to agricultural soils was estimated according to Kupper et al. (2022). Since 2003 it is forbidden in Switzerland to use sewage sludge as a fertiliser. As of 2006, this prohibition has been made effective for all agricultural areas with a transition period to 2008 (UVEK 2003).

Additional to nitrogen from animal manure and sewage sludge the Swiss GHG inventory also considers **other organic fertilisers** applied to soils. These include compost, liquid and solid digestates from industrial biogas plants as well as co-substrates from agricultural biogas plants and nitrogen inputs from decentralised wastewater streams. Total amounts of compost are based on data from CVIS (Inspektorat der Kompostier- und Vergärbranche der Schweiz; CVIS 2023) while amounts of liquid and solid digestates as well as co-substrates from biogas plants are assessed based on the renewable energy statistics (SFOE 2023a). Nitrogen contents of these substrates are based on Kupper et al. (2022). Nitrogen inputs from decentralised human wastewaters treated via manure tanks are estimated based on Vuna (2023, see also EMIS 2024/5D2 Kläranlagen kommunal). Losses of NH_3, N_2O, NO_x and N_2 during liquid storage are subtracted in order to calculate the amount of nitrogen applied to soils. Thereby it is assumed that the respective wastewater enters directly liquid/slurry tanks on farms that keep mainly cattle. Accordingly, the NH_3 loss rate during storage is adopted from cattle and adjusted for the higher content of total ammoniacal nitrogen in human excrements (TAN-content of 55 % and 70 % for cattle and swine/human excreta respectively, Kupper et al. 2022). All other loss rates are assessed as described under chp. 5.3.2.5.4. Note that emissions of CH_4 and N_2O from storage are reported under 7.5 Source category 5D – Wastewater treatment and discharge.

Calculation of emissions from **urine and dung deposited by grazing animals** is based on equation 11.5 of IPCC 2019. Estimation of total livestock nitrogen excretion was described under chp. 5.3.2.5. The share of manure nitrogen excreted on pasture, range and paddock was estimated according to the AGRAMMON-model (Kupper et al. 2022; Table 5-14). For each livestock category the share of animals that have access to grazing, the number of days per year they are actually grazing as well as the number of hours per day grazing takes place was assessed. Estimates are based on values from the literature and expert judgement (1990, 1995) and on surveys on approximatively 3000 Swiss farms (2000, 2007, 2010, 2015, 2019).

N_2O emissions from **crop residues** are based on the amount of nitrogen in crop residues returned to soil. For **arable crops**, data on total annual crop harvests were adopted from the statistical yearbooks of the Swiss Farmers Union (SBV 2023, note that this data refers to total harvest and not to yields per ha). Harvest data is based on surveys at the primary recipients (e.g. mills, sugar processing industry), yield assessment at approximately 1000 producers, as well as on data from central accounting evaluations of roughly 3000 farms (Agroscope, 2019a). To estimate the amount of nitrogen in crop residues, the harvested amount in tonnes is multiplied with the term NR_T/SY_T which corresponds to the amount of nitrogen in crop residues per amount of fresh matter crop yield. Standard values for NR_T and SY_T are published in Richner and Sinaj (2017, chapter 8 table 9; SY_T=”Referenzertrag / Körner, Hauptprodukt”, NR_T=”Nährstoffentzug basierend auf dem Referenzertrag (N) / Körner, Hauptprodukt”) and FAL/RAC (2001, table 2) and are based on long-term field trials by Agroscope.

$$F_{CR,AC} = \sum_{T} \left(Y_T \bullet \frac{NR_T}{SY_T} \right)$$

$F_{CR,AC}$ = amount of nitrogen in crop residues from arable crops returned to soils (t N)

Y_T = amount of fresh matter crop harvest for crop *T* (t)

NR_T = standard amount of nitrogen in crop residues for crop *T* (dt/ha)

SY_T = standard amount of fresh matter crop yield for crop *T* (dt/ha)

For sugar beet and fodder beet it is assumed that 10 % of the crop residues are removed from the fields for animal fodder. The use of crop residues for fuel or the (open) burning of crop residues are not common practice in Switzerland and are subject to strong regulations. These activities are therefore not considered to reduce the amount of N returned to soils. Straw used as bedding material is later applied to soils together with animal manure. In order to prevent double counting, the respective amount of nitrogen is not subtracted here as it is not added to animal manure nitrogen under manure management (see chp. 5.3.2.5).

Crop residues from **meadows and pastures** were also assessed as suggested in the 2019 Refinement (IPCC 2019, other forages including perennial grasses and grass/clover pastures). Two thirds of the agricultural land consist of grassland which underscores the importance of this source for Switzerland. Field losses during harvest, from feed not eaten by the animals and feed losses due to trampling effects are included.

With the elaboration of the “Model-based carbon inventory for national greenhouse gas reporting of mineral agricultural soils” (Wüst-Galley et al. 2020) the estimation of nitrogen inputs from crop residues from meadows and pastures was revised in order to assure consistent reporting of C- and N-fluxes in agricultural soils. For the assessment of total crop dry matter produced a mixed approached based on reported annual harvest data (overall harvest in tonnes, e.g. SBV 2023), standard yields (dt/ha, Richner and Sinaj 2017; attribution to the different grassland types) and surface data of detailed grassland types (in ha, background data of the Federal Statistical Office, unpublished) was applied. The former is affected primarily by meteorological conditions. The latter two data sets allowed fluctuations in the management intensity of the grassland surface to be accounted for. For each year the different yields of the grassland types are weighted according to the respective areas (compare also chp. 6.6.2.1.1). Nitrogen contents of dry matter were adopted from Richner and Sinaj (2017, chapter 9 table 3b) and yield losses in percent were adopted from Agridea (2016).

Estimated values of total crop production, nitrogen incorporated with crop residues $F_{(CR)}$, residue/crop ratio, dry matter fraction of residues and nitrogen content of residues are provided in Annex A5.3.

Assessment of nitrogen **mineralisation/immobilisation associated with loss/gain of soil organic matter** was conducted based on data from the LULUCF sector. For reasons of consistency, losses and gains of soil organic matter on cropland and grasslands were accounted for. The same methodology as described under chp. A5.4.1 was applied. Nitrogen mineralisation was estimated by dividing the carbon loss on Cropland remaining cropland and Grassland remaining grassland with a C/N-ratio of 9.8 according to Leifeld et al. (2007).

It should be noted that for grassland the carbon losses were assessed based on land-use changes on a sub-category level. Only land-use changes that led to a net carbon stock loss were considered, excluding land-use changes that led to a net carbon stock increase. Consequently, the carbon losses used for calculating N_2O emissions from nitrogen mineralisation are not identical with the net carbon stock changes reported in the reporting table (Table4.C). N_2O emissions from nitrogen mineralisation of land converted to cropland or land converted to grassland are reported under category 4(III) “Direct nitrous oxide (N_2O) emissions from nitrogen (N) mineralisation/immobilisation associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils”.

Estimates of N_2O emissions from **cultivated organic soils** are based on the area of cultivated organic soils under cropland and grassland and the IPCC default emission factors for N_2O emissions from cultivated organic soils under cropland (drained 13.0 kg N_2O-N/ha/year, IPCC 2014a) and grassland (deep-drained, nutrient rich 8.2 kg N_2O-N/ha/year; IPCC 2014a). The area of cultivated organic soils corresponds to the total area of organic soils under cropland and grassland as reported in CRT Table4.B and 4.C (see also chp. 6.2.2.1).

The relevant activity data for calculating N_2O emissions from soils are displayed in Table 5-24. Additional information is given in a separate spreadsheet (Agroscope 2024a).

Table 5-24 Activity data for calculating 3D.1 Direct N_2O emissions from managed soils.

Activity Data		**1990-2015**					
		1990	**1995**	**2000**	**2005**	**2010**	**2015**
		t N/yr					
1. Inorganic N fertilisers	Urea	16'284	10'707	7'631	6'605	7'101	7'223
	Other mineral fertilisers	50'390	47'652	43'042	43'478	45'985	36'521
2. Organic N fertilisers	a. Animal manure	115'222	106'497	87'265	82'437	85'964	84'572
	b. Sewage sludge	4'815	4'942	3'356	1'054	0	0
	c. Other organic fertilisers	817	1'286	1'829	2'169	3'281	4'908
3. Urine and dung deposited by grazing animals		13'546	14'279	21'269	23'955	24'234	23'672
4. Crop residues	Arable crops	11'953	11'350	12'345	11'750	10'740	10'925
	Residues M&P	26'440	25'196	26'298	26'155	24'688	21'183
5. Min./imm. associated with loss/gain of SOM		7'202	10'648	9'962	2'681	4'276	13'871
6. Cultivation of organic soils (ha)		20'391	20'249	20'098	19'941	19'806	19'694
7. Other (domestic inorganic fertilisers)		2'778	2'432	2'111	2'087	2'212	1'823

Activity Data		**2016-2022**						
		2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
		t N/yr						
1. Inorganic N fertilisers	Urea	8'872	9'250	8'324	7'752	7'397	8'100	6'915
	Other mineral fertilisers	37'531	40'113	37'432	32'400	33'694	37'265	31'531
2. Organic N fertilisers	a. Animal manure	84'078	83'392	82'824	81'715	81'443	81'675	81'935
	b. Sewage sludge	0	0	0	0	0	0	0
	c. Other organic fertilisers	5'435	5'542	5'668	6'211	6'357	6'548	6'575
3. Urine and dung deposited by grazing animals		23'718	23'767	23'736	23'615	23'464	23'554	23'679
4. Crop residues	Arable crops	10'144	11'850	11'168	11'472	11'960	9'469	11'091
	Residues M&P	26'640	24'315	21'059	25'160	24'590	22'656	20'548
5. Min./imm. associated with loss/gain of SOM		10'367	7'794	7'923	6'764	7'168	11'090	14'678
6. Cultivation of organic soils (ha)		19'673	19'655	19'637	19'619	19'602	19'584	19'566
7. Other (domestic inorganic fertilisers)		1'933	2'057	1'907	1'673	1'712	1'890	1'602

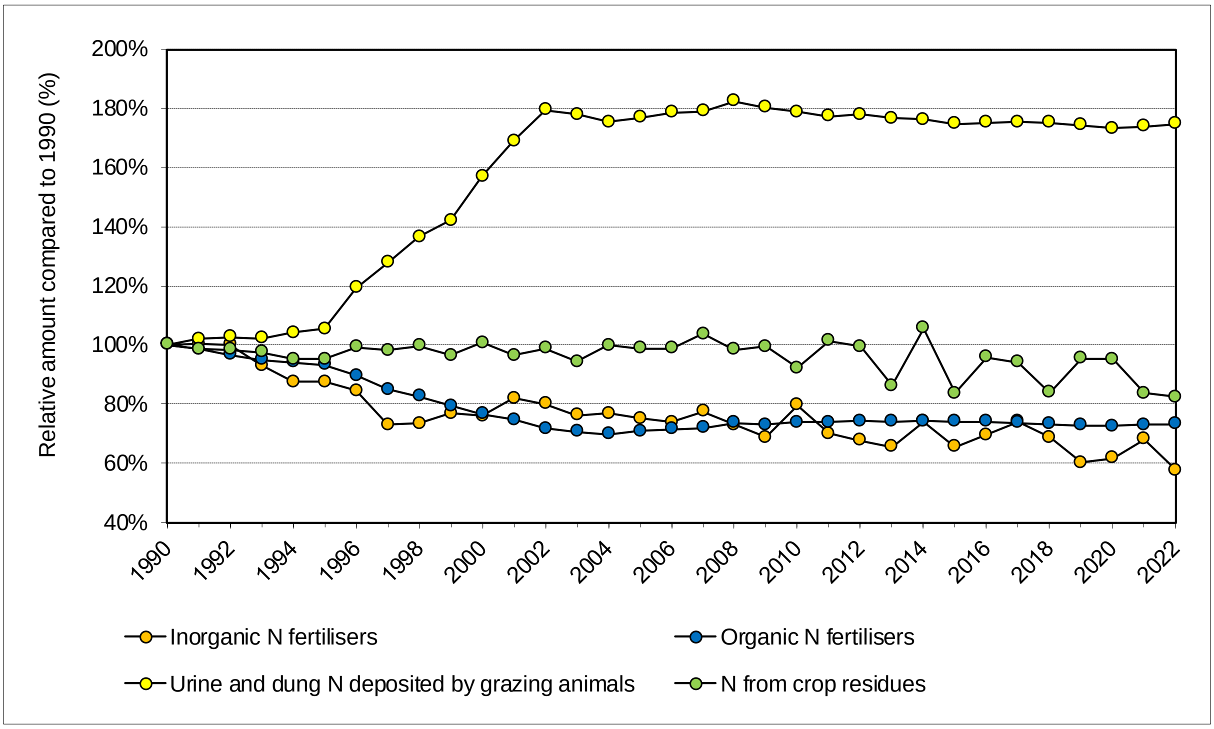

Figure 5-7 Relative development of the most important activity data for 3D.1 Direct N_2O emissions from managed soils.

Figure 5-7 represents the development of the most important activity data for 3D.1 Direct N_2O emissions from managed soils. The use of inorganic N-fertiliser declined mainly during the 1990s due to the agricultural policy reforms and the introduction of the “Proof of Ecological Performance (PEP)” that requires a balanced fertiliser management. Simultaneously, nitrogen input from animal manure declined due to declining livestock populations (mainly cattle). Urine and dung deposited by grazing animals increased substantially due to the shift to more animal-friendly livestock husbandry in the course of the agricultural policy reforms during the 1990s and the early 21st century (see also chp. 5.3.2.2.4). N inputs from crop residues remained more or less constant during the inventory time period due to more or less stable crop production.

5.5.2.3. Indirect N_2O emissions from atmospheric deposition of N volatilised from managed soils (3D.2.a)

N_2O emissions from atmospheric deposition of N volatilised from managed soils were estimated based on equations 11.9 and 11.11 of IPCC 2019 Guidelines. However, the method was adapted to the far more detailed approach of Switzerland:

$$N_2O_{(ATD)} - N = \left\{\left[\sum_i \left(F_{CN_i} * Frac_{GASF_i}\right) + \sum_T \left(F_{AM_T} * Frac_{GASM_T}\right) + \sum_T \left(F_{PRP_T} * Frac_{GASP_T}\right)\right] \right.$$
$$\left. + \left[\left(F_{CN} + F_{AM}\right) * Frac_{NOXA} + F_{PRP} * Frac_{NOXP}\right]\right\} * EF_4$$

$N_2O_{(ATD)}$-N = annual amount of N_2O–N produced from atmospheric deposition of N volatilised from managed soils (kg N_2O–N/year)

F_{CNi} = annual amount of commercial fertiliser N of type *i* applied to soils (kg N/year)

$Frac_{GASFi}$ = fraction of commercial fertiliser N of type *i* that volatilises as NH_3 (kg N/kg N)

F_{AMT} = annual amount of managed animal manure N of livestock category *T* applied to soils (kg N/year)

$Frac_{GASMT}$ = fraction of applied animal manure N of livestock category *T* that volatilises as NH_3 (kg N/kg N)

F_{PRPT} = annual amount of urine and dung N deposited on pasture, range and paddock by grazing animals of livestock category *T* (kg N/year)

$Frac_{GASPT}$ = fraction of urine and dung N deposited on pasture, range and paddock by grazing animals of livestock category *T* that volatilises as NH_3 (kg N/kg of N)

F_{CN} = total amount of commercial fertiliser N applied to soils (kg N/year)

F_{AM} = total amount of managed animal manure N applied to soils (kg N/year)

$Frac_{NOXA}$ = fraction of applied N (commercial fertilisers and animal manure) that volatilises as NO_x (kg N/kg N)

F_{PRP} = total amount of urine and dung N deposited on pasture, range and paddock by grazing animals (kg N/year)

$Frac_{NOXP}$ = fraction of urine and dung N deposited on pasture, range and paddock that volatilises as NO_x (kg N/kg of N)

EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces (kg N_2O-N/ kg N volatilised).

5.5.2.3.1. Emission factor

The emission factor for indirect N_2O emissions from atmospheric deposition of N volatilised from managed soils is the same as used for the assessment of indirect N_2O emissions after volatilisation of NH_3 and NO_x from manure management systems. The emission factor was reassessed by a literature review by Bühlmann et al. (2015) and Bühlmann (2014). Due to slightly changing land use, the resulting emission factor shows some small variations around a mean value of 2.57 %. For further information see chp. 5.3.2.4.

5.5.2.3.2. Activity data

The estimation of volatilisation of ammonia and NO_x was harmonised with the Swiss ammonia model AGRAMMON using the same emission factors and basic parameters (Table 5-25). Losses of commercial fertiliser nitrogen, animal manure N applied to soils, as well as urine and dung N deposited on pasture, range and paddock by grazing animals were considered. For the calculation of NH_3 emissions, changes of agricultural structures (changes to more animal friendly housing systems) and techniques (manure management, measures to reduce NH_3 emissions) are considered and explain temporal dynamics.

Ammonia volatilisation from **commercial fertiliser N** was estimated separately for synthetic fertilisers, sewage sludge, and other organic fertilisers (compost, liquid and solid digestates from industrial biogas plants, co-substrates from agricultural biogas plants and nitrogen inputs from decentralised human wastewaters treated via manure tanks). Ammonia volatilisation of nitrogen in synthetic fertilisers was assessed separately for individual fertiliser types based on the EMEP/EEA guidebook (EMEP/EEA 2019). The weighted mean value for synthetic fertilisers excluding urea is 2.8 % (mean 1990–2022). Furthermore 13.1 % of urea-nitrogen is lost as ammonia. Ammonia emission factors for sewage sludge range from 20 % to 26 % depending on the composition of the sludge (Kupper et al. 2022). Other organic fertilisers include compost, liquid and solid digestates, co-substrates from agricultural biogas plants as well as nitrogen inputs from decentralised human wastewaters treated via manure tanks. Ammonia emission factors are 3.4 % for compost, 21 % to 30 % for liquid digestate (including co-substrates from agricultural biogas plants) and 4.0 % for solid digestate (Kupper et al. 2022). The ammonia loss rate for liquid digestates decreased from 2001 until 2010 due to the increasing use of trailing hoses during field application. For decentralised human wastewaters treated via manure tanks an ammonia loss rate of 11.9 % was assumed for soil application. This value is based on the respective loss rates of cattle manure corrected for the higher content of total ammoniacal nitrogen in human excrements (TAN-content of 55 % and 70 % for cattle and swine/human excreta respectively, Kupper et al. 2022). The average ammonia emission factor for recycling fertilisers varies along the inventory time period due to the development of the relative amounts of the different recycling fertilisers types.

Total $Frac_{GASF}$ (including NO_x emissions) as reported in CRT Table3.D declined considerably from 6.9 % in 1990 to 5.1 % in 2006 and then increased again to 6.4 % in 2022 due to a change in the shares of the different commercial fertilisers.

Different ammonia loss factors were used for **animal manure N applied to soils** from different livestock categories according to the detailed approach of the AGRAMMON model (Kupper et al. 2022). Overall weighted $Frac_{GASMT}$ for animal manure applied to soils slightly declined from 25.3 % in the early 1990s to 21.2 % in 2022 (Table 5-25).

Ammonia volatilisation from **urine and dung N deposited on pasture, range and paddock by grazing animals** was also assessed individually for each livestock category (Kupper et al. 2022). Weighted mean loss rates ($Frac_{GASPT}$) range from 5.2 % to 5.6 %.

NO_x emissions were estimated separately for applied fertiliser N (commercial fertilisers, animal manure) and for urine and dung N deposited on pasture, range and paddock by grazing animals. NO_x emission factors ($Frac_{NOXA}$ and $Frac_{NOXP}$) for applied fertilisers and for urine and dung N deposited on pasture, range and paddock are 0.55 % each, based on Stehfest and Bouwman (2006).

Nitrogen pools and flows for calculating 3D.2 Indirect N_2O emissions from managed soils are displayed in Table 5-26. Additional information is given in a separate spreadsheet (Agroscope 2024a).

Table 5-25 Overview of NH_3 and NO_x emission factors used for the assessment of 3D.2 Indirect N_2O emissions from atmospheric deposition. Complete time series on a livestock sub-category level are provided in a separate spreadsheet (Agroscope 2024a).

Emission factors volatilisation	**1990-2015**					
	1990	**1995**	**2000**	**2005**	**2010**	**2015**
	%					
NH_3 from commercial fertiliser N ($Frac_{GASFi}$)	6.36	6.18	5.54	4.76	4.77	5.65
Urea	13.11	13.11	13.11	13.11	13.11	13.11
Other Mineral Fertilisers	2.72	2.72	2.51	2.76	3.07	3.29
Recycling Fertilisers (weighted average)	17.60	19.97	18.80	13.40	9.37	11.74
Sewage Sludge	20.00	23.94	26.07	26.07	26.07	26.07
Compost	3.43	3.43	3.43	3.43	3.43	3.43
Digestate Liquid	30.00	30.00	30.00	26.06	21.00	21.00
Digestate Solid	4.00	4.00	4.00	4.00	4.00	4.00
Decentralised wastewater	11.95	11.95	11.95	11.95	11.95	11.95
NH_3 from application of animal manure N ($Frac_{GASMT}$)	24.72	24.54	23.47	23.32	21.95	20.70
Mature Dairy Cattle	26.85	26.78	26.04	26.21	24.94	23.31
Other Mature Cattle	22.86	22.06	22.38	22.72	22.47	21.59
Growing Cattle (weighted average)	23.68	23.51	23.14	23.48	22.71	21.22
Sheep (weighted average)	4.89	4.89	4.75	5.33	5.45	4.93
Swine (weighted average)	24.20	23.95	21.93	21.28	19.09	18.22
Other Livestock (weighted average)	10.12	10.09	9.09	9.54	9.98	10.04
NH_3 from urine and dung N deposited on PR&P ($Frac_{GASPT}$)	4.65	4.69	4.80	4.89	4.89	4.91
Mature Dairy Cattle	4.67	4.65	4.63	4.61	4.60	4.59
Other Mature Cattle	4.56	4.57	4.56	4.56	4.56	4.56
Growing Cattle (weighted average)	4.56	4.56	4.57	4.57	4.57	4.57
Sheep (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00
Swine (weighted average)	NA	NA	14.00	14.00	14.00	14.00
Other Livestock (weighted average)	5.00	6.47	7.58	8.48	8.51	8.76
NO_x from applied fertilisers ($Frac_{NOXA}$)	0.55	0.55	0.55	0.55	0.55	0.55
NO_x from urine and dung N deposited on PR&P ($Frac_{NOXP}$)	0.55	0.55	0.55	0.55	0.55	0.55

Emission factors volatilisation	**2016-2022**						
	2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	%						
NH_3 from commercial fertiliser N ($Frac_{GASFi}$)	5.54	5.63	5.72	6.03	6.00	5.80	5.87
Urea	13.11	13.11	13.11	13.11	13.11	13.11	13.11
Other Mineral Fertilisers	2.80	2.99	3.05	3.12	3.20	3.01	2.85
Recycling Fertilisers (weighted average)	11.64	11.83	12.07	12.04	12.30	12.35	12.40
Sewage Sludge	26.07	26.07	26.07	26.07	26.07	26.07	26.07
Compost	3.43	3.43	3.43	3.43	3.43	3.43	3.43
Digestate Liquid	21.00	21.00	21.00	21.00	21.00	21.00	21.00
Digestate Solid	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Decentralised wastewater	11.95	11.95	11.95	11.95	11.95	11.95	11.95
NH_3 from application of animal manure N ($Frac_{GASMT}$)	20.69	20.69	20.71	20.69	20.64	20.62	20.60
Mature Dairy Cattle	23.32	23.33	23.34	23.36	23.36	23.35	23.35
Other Mature Cattle	21.53	21.46	21.40	21.34	21.33	21.33	21.33
Growing Cattle (weighted average)	21.28	21.37	21.42	21.48	21.46	21.47	21.47
Sheep (weighted average)	4.98	5.03	5.07	5.11	5.12	5.12	5.11
Swine (weighted average)	18.24	18.27	18.30	18.32	18.34	18.34	18.34
Other Livestock (weighted average)	10.16	10.16	10.41	10.43	10.57	10.61	10.63
NH_3 from urine and dung N deposited on PR&P ($Frac_{GASPT}$)	4.94	4.96	4.98	5.00	5.03	5.04	5.04
Mature Dairy Cattle	4.59	4.59	4.59	4.59	4.59	4.59	4.59
Other Mature Cattle	4.56	4.56	4.56	4.56	4.56	4.56	4.56
Growing Cattle (weighted average)	4.57	4.57	4.57	4.57	4.57	4.57	4.57
Sheep (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Swine (weighted average)	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Other Livestock (weighted average)	9.09	9.24	9.67	9.83	10.27	10.27	10.32
NO_x from applied fertilisers ($Frac_{NOXA}$)	0.55	0.55	0.55	0.55	0.55	0.55	0.55
NO_x from urine and dung N deposited on PR&P ($Frac_{NOXP}$)	0.55	0.55	0.55	0.55	0.55	0.55	0.55

Table 5-26 Overview of N pools and flows for calculating 3D.2 Indirect N_2O emission from managed soils. Complete time series are provided in a separate spreadsheet (Agroscope 2024a).

Nitrogen pools and flows		**1990-2015**					
		1990	**1995**	**2000**	**2005**	**2010**	**2015**
		t N/yr					
	Animals manure N applied to soils	115'222	106'497	87'265	82'437	85'964	84'572
	Commercial fertiliser	75'084	67'019	57'969	55'394	58'579	50'475
Deposition	Sum volatised N (NH_3 and NO_x)	35'178	32'081	25'689	23'961	23'811	22'435
	NH_3 emissions from commercial fertilisers	4'926	4'234	3'267	2'669	2'825	2'886
	NH_3 emissions from applied animal manure	28'487	26'136	20'479	19'226	18'868	17'509
	NH_3 emissions from pasture, range and paddock	630	670	1'021	1'172	1'185	1'163
	NO_x emissions from commercial fertilisers	426	377	325	309	326	281
	NO_x emissions from applied animal manure	634	586	480	453	473	465
	NO_x emissions from PR&P	75	79	117	132	133	130
Leaching and run-off	Sum leaching and run-off	51'894	48'731	42'552	38'106	37'287	36'600
	Leaching and run-off from commercial fertilisers	15'961	14'115	11'619	10'529	10'546	9'088
	Leaching and run-off from applied animal manure	23'745	21'947	17'178	15'467	15'335	15'087
	Leaching and run-off from pasture, range and paddock	2'791	2'943	4'187	4'495	4'323	4'223
	Leaching and run-off from crop residues	7'912	7'531	7'607	7'112	6'320	5'728
	Leaching and run-off from mineralisation of SOM	1'484	2'194	1'961	503	763	2'475

Nitrogen pools and flows		**2016-2022**						
		2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
		t N/yr						
	Animals manure N applied to soils	84'078	83'392	82'824	81'715	81'443	81'675	81'935
	Commercial fertiliser	53'771	56'962	53'331	48'036	49'160	53'803	46'622
Deposition	Sum volatised N (NH_3 and NO_x)	22'472	22'576	22'300	21'864	21'828	22'065	21'691
	NH_3 emissions from commercial fertilisers	3'014	3'241	3'085	2'933	2'988	3'158	2'777
	NH_3 emissions from applied animal manure	17'394	17'252	17'150	16'905	16'809	16'843	16'880
	NH_3 emissions from pasture, range and paddock	1'172	1'178	1'182	1'180	1'181	1'186	1'193
	NO_x emissions from commercial fertilisers	299	317	297	268	274	299	260
	NO_x emissions from applied animal manure	462	459	456	449	448	449	451
	NO_x emissions from PR&P	130	131	131	130	129	130	130
Leaching and run-off	Sum leaching and run-off	37'310	37'146	35'684	35'052	35'238	36'032	35'411
	Leaching and run-off from commercial fertilisers	9'669	10'188	9'512	8'520	8'725	9'551	8'308
	Leaching and run-off from applied animal manure	14'999	14'876	14'775	14'577	14'529	14'570	14'617
	Leaching and run-off from pasture, range and paddock	4'231	4'240	4'234	4'213	4'186	4'202	4'224
	Leaching and run-off from crop residues	6'562	6'452	5'749	6'535	6'520	5'731	5'644
	Leaching and run-off from mineralisation of SOM	1'849	1'390	1'413	1'207	1'279	1'978	2'619

Figure 5-8 shows the development of the most important activity data for 3D.2 Indirect N_2O emissions from managed soils. Ammonia emissions from application of commercial fertilisers declined mainly due to reduced fertiliser use and partly also due to the decreasing share of fertilisers with high ammonia emission rates (i.e. urea and sewage sludge). Ammonia emissions from applied animal manure declined mainly due to declining livestock populations and hence due to the reductions of available manure N. The fraction of applied animal manure N that volatilises as NH_3 ($Frac_{GASMT}$) declined slightly and also contributed to the decreasing trend.

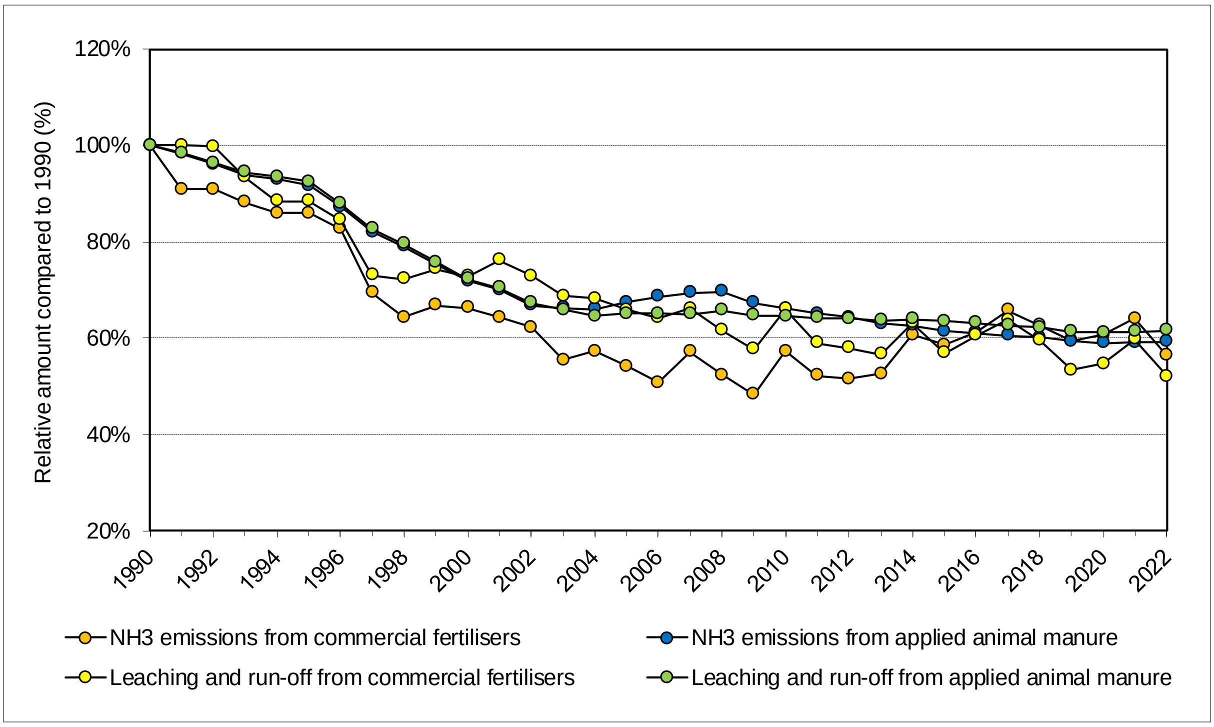

Figure 5-8 Relative development of the most important activity data for 3D.2 Indirect N_2O emissions from managed soils.

5.5.2.4. Indirect N_2O emissions from leaching and run-off from managed soils (3D.2.b)

N_2O emissions from leaching and run-off from managed soils are estimated based on equation 11.10 of IPCC 2019:

$$N_2O_{(L)} - N = (F_{CN} + F_{AM} + F_{PRP} + F_{CR} + F_{SOM}) \bullet Frac_{LEACH-(H)} \bullet EF_5$$

$N_2O_{(L)}$–N = annual amount of N_2O–N produced from leaching and run-off of N additions to managed soils (kg N_2O–N/year)

F_{CN} = annual amount of commercial fertiliser N applied to soils (kg N/year)

F_{AM} = annual amount of managed animal manure N applied to soils (kg N/year)

F_{PRP} = annual amount of urine and dung N deposited by grazing animals (kg N/year)

F_{CR} = annual amount of N in crop residues, including N-fixing crops, returned to soils (kg N/year)

F_{SOM} = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes of land use or management (kg N/year)

$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralised in managed soils that is lost through leaching and runoff (kg N/kg of N additions)

EF_5 = emission factor for N_2O emissions from N leaching and run-off (kg N_2O–N/kg N leached and run-off)

5.5.2.4.1. Emission factor

The emission factor for indirect N_2O emissions from leaching and run-off from managed soils is 0.011 kg N_2O–N/kg N according to IPCC (2019).

5.5.2.4.2. Activity data

For the calculation of N_2O emissions from leaching and run-off from managed soils, N-leaching from commercial fertilisers (including synthetic fertilisers, sewage sludge, compost, liquid and solid digestates from industrial biogas plants, co-substrates of agricultural biogas plants as well as nitrogen inputs from decentralised human wastewaters treated via manure tanks) (F_{CN}), managed animal manure N applied to soils (F_{AM}), urine and dung N deposited by grazing animals (F_{PRP}), N in crop residues returned to soils (F_{CR}) and N mineralised in mineral soils (F_{SOM}) were accounted for. The method for the assessment of the respective amounts of nitrogen is described in chp. 5.5.2.2 and activity data are contained in Table 5-24.

$Frac_{LEACH-H}$ was estimated for the years 1990 and 2010 by dividing the available amount of nitrogen by the amount of nitrogen that is lost due to leaching and run-off in Switzerland according to model estimates of Prasuhn (2016). The respective loss rates are 20.6 % for 1990 and 17.8 % for 2010 (Table 5-27). Spiess and Prasuhn (2006) confirm that the loss rates were somewhat higher in the early 1990s and then declined due to the agricultural policy reforms. Accordingly, the reduction in the nitrate loss rate was implemented between 1995 and 2010 with constant loss rates after 2010. The same loss rates were applied to all nitrogen pools independent of their origin and composition. An additional reduction of the nitrate loss rate originates from the application of fertilisers with nitrification inhibitors. The nitrogen loss rate is reduced by 23 % for fertilisers with nitrification inhibitors (Weiske et al. 2001). Due to the limited application of nitrification inhibitors the respective effect is still small (see also chp. 5.5.2.2.1). The overall amount of nitrogen that is lost through leaching and run-off is given in Table 5-26.

Table 5-27 Fractions of N lost by leaching or run-off ($Frac_{LEACH-(H)}$).

Leaching of nitrogen	1990-2015					
	1990	**1995**	**2000**	**2005**	**2010**	**2015**
	%					
$Frac_{LEACH(H)}$	0.206	0.206	0.197	0.188	0.178	0.178

Leaching of nitrogen	2016-2022						
	2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	%						
$Frac_{LEACH(H)}$	0.178	0.178	0.178	0.178	0.178	0.178	0.178

Figure 5-8 illustrates the development of the most important activity data for 3B.2 Indirect N_2O emissions from managed soils. Both leaching and run-off from commercial fertiliser and animal manure N declined during the inventory time period due to the reduced nitrogen inputs and the decreasing nitrate loss rates ($Frac_{LEACH-H}$).

5.5.2.5. NMVOC emissions from agricultural soils

The NMVOC emissions from crop production and agricultural soils are calculated based on the Tier 2 approach of the EMEP/EEA guidebook (EMEP/EEA 2019). Three types of agricultural areas are differentiated, i.e. cropland, grassland and summer pastures. The NMVOC emission factors for cropland and grassland are based on the values for wheat and grass (15°C), respectively, of Table 3.3 of the EMEP/EEA guidebook (EMEP/EEA 2019) taking into account country-specific values for the mean dry matter yield (Richner and Sinaj 2017). For summer pastures, the same NMVOC emission value as for grass (15°C) and a fraction of the growing period of 0.3 (Bühler and Kupper 2018) are assumed using a country-specific value for the mean dry matter yield (Richner and Sinaj 2017). The resulting NMVOC emission factors are constant for the entire time series.

5.5.3. Uncertainties and time-series consistency for 3D

For the uncertainty analysis the input data from ART (2008a) were used and were updated with current activity and emission data as well as with new default uncertainties of the 2019 Refinement (IPCC 2019). The detailed input uncertainty values for category 3D are reported in Annex A2.1. The resulting, combined uncertainty for emissions according to approach 1 (uncertainty propagation) are reported in Annex A2.2 and in Annex A2.3 for results obtained by approach 2 (Monte Carlo simulations). The 95 % confidence intervals obtained by Monte Carlo simulations are slightly narrower and, for non-symmetric distributions, slightly shifted towards the lower edge.

Table 5-28 Uncertainties for 3D Agricultural soils. Approach 1: intervals are exactly from 2.5 % to 97.5 % of the distribution; Approach 2: the narrowest interval representing 95 % of the distribution is given.

Source category	Gas	Activity data uncertainty 2022		Emission factor uncertainty 2022		Emission combined uncertainty 2022	
		(-)%	(+)%	(-)%	(+)%	(-)%	(+)%
Uncertainty propagation (approach 1)							
3Da Direct emissions from managed soils	N2O	13	13	61	89	62	90
3Db Indirect emissions from managed soils	N2O	28	33	52	72	59	79
Monte Carlo simulations (approach 2)							
3Da Direct emissions from managed soils	N2O	13	13	68	77	68	79
3Db Indirect emissions from managed soils	N2O	30	31	57	63	62	72

The time series 1990–2022 are all considered consistent, although the following issues should be considered:

- For time series consistency of livestock population data see chp. 5.2.3.
- Input data from the AGRAMMON model are available for the years 1990 and 1995 (expert judgement and literature) as well as for 2002, 2007, 2010, 2015 and 2019 (extensive surveys on approximatively 3000 farms). Values in-between the assessment years were interpolated linearly. For 2020 to 2022 the same values as in 2019 were used.
- $Frac_{GASF}$, $Frac_{GASM}$ and $Frac_{GASP}$ are fluctuating along the time series due to fluctuating shares of different fertiliser types and animal populations with different ammonia emission factors.

- The emission factor for indirect N_2O emissions following volatilisation of NH_3 and NO_x from applied fertilisers and urine and dung excreted on pasture, range and paddock varies according to varying land use as described in chp. 5.3.2.4.

For more details on time-series consistency see also chp. 5.2.3 and 5.3.3.

5.5.4. Category-specific QA/QC and verification for 3D

General QA/QC measures are described in NID chp. 1.5.

All further category-specific QA/QC activities are described in a separate document (Agroscope 2019a). General information on agricultural structures and policies is provided and eventual differences between national and (IPCC 2006, 2019) standard values are being analysed and discussed.

The Swiss ammonium emission model AGRAMMON is documented in Kupper et al. (2022) and Agrammon (2023). Generally the reporting of N_2O emissions in the national GHG inventory is consistent with the reporting of other nitrogen compounds (NH_3, NO_x) under the CLRTAP.

All relevant parameters needed for the calculation of direct and indirect nitrogen inputs to agricultural soils (e.g. F_{CN}, MS-distribution, $Frac_{GASF}$, N_{ex}, $Frac_{GASMT}$, F_{ON}, F_{CR}, $Frac_{LEACH-H}$) were checked for consistency and confidence and were compared (where possible) to IPCC default values (IPCC 2006, 2019), values of other countries as well as values in the literature. Nitrogen excretion, being one of the most important parameters, was analysed in more detail as described in chp. 5.3.4.2.

For quality assurance of livestock population data consult chp. 5.2.4.

N_2O emission factors were compared to values in the literature to ensure plausibility. Implied emission factors are similar to measured values from the literature representative for Swiss conditions (Agroscope 2019a). In 2018 a focus study in the context of the national research programme 68 (Nationales Forschungsprogramm 68: Ressource Boden) made an independent assessment of the N_2O emission factors under Swiss conditions based on a literature review (Krause et al. 2018). The authors found that the N_2O emission factors of mineral soils were 2.06±2.66 % for arable soils and 1.45±1.07 % for grassland soils. Based on the limited data availability and on the great variability between the different measurements they concluded, that these emission factors are not significantly different to the IPCC (2019) values. Still, the numerical difference indicated that further efforts should be made to development country-specific emission factors (see chp. 5.5.6). In 2020, Ammann et al. (2020) investigated the effect of management and weather variations on N_2O emissions and the greenhouse gas budget of two grasslands in the central plateau of Switzerland during a 10-year experiment. N_2O emissions were measures quasi-continuously with the eddy-covariance method. The total N_2O-flux was partitioned to the different categories using the IPCC emission factor approach and confirmed the validity of the respective default values. More recently dos Reis Martins et al. (2022) modelled N_2O emissions of complex cropland management in Western Europe using DayCent and compared results with measurements and the IPCC default emission factor approaches. They also found that the IPCC default emission factors tend to underestimate emissions although modelled mean values were still well within the great range of the measurements. Within this same project a process-oriented model-framework will be developed to improve estimation of N_2O emissions from agricultural soils in Switzerland (see chp. 5.5.6).

For the time being Switzerland is still using the aggregated default emission factor for direct soil emissions (EF_1) from the 2019 Refinement (IPCC 2019) instead of using disaggregated emission factors for synthetic fertiliser and other nitrogen inputs in wet climates. Reasons for this are:

- Measurements conducted in Switzerland and neighbouring countries have not yet been fully evaluated in this respect. An extensive study in Germany did not indicate higher emission factors of synthetic fertilisers as compared to organic nitrogen inputs (Mathivanan 2021).
- Animal manure is mainly applied to grasslands whereas synthetic fertilisers are mainly applied on croplands. The effect of fertiliser type is thus interacting with land use, management and seasonal weather conditions potentially confounding systematic differences between organic and synthetic fertilisers.
- Emission factors may also differ between different types of synthetic fertilisers (e.g. Cowan et al. 2020, Harty et al. 2016) and different types of organic fertilisers (e.g. Charles et al. 2017) pointing out that the question of fertiliser type should be addressed in a broader way.

The question of the effect of fertiliser type on N_2O emission factors will be further explored within ongoing field experiments and the current work on a process-oriented model-framework for the estimation of N_2O emissions from agricultural soils in Switzerland (see chp. 5.5.6).

The N_2O emission factor for cultivated organic soils was validated by a study from Leifeld (2018) that used a large dataset of C/N ratios in Swiss organic soils to predict N_2O emissions. The study concluded that the current national GHG inventory neither systematically over- nor underestimates total emissions.

A study by Agroscope (2019b) analysed the greenhouse gas flux measurements of a grazed pasture system for dairy cows in western Switzerland over five years. The fertiliser-related N_2O emission factor was on average close to the corresponding IPCC default value of 1%. The excreta-related factor was considerably lower than the 2 % proposed in IPCC (2006) albeit higher than the default emission factor of 0.6 % for cattle in wet climate of IPCC (2019). It could also be shown that there is a clear difference in the individual emission factors for urine and dung patches on the pasture. More recently, another study by Barczyk et al. (2023) investigated emissions from pasture, range and paddock. The resulting overall average EF_{urine} was 0.67 % confirming the IPCC default approach (IPCC 2019). Further data analysis as well as process-based modelling are being conducted in order to consolidate these results (see chp. 5.5.6).

The estimate for the area of cultivated histosols in the agricultural sector is consistent with the estimates reported under cropland and grassland in the LULUCF sector. A literature study conducted by Leifeld et al. (2003) estimates 17’000±5’000 ha. The current average area of organic soils (approximately 20’000 ha) is somewhat higher than the mean estimate of 17’000 ha, however, still well within the uncertainty range.

The country-specific value of $Frac_{LEACH-H}$ is based on a very detailed model for the assessment of leaching and run-off in Switzerland (Hürdler et al. 2015, Prasuhn 2016) that takes into account regional parameters such as topography, different crop species as well as fertiliser application levels.

Henne et al. (2019) conducted a top-down assessment of Swiss N_2O emissions using atmospheric measurements and an inverse modelling framework. With recent updates in the present NID, inverse estimates and NID estimates agree very closely for two different atmospheric transport model versions used in the inversion (see also Annex A6.2).

5.5.5. Category-specific recalculations for 3D

General information on recalculations is provided in chp. 10.

Recalculations with an overall impact of >0.5 kt CO_2 equivalent are assessed quantitatively. All other recalculations are only described qualitatively.

- For recalculations of livestock population data and emissions from manure management (affecting the amount of animal manure applied to soils) refer to chp. 5.2.5 and chp.5.3.5.
- N_2O emissions from other organic fertilizers applied to soils were recalculated for 1990-2021. Nitrogen from wastewater from decentralized human wastewater treatment from remote farms was added to the amount of other organic fertilizers (AD). The impact on overall emissions is +15.1 kt CO_2 equivalents for 1990 and subsequently declining to +4.0 kt CO_2 equivalents in 2021.
- N_2O emissions from other organic fertilizers applied to soils were recalculated for 2021. Provisional data for the amount of nitrogen from compost applied to soils (AD) was updated. The impact on overall emissions is negligible (<-0.5 kt CO2 equivalents).
- N_2O emissions from crop residues were recalculated for the years 2019–2021. AD was revised due to updated values for arable crop yields from the Swiss Farmers Union (SFU/SBV) and updated values for grassland yields. The impact on overall emissions is negligible (<±1.0 kt CO_2 equivalents) for all years except for 2021 where emissions declined by -9.4 kt CO_2 equivalents.
- N_2O emissions from mineralization/immobilization associated with loss/gain of soil organic matter were recalculated for 1990–2021. AD was revised due to new values for the amount of nitrogen mineralized in the LULUCF sector. The impact on overall emissions ranges from -20.5 to +3.6 kt CO_2 equivalents.
- N_2O emissions from cultivated organic soils were recalculated for 1990–2021. New updated area estimates (AD) from the LULUCF sector were adopted. The impact on overall emissions fluctuated slightly around +9.0 kt CO_2 equivalents.
- N_2O emissions from cultivated organic soils were recalculated for 1990–2021. New disaggregated emission factors for grassland and cropland were adopted from the IPCC Wetland Supplement (IPCC 2014a). The impact on overall emissions was +25.0 kt CO_2 equivalents for 1990 and declined to +21.5 kt CO_2 equivalents in 2021.
- N_2O emissions from volatilized N from agricultural inputs of mineral N were recalculated for 1990-2021. The amount of ammonia volatilised from inorganic fertilizers (AD) was revised due to revised emission factors from the AGRAMMON model. The impact on overall emissions was negligible (<±0.05 kt CO_2 equivalents).

5.5.6. Category-specific planned improvements for 3D

FOEN funds the development of a process-oriented model for N_2O emissions in agricultural soils subject to common Swiss management practices. Model selection, calibration, evaluation and first, simplified country-scale simulations were the components of the first phase of the project (LACHSIM; dos Reis Martins and Keel 2024). The results suggest that DayCent is an adequate model for reporting N_2O emissions from Swiss agricultural soils with complex management, diverse crop rotations in croplands and different levels of management intensity in grasslands. DayCent simulations were clearly more accurate than default IPCC emission factor approaches. The remaining challenge is now to collect accurate management data in order to improve the quality of the upscaling to national scales. The combination of new FOAG geodata on cultivated agricultural areas ("Surfaces agricoles cultivées", https://www.blw.admin.ch/blw/fr/home/politik/datenmanagement/geografisches-informationssystem-gis.html; visualisation at https://s.geo.admin.ch/7fc3d8bcf4) and surveys of management activity at cantonal and national levels could provide robust support. A difficult step, however, will be how to create a consistent time series back to 1990.

A number of measurement projects at Agroscope, partially financed by FOEN, contribute to the establishment of a country-specific emission factor for direct N_2O emissions from urine and dung deposited by grazing animals ($EF_{3PRP,CPP}$). Accordingly, it is foreseen that the respective estimates for direct N_2O emissions may be revised during the submission 2025.

During the submission 2024 the methodology for the calculation of emission from nitrogen in crop residues returned to soils was revised in order to improve consistency with the methodologies for land-use categories 4B Cropland and 4C Grassland in the LULUCF sector. After plausibility check the results will be implemented during the submission 2025.

5.6. Source category 3E – Prescribed burning of savannahs

Burning of savannahs does not occur (NO) in Switzerland.

5.7. Source category 3F – Field burning of agricultural residues

Field burning of agricultural residues does not occur (NO) in Switzerland.

Open burning of natural forest, field and garden waste is regulated in the Ordinance on Air Pollution Control OAPC, (Swiss Confederation 1985: Art. 26b). In Switzerland, cantonal authorities are responsible for the enforcement of the OAPC regulations. The 26 cantons have thus probably slightly different interpretations and implementations of the federal ordinance. An inquiry of some cantonal authorities was performed in order to assess the activity data for these processes (INFRAS 2014).

Emissions from open burning of branches in agriculture and forestry were reported here in the past. However, the respective emissions were moved to the sectors 4 LULUCF and 5 Waste based on recommendations from the UNFCCC expert review teams (e.g. FCCC/ARR/2016/CHE W12 and W13). Respective information can be found under category 4IV “Biomass Burning” (see chp. 6.4.2.6.4) and source category 5C “Incineration and open burning of waste” (see chp. 7.4).

5.8. Source category 3G – Liming

5.8.1. Source category description

Table 5-29 Key categories of 3G Liming. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

CO_2 emission from 3G Liming is not a key category.

Emissions from the application of lime ($Ca(CO_3)$) and dolomite ($CaMg(CO_3)_2$) to agricultural soils are reported.

The emissions due to liming of agricultural soils range from 22.2 to 32.9 kt CO_2 per year.

5.8.2. Methodological issues

A simple Tier 1 approach was adopted using estimated amounts of lime and dolomite applied and IPCC (2006) default emission factors.

5.8.2.1. Emission factor

The availability of country-specific emission factors for agricultural lime and dolomite application was investigated, but no domestic measurement data could be found. Consequently, the IPCC default carbon conversion factors for carbonate containing lime (0.12 t C per t $Ca(CO_3)$) and for dolomite (0.13 t C per t $CaMg(CO_3)_2$) were used (IPCC 2006).

5.8.2.2. Activity data

The total annual amount of lime and dolomite applied to agricultural soils is between 50’300 Mg (1990) and 74'050 Mg (2008–2022). It was estimated by Agroscope in 2009 for the period 1990–2008. Major retailers / providers of lime in Switzerland were directly contacted and interviewed. For 2009–2022 the same value as for 2008 was used: An inquiry in 2013 including the most important production and trading companies of lime products suggests that the consumption of limestone remains constant (Agroscope 2014a). This assumption is further supported by the fact that agricultural structures and management did not change fundamentally in recent years. Furthermore, the import of calcium carbonate mixed with ammonium nitrate (contributing 20 % to lime use in Switzerland) is assessed yearly via the import statistics. These statistics do not show a significant trend along the past 20 years (FOCBS 2023a).

The split of lime into calcium carbonate and dolomite is based on the following assumptions and data:

- $Ca(CO_3)$ contained in mixed compound fertilisers as reported by Agricura (2022)
- All material originating from nuclear power plants and from the sugar beet industry is $Ca(CO_3)$
- The remaining lime not covered under the points above was divided equally into $Ca(CO_3)$ and $CaMg(CO_3)_2$.

5.8.3. Uncertainties and time-series consistency for 3G

The amount of total lime applied in agriculture is mainly based on expert judgement; the resulting number is uncertain. A normal distribution with a relative uncertainty of ±40 % for a 95 % coverage interval was used as an approximation (Agroscope 2014a). For the emission factor of lime a lower uncertainty of ±5 % was chosen, because it is a simple chemical process. The detailed input uncertainty values for category 3G are reported in Annex A2.1. The resulting, combined uncertainty for emissions according to approach 1 (uncertainty propagation) is thus ±40 % (see Annex A2.2), in general concordance with results from approach 2 (Monte Carlo simulations, Annex A2.3).

Consistency: Time series for 3G Liming are all considered consistent.

5.8.4. Category-specific QA/QC and verification for 3G

General QA/QC measures are described in NID chp. 1.5. No category-specific QA/QC activities were undertaken.

5.8.5. Category-specific recalculations for 3G

General information on recalculations is provided in chp. 10.

There were no recalculations implemented in submission 2024.

5.8.6. Category-specific planned improvements for 3G

No category-specific improvements are planned.

5.9. Source category 3H – Urea application

5.9.1. Source category description

Table 5-30 Key categories of 3H Urea application. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

CO_2 emission from 3H Urea application is not a key category.

Adding urea to soils during fertilisation leads to a loss of CO_2 that was fixed during the industrial production process of the fertiliser. Emissions in Switzerland range from 8.7 to 26.7 kt CO_2 per year with a general decreasing trend during the 1990s and values near 12 kt CO_2 per year for the later part of the time series.

5.9.2. Methodological issues

A simple Tier 1 approach was adopted using estimated amounts of urea applied and IPCC (2006) default emission factors.

5.9.2.1. Emission factor

No country-specific emission factors are available. Consequently, the IPCC (2006) default emission factor of 0.20 t of C per t of urea was applied.

5.9.2.2. Activity data

The amount of urea applied to agricultural soils was obtained from Agricura (2022). Two positions of the customs tariff list were considered, namely “urea” (tariff number 3102.1000.011) and “urea-ammonia-nitrate” (tariff number 3102.8000.011). Fertiliser statistics are based on sales statistics by the compulsory stockpiler of fertilisers (Pflichtlagerhalter) and small importers. Agricura conducts plausibility checks with import-data received by the Federal Office for Customs and Border Security (FOCBS).

5.9.3. Uncertainties and time-series consistency for 3H

An uncertainty of ±5 % for the activity data was estimated according to ART (2008a). An uncertainty of ±5 % was assumed for the emission factor since it is a simple chemical process (see input uncertainty values in Annex A2.1). The resulting, combined uncertainty for emissions according to approach 1 (uncertainty propagation) is reported in Annex A2.2 and in Annex A2.3 for approach 2 (Monte Carlo simulations).The combined approach 1 uncertainty is ±7 %, in concordance with approach 2.

Consistency: Time series for 3H Urea application are all considered consistent.

5.9.4. Category-specific QA/QC and verification for 3H

General QA/QC measures are described in NID chp. 1.5. No category-specific QA/QC activities were undertaken.

5.9.5. Category-specific recalculations for 3H

General information on recalculations is provided in chp. 10.

There were no recalculations implemented in submission 2024.

5.9.6. Category-specific planned improvements for 3H

No category-specific improvements are planned.

6. Land use, land-use change and forestry (LULUCF)

Responsibilities for sector Land use, land-use change and forestry (LULUCF)	
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6.1. Overview of LULUCF

6.1.1. Methodology

Chapter 6 presents estimates of GHG emissions by sources and removals by sinks from land use, land-use change and forestry (LULUCF). The sector LULUCF includes emissions and removals from the carbon pool in Harvested wood products (HWP). Data acquisition and calculations are based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and their 2019 Refinement (IPCC 2006, 2019, Volume 4 "Agriculture, Forestry and Other Land Use" (AFOLU)).

In 1979, the Swiss Land Use Statistics AREA was launched. Aerial photos from the periods 1979–1985, 1990–1998, 2004–2009, 2012–2019 and 2020 were evaluated by the Federal Statistical Office. AREA produces geographically explicit land use data with a resolution of one hectare (following approach 3 for representing land areas; IPCC 2006). Since 2022, results of the fifth survey are available. The repeated assessment of land use allows for a harmonised tracking of land use and land-use change across the entire national territory over the inventory period.

The six main land-use categories required by IPCC (2006) are: A. Forest land, B. Cropland, C. Grassland, D. Wetlands, E. Settlements and F. Other land. These were subdivided into 17 land-use categories, which form the basis for LULUCF reporting. The land-use categories are usually referred to in this document together with their combination category (CC) code. Following the guidelines, lands in each land-use category were stratified by mineral and organic soil. Due to the mountainous topography of Switzerland, Forest land, Cropland and permanent grassland were further stratified by three elevation zones. For Forest land, an additional stratification based on the five production regions of the National Forest Inventory (NFI) was used.

For Forest land, country-specific carbon stocks and carbon stock change factors were derived from five National Forest Inventories (the completed NFI1, NFI2, NFI3, NFI4 and the ongoing NFI5). The inventories comprised ca. 3'400 (NFI5), 6'000 (NFI2, NFI3, NFI4) and 11'000 (NFI1) terrestrial plots, where biomass stock, gross growth, and cut and mortality were measured. The carbon dynamics in dead wood, litter and mineral soil were simulated with the model Yasso20. For Cropland and permanent grassland, a modelling approach with RothC formed the basis for reporting carbon fluxes in mineral soil. Living biomass on these two land-use categories was calculated using an allometric equation.

For the remaining land-use categories and carbon pools, carbon stocks and carbon stock change factors were derived from domestic surveys, particular research activities, measurements and expert estimates. Partially, mainly for non-CO_2 emission factors, IPCC (2006, 2019) default values were used (see CRT Summary3).

6.1.2. Emissions and removals

6.1.2.1. CO_2 emissions and removals

Over the inventory period, total net emissions and removals of CO_2 varied between -6'313 kt (1996) and 4'350 kt (2000). Table 6-1 and Figure 6-1 show a breakdown of Switzerland's CO_2 balance in the LULUCF sector. Five components were differentiated:

- Carbon gains in living biomass on all land uses and due to land-use changes; this component acts as the largest sink of carbon.
- Carbon losses in living biomass on all land uses and due to land-use changes; this component acts as the largest source of carbon. The highest losses were observed in the year 2000 after a heavy storm with windfall in December 1999.
- Net carbon stock changes in dead organic matter (DOM; consisting of dead wood and litter) on Forest land remaining forest land as well as on Land converted to or from Forest land. This component acted as a sink of carbon in most years.
- Net carbon stock changes in organic and mineral soils due to land use and land-use changes. After 1998, soils were net emitters of CO_2; before that, the balance was the opposite in most years since 1990.
- Net carbon stock changes in Harvested wood products. With the exception of the years 2013, 2017, 2019 and 2020 this component acted as a sink of carbon, i.e. the overall carbon stock stored in wood products was increasing.

The largest part of carbon gains and carbon losses in living biomass occurred in forests, where gross growth of biomass (carbon gains) exceeded cut and mortality (carbon losses), except for the year 2000 (see also chp. 2.2.2.3). Overall, the LULUCF sector acted as a net sink of on average -2'173 kt CO_2 yr^{-1} over the inventory period (see Table 6-1), but was a net source in the years 2000, 2018 and 2022.

Table 6-1 CO_2 emissions and removals in the LULUCF sector broken down by (1) CO_2 removals due to carbon gains in living biomass, (2) CO_2 emissions due to carbon losses in living biomass, (3) net CO_2 changes in dead organic matter, (4) net CO_2 changes in organic and mineral soils, and (5) net CO_2 changes in Harvested wood products. Mean indicates the mean value 1990 to 2022. Positive values refer to emissions; negative values refer to removals.

LULUCF	Unit	1990	1995	2000	2005	2010
Gains in living biomass	kt CO_2	-13’131	-13’188	-12’756	-12’937	-13’338
Losses in living biomass	kt CO_2	11’742	9’648	17’908	11’752	11’934
Net change in dead organic matter	kt CO_2	164	-441	-401	-1’485	-1’566
Net change in mineral and organic soils	kt CO_2	-704	46	299	90	218
LULUCF (excluding HWP)	kt CO_2	-1’929	-3’934	5’051	-2’581	-2’752
Net change in Harvested wood products (HWP)	kt CO_2	-1’119	-443	-700	-690	-426
Total LULUCF	kt CO_2	-3’047	-4’377	4’350	-3’271	-3’178

LULUCF	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Mean
Gains in living biomass	kt CO_2	-13’362	-13’401	-13’440	-13’432	-13’419	-12’896	-12’594	-12’605	-12’867	-12’642	-13’068
Losses in living biomass	kt CO_2	11’525	11’849	11’077	10’881	11’505	12’916	12’111	12’358	12’620	13’202	11’528
Net change in dead organic matter	kt CO_2	-609	183	146	-83	-2	-434	-717	-946	-1’542	-864	-525
Net change in mineral and organic soils	kt CO_2	499	695	682	557	516	522	426	457	586	704	204
LULUCF (excluding HWP)	kt CO_2	-1’947	-675	-1’535	-2’076	-1’400	109	-773	-735	-1’204	400	-1’861
Net change in Harvested wood products (HWP)	kt CO_2	76	-90	-70	-27	7	-54	83	24	-132	-35	-312
Total LULUCF	kt CO_2	-1’870	-765	-1’605	-2’104	-1’393	54	-690	-712	-1’336	365	-2’173

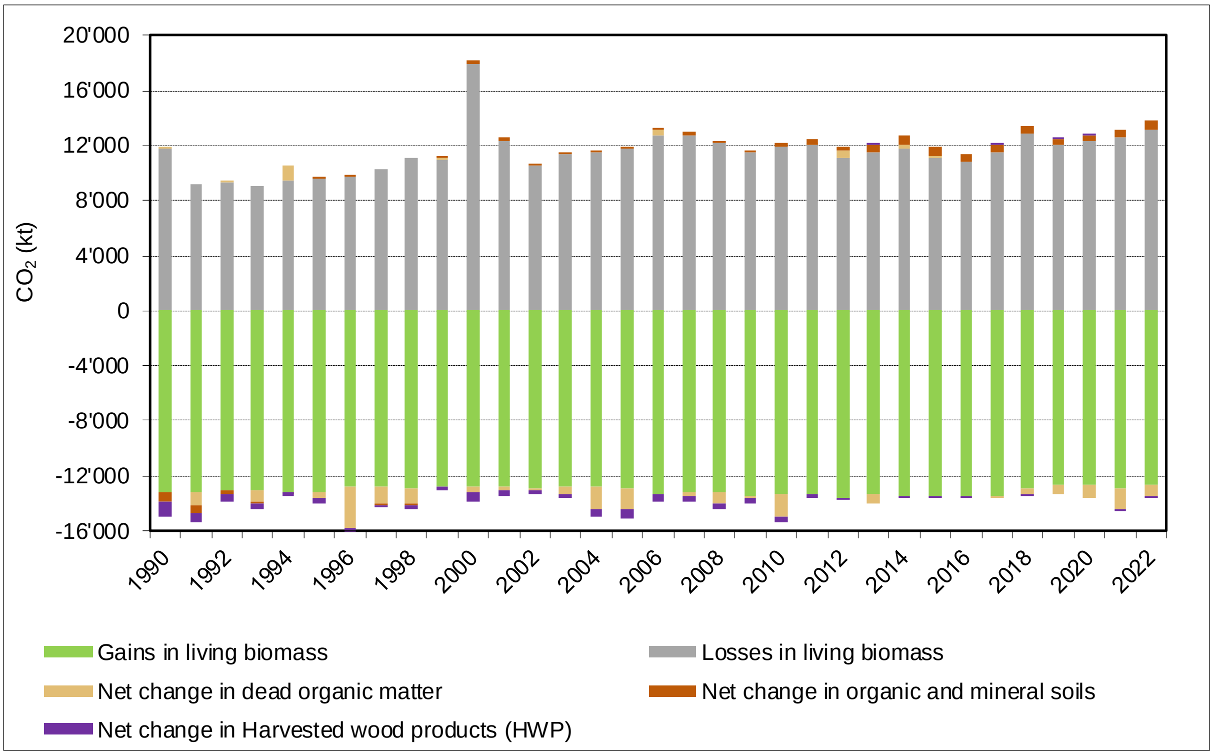

Figure 6-1 CO_2 emissions and removals in the LULUCF sector (in kt CO_2) broken down by (1) carbon gains in living biomass, (2) carbon losses in living biomass, (3) net changes in dead organic matter, (4) net changes in organic and mineral soils, and (5) net changes in Harvested wood products. Positive values refer to net emissions, negative values refer to net removals.

6.1.2.2. Non-CO_2 emissions

The non-CO_2 emissions associated with land use, land-use change and forestry were small. Maximum annual CH_4 emissions were 1.40 kt yr^{-1} (39 kt CO_2 eq; 1997), and maximum annual N_2O emissions were 0.21 kt yr^{-1} (57 kt CO_2 eq; 1997) (Figure 6-2). The emissions arose from (1) drained organic soil (N_2O; CRT Table4(II)), (2) flooded lands/reservoirs (CH_4; CRT Table4(II)), (3) nitrogen mineralisation associated with loss of soil organic matter resulting from change of land use or management of mineral soils (direct and indirect N_2O emissions; CRT Table4(III)), (4) wildfires on Forest land and Grassland (CH_4 and N_2O; CRT Table4(IV)), and (5) controlled burning of residues from forestry (CH_4 and N_2O; CRT Table4(IV)).

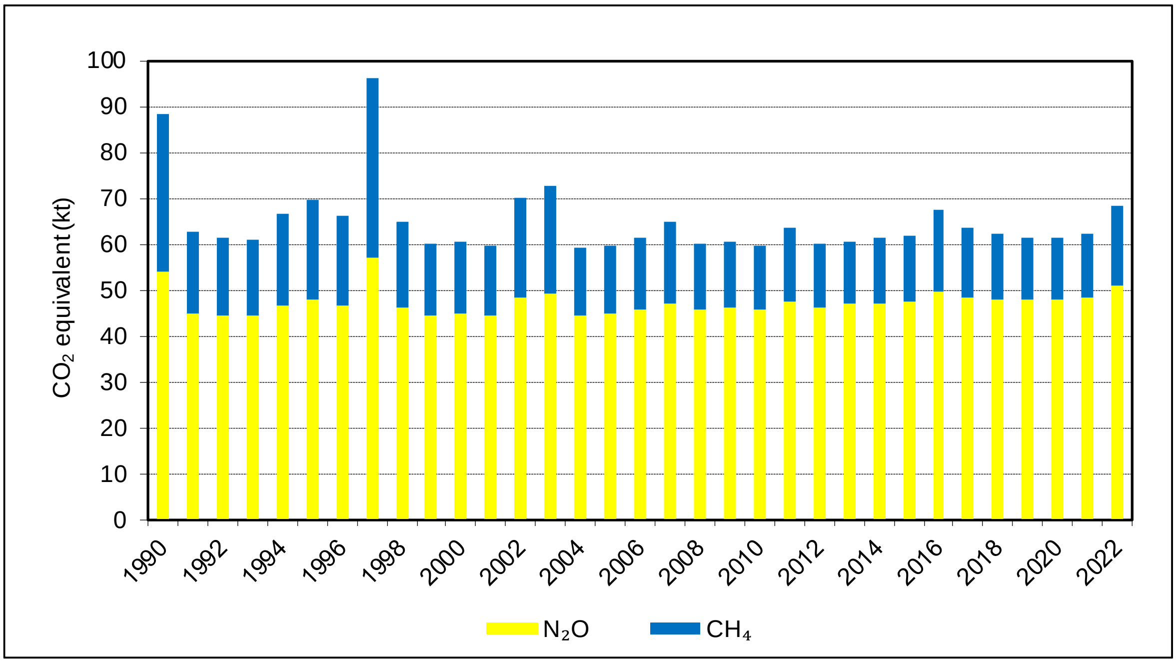

Figure 6-2 N_2O and CH_4 emissions in the LULUCF sector (in kt CO_2 eq).

6.1.2.3. GHG emissions and removals

Figure 6-3 shows the resulting net GHG (CO_2, CH_4, N_2O) emissions and removals in the LULUCF sector over the inventory period broken down by categories 4A–4G. GHG fluxes were dominated by biomass dynamics in forests (4A). Further explanatory notes on LULUCF trends can be found in chp. 2.2.2.3 “Emission and removal trends in sector 4 LULUCF”.

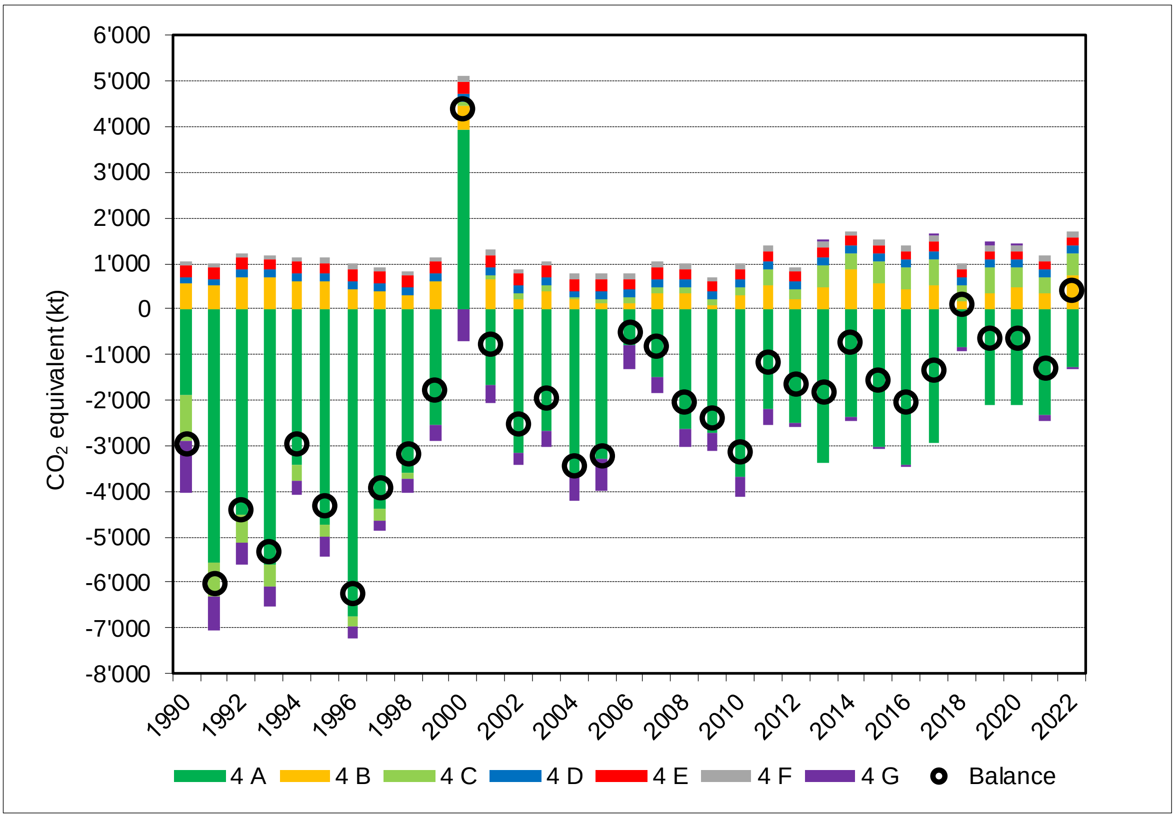

Figure 6-3 Stacked net GHG (CO_2, CH_4, N_2O) emissions and removals in the LULUCF sector (in kt CO_2 eq) broken down by categories 4A–4G. Balance indicates the annual net total. Positive values refer to net emissions, negative values refer to net removals. Figure 2-8 shows a simplified and Figure 2-9 an unstacked representation of the data set.

6.1.3. Approach for calculating carbon emissions and removals

6.1.3.1. Work steps

The selected procedure for calculating carbon emissions and removals in the LULUCF sector corresponds to a Tier 2 approach as described in IPCC 2006 (Volume 4, chp. 3). It can be summarised as follows:

- Define managed and unmanaged land: In Switzerland, all land besides Other land is considered to be managed. Other land (see Table 6-2) is unmanaged. It is defined as the residual country's land area without relevant human activity.
- Define land-use categories with respect to available land use data (see Table 6-2). Land-use categories were introduced as combination categories (CC), defined on the basis of the AREA land-use and land-cover categories (see chp. 6.2.1 and Table 6-6; SFSO 2006a; FSO 2022i).
- Define criteria and collect data for the spatial stratification of the land-use categories.
- Derive carbon stocks in living biomass (stockC_l), dead wood (stockC_d), litter (stockC_h), and soil (stockC_s) for each spatial stratum of the land-use categories.
- Derive carbon gains in living biomass (gainC_l), carbon losses in living biomass (lossC_l), net carbon stock change in dead wood (changeC_d), litter (changeC_h), and soil (changeC_s) for each spatial stratum of the land-use categories.
- Calculate land use and land-use change matrices for each spatial stratum over the inventory period.

- For Forest land: Calculate net carbon stock changes in living biomass (deltaC$_l$), dead wood (deltaC$_d$), litter (deltaC$_h$), and soil (deltaC$_s$) for all cells of the land-use change matrix for each year under consideration.
- For non-Forest land: Calculate net carbon stock changes in living biomass (deltaC$_l$), dead organic matter (deltaC$_{dom}$), and soil (deltaC$_s$) for all cells of the land-use change matrix for each year under consideration, where dead organic matter is the sum of dead wood and litter.
- Finally, aggregate the results by summarising the carbon stock changes over land-use categories and spatial strata according to the level of disaggregation displayed in the reporting tables.
- Calculate CO_2 emissions and removals of the carbon pool in Harvested wood products (HWP).

Table 6-2 Six main land-use categories (according to IPCC 2006) and 17 land-use categories used for LULUCF reporting. Additionally, descriptive remarks, abbreviations used in the reporting tables, and combination categories codes are given (CC code; see chp. 6.2.1 and Table 6-6).

Main category	Land-use category	Remarks	Terminology in CRT tables	CC code
A. Forest land	productive forest	dense and open forest meeting the criteria of forest land	4A1: CC12 4A2: productive	12
	unproductive forest	brush forest and forest on unproductive areas meeting the criteria of forest land	4A1: CC13 4A2: unproductive	13
B. Cropland	cropland	arable and tillage land (annual crops and leys in arable rotations)	CC21	21
C. Grassland	permanent grassland	meadows, pastures (low-land and alpine)	4C1: CC31 4C2: permanent	31
	shrub vegetation	agricultural and unproductive areas predominantly covered by shrubs	4C1: CC32 4C2: woody	32
	vineyard, low-stem orchard, tree nursery	perennial agricultural plants with woody biomass and grass understorey	4C1: CC33 4C2: woody	33
	copse	agricultural and unproductive areas covered by perennial woody biomass including trees, with grass understorey	4C1: CC34 4C2: woody	34
	orchard	permanent grassland with fruit trees and grass understorey	4C1: CC35 4C2: woody	35
	stony grassland	grass, herbs and shrubs on stony surfaces	4C1: CC36 4C2: unproductive	36
	unproductive grassland	unproductive grass vegetation	4C1: CC37 4C2: unproductive	37
D. Wetlands	surface water	lakes and rivers	surface water	41
	unproductive wetland	reed, extensively managed wetland	unprod wetland	42
E. Settlements	buildings and constructions	areas without vegetation such as houses, roads, construction sites, dumps	building	51
	herbaceous biomass in settlements	areas with low vegetation, e.g. lawns	herb	52
	shrubs in settlements	areas with perennial woody biomass (no trees)	shrub	53
	trees in settlements	areas with perennial woody biomass including trees	tree	54
F. Other land	other land	unmanaged areas without soil and vegetation: rocks, sand, scree, glaciers		61

6.1.3.2. Calculating carbon stock changes

For calculating carbon stock changes, the following input parameters (mean values per hectare) were quantified for all land-use categories (coded as CC) and spatial strata (i):

$stockC_{l,i,CC}$	carbon stock in living biomass (t C ha^{-1})
$stockC_{d,i,CC}$	carbon stock in dead wood (t C ha^{-1})
$stockC_{h,i,CC}$	carbon stock litter (organic soil horizons) (t C ha^{-1})
$stockC_{s,i,CC}$	carbon stock in soil (t C ha^{-1})
$gainC_{l,i,CC}$	annual carbon gain in living biomass (t C ha^{-1} yr^{-1})
$lossC_{l,i,CC}$	annual carbon loss in living biomass (t C ha^{-1} yr^{-1})
$changeC_{d,i,CC}$	annual net carbon stock change in dead wood (t C ha^{-1} yr^{-1})
$changeC_{h,i,CC}$	annual net carbon stock change in litter (t C ha^{-1} yr^{-1})
$changeC_{s,i,CC}$	annual net carbon stock change in soil (t C ha^{-1} yr^{-1})

In the reporting tables on non-Forest land under the UNFCCC (Table4.B to Table4.F), the carbon stocks and carbon stock changes of dead wood and litter are merged into dead organic matter (DOM):

$$stockC_{dom,i,CC} = stockC_{d,i,CC} + stockC_{h,i,CC}$$

$$changeC_{dom,i,CC} = changeC_{d,i,CC} + changeC_{h,i,CC}$$

On this basis, the total changes in carbon stocks (t C yr^{-1}) in living biomass ($deltaC_l$), dead wood ($deltaC_d$), litter ($deltaC_h$), or dead organic matter ($deltaC_{dom}$), respectively, and soils ($deltaC_s$) were calculated for all cells of the land-use change matrix for each year under consideration. Each cell is characterized by a land-use category before the conversion (b), a land-use category after the conversion (a), and the area of converted land within the spatial stratum (i). This approach includes cases without any land-use change (a = b).

Equations 6.1–6.8 show, according to the IPCC Guidelines (IPCC 2006, Volume 4), two approaches and their application for calculating carbon gains and losses: (1) the gain-loss approach (Equation 2.4; IPCC 2006, Volume 4) and (2) the stock-difference approach (Equation 2.5; IPCC 2006, Volume 4).

The gain-loss approach for calculating (net) carbon stock changes is defined as:

$$deltaC_{l,i,ba} = (gainC_{l,i,a} - lossC_{l,i,a}) * A_{i,ba} \tag{6.1}$$

$$deltaC_{d,i,ba} = changeC_{d,i,a} * A_{i,ba} \tag{6.2}$$

$$deltaC_{h,i,ba} = changeC_{h,i,a} * A_{i,ba} \tag{6.3}$$

$$deltaC_{s,i,ba} = changeC_{s,i,a} * A_{i,ba} \tag{6.4}$$

The stock-difference approach for calculating carbon stock changes is defined as:

$$deltaC_{l,i,ba} = [(stockC_{l,i,a} – stockC_{l,i,b}) / CT] * A_{i,ba} \quad (6.5)$$

$$deltaC_{d,i,ba} = [(stockC_{d,i,a} – stockC_{d,i,b}) / CT] * A_{i,ba} \quad (6.6)$$

$$deltaC_{h,i,ba} = [(stockC_{h,i,a} – stockC_{h,i,b}) / CT] * A_{i,ba} \quad (6.7)$$

$$deltaC_{s,i,ba} = [(stockC_{s,i,a} – stockC_{s,i,b}) / CT] * A_{i,ba} \quad (6.8)$$

The change in dead organic matter (DOM) is the sum of the changes in dead wood and litter:

$$deltaC_{dom,i,ba} = deltaC_{d,i,ba} + deltaC_{h,i,ba} \quad (6.9)$$

where:

a	land-use category after conversion (CC = a)
b	land-use category before conversion (CC = b)
ba	land-use conversion from b to a
i	spatial stratum
$A_{i,ba}$	area of land (ha) converted from b to a in the spatial stratum i (area converted in the inventory year if CT=1 year, or the sum of the areas converted within the last 20 years if CT=20 years)
CT	conversion time (yr), see chp. 6.1.3.3.

Table 6-3 defines the calculation approaches. The gain-loss approach was used in cases of no change in land use and generally for continuous transitions, e.g. the growth of living biomass on Land converted to forest land. The stock-difference approach was used for abrupt changes following discrete events (e.g. loss of biomass by deforestation, CT = 1 year) as well as for slow processes such as the change in soil carbon content (CT = 20 years, see chp. 6.1.3.3).

Conversions between both forest land-use categories were dealt with as follows: For CC12 to CC13 the stock-difference approach and for CC13 to CC12 the gain-loss approach was used, respectively (see Table 6-3).

In case of a land-use change to "Buildings and constructions" (CC51) a loss of 20 % of the initial soil carbon stock was reported (for a detailed documentation see chp. 6.8.2.2.3). In case of land-use changes from CC51 to other categories the regular stock-difference approach according to equation 6.8 and Table 6-3, respectively, were applied.

Table 6-3 Calculation approaches (gain-loss or stock-difference with conversion time in years) applied for different land-use changes and carbon pools. Combination category codes CC12–CC61 were introduced in Table 6-2.

Change in land-use category	**Living biomass**	**Dead wood, litter (dead organic matter)**	**Mineral soil**	**Organic soil**	**Remarks**
no change in category	gain-loss	gain-loss	gain-loss	gain-loss	
4A1: CC13 to CC12	gain-loss	stock-diff., 20	stock-diff., 20	gain-loss	forest land internal changes
4A1: CC12 to CC13	stock-diff., 20	stock-diff., 20	stock-diff., 20	gain-loss	forest land internal changes
4A2: change to CC12-13	gain-loss	stock-diff., 20	stock-diff., 20	gain-loss	change to forest land
4B2: change to CC21	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	change to cropland
4C1: change among CC31-37	stock-diff., 1	stock-diff., 1	stock-diff., 1	gain-loss	grassland internal changes
4C2: change to CC31, CC36, CC37	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	change to permanent and unproductive grassland categories
4C2: change to CC32-35	stock-diff., 20	stock-diff., 1	stock-diff., 20	gain-loss	change to woody grassland categories
4D1: change among CC41-42	stock-diff., 1	stock-diff., 1	stock-diff., 1	gain-loss	wetlands internal changes
4D2: change to CC41	stock-diff., 1	stock-diff., 1	stock-diff., 1	gain-loss	change to surface water
4D2: change to CC42	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	change to unproductive wetland
4E1: change among CC51-54	stock-diff., 1	stock-diff., 1	stock-diff., 1	gain-loss	settlements internal changes
4E2: change to CC51	stock-diff., 1	stock-diff., 1	stock-diff., 20 (20%)	stock-diff., 20 (20%)	change to sealed settlement areas; soil carbon stock reduced by 20%
4E2: change to CC52-54	stock-diff., 1	stock-diff., 1	stock-diff., 20	gain-loss	change to unsealed settlement areas
4F2: change to CC61	stock-diff., 1	stock-diff., 1	stock-diff., 20	stock-diff., 20	change to other land

6.1.3.3. Conversion time in the stock-difference approach

Table 6-3 shows the conversion times applied in the stock-difference approach to carbon stock changes in living biomass, dead organic matter (dead wood, litter), and soil for different land-use changes.

Changes in the soil carbon stock, and this is also true for the increase of woody biomass, as a result of land-use changes are slow processes that might take decades. Therefore, IPCC (2006, Volume 4, chp. 2) suggests implementing a conversion time (CT). Following the IPCC default value (CT = 20 years), carbon emissions or removals due to a soil carbon stock difference ($stockC_{s,i,a}$ – $stockC_{s,i,b}$) do not occur in one year but are distributed evenly over the 20 years following the land-use change.

A conversion time of 20 years was applied to all mineral soil carbon stock changes except for land converted to surface water and for internal changes in Grassland, Wetlands and Settlements. Accordingly, the area of mineral soil of each category 2 in reporting tables Table4.A to Table4.F contains the cumulative area remaining in the respective category in the reporting year.

There are no consistent data sources on land-use changes before 1990, but it is well known, that the main trends of the Swiss land-use dynamics, e.g. increase of forest area (FOEN 2024f: Figure 1.4; Ginzler et al. 2011) and settlements (ARE/FOEN 2007) arose before 1972. Therefore, it was assumed that between 1971 and 1989 the annual rate of all land-use changes was the same as in 1990. Based on this assumption it was possible to produce the land-use data required for the consideration of the conversion time in that period.

6.1.3.4. Displaying results in the Common Reporting Tables

In the reporting tables CRT Table4.A to CRT Table4.F, a part of the land-use categories and associated spatial strata are shown at an aggregated level. The values of deltaC are accordingly summarised. Positive values of deltaC$_{l,i,ba}$ were inserted in the column “Gains” and negative values in the column “Losses”, respectively. The values of deltaC$_{d,i,ba}$ and deltaC$_{h,i,ba}$ were inserted into columns “Net carbon stock change in dead wood” and “Net carbon stock change in litter” in CRT Table4.A, and the values of deltaC$_{dom,i,ba}$ were inserted into columns “Net carbon stock change in dead organic matter” in the reporting tables CRT Table4.B to CRT Table4.F. The values of deltaC$_{s,i,ba}$ were inserted into columns "Net carbon stock change in soils" in the reporting tables CRT Table4.A to CRT Table4.F, separated into mineral and organic soils.

The reporting tables Table4.A to Table4.F are subdivided in two parts: (1) X land remaining X land and (2) Land converted to X land. Changes of areas from one land use to another within the same main land-use category are reported in part (1) of the reporting tables. For example, the area of shrub vegetation (CC32) converted to permanent grassland (CC31) is reported in CRT Table4.C1 in the subdivision “permanent grassland”. As CC31 and CC32 do have different carbon stocks in biomass and soils, carbon stock changes are calculated according to the equations presented in chp. 6.1.3.2.

The CRF reporter generated errors or inconsistent content in several reporting tables related to the LULUCF sector (see Annex 7). Information related to the CRT reporter will be added in the next NID.

6.1.4. Overview: Carbon stocks and carbon stock changes in the land-use categories

Table 6-4 presents carbon stocks, carbon gains, carbon losses and net changes in carbon stocks for the pools living biomass, dead wood, litter, and mineral and organic soil stratified by land-use category and spatial strata for the year 1990. For non-Forest land, dead wood and litter were merged and shown as dead organic matter. These data were used to calculate the net CO_2 emissions and removals presented in the reporting tables according to the methods in chp. 6.1.3.

The values shown in Table 6-4 remain constant during the inventory period with the following exceptions (highlighted cells):

- Productive forest (CC12): (1) Carbon stocks in living biomass, carbon gains and carbon losses in living biomass, (2) carbon stocks and net carbon stock changes in dead wood, (3) carbon stocks and net carbon stock changes in litter, and (4) net carbon stock changes in mineral soil. Derivation of data and annual values are described in chp. 6.4.2.2 and chp. 6.4.2.3.

- Cropland (CC21): (1) Carbon stocks in living biomass, carbon gains and carbon losses in living biomass, (2) carbon stocks and net carbon stock changes in mineral soil. Derivation of data and annual values are described in chp. 6.5.2.
- Permanent grassland (CC31): (1) Carbon stocks in living biomass, carbon gains and carbon losses in living biomass, (2) carbon stocks and net carbon stock changes in mineral soil. Derivation of data and annual values are described in chp. 6.6.2.

The derivation of the individual carbon stocks, carbon gains, carbon losses, and net carbon stock changes is explained in detail in chapters 6.4 to 6.9.

With regard to the columns "Carbon stock in" in Table 6-4, the entry "0" indicates the absence of biomass or soil organic carbon in the corresponding carbon pool.

With regard to the columns "Carbon gains in living biomass", "Carbon losses in living biomass", and "Net change in", the following applies:

- Positive values refer to gains, negative values refer to losses in the respective carbon pool.
- The notation key NA indicates a Tier 1 approach, where the carbon pool is assumed to be in equilibrium (in accordance with the conclusions and recommendations from the 16th meeting of the GHG inventory Lead Reviewers, Bonn, March 2019). In the calculation with the formulas from chapter 6.1.3.2, this entry is transferred into the numerical value 0.
- The notation key NO indicates that the process did not exist in 1990. In the calculation with the formulas from chapter 6.1.3.2, this entry is transferred into the numerical value 0.
- For Forest land, the net change of carbon stocks in drained organic soil is -2.6 t C ha^{-1} yr^{-1}. 3 % of the area of organic soil is estimated to be drained (see chp. 6.4.2.3.8), which leads to a correspondingly smaller implied carbon stock change factor of -0.08 t C ha^{-1} yr^{-1} in CRT Table4.A. In contrast, organic soil on non-Forest land is assumed to have 100 % drainage with the land-use category surface waters (CC41) as the only exception (see chp. 6.7.2.2.2).

6.1.5. Uncertainty estimates

Note that in this submission the four categories according to the CRF nomenclature 4(II), 4(III), 4(IV) and 4(V) are still used.

Table 6-5 gives an overview of uncertainty estimates of activity data, carbon stock change factors (CO_2 emissions and removals in 4A–4G), and emission factors (CH_4 and N_2O emissions in 4(II)–4(V)).

For categories 4A–4F, the uncertainties of activity data mainly depend on the uncertainty of the AREA survey data (see chp. 6.3.1.3.1 and Table 6-10). For categories 4D1, 4(II)–4(V), and 4G other data sources are relevant, e.g. for 4D1 the uncertainty of the area of organic soil. Details are presented in the chapters 6.4.3 to 6.10.3, along with the uncertainty estimates for carbon stock change factors and emission factors.

For categories 4B, 4C and 4D2, the uncertainties are given separately for the carbon pools living biomass, dead organic matter, mineral soil and organic soil. The overall uncertainty is calculated as described in chp. 1.6.2.

Table 6-4 Carbon stocks and carbon stock changes in living biomass, dead wood, litter, mineral and organic soil for land-use categories, stratified by elevation zone, NFI production region, and soil type. For non-Forest land, dead organic matter is shown. The values are valid for the whole inventory period with the exception of the values in the highlighted cells, which change annually (numbers given here are for the year 1990); see main text. Carbon stocks are used for the stock-difference calculation approach, whereas data on carbon stock changes apply where the gain-loss calculation approach is used (see Table 6-3 and equations 6.1–6.8 in chp. 6.1.3.2).

CC code, land-use category	**NFI region**	**Elevation zone**	**Carbon stock in living biomass (stockCl,i)**	**Carbon stock in dead wood (stockCd,i)**	**Carbon stock in litter (stockCh,i)**	**Carbon stock in mineral soil (stockCs,i)**	**Carbon stock in organic soil (stockCs,i)**	**Carbon gains in living biomass (gainCl,i)**	**Carbon losses in living biomass (lossCl,i)**	**Net change in dead wood (changeCd,i)**	**Net change in litter (changeCh,i)**	**Net change in mineral soil (changeCs,i)**	**Net change in (drained) organic soil (changeCs,i)**
	Strata		**[t C ha^{-1}]**					**[t C ha^{-1} yr^{-1}]**					
12 Productive forest	L1	Z1	126.71	5.57	13.81	56.54	145.6	3.66	-2.71	-0.02	-0.22	0.01	-2.6
	L1	Z2	121.77	6.34	15.06	101.16	145.6	3.32	-2.76	-0.02	-0.17	0.01	-2.6
	L1	Z3	85.09	6.01	13.80	129.46	145.6	2.08	-1.70	-0.07	-0.29	0.00	-2.6
	L2	Z1	134.45	9.12	14.18	50.30	145.6	4.75	-4.72	-0.05	-0.25	0.01	-2.6
	L2	Z2	146.60	9.05	15.62	64.13	145.6	4.66	-4.48	-0.05	-0.23	0.01	-2.6
	L2	Z3	146.60	9.05	15.62	128.23	145.6	4.66	-4.48	-0.05	-0.23	0.01	-2.6
	L3	Z1	148.46	8.92	17.20	63.42	145.6	4.23	-3.58	0.02	-0.15	0.02	-2.6
	L3	Z2	148.46	8.92	17.20	80.18	145.6	4.23	-3.58	0.02	-0.15	0.02	-2.6
	L3	Z3	116.33	7.71	18.43	103.28	145.6	2.49	-2.56	-0.03	-0.12	0.02	-2.6
	L4	Z1	97.95	6.45	13.50	69.96	145.6	2.63	-2.14	0.04	-0.06	0.02	-2.6
	L4	Z2	97.95	6.45	13.50	77.51	145.6	2.63	-2.14	0.04	-0.06	0.02	-2.6
	L4	Z3	92.93	7.11	18.26	73.68	145.6	1.91	-1.94	0.08	0.07	0.02	-2.6
	L5	Z1	71.14	2.14	9.40	119.86	145.6	2.42	-1.00	0.05	0.09	0.02	-2.6
	L5	Z2	71.14	2.14	9.40	112.91	145.6	2.42	-1.00	0.05	0.09	0.02	-2.6
	L5	Z3	74.88	2.25	12.25	97.05	145.6	1.65	-0.61	0.01	0.13	0.01	-2.6
13 Unproductive forest	L1	Z1	38.53	0	12.10	57.08	145.6	NA	NA	NA	NA	NA	-2.6
	L1	Z2	51.10	0	12.92	106.91	145.6	NA	NA	NA	NA	NA	-2.6
	L1	Z3	51.34	0	10.57	123.61	145.6	NA	NA	NA	NA	NA	-2.6
	L2	Z1	20.45	0	12.07	52.49	145.6	NA	NA	NA	NA	NA	-2.6
	L2	Z2	35.83	0	13.01	65.35	145.6	NA	NA	NA	NA	NA	-2.6
	L2	Z3	51.33	0	13.01	125.59	145.6	NA	NA	NA	NA	NA	-2.6
	L3	Z1	20.45	0	14.62	61.82	145.6	NA	NA	NA	NA	NA	-2.6
	L3	Z2	47.53	0	14.62	80.81	145.6	NA	NA	NA	NA	NA	-2.6
	L3	Z3	42.36	0	13.55	103.24	145.6	NA	NA	NA	NA	NA	-2.6
	L4	Z1	21.60	0	12.02	70.90	145.6	NA	NA	NA	NA	NA	-2.6
	L4	Z2	31.48	0	12.02	77.52	145.6	NA	NA	NA	NA	NA	-2.6
	L4	Z3	29.88	0	14.86	82.29	145.6	NA	NA	NA	NA	NA	-2.6
	L5	Z1	20.83	0	8.74	100.90	145.6	NA	NA	NA	NA	NA	-2.6
	L5	Z2	23.82	0	11.45	99.71	145.6	NA	NA	NA	NA	NA	-2.6
	L5	Z3	24.35	0	12.53	102.48	145.6	NA	NA	NA	NA	NA	-2.6

Legend

Elevation zones:

Z1	< 601 m
Z2	601 - 1200 m
Z3	> 1200 m

NFI regions:

L1	Jura
L2	Central Plateau
L3	Pre-Alps
L4	Alps
L5	Southern Alps

n.s. = no stratification

Annual data

(Table 6-4 continued)

CC code, land-use category	NFI region	Elevation zone	Carbon stock in living biomass (stockCl,i)	Carbon stock in dead organic matter (DOM) (stockCd,i + stockCh,i)	Carbon stock in mineral soil (stockCs,i)	Carbon stock in organic soil (stockCs,i)	Carbon gains in living biomass (gainCl,i)	Carbon losses in living biomass (lossCl,i)	Net change in dead organic matter (DOM) (changeCd,i + changeCh,i)	Net change in mineral soil (changeCs,i)	Net change in (drained) organic soil (changeCs,i)
	Strata		[t C ha^{-1}]				[t C ha^{-1} yr^{-1}]				
21 Cropland	n.s.	Z1	6.38	0	58.25	240	0.05	NO	NA	-0.14	-9.52
	n.s.	Z2	6.39	0	59.82	240	0.04	NO	NA	-0.16	-9.52
	n.s.	Z3	6.07	0	51.91	240	0.08	NO	NA	0.07	-9.52
31 Permanent Grassland	n.s.	Z1	5.78	0	63.02	240	NO	-0.05	NA	-0.03	-9.52
	n.s.	Z2	5.30	0	58.99	240	NO	-0.04	NA	0.21	-9.52
	n.s.	Z3	3.34	0	46.22	240	NO	0.00	NA	0.71	-9.52
32 Shrub Vegetation	n.s.	Z1	20.45	0	58.3	240	NA	NA	NA	NA	-5.30
	n.s.	Z2	20.45	0	63.8	240	NA	NA	NA	NA	-5.30
	n.s.	Z3	20.45	0	64.5	240	NA	NA	NA	NA	-5.30
33 Vineyards et al.	n.s.	n.s.	5.5	0	49.9	240	NA	NA	NA	NA	-9.52
34 Copse	n.s.	Z1	20.45	0	58.3	240	NA	NA	NA	NA	-5.30
	n.s.	Z2	20.45	0	63.8	240	NA	NA	NA	NA	-5.30
	n.s.	Z3	20.45	0	64.5	240	NA	NA	NA	NA	-5.30
35 Orchards	n.s.	n.s.	23.1	0	59.4	240	NA	NA	NA	NA	-9.52
36 Stony Grassland	n.s.	n.s.	7.2	0	22.6	240	NA	NA	NA	NA	-5.30
37 Unproductive Grassland	n.s.	n.s.	3.5	0	64.2	240	NA	NA	NA	NA	-5.30
41 Surface Waters	n.s.	n.s.	0	0	0	240	NA	NA	NA	NA	0
42 Unproductive Wetland	n.s.	n.s.	6.5	0	63.1	240	NA	NA	NA	NA	-5.30
51 Buildings, Constructions	n.s.	n.s.	0	0	0	0	NA	NA	NA	NA	NA
52 Herbaceous Biomass in S.	n.s.	n.s.	9.54	0	49.7	240	NA	NA	NA	NA	-9.52
53 Shrubs in Settlements	n.s.	n.s.	15.43	0	49.7	240	NA	NA	NA	NA	-5.30
54 Trees in Settlements	n.s.	n.s.	20.72	0	49.7	240	NA	NA	NA	NA	-5.30
61 Other Land	n.s.	n.s.	0	0	0	0	NA	NA	NA	NA	NA

Legend

Elevation zones:

Z1	< 601 m
Z2	601 - 1200 m
Z3	> 1200 m

NFI regions:

L1	Jura
L2	Central Plateau
L3	Pre-Alps
L4	Alps
L5	Southern Alps

n.s. = no stratification

Annual data

In general, the uncertainty of activity data is lower than the uncertainty of carbon stock change factors and emission factors, because activity data are mostly based on a systematic survey with high spatial resolution (such as AREA), while carbon stock change factors and emission factors include parameters that are difficult to measure or to model such as carbon stocks in biomass, growth rates and biogeochemical processes.

Possible very large relative uncertainties for carbon stock change factors in categories 4B and 4C are due to the calculation approach, in which absolute uncertainties (in t C ha^{-1} yr^{-1}) of the carbon stock changes in categories 4B1, 4B2, 4C1 and 4C2 were divided by the associated net carbon stock changes (chp. 6.5.3.1.2 and chp. 6.6.3.1.2).

For the N_2O emission factors in categories 4(III) and 4(IV2), the uncertainty is modelled by an (asymmetrical) gamma distribution.

The detailed input parameters used for uncertainty computation, approaches 1 and 2, are documented in Annex A2.1. Detailed results of approach 1 and approach 2 uncertainty analyses are given in Annex A2.2 and Annex A2.3, respectively.

Table 6-5 Uncertainty estimates expressed as half of the 95 % confidence intervals. Transcriptions used: CS-CH-LB Carbon gains: carbon gains in living biomass; CS-CH-LB Carbon losses: carbon losses in living biomass; Net CS-CH-S Carbon min soils: net carbon stock change in mineral soil; Net CS-CH-S Carbon org soils: net carbon stock change in organic soil; Net CS-CH-DOM Carbon: net carbon stock change in dead organic matter.

Code	Gas	Activity data uncertainty					Emission factor uncertainty				
		Distribu-tion type	2*std. dev. %	(-)%	(+)%	Corr.	Distribu-tion type	2*std. dev. %	(-)%	(+)%	Corr.
Year 2022											
4A1	CO2	normal	1.1	1.1	1.1	yes	normal	34.9	34.9	34.9	yes
4A2	CO2	normal	1.5	1.5	1.5	yes	normal	34.9	34.9	34.9	yes
4B1; CS-CH-LB Carbon gains	CO2	normal	4.9	4.9	4.9	yes	normal	13.0	13.0	13.0	yes
4B1; CS-CH-LB Carbon losses	CO2	normal	4.9	4.9	4.9	yes	normal	13.0	13.0	13.0	yes
4B1; Net CS-CH-S Carbon min soils	CO2	normal	4.9	4.9	4.9	yes	normal	135.9	135.9	135.9	no
4B1; Net CS-CH-S Carbon org soils	CO2	normal	37.3	37.3	37.3	yes	normal	23.0	23.0	23.0	yes
4B1; Net CS-CH-DOM Carbon	CO2	normal	4.9	4.9	4.9	yes	normal	0.5	0.5	0.5	yes
4B2; CS-CH-LB Carbon gains	CO2	normal	5.1	5.1	5.1	yes	normal	13.0	13.0	13.0	yes
4B2; CS-CH-LB Carbon losses	CO2	normal	5.1	5.1	5.1	yes	normal	13.0	13.0	13.0	yes
4B2; Net CS-CH-S Carbon min soils	CO2	normal	5.1	5.1	5.1	yes	normal	450.1	450.1	450.1	no
4B2; Net CS-CH-S Carbon org soils	CO2	normal	37.3	37.3	37.3	yes	normal	23.0	23.0	23.0	yes
4B2; Net CS-CH-DOM Carbon	CO2	normal	5.1	5.1	5.1	yes	normal	0.5	0.5	0.5	yes
4C1; CS-CH-LB Carbon gains	CO2	normal	5.2	5.2	5.2	yes	normal	13.0	13.0	13.0	yes
4C1; CS-CH-LB Carbon losses	CO2	normal	5.2	5.2	5.2	yes	normal	13.0	13.0	13.0	yes
4C1; Net CS-CH-S Carbon min soils	CO2	normal	5.2	5.2	5.2	yes	normal	1'108.0	1'108.0	1'108.0	no
4C1; Net CS-CH-S Carbon org soils	CO2	normal	68.6	68.6	68.6	yes	normal	23.0	23.0	23.0	yes
4C1; Net CS-CH-DOM Carbon	CO2	normal	5.2	5.2	5.2	yes	normal	0.5	0.5	0.5	yes
4C2; CS-CH-LB Carbon gains	CO2	normal	5.3	5.3	5.3	yes	normal	13.0	13.0	13.0	yes
4C2; CS-CH-LB Carbon losses	CO2	normal	5.3	5.3	5.3	yes	normal	13.0	13.0	13.0	yes
4C2; Net CS-CH-S Carbon min soils	CO2	normal	5.3	5.3	5.3	yes	normal	107.8	107.8	107.8	no
4C2; Net CS-CH-S Carbon org soils	CO2	normal	68.6	68.6	68.6	yes	normal	23.0	23.0	23.0	yes
4C2; Net CS-CH-DOM Carbon	CO2	normal	5.3	5.3	5.3	yes	normal	0.5	0.5	0.5	yes
4D1	CO2	normal	90.8	90.8	90.8	yes	normal	72.2	72.2	72.2	yes
4D2; CS-CH-LB Carbon gains	CO2	normal	3.7	3.7	3.7	yes	normal	13.0	13.0	13.0	yes
4D2; CS-CH-LB Carbon losses	CO2	normal	3.7	3.7	3.7	yes	normal	13.0	13.0	13.0	yes
4D2; Net CS-CH-S Carbon min soils	CO2	normal	3.7	3.7	3.7	yes	normal	50.0	50.0	50.0	yes
4D2; Net CS-CH-S Carbon org soils	CO2	normal	90.8	90.8	90.8	yes	normal	72.2	72.2	72.2	yes
4D2; Net CS-CH-DOM Carbon	CO2	normal	3.7	3.7	3.7	yes	normal	0.5	0.5	0.5	yes
4E1	CO2	normal	4.4	4.4	4.4	yes	normal	50.0	50.0	50.0	yes
4E2	CO2	normal	4.6	4.6	4.6	yes	normal	50.0	50.0	50.0	yes
4F2	CO2	normal	3.1	3.1	3.1	yes	normal	50.0	50.0	50.0	yes
4G	CO2	normal	11.2	11.2	11.2	yes	normal	54.8	54.8	54.8	yes
4II	CH4	normal	10.0	10.0	10.0	yes	normal	70.0	70.0	70.0	yes
4II	N2O	normal	50.8	50.8	50.8	yes	normal	66.9	66.9	66.9	yes
4III	N2O	normal	83.5	83.5	83.5	yes	gamma	90.0	90.0	90.0	yes
4IV	N2O	normal	85.8	85.8	85.8	yes	gamma	100.0	100.0	100.0	yes
4V	CH4	normal	30.0	30.0	30.0	yes	normal	70.0	70.0	70.0	yes
4V	N2O	normal	30.0	30.0	30.0	yes	normal	70.0	70.0	70.0	yes
Specific uncertainties for the year 1990											
4B1; Net CS-CH-S Carbon min soils	CO2	normal	4.9	4.9	4.9	yes	normal	237.8	237.8	237.8	no
4B2; Net CS-CH-S Carbon min soils	CO2	normal	5.1	5.1	5.1	yes	normal	156.1	156.1	156.1	no
4C1; Net CS-CH-S Carbon min soils	CO2	normal	5.2	5.2	5.2	yes	normal	86.0	86.0	86.0	no
4C2; Net CS-CH-S Carbon min soils	CO2	normal	5.3	5.3	5.3	yes	normal	103.3	103.3	103.3	no

6.2. Land-use definitions and classification systems

6.2.1. Combination Categories (CC) as derived from AREA Land Use Statistics

The standard nomenclature version 2004 (NOAS04; SFSO 2006a; FSO 2022i) of the Swiss Land Use Statistics (AREA) processed by the Federal Statistical Office is the basis for the selection of the land-use categories used for land area representation. In the course of an AREA survey (see chp. 6.3.1.1), every sample point on a hectare-grid in Switzerland is assigned to a land-use category (NOLU04) and to a land-cover category (NOLC04). The interpretation is backed by a large set of geodata that can be superimposed if required (For just a public subset of geodata available to the FSO interpreters see the federal geoportal, e.g. topic FOEN: https://s.geo.admin.ch/378b0vophaie, topic swisstopo: https://s.geo.admin.ch/9cecf4d9d6 or topic FOAG: https://s.geo.admin.ch/b8hseaqdwe4a). These geodata also include data sets indicating the legal status of land use (e.g. residential zones, crop rotation areas, nature reserves). Ambiguous sample points are also visited by the AREA staff to verify the on-screen classification of land use (ground control).

The AREA survey is an advanced and well-established land use statistic (see the links to visualization examples in chp. 6.3.1.4.3. It allows for the identification of country-specific categories that are more detailed than those defined in IPCC (2006) (see Table 6-2). The 46 NOLU04 categories and 27 NOLC04 categories were aggregated to 17 combination categories (CC), following the assignment shown in Table 6-6, and adopted as land-use categories for LULUCF reporting. The first digit of the CC code represents the IPCC (2006) main land-use category, whereas the second digit stands for the respective land-use category. The approach enables more accurate estimates for carbon stocks and carbon stock changes than on the basis of the IPCC (2006) main categories alone because each land-use catgory can be fed with individual carbon data and distinctive carbon dynamics can be assumed (see below).

The combination categories were defined in 2006 in an evaluation process involving experts from the FOEN, the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), the Federal Statistical Office and Agroscope as well as private consultants. The evaluation process resulted in the elaboration of Table 6-6.

With regard to carbon stock in living biomass, there is a strong relation to the vegetation type (i.e. to land cover in most cases). This is exemplarily reflected by the mainly horizontal arrangement of the individual combination categories in Table 6-6. With regard to carbon stock changes in living biomass, dead organic matter, and soil the definition was driven by the consideration that frequently individual vegetation units – like e.g. orchards – are subject to a similar management all over Switzerland leading to comparable carbon fluxes in living biomass, dead organic matter, and soil.

For individual combination categories (especially for Forest land) further spatial stratifications were introduced (see chp. 6.2.2) with the intention to match the spatial variability of vegetation and soil conditions as closely as possible.

The underlying criteria to include land-use categories such as shrub vegetation, vineyards, low-stem orchards, tree nurseries, copse and orchards under Grassland with woody biomass are: (1) They do not fulfil the criteria for forests; (2) There is an agricultural management in general; (3) They all have woody biomass (i.e. perennial vegetation) with grass understory. Under Cropland, in contrast, there are no perennial crops, but annual crops and leys in arable rotations. All perennial crops are included in the Grassland land-use categories.

Table 6-6 Derivation of 17 combination categories (CC) from AREA NOLU04 and NOLC04 categories. They were adopted as land-use categories for LULUCF reporting.

Combination Categories (CC)

Land Use (NOLU04) acc. to AREA

Land Cover (NOLC04) acc. to AREA	Settlement and urban areas – Building areas								Transport surfaces					Special urban areas							Recreational areas and cemeteries					
	101 Industrial and commercial areas > 1 ha	102 Industrial and commercial areas < 1 ha	103 Residential areas (one and two-family house	104 Residential areas (terraced houses)	105 Residential areas (blocks of flats)	106 Public buildings and surroundings	107 Agricultural buildings and surroundings	108 Unspecified buildings and surroundings	121 Motorways	122 Roads	123 Parking areas	124 Railway surface	125 Airports and airfields	141 Energy supply plants	142 Waste treatment plants	143 Other supply or waste treatment plants	144 Dumps	145 Quarries, mines	146 Construction sites	147 Unexploited urban areas	161 Public parks	162 Sport facilities	163 Golf courses	164 Camping areas	165 Garden allotments	166 Cemeteries
10 Artificial areas																										
11 Sealed surfaces	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
12 Buildings	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
13 Greenhouses	52	52	52	52	52	52	52	52			52	52	52						52	52	52	52	52	52	52	52
14 Gardens with border and patch structures	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52			52	52	52	52	52	52	52	52
15 Lawns	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52			52	52	52	52	52	52	52	52
16 Trees in artificial areas	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54			54	54	54	54	54	54	54	54
17 Mix of small structures	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52			52	52	52	52	52	52	52	52
20 Grass and herb vegetation																										
21 Grass and herb vegetation	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
30 Brush vegetation																										
31 Shrub	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53
32 Brush meadows	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53
33 Short-stem fruit trees	53	53	53	53	53	53	53	53	53	53	53	53								53	53				53	53
34 Vines	53	53	53	53	53	53	53	53	53	53	53	53								53	53				53	53
35 Permanent garden plants and brush crops	52	52	52	52	52	52	52	52	52	52	52	52								52	52				52	52
40 Tree vegetation																										
41 Closed forest	54	54	54	54	54	54	54	54	54		54									54	54	54		54	54	54
42 Forest edges	54	54	54	54	54	54	54	54	54		54			54	54	54				54	54	54	54	54	54	54
43 Forest strips	54	54	54	54	54	54	54	54	54		54			54	54	54				54	54	54		54	54	54
44 Open forest	54	54	54	54	54	54	54	54	54		54			54	54	54				54	54	54		54	54	54
45 Brush forest																					53			53		
46 Linear woods	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54
47 Clusters of trees	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54
50 Bare land																										
51 Solid rock	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
52 Granular soil	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
53 Rocky areas	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52
60 Watery areas																										
61 Water	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
62 Glacier, perpetual snow																										
63 Wetlands	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
64 Reedy marshes	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42

Land Cover (NOLC04) acc. to AREA	Agricultural areas – Orchards, vineyards, horticulture			Arable and grassland			Alpine grazing areas			Forest areas – Forest (not used for agriculture)				Unproductive areas – Lakes and rivers			Unproductive land			
	201 Orchards	202 Vineyards	203 Horticulture	221 Arable land, in general	222 Semi-natural grassland, in general	223 Farm pastures, in general	241 Alpine meadows, in general	242 Alpine pastures, in general	243 Alpine sheep grazing pastures, in general	301 Forest	302 Afforestation	303 Lumbering areas	304 Damaged forest	401 Lakes	402 Streams, rivers	403 Flood protection structures	421 Unused	422 Avalanche and rockfall protection structures	423 Alpine sports facilities	424 Landscape intervention
10 Artificial areas																				
11 Sealed surfaces		51	51											51	51	51		51	51	51
12 Buildings																				
13 Greenhouses			21																	
14 Gardens with border and patch structures		21	21	21	21		21			12										
15 Lawns		31	31																	
16 Trees in artificial areas																				
17 Mix of small structures		21	21																	
20 Grass and herb vegetation																				
21 Grass and herb vegetation	31	31	31	21	31	31	31	31	31		12	12	12	37	37	37	37	37	37	31
30 Brush vegetation																				
31 Shrub		32	32								12	12	12	32	32	32	32	32	32	32
32 Brush meadows		32	32		32	32	32	32			12	12	12	32	32	32	32	32	32	32
33 Short-stem fruit trees	33		33																	
34 Vines		33	33																	
35 Permanent garden plants and brush crops			33							12										
40 Tree vegetation																				
41 Closed forest	35									12	12					12		12		
42 Forest edges	35									12	12	12	12			12		12		
43 Forest strips	35									12	12					12		12		
44 Open forest	35				12	12	12	12	13	12	12	12	12			12		12	12	12
45 Brush forest										13						13		13		
46 Linear woods	34	34	34	34	34	34	34	34	34		12	12	12	34	34	34	34	34	34	34
47 Clusters of trees	34	34	34	34	13	13	34	13	34		12	12	12	34	34	34	34	34	34	34
50 Bare land																				
51 Solid rock												13	13	61	61	61	61	61	61	61
52 Granular soil		61	61									12	12	61	61	61	61	61	61	61
53 Rocky areas		36	36			36	36	36			12	13	13	36	36	36	36	36	36	36
60 Watery areas																				
61 Water														41	41	41				41
62 Glacier, perpetual snow																	61		61	
63 Wetlands					42	42	42	42	42			12	13	42	42	42	42	42	42	42
64 Reedy marshes				21	42	42	42	42	42					42	42	42	42			

Combination Categories (CC):

12 Productive forest
13 Unproductive forest
21 Cropland
31 Permanent grassland
32 Shrub vegetation
33 Vineyards, Low-stem Orchads, Tree nurseries
34 Copse
35 Orchards
36 Stony grassland
37 Unproductive grassland
41 Surface water
42 Unproductive wetland
51 Buildings and constructions
52 Herbaceous biomass in settlements
53 Shrubs in settlements
54 Trees in settlements
61 Other land

All land-use categories of Forest land, Grassland and Wetlands are defined as managed and reported under managed land in CRT Table4.1. Cropland and Settlements are regarded to be managed by default. Other land is regarded to be unmanaged by default. In a nutshell, the entire land area of Switzerland – except for 4F Other land – is reported to be managed.

6.2.2. Spatial stratification

6.2.2.1. Soil type

Most soils in Switzerland are mineral soil types. A digital map estimating the surface of organic soils in Switzerland was generated by Wüst-Galley et al. (2015) and updated by Wüst-Galley and Zehnder (2024). As there is no single data set from which the location of organic soils across the country could be adequately deduced, the authors evaluated numerous spatial and non-spatial data sets providing information on geology, soils, forest habitats and vegetation. Two important spatially explicit and recent data sets are the Federal Inventory of Raised and Transition Bogs of National Importance and the Federal Inventory of Fens of National Importance (cf. https://s.geo.admin.ch/tg32oazxx70z). According to Wüst-Galley and Zehnder (2024) the total area of organic soils is 34.3 kha (0.83 % of the total area covered by soils) (see Figure 6-4).

The definition of organic soil in the GHG inventory is as follows: Intact or degraded peaty soils are considered organic soils. Where information on soil organic carbon (SOC) is known, the definition of organic soil from the IPCC (IPCC 2006, Volume 4, chp. 3, Annex 3A.5) was used to classify soils as mineral / organic (see Wüst-Galley et al. 2015: 11; Wüst-Galley and Zehnder 2024). This definition was also used for the ground-truthing of forest habitat maps and fen inventories. It also formed the basis of the classification of soil types from the soils maps, as organic or mineral (soil types ‘Halbmoor’ and ‘Moor’ were considered organic soils). Here however, two soil sub-types (“anmoorig” and “antorfig”) could not be classified; the ranges of SOC values and peat depths characterising these sub-types overlap only partially with those SOC values and peat depths used to define organic soil (IPCC 2006), meaning they cannot be classified ambiguously as either mineral or organic soils. Also, because their distribution is poorly known, they were not explicitly considered in the estimate of organic soil (see Wüst-Galley et al. 2015: 14–15 and 61).

For the other data sets used in the construction of the organic soils map (geology maps, hydrogeology maps and habitat maps), no information on SOC is available, and the presence of peat was used as evidence of organic soil. The carbon content of peat meets the IPCC (2006) definition of organic soil.

Consistency: A single map of organic soil is applied to all years (1990 to present), meaning the classifications used are consistent through time. The same definition of organic soil was used across the whole country.

6.2.2.2. Elevation

For Forest land (CC12, CC13), Cropland (CC21) and permanent grassland (CC31) three elevation zones were differentiated: <601 m a.s.l. (meters above sea level), 601–1200 m a.s.l., and >1200 m a.s.l. (Figure 6-4). Elevation data from the Federal Office of Topography (swisstopo) on a 25x25 m raster (product DHM25) were used to map the three zones. The elevation zones are coded Z1, Z2 and Z3 in the reporting tables (with increasing elevation).

6.2.2.3. Forest production region

Forest land was differentiated into the five production regions of the National Forest Inventory (Brändli and Hägeli 2019: chp. 1.5.2; Figure 6-4, see also https://s.geo.admin.ch/8d972b5708). These are (in brackets the coding in the reporting tables):

Jura (L1), Central Plateau (L2), Pre-Alps (L3), Alps (L4) and Southern Alps (L5).

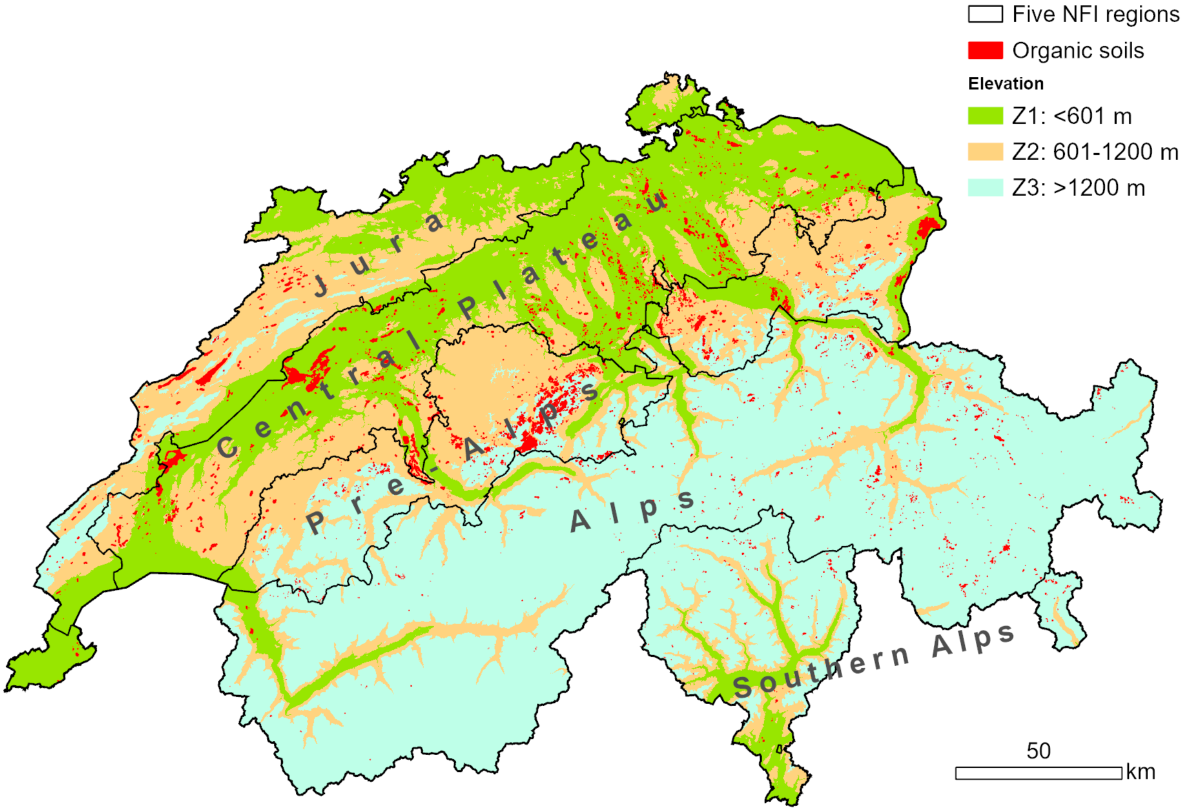

Figure 6-4 Map showing the spatial stratification according to NFI production region, elevation zone, and soil type.

6.2.2.4. Strata

Applying all spatial stratifications, 30 different strata (referred to as subscript i in chp. 6.1.3.2) would be theoretically possible. Not all of them, but altogether 29 have been actually realised and applied for the calculation of CO_2 eq emissions and removals.

6.2.3. Land-use tables and change matrices

In Table 6-7 the land-use statistics resulting from spatial stratification (chp. 6.2.2) and interpolation in time (chp. 6.3.1.2) are exemplarily shown for the year 1990. The table gives also the area size of the individual spatial strata (column "Sum").

Table 6-7 Land use projection by the end of 1990 for land-use categories (shown by their CC codes), stratified separately for elevation (Z1-Z3), soil type (mineral or organic) and NFI production region (L1-L5), in kha, rounded values. The country’s total area is 4'129'073 ha (FSO 2023).

CC	12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61	Sum
Elevation																		
Z1	225.9	6.2	299.8	153.8	2.6	22.5	32.4	1.2	0.5	2.9	138.6	5.2	116.7	47.5	2.8	18.6	2.0	1079.1
Z2	505.7	18.1	131.7	358.2	8.7	3.9	29.9	0.3	2.5	1.5	9.7	5.7	46.4	17.0	0.9	5.3	8.1	1153.9
Z3	379.2	79.9	0.4	425.4	144.4	0.0	27.1	0.0	148.7	61.9	13.3	14.3	11.4	3.7	0.2	1.0	585.2	1896.1
	1110.8	104.2	432.0	937.4	155.7	26.5	89.3	1.6	151.6	66.3	161.6	25.1	174.6	68.2	3.9	24.9	595.3	4129.1
Soil																		
mineral	1105.7	103.9	419.8	930.2	155.5	26.4	88.9	1.6	151.6	66.1	161.3	18.9	173.3	67.6	3.9	24.9	595.3	4094.8
organic	5.0	0.4	12.2	7.2	0.2	0.0	0.5	0.0	0.0	0.2	0.3	6.2	1.3	0.6	0.0	0.1	0.051	34.3
	1110.8	104.2	432.0	937.4	155.7	26.5	89.3	1.6	151.6	66.3	161.6	25.1	174.6	68.2	3.9	24.9	595.3	4129.1
NFI region																		
L1	197.9	8.3	78.0	122.6	0.9	4.7	11.9	0.3	0.2	0.6	23.6	1.2	26.8	10.9	0.5	4.7	0.5	493.5
L2	227.9	4.1	307.0	152.4	0.9	9.9	27.4	1.0	0.2	1.6	70.4	4.1	84.9	34.7	1.6	12.6	0.7	941.5
L3	215.3	13.0	30.2	261.3	10.4	0.8	17.8	0.1	8.5	6.8	30.6	12.0	26.8	9.2	0.5	2.9	15.0	661.2
L4	332.8	56.1	13.8	365.4	110.2	9.5	24.5	0.2	118.1	49.2	26.2	7.2	26.9	9.8	0.8	3.0	524.8	1678.2
L5	136.9	22.6	3.0	35.7	33.3	1.5	7.8	0.0	24.6	8.1	10.7	0.7	9.2	3.7	0.6	1.9	54.3	354.6
	1110.8	104.2	432.0	937.4	155.7	26.5	89.3	1.6	151.6	66.3	161.6	25.1	174.6	68.2	3.9	24.9	595.3	4129.1

Table 6-8 shows the overall trends of land-use changes over the inventory period. For example, the area of cropland (CC21) decreased by 13 % during this period, while the area of productive forests (CC12) increased by 5 %.

Table 6-8 Statistics of land use for land-use categories (shown by their CC codes; in kha, rounded values) and relative change (in %, rounded values; see bottom line) between 1990 and 2022. The country’s total area is 4'129'073 ha (FSO 2023).

CC	12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61	Sum
Year																		
1990	1’110.8	104.2	432.0	937.4	155.7	26.5	89.3	1.6	151.6	66.3	161.6	25.1	174.6	68.2	3.9	24.9	595.3	4’129.1
1991	1’112.9	104.4	431.2	935.6	155.2	26.5	88.3	1.5	151.4	66.2	161.6	25.1	176.2	68.7	4.0	25.3	595.0	4’129.1
1992	1’115.0	104.7	430.4	933.8	154.7	26.6	87.3	1.4	151.1	66.0	161.6	25.1	177.9	69.3	4.0	25.6	594.6	4’129.1
1993	1’116.9	104.9	429.4	932.3	154.2	26.5	86.2	1.4	150.9	65.8	161.6	25.1	179.5	69.9	4.1	25.9	594.2	4’129.1
1994	1’118.7	105.1	428.0	931.7	153.7	26.5	85.2	1.3	150.8	65.7	161.6	25.1	181.1	70.4	4.2	26.2	593.8	4’129.1
1995	1’120.3	105.3	426.1	931.6	153.2	26.5	84.3	1.3	150.6	65.5	161.6	25.2	182.7	71.2	4.2	26.2	593.4	4’129.1
1996	1’121.7	105.4	424.2	931.8	152.7	26.4	83.3	1.3	150.5	65.3	161.6	25.2	184.2	71.9	4.2	26.2	592.9	4’129.1
1997	1’123.0	105.6	422.1	932.3	152.3	26.3	82.4	1.2	150.4	65.2	161.7	25.2	185.8	72.7	4.2	26.2	592.5	4’129.1
1998	1’124.1	105.6	420.0	932.7	152.1	26.3	81.5	1.2	150.5	65.0	161.7	25.2	187.3	73.6	4.2	26.1	592.0	4’129.1
1999	1’125.2	105.7	418.0	933.2	151.9	26.2	80.5	1.2	150.5	64.8	161.8	25.3	188.8	74.4	4.2	26.0	591.5	4’129.1
2000	1’126.4	105.7	415.9	933.6	151.7	26.1	79.6	1.2	150.6	64.6	161.8	25.3	190.3	75.2	4.2	25.9	591.0	4’129.1
2001	1’127.5	105.8	413.8	934.0	151.5	26.0	78.6	1.1	150.7	64.3	161.9	25.4	191.9	76.1	4.2	25.8	590.6	4’129.1
2002	1’128.6	105.8	411.8	934.5	151.3	25.9	77.7	1.1	150.7	64.1	161.9	25.4	193.4	76.9	4.2	25.7	590.1	4’129.1
2003	1’129.7	105.9	409.7	934.9	151.1	25.8	76.7	1.1	150.8	63.9	162.0	25.4	194.9	77.7	4.2	25.6	589.6	4’129.1
2004	1’130.8	106.0	407.6	935.4	150.9	25.7	75.8	1.1	150.8	63.7	162.0	25.5	196.4	78.6	4.2	25.5	589.1	4’129.1
2005	1’132.0	105.9	406.0	935.1	150.7	25.6	74.9	1.1	150.9	63.5	162.1	25.5	198.1	79.4	4.2	25.4	588.7	4’129.1
2006	1’133.3	106.0	404.1	934.9	150.6	25.5	74.1	1.0	151.1	63.3	162.1	25.5	199.7	80.0	4.2	25.4	588.2	4’129.1
2007	1’134.9	105.8	402.3	934.3	150.7	25.5	73.5	1.0	151.2	63.0	162.2	25.6	201.4	80.5	4.2	25.5	587.5	4’129.1
2008	1’136.8	105.6	400.6	933.2	151.1	25.4	73.2	1.0	151.6	62.7	162.3	25.6	203.0	80.6	4.1	25.8	586.4	4’129.1
2009	1’138.8	105.4	398.9	931.9	151.4	25.3	73.1	1.1	152.0	62.5	162.3	25.6	204.6	80.7	4.1	26.2	585.3	4’129.1
2010	1’140.9	105.3	397.2	930.4	151.6	25.3	73.1	1.1	152.4	62.2	162.3	25.6	206.2	80.7	4.1	26.7	584.1	4’129.1
2011	1’143.0	105.1	395.5	929.0	151.8	25.3	73.1	1.1	152.8	61.9	162.4	25.6	207.8	80.7	4.0	27.1	582.8	4’129.1
2012	1’145.0	105.0	393.9	927.6	152.0	25.2	73.1	1.2	153.2	61.6	162.4	25.6	209.5	80.7	4.0	27.5	581.5	4’129.1
2013	1’147.1	104.8	392.1	926.3	152.2	25.2	73.1	1.2	153.6	61.3	162.5	25.6	211.1	80.7	3.9	27.9	580.3	4’129.1
2014	1’149.1	104.8	390.1	925.3	152.4	25.2	73.2	1.3	154.0	61.1	162.5	25.7	212.6	80.7	3.9	28.4	579.0	4’129.1
2015	1’151.0	104.7	388.2	924.2	152.7	25.1	73.3	1.3	154.4	60.9	162.6	25.7	214.1	80.7	3.8	28.8	577.7	4’129.1
2016	1’153.0	104.7	386.2	923.2	152.9	25.1	73.3	1.4	154.8	60.6	162.6	25.7	215.5	80.7	3.8	29.2	576.4	4’129.1
2017	1’154.9	104.8	384.5	922.1	152.9	25.1	73.3	1.4	155.2	60.4	162.6	25.7	217.0	80.7	3.7	29.5	575.2	4’129.1
2018	1’156.8	104.8	382.7	920.9	152.9	25.1	73.4	1.5	155.7	60.2	162.7	25.7	218.5	80.8	3.7	29.9	573.9	4’129.1
2019	1’158.8	104.9	381.0	919.7	152.8	25.0	73.5	1.5	156.1	60.0	162.7	25.6	220.0	80.9	3.6	30.2	572.6	4’129.1
2020	1’160.8	104.8	379.3	918.5	152.9	25.0	73.6	1.5	156.5	59.8	162.7	25.6	221.5	81.0	3.6	30.5	571.4	4’129.1
2021	1’162.8	104.8	377.5	917.2	153.0	24.9	73.6	1.6	156.9	59.6	162.8	25.6	223.0	81.1	3.5	30.8	570.1	4’129.1
2022	1’164.9	104.8	375.8	916.0	153.1	24.9	73.7	1.6	157.3	59.4	162.8	25.6	224.5	81.2	3.5	31.2	568.9	4’129.1
Change:	5	1	-13	-2	-2	-6	-18	3	4	-10	1	2	29	19	-10	25	-4	0

The annual land-use changes across the entire territory of Switzerland (change matrices, see examples for 1990 and 2022 in Table 6-9) were obtained by adding up the annual changes on a hectare basis per land-use category. For calculating the carbon stock changes, fully stratified (see chp. 6.2.2) land-use change tables were used for each year (Meteotest 2024). More aggregated land transition matrices are reported in CRT Table4.1 for each year of the inventory period.

In general, the numbers given in the change matrices (Table 6-9) cannot be directly compared with the activity data in categories 2 in CRT Table4.A, Table4.B, Table4.C, Table4.D, Table4.E and Table4.F (Land converted to X), where the cumulative area remaining in the respective category in the reporting year is recorded (see the description of conversion time of 20 years in chp. 6.1.3.3). In contrast, the change matrices below present the land-use changes occurring in the specified year only.

Table 6-9 Annual land-use changes in 1990 and in 2022 (change matrices). Units: ha/year, rounded values. Empty cells indicate that no change occurred.

1990		change to CC																	
		12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61	decrease
change from CC	12		159	5	126	86	6	59		12	19	11	7	118	27	11	17	50	712
	13	678		8	354	48	5	89	0	3	3	1	3	41	20	3	15	10	1280
	21	9	5		663	6	181	35	1	4	4	4	4	632	317	21	18	22	1926
	31	302	480	717		1007	123	311	4	46	43	9	11	870	490	27	44	67	4554
	32	1046	715	2	126		9	309		14	15	6	0	24	8	5	3	30	2313
	33	3	4	126	65	4		28	2	0	1	0		50	26	4	3	5	323
	34	556	63	143	866	49	35		11	9	23	4	3	171	94	6	41	14	2087
	35	0	0	8	13	0	4	46						4	2	0	1	0	80
	36	30	26	2	162	243	1	41			89	4	0	8	1	0		45	652
	37	33	6	1	8	234	1	68		10		3	0	6	2		0	13	384
	41	5	1	2	2	6	0	4		4	1		17	11	2	1	0	99	156
	42	32	6	1	3	2	0	2		0	0	6		4	1	0	0	1	59
	51	56	4	86	158	11	5	7		3	5	6	4		271	58	46	5	726
	52	11	1	16	32	3	1	1		0	1	1	2	349		68	387	0	874
	53	13	0	6	7	2	0	2				0	2	45	28		46	0	150
	54	8	0	1	2	0	0	3			0	0	1	78	152	8		0	253
	61	45	17	16	67	93	8	31		287	33	96	2	13	1	0	1		709
	increase	2828	1489	1140	2653	1794	381	1036	18	394	236	152	55	2425	1443	211	621	361	17238

2022		change to CC																	
		12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61	decrease
change from CC	12		459	2	327	132	4	115	6	38	21	31	21	105	35	10	23	75	1404
	13	1243		2	436	183	2	116	0	15	5	1	3	25	17	2	17	22	2088
	21	3	3		2973	5	171	56	11	4	8	4	6	486	201	5	4	17	3955
	31	204	625	1937		1489	92	477	14	138	88	12	27	843	445	13	21	83	6510
	32	915	771	1	231		2	691		37	22	8	2	9	3	2	1	46	2739
	33	6	1	104	108	5		37	4	0	1	0	0	43	27	2	1	2	342
	34	780	96	31	549	53	8		28	12	27	10	1	80	46	1	36	18	1776
	35	0		1	12		1	17						1			1		32
	36	51	41	2	231	453	0	104			147	7	1	7	2			94	1140
	37	31	4	0	25	365	0	85		56		8	2	5	1			19	600
	41	7	2	0	2	10		5		7	6		18	8	2	0	1	147	213
	42	40	9	1	5	1		18		1	0	11		2	2	0	1	1	92
	51	52	3	78	182	8	6	7		8	10	8	3		534	50	66	11	1026
	52	18	2	22	81	3	1	4		2	4	2	2	709		66	695	1	1612
	53	21	1	3	8	3		1		0	1	0	0	49	51		61		200
	54	14	4	0	5	1		6		0	0	1	1	189	352	28		0	601
	61	59	27	12	83	130	5	78		1212	30	141	2	7	0	0			1789
	increase	3444	2047	2195	5256	2841	292	1818	63	1532	372	246	88	2567	1717	179	926	536	26118

6.3. Country-specific approaches

6.3.1. Information on approaches used for representing land areas and on land-use databases used for the inventory preparation

6.3.1.1. Swiss Land Use Statistics (AREA)

Data of the Swiss Land Use Statistics (AREA) processed by the Federal Statistical Office form the basis of activity data. In the course of an AREA survey, every hectare of Switzerland’s territory (4'129'073 ha) is assigned to one of 46 land-use categories and to one of 27 land-cover categories by means of stereographic interpretation of aerial photos (SFSO 2006a; FSO 2022i).

For the reconstruction of the land use conditions in Switzerland during the inventory period data from five surveys were available:

- Land Use Statistics “1979/85” (AREA1), status: completed
- Land Use Statistics “1992/97” (AREA2), status: completed
- Land Use Statistics “2004/09” (AREA3), status: completed
- Land Use Statistics "2013/18" (AREA4), status: completed
  (see press conference: https://www.bfs.admin.ch/bfs/en/home.gnpdetail.2021-0316.html)
- Land Use Statistics "2020/25" (AREA5), status: 7.5 % of national territory processed.

The aerial photos for AREA1, AREA2, AREA3, AREA4 and AREA5 were taken 1979–1985, 1990–1998, 2004–2009, 2012–2019 and in 2020, respectively. All photos were interpreted according to the standard nomenclature NOAS04 (SFSO 2006a; FSO 2022i).

The inter-survey period is not identical throughout the Swiss territory, but varies regionally (see flyover periods shown above). It averages approximately 12 years for AREA1, AREA2 and AREA3. For AREA4 and AREA5 it was shortened to approximately 9 and 7 years, respectively. This methodical characteristic needs to be considered when reconstructing the annual country-wide status of land use or when calculating annual rates of land-use change.

6.3.1.2. Interpolation of the status for each year

The exact dates of aerial photo shootings are known for each hectare. However, the exact occurrence date (year) of a land-use change on a specific hectare is unknown. The actual change can have taken place in any year between two AREA surveys. In this study, it was assumed that the probability of a land-use change between two surveys is uniformly distributed over the respective interim period. Therefore, the land-use change of each hectare has to be equally distributed over its specific interim period.

The land-use status for the years between two data collection dates can be calculated by linear interpolation. Dates of aerial photo shootings (i.e. starting and ending year of the inter-survey period) and the land-use categories of AREA1–AREA5 for every hectare were used for these calculations. An example is shown in Figure 6-5: A hectare had been assigned to the land-use category Cropland in AREA1 (aerial photo in 1980). A land-use change to 'Surrounding of Buildings' was discovered 10 years later (1990) in AREA2.

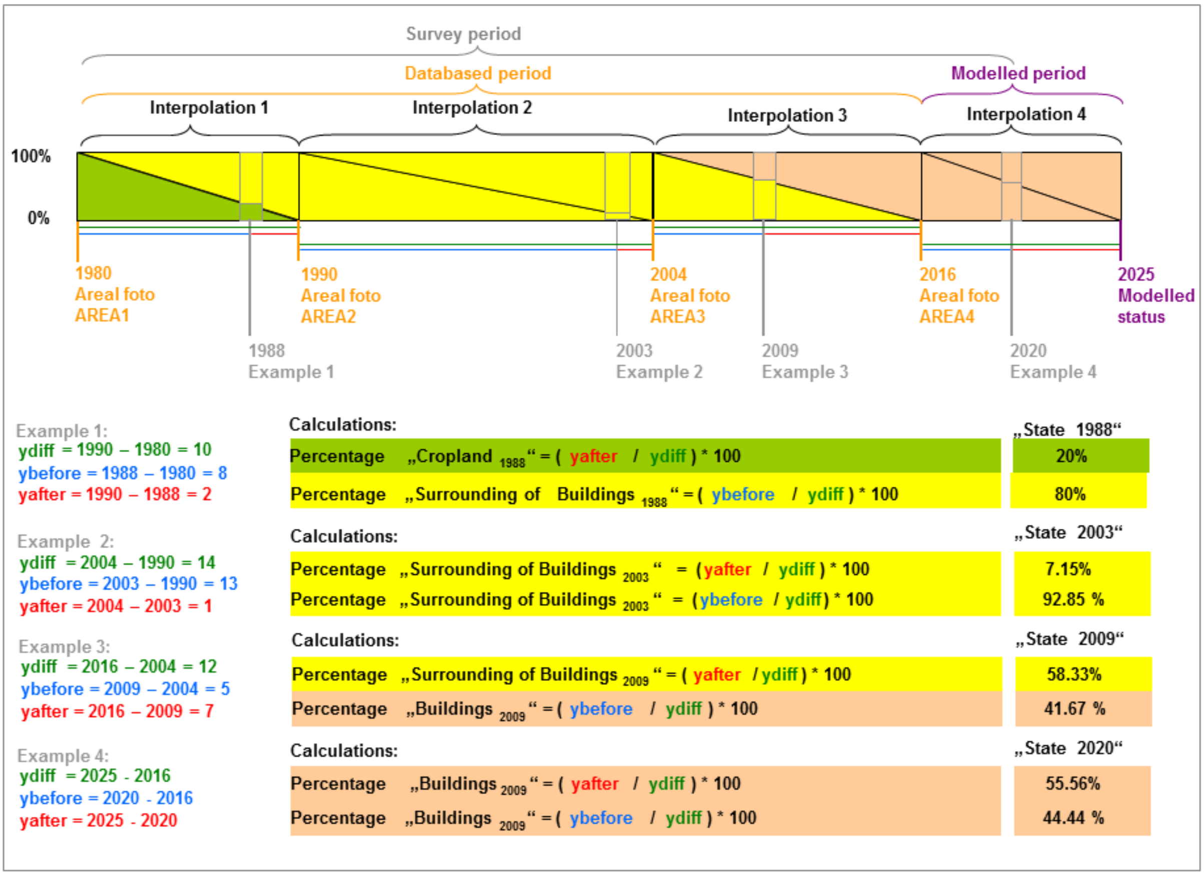

Figure 6-5 Hypothetical development of land use for a supposed survey period 1980–2020. The linear land-use changes between AREA1, AREA2, AREA3 and AREA4 considering as example a hectare changing from “Cropland” to “Surrounding of Buildings” and later from "Surrounding of Buildings" to "Buildings". For 2020, a linear interpolation was carried out between AREA4 and a virtual fifth survey (AREA5v) that was modelled for the year 2025 (here resulting in no change of land use).

The “state 1988” of that hectare is determined by calculating the fractions of the two land-use categories for the year 1988. A linear development from “Cropland” to “Surrounding of Buildings” during the whole interim period was assumed. Thus, in 1988 the hectare was split up in two fractions: 80 % is “Surrounding of Buildings” and 20 % is “Cropland”. The same procedure can be applied for two survey dates between AREA2 and AREA3 (here exemplarily shown for the period 1990–2004, highlighting “state 2003”) or between AREA3 and AREA4 (here exemplarily shown for the period 2004–2016, highlighting “state 2009”).

To obtain consistent and complete nationwide data for each year, the following analysis is required (Sigmaplan 2024):

1) For hectares not yet covered by AREA5 (92.5 % of national territory), the land-use states after AREA4 were interpolated between AREA4 and a "virtual" 5th survey (AREA5v; see example 4 in Figure 6-5). AREA5v was modelled for each sample point using a Markov-chain approach, where transition probabilities between AREA4 and AREA5v were assessed based on the transition distribution between AREA3 and AREA4 within each spatial stratum.

2) For hectares already covered by AREA5 (7.5 % of national territory), the land-use states after the flight year of AREA5 were interpolated between AREA5 and a "virtual" 6th survey (AREA6v; not shown in Figure 6-5). AREA6v was modelled for each sample point using a Markov-chain approach, where transition probabilities between AREA5 and AREA6v were assessed based on the transition distribution between AREA4 and AREA5 within each

spatial stratum. By doing so, the land-use changes occurring after the flight year of AREA5 (i.e. when the hectare was covered) were calculated from the linear development detected between AREA5 and the virtual 6th survey AREA6v for this type of hectare (regarding CC and spatial strata).

The wall-to-wall land-use status within Switzerland for each individual year in the inventory period results from the summation of the fractions of all hectares per land-use category, additionally considering the spatial strata where appropriate.

6.3.1.3. Uncertainties and time-series consistency of activity data

6.3.1.3.1. Land Use Statistics (AREA)

An overview of uncertainty estimates of activity data, carbon stock change factors and emission factors is shown in Table 6-5. Details related to uncertainties of AREA data are presented in this chapter, while the remaining uncertainties of other activity data (such as consumption of Harvested wood products) and of carbon stock change factors and emission factors are presented in the respective chapters 6.4.3 to 6.10.3.

In most cases, the uncertainty of activity data for categories 4A–4F depends on the quality of the AREA survey data. For categories with relevant emissions from drained organic soil, also the uncertainty of the spatial allocation of organic soil (see chp. 6.2.2.1 and below) was considered.

The uncertainty of AREA-based activity data (FSO 2023) has two main sources (Table 6-10). They were quantified as follows:

1) Interpretation uncertainty: In the AREA survey, the first classification of the aerial photos is checked by a second independent interpreter. The portion of sampling points with a mismatch of the first and the second interpretation was used as the uncertainty of the interpretation. This uncertainty of interpretation integrates all errors related to the manual interpretation of land-use and land-cover classes on aerial photographs. While it is clear that this is rather an estimate of the maximum potential interpretation error than of the actual interpretation error, it is reported hereafter unless better information is available.

2) Statistical sampling uncertainty: In the AREA survey, the land-use types are interpreted on points situated on a regular 100x100 m grid. Thus, the uncertainty of the measured surface area covered by a certain land-use type or land-use change decreases with increasing numbers of sampling points that are used for the measurement. Assuming a binomial distribution of the errors, this uncertainty was calculated as

$$U_{sampling} = 100 * 1.96 * (\text{number of points})^{-0.5}$$

The number of sampling points lies between 2’905 (for 4D2) and 1'333’938 (for 4C1) leading to values of $U_{sampling}$ between 3.6 % and 0.2 %.

The overall uncertainty was calculated as:

$$U_{overall} = (U_{interpret}^2 + U_{sampling}^2)^{0.5}$$

Table 6-10 Sources of uncertainty of activity data and overall uncertainties in the allocation of land-use categories, expressed as half of the 95 % confidence intervals. Calculations are based only on AREA data from FSO (2023); uncertainties with respect to other data sources (organic soil, wildfires) are not included, see main text.

Category	Description	Interpretation uncertainty	Sampling uncertainty	Overall uncertainty
4A1	Forest land remaining forest land	1.1	0.2	1.1
4A2	Land converted to forest land	1.1	1.1	1.5
4B1	Cropland remaining cropland	4.9	0.3	4.9
4B2	Land converted to cropland	4.9	1.4	5.1
4C1	Grassland remaining grassland	5.2	0.2	5.2
4C2	Land converted to grassland	5.2	0.8	5.3
4D1	Wetlands remaining wetlands	0.9	0.5	1.0
4D2	Land converted to wetlands	0.9	3.6	3.7
4E1	Settlements remaining settlements	4.4	0.4	4.4
4E2	Land converted to settlements	4.4	1.3	4.6
4F1	Other land remaining other land	1.4	0.3	1.4
4F2	Land converted to other land	1.4	2.8	3.1

6.3.1.3.2. Organic soil

An update of the uncertainty analysis of the spatial allocation of organic soil published by Wüst-Galley et al. (2015) (Wüst-Galley 2019) resulted in 35.3 % for Forest land, 37.3 % for Cropland, 68.6 % for Grassland and 90.8 % for Wetlands. For Forest land (chp. 6.4.3.1), CO_2 emissions from organic soil were not considered in the calculation of the overall uncertainty (Meteotest 2024). For Settlements (chp. 6.8.3.1), the uncertainty of CO_2 emissions from organic soil was not calculated separately.

6.3.1.3.3. Wildfires

Activity data for wildfires were taken from the Swissfire database (see chp. 6.4.2.6.4 and chp. 6.6.2.3.3). The uncertainty for areas affected by wildfires was estimated between 10 % (NFI production region 5) and 30 % (other NFI production regions) for Forest land by expert judgment (Pezzatti 2017). For Grassland the mean uncertainty is probably higher than for Forest land. As a consequence, a value of 30 % was agreed on for both land uses.

6.3.1.3.4. Time-series consistency

Time series for activity data are all considered consistent; they were calculated based on consistent methods for interpolation and extrapolation and homogenous databases.

6.3.1.4. QA/QC and verification of activity data

The general QA/QC measures are described in chp. 1.5.

6.3.1.4.1. QA/QC measures

The AREA survey is a well-defined and controlled, long-term process in the responsibility of the Federal Statistical Office (SFSO 2006a; FSO 2022i). The data supplied by FSO (2023) were checked for consistency (Sigmaplan 2024).

The temporal interpolation and extrapolation of the AREA sample is quite a complex procedure, whose internal consistency is checked systematically as described in Sigmaplan (2024). Further checks (interannual comparisons, plausibility) were carried out after producing the land-use change tables presented in chp. 6.2.3.

6.3.1.4.2. Country area

The total country area remains constant over the inventory period.

6.3.1.4.3. Federal geoportal

The federal geoportal https://www.geo.admin.ch/en provides digital access to the maps, aerial photographs and geographic information of the federal administration covering the entire territory of Switzerland. The map viewer https://map.geo.admin.ch allows a visualization of the completed AREA surveys. See the example https://s.geo.admin.ch/96e44254c8 for the change in direct neighbourhood of a FOEN building in Bern-Ittigen. Legend: yellow crosses represent sample points; circles represent land cover, triangles (they appear when clicking on “Land use statistics standard”) represent land use statistics based on the standard nomenclature. Click circles and triangles for object information. To get a clue on the situation prior to the construction of the FOEN building check the box “Journey through time – Maps” (pre-set 1986, but year is freely selectable) and look out for the former course of the stream nowadays bound to the south of the rail tracks. Please note: The background aerial photograph is of recent age. Examples of characteristic landscape changes in Switzerland across the four survey phases can be found under "Documentation of landscape change".

The free availability and ease of use of the federal geoportal increase the transparency of the (raw) activity data used in the LULUCF reporting and provides an opportunity for public reviewing.

6.3.1.5. Recalculations of activity data

- 4: Land use areas: The most recent land-use data from the fifth area survey (AREA5) were included (based on aerial photographs from 2020; FSO 2023), leading to recalculations of the areas of all land-use categories from 2013 onwards (Table 6-11). The two smallest land-use categories orchards (CC35) and shrubs in settlements (CC53) (see Table 6-8) exceed a relative change of 1 %. The 6.6 % decrease for 2021 in CC53 indicates that in the survey area added in this submission there are clearly fewer shrub settlement areas than had been predicted by AREA5v (albeit for the relevant spatial strata as a whole; see chp. 6.3.1.2). There are no recalculations in the years before 2013, as the AREA1 to AREA4 results are kept unchanged by the Federal Statistical Office.
- 4: Organic soil: The dataset defining the geographical distribution of organic soils in Switzerland was updated (Wüst-Galley and Zehnder 2024). The total area of organic soil increased from 27.7 to 34.3 kha (Table 6-7). Category-specific differences in areas of organic soil between the latest and the previous submissions are shown in Figure 6-6.

Table 6-11 Differences of areas per year and land-use category (shown by their CC codes) between the latest and the previous submissions (in kha). The bottom line shows the percentage change in 2021. Green text colour indicates that no change occurred.

CC	12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61
Year																	
1990	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1991	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1992	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1993	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1994	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1995	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1996	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1997	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2013	-0.013	0.009	-0.103	0.053	-0.001	0.032	-0.006	0.000	0.000	0.001	0.002	-0.004	0.009	0.056	-0.012	-0.026	0.002
2014	-0.021	0.037	-0.288	0.214	-0.045	0.059	0.008	-0.001	0.009	0.028	0.004	-0.014	-0.012	0.141	-0.031	-0.061	-0.028
2015	-0.058	0.047	-0.445	0.416	-0.096	0.079	0.048	-0.002	0.013	0.058	0.007	-0.032	-0.063	0.234	-0.059	-0.096	-0.051
2016	-0.085	0.069	-0.610	0.650	-0.153	0.090	0.073	-0.003	0.010	0.085	0.013	-0.051	-0.120	0.314	-0.090	-0.124	-0.069
2017	-0.105	0.091	-0.829	0.913	-0.215	0.094	0.108	0.001	0.021	0.110	0.023	-0.065	-0.160	0.368	-0.125	-0.144	-0.087
2018	-0.135	0.116	-1.054	1.201	-0.282	0.091	0.149	0.005	0.023	0.134	0.030	-0.080	-0.198	0.423	-0.160	-0.167	-0.094
2019	-0.168	0.136	-1.280	1.487	-0.350	0.089	0.195	0.010	0.026	0.158	0.037	-0.095	-0.233	0.472	-0.196	-0.185	-0.102
2020	-0.208	0.162	-1.514	1.791	-0.417	0.087	0.233	0.015	0.034	0.189	0.045	-0.111	-0.261	0.520	-0.234	-0.205	-0.126
2021	-0.249	0.183	-1.750	2.066	-0.468	0.084	0.271	0.018	0.041	0.216	0.052	-0.123	-0.272	0.564	-0.249	-0.229	-0.156
2021 (in %)	0.0%	0.2%	-0.5%	0.2%	-0.3%	0.3%	0.4%	1.1%	0.0%	0.4%	0.0%	-0.5%	-0.1%	0.7%	-6.6%	-0.7%	0.0%

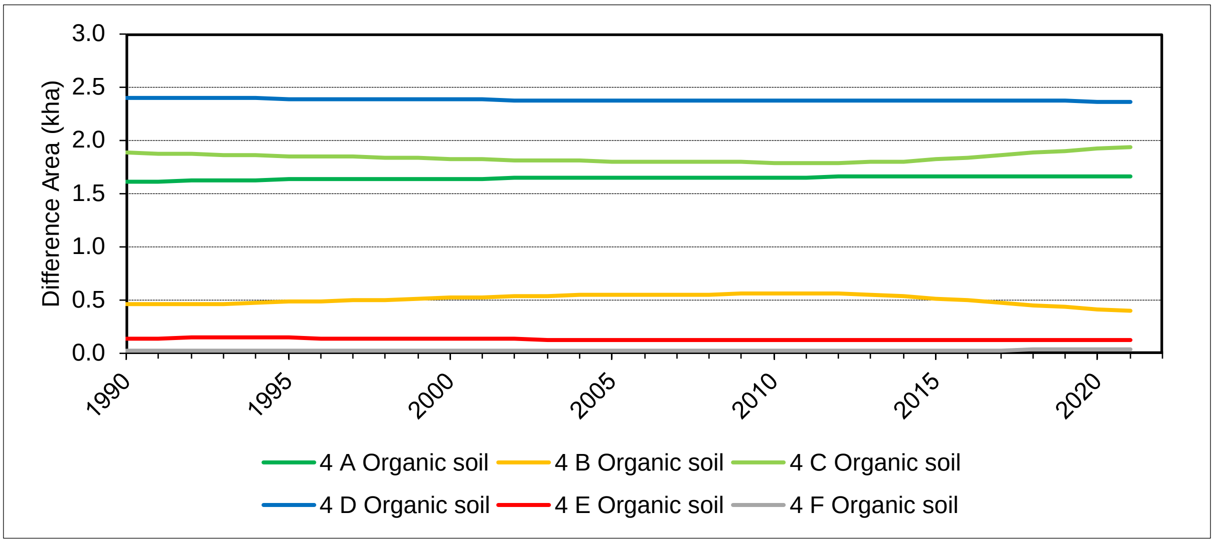

Figure 6-6 Differences in areas of organic soil (in kha) between the latest and the previous submissions for main land-use categories 4A–4F.

6.3.1.6. Planned improvements for activity data

6.3.1.6.1. AREA5 data

Interpretation and processing of AREA4 were completed in 2021; results of AREA5 are available since 2022. New AREA5 data will be successively added as they become available. The survey is planned with aerial photographs from 2020 to 2025, which would shorten the period between the last two image recordings to six years towards the end.

6.3.1.6.2. Organic soil

The ongoing update of the surface of organic soils will be finalised shortly. The stratification by soil type will be adjusted once again in the next submission.

6.3.1.6.3. Use of remote sensing data

The FOEN is evaluating the suitability of newly available satellite data (e.g. Sentinel 2) in the field of environmental reporting. Several feasibility studies were commissioned. Depending on the results (and on the future availability of Copernicus LMS data in Switzerland) it is intended to refine the spatio-temporal pattern of land use dynamics in Switzerland provided by the Land Use Statistics AREA by the use of satellite data in the medium term. In the course of this evaluation the design of the land-use categories used for LULUCF reporting will be scrutinised.

6.3.1.6.4. Switch to georeferenced reporting

The technical basis for georeferenced reporting is currently being established. After a successful test phase, LULUCF reporting will be switched to the new system.

6.3.2. Information on approaches used for natural disturbances

6.3.2.1. Forest land

6.3.2.1.1. Application of the provision of natural disturbances

Under the Paris Agreement, Switzerland indicated to apply the provision of natural disturbances (FOEN 2021n). In cases or events in which emissions from natural disturbances on Forest land are higher than the nationally established threshold value and in which all other requirements defined in 2/CMP.7, IPCC (2014) and IPCC (2019) are met, Switzerland will evaluate whether to exclude them.

The parameters for natural disturbances (background level and margin) on Forest land applicable under the Paris Agreement are documented in FOEN (2024j).

In the reporting year 2022 and in 2021 the emissions from natural disturbances exceeded the upper confidence interval (background level plus margin) of the provision natural disturbances.

6.3.2.1.2. Technical correction of the background level and margin

Background level and margin as documented in FOEN (2024j) will be checked in the case that the clause of natural disturbances is applied. If necessary, it will be updated.

6.3.2.2. Non-Forest land

For non-Forest land, no provisions for natural disturbances will be applied (FOEN 2021n).

6.3.3. Information on approaches used for harvested wood products

For reporting harvested wood products (HWP), the approach B (production approach) as described in chp. 12, Volume 4 of IPCC (2019) was applied. The wood products pool contains only products made from wood harvested in Switzerland. It includes products made from domestic harvest that are exported to foreign countries. Details and results are presented in chp. 6.10.

6.4. Category 4A – Forest land

6.4.1. Description

Table 6-12 Key categories in category 4A Forest land. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
4A1	Forest land remaining forest land	CO2	L1, L2, T1, T2
4A2	Land converted to forest land	CO2	L1, L2, T1

6.4.1.1. Forest land

Only temperate forests occur in Switzerland. Forest is defined as a minimum area of land of 0.0625 ha with crown cover of at least 20 % and a minimum width of 25 m. The minimum height of the dominant trees must be 3 m or have the potential to reach 3 m at maturity in situ (FOEN 2006h). The following forest areas are not subject to the criteria of minimum stand height and minimum crown cover, but must have the potential to achieve it: afforested, regenerated, as well as burnt, cut or damaged areas. Some land categories were explicitly excluded from the land-use category Forest land, although they may partly fulfil the (quantitative) requirements of the Swiss forest definition (FOEN 2006h; Table 6-6):

- Vineyards, low-stem orchards, tree nurseries, copses and orchards in the main land-use category Grassland;
- Cemeteries, public parks, open tree formations in settlements, gardens, sports and parking fields in the main land-use category Settlements.

According to the Federal Act on Forest, it is one objective to “conserve the forest in its area and spatial distribution” (Swiss Confederation 1991: Art. 1a). Any deliberate reduction in forest area has to be authorized. Therefore, all forests in Switzerland are considered to be under management.

Forest land is reported using two land-use categories, productive forest (CC12) and unproductive forest (CC13) (chp. 6.1.3 and Table 6-2).

6.4.1.2. Productive forest

The methodological approach for calculating carbon stocks and carbon stock changes in productive forest is described in chp. 6.4.2.2 and chp. 6.4.2.3.

6.4.1.3. Unproductive forest

The land-use category unproductive forest consists of brush forests, inaccessible stands and unproductive forest not covered by the NFI. Unproductive forests exhibit a high variability (see examples of unproductive forests in Switzerland in FOEN 2014f).

For transparency reasons, productive and unproductive forest areas are reported separately. However, there is only scarce information available on unproductive forest. In unproductive forest, wood is not harvested for economic reasons. Only in exceptional cases there can be an intervention (e.g. moving a wood log that is blocking a hiking trail), but no wood is removed from the stand.

The NFI does not include unproductive stands in its regular inventory scheme because (1) the plots are not relevant for timber production or it is not possible to carry out precise measurements (brush forests), (2) the plots are inaccessible or (3) the NFI forest definition is not fulfilled (unproductive forest not covered by the NFI).

- Brush forests: Since brush forests have no direct economic value in terms of wood harvest, an inventory of these stands has not been attributed high priority. During NFI3, some plots in brush forests were visited for the first time, but only a limited number of attributes such as tree species, stem diameter and crown cover were collected.
- Inaccessible stands: Inaccessible stands are forests which cannot be visited because of safety reasons (see description in Brändli 2010: p. 89). They are mainly located in the Alps and often grow on sites of low productivity, including rocky sites and sites at high elevation near the tree line with a short vegetation period and low biological activity.
- Unproductive forest not covered by NFI: After the review of its first Initial Report (FOEN 2006h), Switzerland had to apply a forest definition for reporting activities under the Kyoto Protocol Art. 3.3 and Art. 3.4, which is different from the definition applied by the Swiss NFI and the Land Use Statistics AREA. Because the definition of NFI and AREA was not in line with the specific requirements of the Kyoto Protocol forest definition, Switzerland had to develop an approach to classify certain AREA categories as forest. Those areas are not covered by the regular NFI and are situated in the threshold range between forests and alpine pastures with woody biomass of very low productivity. More specifically, it concerns combinations of “pastures or grasslands with clusters of trees” (NOLC04 47/NOLU04 222, NOLC04 47/NOLU04 223, NOLC04 47/NOLU04 242) and “alpine sheep grazing pastures, in general with open forest” with “clusters of trees”) NOLC04 44/NOLU04 243; see Table 6-6).

The methodology for reporting unproductive forest is covered in chp. 6.4.2.4.

6.4.1.4. Temporal development of net emissions and removals

In the inventory period, the total net emissions and removals of category 4A1 Forest land remaining forest land range from 4’441 kt CO_2 in 2000 to -6'047 kt CO_2 in 1996 (average -2’204 kt CO_2; Figure 6-7 top panel). Particularly the pools losses in living biomass, dead wood and litter introduce temporal variability (Figure 6-7 both panels).

Category 4A2 Land converted to forest land was a net sink in all years (average -633 kt CO_2; Figure 6-7 top panel) with small fluctuations mainly due to slight variations in land use change rates over the inventory period and the associated living biomass on these areas.

More information on the temporal development of net emissions and removals in category 4A Forest land can be found in chp. 2.2.2.3.

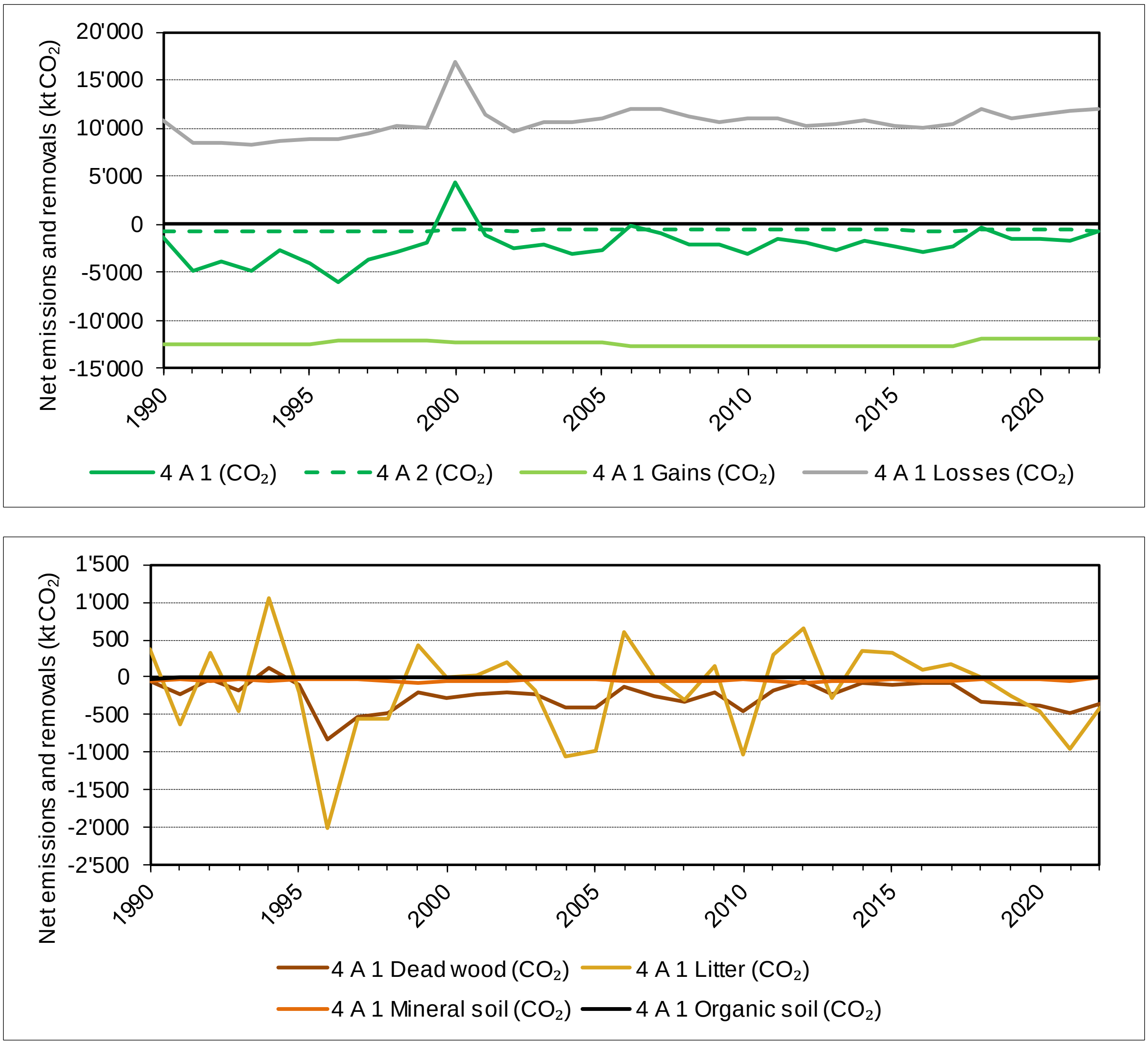

Figure 6-7 Net CO_2 emissions (positive values) and removals (negative values) from categories 4A1 and 4A2. Category 4A1 is broken down by gains and losses in living biomass (top panel), and net carbon stock changes in dead wood, litter, mineral soil and organic soil (bottom panel). Note the different scaling of the y-axis. The net changes in organic soil are too small to be distinguished from the zero line.

6.4.1.5. Temporal development of Forest land area

Forest land is expanding in Switzerland (see areas of productive forest CC12 and unproductive forest CC13 and the relative changes since 1990 in Table 6-8). The land-use change matrices show that expansions are mainly occurring on former grasslands (CC3X to CC12 or to CC13; Table 6-9) and are primarily due to natural forest regeneration in the alpine are and not by plantation (Gehrig-Fasel et al. 2007; Rutherford et al. 2008; SWI 2009; Brändli 2014; Rigling and Schaffer 2015; Brändli et al. 2020; Allgaier Leuch and Fischer

2023). Such newly forested areas typically exhibit a large diversity in diameter at breast height and tree age.

6.4.2. Methodological issues

6.4.2.1. Choice of methods

6.4.2.1.1. National Forest Inventory

6.4.2.1.1.1. National Forest Inventory data

The National Forest Inventory (NFI) is the primary source for estimating carbon stock change factors for Forest land. The estimates are based on measurements of tally trees with a diameter at breast height (DBH) ≥12 cm. For tally trees, allometric relationships were developed to obtain accurate data on whole tree volume and biomass (Lanz et al. 2019).

Data from four completed National Forest Inventories (NFI1, NFI2, NFI3, NFI4, finalized in 1985, 1995, 2006 and 2017, respectively) and from the first five years (2018–2022) of the ongoing NFI5 (2018–2026) are currently available (Table 6-13). Descriptions of NFI1, NFI2, and NFI3 results can be found in EAFV/BFL (1988), in Brassel and Brändli (1999), and in Brändli (2010), respectively. These inventories were based on full surveys that were repeated in intervals of approximately 10 years. Starting with the NFI4, a continuous survey approach is used where annually a nationally representative subsample of approximately 12 % of the Swiss forests is surveyed and evaluated (Brändli et al. 2020). Otherwise, the methodology remained consistent with previous inventories. A detailed description of the current methods to estimate volume based on section-wise measured stems and branches, biomass based on measured wood densities, and carbon for LULUCF reporting can be found in Herold et al. (2019) and Didion et al. (2019). Results of the first five years of the NFI5 are available online in Abegg et al. (2023) and summarized in Allgaier Leuch and Fischer (2023) and FOEN (2023g).

For compiling the results for the latest GHG inventory, NFI5 data for the years 2018–2022 were used in addition to the data from NFI1, NFI2, NFI3 and NFI4, and the respective inventory periods NFI1-2, NFI2-3, NFI3-4, and NFI4-5 (2018–2022). The calculation approaches for land-use changes within, from and to Forest land are shown in Table 6-3.

Table 6-13 Number of surveyed sample plots and tally trees in the National Forest Inventories NFI1, NFI2, NFI3, NFI4, and NFI5 (first five years 2018–2022) for accessible forest plots without brush forest based on the 1.41x1.41 km grid (Brändli and Hägeli 2019). Note that for the NFI5 intermediate results are presented and that for the NFI1 the number of sample plots and tally trees based on the 1x1 km grid originally used is given in brackets.

	NFI1	NFI2	NFI3	NFI4	NFI5
Inventory cycle	1983-1985	1993-1995	2004-2006	2009-2017	2018-2022
Terrestrial sample plots	5'517 (10'981)	5'679	5'920	6'042	3'435
Tally trees	64'414 (128'441)	67'297	70'061	71'962	40'537

6.4.2.1.1.2. Updating NFI data

In general, new NFI data have an influence on the time series of carbon stock changes (gains and losses in living biomass, dead wood, litter and mineral soil) because they are calculated based on observed changes between two consecutive forest inventories.

The change from periodic sampling (NFIs 1 to 3) to a continuous sampling starting with the NFI4 required a modification of the estimation of carbon stock changes affecting estimates from 2006 onwards. The adapted method requires NFI data from a shifting five-year window to ensure accuracy and consistency of the estimates of carbon stock changes. The method based on a shifting five-year window of NFI data will also be used in future submissions and thus, recalculations will be performed when new NFI data become available (see Didion et al. 2023: chp. 1.1 and chp. 2.3). The continuous survey approach allows regular updates of data to obtain the most current and accurate estimates for carbon stocks as well as gains and losses in living biomass. The differences in the results arising by an update of the five-year period reflect the uncertainty in the data as the sample plots used for the estimate are exchanged, but time series remain consistent as carbon stock change estimates are still based on representative subsamples of the NFI sample plots.

6.4.2.1.1.3. Data available in the NFI for estimating biomass

In the field surveys standing and lying stems are measured on two nested circular sample plots with 200 m^2 and 500 m^2 in area, respectively. On the smaller plot, trees and shrubs with DBH ≥12 cm are measured, whereas all trees with DBH ≥36 cm are measured on the larger plot. In order to assess the regeneration of the forest, young trees and the main shrub species with a minimum height of 10 cm and DBH <12 cm are assessed on a separate set of four circular sample plots with radii between 0.9 and 4 m (Brändli and Hägeli 2019).

For estimating carbon stocks and carbon stock changes for LULUCF reporting, currently, (1) trees with DBH <12 cm with branches, foliage, and roots, and (2) non-tree understory vegetation including shrubs, ferns, grasses, sedges, and herbs are not considered because Switzerland's country-specific allometric functions only apply to trees ≥12 cm DBH. The omission is justified because of their negligible effect on carbon stocks and carbon stock changes of living biomass, dead wood, litter, and soil in productive forests in Switzerland (see chp. 6.4.4.1 for more information).

6.4.2.1.2. Forest land stratification

Forests in Switzerland reveal a high heterogeneity in terms of elevation, growth conditions, tree species composition, and interannual growth variability. The suitability of a spatial stratification was analysed for Forest land (Thürig et al. 2005a: Table 2b; Didion et al. 2023: Table 3). The analyses indicated that tree species type, production region and elevation all significantly explain differences in gross growth. Accordingly, a spatial stratification into five productions regions and three elevation zones was applied (see chp. 6.2.2). For the calculation of growing stock, gross growth, harvesting and mortality these strata were then further divided into two tree species types: coniferous and broadleaved species (Didion et al. 2023).

Forest land was further stratified by soil type (mineral or organic; see chp. 6.2.2.1).

The continuous survey approach since the NFI4 and the use of a five-year shifting window to regularly update estimates of carbon stocks, gains and losses resulted in a reduced number of sample plots that are simultaneously available for estimating the forest carbon balance (Table 6-14), and several spatial strata are represented by a low number of plots. Due to the large variability of the forest structure and composition between sample plots a minimum number of sample plots is needed to obtain reliable estimates of means and sampling errors. Smaller strata are thus merged with neighbouring strata and treated as single strata. This applies to:

- NFI production region 2 Central Plateau 601-1200 m and >1200 m:
  stratum NFI production region 2 Central Plateau >600 m
- NFI production region 3 Pre-Alps ≤600 m and 601-1200 m:
  stratum NFI production region 3 Pre-Alps ≤1200 m
- NFI production region 4 Alps ≤600 m and 601-1200 m:
  stratum NFI production region 4 Alps ≤1200 m
- NFI production region 5 Southern Alps ≤600 m and 601-1200 m:
  stratum NFI production region 5 Southern Alps ≤1200 m

6.4.2.1.3. Carbon content

A mean carbon content of 50 % was used to convert the biomass of alive trees to carbon stocks. The carbon content estimate represents an approximation which was based on carbon fractions for coniferous and broadleaved trees in temperate forests provided in IPCC (2006, Volume 4, Table 4.3) and on the fact that in Switzerland coniferous trees are more abundant than broadleaved trees (Brändli et al. 2020: Table 056).

6.4.2.1.4. Soil carbon model Yasso20

The soil carbon model Yasso20 (Viskari et al 2022) is used to estimate temporal changes in carbon stocks in dead wood, organic soil horizons (LFH; litter) and mineral forest soil (0–100 cm depth) for the land-use category productive forest. Yasso20 is a model of carbon cycling in mineral soil, litter and dead wood. For estimating stocks of organic carbon in mineral soil up to a depth of ca. 100 cm and the temporal dynamics of the carbon stocks, Yasso20 requires information on carbon inputs (see below) and climate (annual mean monthly temperature and annual precipitation sum). By default, Yasso20 does not provide separate estimates of carbon pool sizes for dead wood, litter and mineral soil. In order to report estimates for each pool, the model structure of Yasso07 was examined to obtain separate estimates. Dead wood, litter and soil pools could be correlated with modelled data based on the category of carbon input (non-woody and woody material) and the five carbon compartments in Yasso07, i.e. four chemical compounds (insoluble, soluble in ethanol, soluble in water or in acid) and a more stable compartment. The approach was validated using independent, measured data (Didion et al. 2012). The basic model structure, i.e., five carbon compartment, is still the same in Yasso20 (Viskari et al. 2022). The separation of the model results into dead wood, litter, and mineral soil was examined and found to still be plausible although the fluxes between the three pools and within the mineral soil pool are more dynamic (Didion 2023: chp. 2.2 and chp. 3.1) due to improved and more realistic model calibration (Viskari et al. 2022).

The implementation of Yasso20 for LULUCF reporting is described in detail in Didion (2023). Didion et al. (2014a) demonstrated the validity of the previous model version Yasso07 for application in Swiss forests by comparing simulated with measured mass loss in foliage and fine root litter and in coarse dead wood. This evaluation was repeated using Yasso20 (Didion 2023: chp. 2.2). The results demonstrated a moderately higher accuracy of the new model version Yasso20. Following these findings and consideration of the further improvements introduced in Yasso20, including a revision of decomposition rates of the carbon compartments based on experimental data, it was decided to use the new model version. The Yasso model is currently also used for LULUCF reporting in Austria (Yasso20 for the combined litter and mineral soil pools; Umweltbundesamt 2023), Finland (Yasso07 for the combined dead wood, litter, and soil pools; Statistics Finland 2023), and in Norway (Yasso07, separately for dead wood, litter and soil; Norwegian Environment Agency 2023).

6.4.2.2. Productive forest: carbon stocks and carbon stock changes in living biomass

To estimate carbon stocks and carbon stock changes in above- and belowground living biomass NFI data for trees ≥12 cm DBH were used. Total tree biomass and carbon stocks comprise stemwood over bark including tree top and stump, large and small branches, foliage, and coarse roots (Didion et al. 2019). The stock was estimated based on sample plots in a particular NFI (Table 6-13) to also account for sample plots that have been converted to forest since the previous inventory. Carbon stock change factors were derived from the observed changes on sample plots common to two consecutive NFIs (Table 6-14; for a detailed description, see Didion et al. 2023).

6.4.2.2.1. Carbon stocks in living biomass – growing stock

Carbon stocks are represented by the state of total tree biomass of all living and standing tally trees (see chp. 6.4.2.1.1.1; Didion et al. 2023: chp. 2.3).

6.4.2.2.2. Carbon stock changes in living biomass

6.4.2.2.2.1. Carbon gains – gross growth

Carbon gains in living biomass are represented by the change in total biomass increment of tally trees between two forest inventories and are assumed to remain constant within a particular inter-survey period. Temporal dynamics of forest land (see chp. 6.4.1.5) lead to different totals of plots common to two consecutive NFIs due to land-use changes to or from Forest land (see Table 6-14).

Table 6-14 Number of NFI sample plots in each NFI inter-survey period: number of plots which were forest also in the previous NFI inter-survey period, the number of plots newly converted to forest in the following period, and the resulting total for a particular period. Footnote 1: not applicable in the first NFI period; footnote 2: for the period NFI4-5 sample plots common to the NFI4 and NFI5 visited in the years 2018 to 2022 were considered.

NFI period	NFI inter-survey period	Forest in previous period	Converted to forest since previous period	Total for period
		Number of sample plots		
NFI1-2	1985-1995	NA[1]	NA[1]	5'456
NFI2-3	1996-2005	5'370	211	5'581
NFI3-4	2006-2017	5'521	303	5'824
NFI4-5[2]	2018-2022	3'242	95	3'337

6.4.2.2.2.2. Carbon losses – cut and mortality

Carbon losses in living biomass are represented by the change in total biomass drain due to fellings and natural mortality. Carbon losses were annualised using data of the national forest statistics (Table 6-15; FOEN 2024f and previous editions; Federal Statistical Office: Wood harvest in Switzerland 1975–2022, https://www.pxweb.bfs.admin.ch) and the fellings obtained from the NFI. The fraction affected by natural mortality was not annualised as this process is not related to the harvest statistics. To annualise the mean annual felling estimates for conifers and broadleaves (represented by constant values for an NFI inter-survey period), harvest statistics data were used to calculate annual weighting factors for both tree species based on the ratio between the harvested volume in a given year and the mean of the annual harvests within an NFI inter-survey period (Didion et al. 2023: Table 5).

For the annualisation of fellings the harvesting statistics data were used as they capture the annual variability due to forest management. Fellings and the resulting losses of living biomass were particularly high after the storms Vivian (February 1990) and Lothar (December 1999). Harvesting rates in Swiss forests gradually increased between 1991 and 2007. After two minor peaks in 2006 and 2007 harvesting rates showed a decreasing trend that was reinforced by international and domestic economic framework conditions. However, since 2019 harvesting rates tend to increase again.

Table 6-15 Annual domestic harvesting amount in m³ merchantable wood specified for five NFI production region as well as for coniferous (Conif.) and broadleaved (Broadl.) tree species (FOEN 2024f and previous editions; https://www.pxweb.bfs.admin.ch).

Year	1. Jura		2. Central plateau		3. Pre-Alps		4. Alps		5. Southern Alps		Country		
	Conif.	Broadl.	Conif.	Broadl.	Conif.	Broadl.	Conif.	Broadl.	Conif.	Broadl.	Conif.	Broadl.	Total
	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]	[m^3]
1990	687'327	358'647	1'769'813	606'718	1'285'639	138'126	1'301'313	70'064	21'575	22'456	5'065'667	1'196'011	6'261'678
1991	476'956	354'002	1'017'232	489'742	877'851	133'155	1'064'650	72'229	24'356	26'736	3'461'045	1'075'864	4'536'909
1992	555'523	372'249	1'199'596	571'610	735'680	128'934	736'230	70'706	47'388	28'637	3'274'417	1'172'136	4'446'553
1993	550'536	373'298	1'206'294	562'232	723'565	132'676	649'938	63'940	42'511	32'785	3'172'844	1'164'931	4'337'775
1994	621'726	392'967	1'270'296	530'906	798'449	136'103	717'840	66'896	40'986	33'746	3'449'297	1'160'618	4'609'915
1995	650'572	407'119	1'388'932	570'552	774'040	154'108	590'859	56'714	51'643	33'869	3'456'046	1'222'362	4'678'408
1996	520'335	381'365	1'066'770	567'769	654'554	151'164	506'107	59'674	48'288	38'889	2'796'054	1'198'861	3'994'915
1997	599'981	394'846	1'176'333	576'415	742'830	153'719	574'152	63'650	61'043	40'189	3'154'339	1'228'819	4'383'158
1998	604'703	422'216	1'330'973	627'633	836'806	164'348	657'409	108'848	50'626	41'485	3'480'517	1'364'530	4'845'047
1999	602'652	398'648	1'342'905	639'150	824'142	173'845	593'844	68'786	44'556	39'181	3'408'099	1'319'610	4'727'709
2000	994'262	387'183	3'916'680	934'372	2'241'486	213'858	436'743	57'105	21'236	35'049	7'610'407	1'627'567	9'237'974
2001	443'612	338'751	2'020'561	594'616	1'477'489	157'710	510'730	60'152	22'237	35'722	4'474'629	1'186'951	5'661'580
2002	442'519	329'480	1'406'758	493'905	1'090'875	134'603	528'144	63'303	31'236	35'794	3'499'532	1'057'085	4'556'617
2003	557'454	315'096	1'669'605	518'273	1'195'090	142'055	588'062	62'739	37'111	35'486	4'047'322	1'073'649	5'120'971
2004	655'757	305'681	1'774'841	515'877	1'119'243	164'745	488'722	70'090	29'995	35'571	4'068'558	1'091'964	5'160'522
2005	653049	359808	1810839	614845	1010979	180546	514905	70603	35462	33614	4025234	1259416	5'284'650
2006	735'256	405'850	1'779'973	687'428	1'116'868	229'781	569'673	84'656	43'443	48'599	4'245'213	1'456'314	5'701'527
2007	793'459	425'790	1'587'494	699'076	1'144'370	230'284	621'234	82'414	62'799	43'638	4'209'356	1'481'202	5'690'558
2008	705'815	459'994	1'281'782	727'581	1'018'497	224'634	664'086	82'623	53'064	44'123	3'723'244	1'538'955	5'262'199
2009	598'292	461'055	1'149'202	701'188	878'565	224'490	678'212	90'001	56'375	42'316	3'360'646	1'519'050	4'879'696
2010	647'176	494'739	1'090'994	722'644	992'435	248'151	720'659	99'773	60'391	52'037	3'511'655	1'617'344	5'128'999
2011	617'887	513'720	1'061'986	741'587	983'040	253'300	686'797	101'644	61'822	53'305	3'411'532	1'663'556	5'075'088
2012	566'782	488'626	970'748	719'003	825'019	225'988	665'506	94'480	51'475	50'757	3'079'530	1'578'854	4'658'384
2013	576'744	521'122	948'706	739'180	834'166	254'726	670'170	117'841	64'745	50'928	3'094'531	1'683'797	4'778'328
2014	619'002	539'721	945'695	777'852	863'150	259'888	654'300	110'816	95'192	47'603	3'177'339	1'735'880	4'913'219
2015	528'202	505'431	916'020	766'645	753'783	244'149	625'555	96'230	62'233	53'649	2'885'793	1'666'104	4'551'897
2016	549'561	509'699	859'677	737'207	766'647	236'279	570'415	103'416	65'254	60'836	2'811'554	1'647'437	4'458'991
2017	545'998	514'176	993'430	765'711	806'033	242'423	596'105	96'622	72'298	54'746	3'013'864	1'673'678	4'687'542
2018	564'468	492'343	1'421'416	719'879	910'871	216'813	649'759	94'766	61'417	66'470	3'607'931	1'590'271	5'198'202
2019	537'886	478'869	1'181'674	630'237	787'296	214'837	530'476	94'646	92'495	65'622	3'129'827	1'484'211	4'614'038
2020	604'675	457'399	1'360'224	633'451	814'466	205'946	543'583	74'541	45'401	62'539	3'368'349	1'433'876	4'802'225
2021	695'736	473'009	1'195'542	684'866	907'322	236'511	594'717	83'734	54'734	71'712	3'448'051	1'549'832	4'997'883
2022	660'511	513'857	1'119'397	784'029	985'351	252'863	638'486	93'503	59'118	71'284	3'462'863	1'715'536	5'178'399

6.4.2.2.3. *Carbon stocks in living biomass – calculation of time series*

In order to develop a consistent time series, annual carbon stocks of living biomass (growing stocks) per species type ($stockC_l$) were calculated per spatial strata (i) for productive forests (CC12) forward starting from the growing stock in 1985. This was obtained based on all living trees on the total sample plots of the NFI1 (EAFV/BFL 1988). The forward calculation used the net change of the growth estimated for subsequent NFI periods (carbon gains in living biomass, $gainC_l$) and annualised carbon losses in living biomass ($lossC_l$) (abbreviations were introduced in chp. 6.1.3.2).

$$f_{stockC_{l,i,CC12}}(\mathrm{y}) = stockC_{l,i,CC12,1985} + \sum_{n=1986}^{y} \left(gainC_{l,i,CC12,n} + lossC_{l,i,CC12,n}\right)$$

where *y* is the inventory year (running from 1986 to the latest reported inventory year).

Since the growth and drain estimates were based on plots common to two consecutive NFIs and thus do not account for sample plots converted to forest between two inventories, forward calculated stocks were scaled to the observed stocks in subsequent inventories NFIs 2–4 and 5 (2018–2022) (Didion et al. 2023: Figure 2).

Table 6-16 shows the time series of growing stocks (carbon stocks in living biomass), gross growth (carbon gains in living biomass), and cut and mortality (carbon losses in living biomass), specified for all spatial strata.

Table 6-16 Carbon stocks in living biomass (stockC$_l$), carbon gains in living biomass (gross growth, gainC$_l$), and carbon losses in living biomass (cut and mortality, lossC$_l$) for the land-use category productive forest (CC12) stratified for NFI production region (NFI) and elevation zone (Elev.). Highlighted data for 1990 are displayed in Table 6-4.

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: carbon stock in living biomass (stockCl,i) [t C ha^{-1}]									
L1	Z1	126.71	128.14	129.49	130.86	132.19	133.44	133.32	133.02	132.35	131.80
L1	Z2	121.77	123.12	124.47	125.87	127.18	128.44	129.59	130.61	131.43	132.31
L1	Z3	85.09	85.39	85.73	86.08	86.34	86.59	87.32	88.00	88.61	89.23
L2	Z1	134.45	135.65	136.84	138.09	139.19	140.22	140.54	140.57	140.19	139.91
L2	Z2, Z3	146.60	148.06	149.52	151.06	152.44	153.76	154.24	154.41	154.20	154.09
L3	Z1, Z2	148.46	150.19	151.97	153.80	155.51	157.18	157.79	158.15	158.23	158.37
L3	Z3	116.33	116.82	117.38	117.97	118.47	118.96	119.16	119.26	119.25	119.26
L4	Z1, Z2	97.95	98.81	99.67	100.56	101.38	102.18	103.24	104.23	105.14	106.06
L4	Z3	92.93	92.98	93.08	93.21	93.26	93.30	93.72	94.06	94.34	94.62
L5	Z1, Z2	71.14	72.88	74.59	76.33	78.07	79.79	80.91	82.02	83.08	84.15
L5	Z3	74.88	75.54	76.19	76.83	77.46	78.06	78.45	78.79	79.10	79.38
Country		113.53	114.46	115.40	116.38	117.26	118.11	118.58	118.91	119.06	119.25

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: carbon stock in living biomass (stockCl,i) [t C ha^{-1}]									
L1	Z1	129.29	128.64	128.57	128.28	127.95	127.31	127.33	127.33	127.43	127.65
L1	Z2	131.71	132.39	133.46	134.35	135.23	135.99	136.19	136.39	136.80	137.41
L1	Z3	89.19	89.69	90.35	90.93	91.50	92.05	92.45	92.85	93.38	94.01
L2	Z1	136.23	135.38	135.40	135.01	134.58	133.95	133.01	132.05	131.39	131.01
L2	Z2, Z3	150.36	149.54	149.61	149.23	148.82	148.29	147.61	146.93	146.60	146.58
L3	Z1, Z2	155.63	155.14	155.34	155.17	154.98	154.73	154.47	154.22	154.30	154.66
L3	Z3	117.96	117.64	117.62	117.43	117.24	117.05	116.96	116.88	116.96	117.16
L4	Z1, Z2	106.21	106.98	107.96	108.83	109.70	110.53	110.62	110.71	110.89	111.16
L4	Z3	94.12	94.21	94.46	94.61	94.75	94.89	95.39	95.89	96.47	97.09
L5	Z1, Z2	85.14	86.21	87.30	88.37	89.43	90.45	91.40	92.34	93.27	94.20
L5	Z3	79.47	79.66	79.86	80.02	80.15	80.25	80.91	81.57	82.24	82.93
Country		117.84	117.73	118.01	118.09	118.15	118.15	118.16	118.17	118.35	118.68

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC12: carbon stock in living biomass (stockCl,i) [t C ha^{-1}]									
L1	Z1	127.73	127.78	128.03	128.16	126.04	124.08	122.14	120.09	116.64	113.48
L1	Z2	137.88	138.37	139.07	139.71	138.44	137.34	136.28	135.09	132.70	130.60
L1	Z3	94.59	95.19	95.90	96.59	96.24	95.98	95.73	95.41	94.57	93.90
L2	Z1	130.40	129.80	129.55	129.16	128.13	127.41	126.76	125.94	124.43	123.36
L2	Z2, Z3	146.33	146.12	146.26	146.29	146.02	146.06	146.17	146.08	145.42	145.23
L3	Z1, Z2	154.85	155.09	155.63	156.10	155.25	154.66	154.12	153.43	151.87	150.68
L3	Z3	117.30	117.47	117.74	118.00	119.32	120.75	122.22	123.63	124.81	126.12
L4	Z1, Z2	111.35	111.56	111.87	112.13	111.77	111.50	111.24	110.93	110.25	109.72
L4	Z3	97.69	98.29	98.95	99.59	99.97	100.39	100.81	101.19	101.41	101.69
L5	Z1, Z2	95.11	96.00	96.91	97.79	98.74	99.70	100.65	101.57	102.11	102.67
L5	Z3	83.60	84.26	84.94	85.61	86.47	87.34	88.21	89.07	89.50	89.99
Country		118.90	119.14	119.55	119.91	119.67	119.58	119.51	119.35	118.67	118.19

NFI	Elev.	2020	2021	2022
		CC12: carbon stock in living biomass (stockCl,i) [t C ha^{-1}]		
L1	Z1	110.30	109.21	107.98
L1	Z2	128.46	127.85	127.11
L1	Z3	93.18	93.22	93.23
L2	Z1	122.20	121.55	120.69
L2	Z2, Z3	144.91	144.60	144.10
L3	Z1, Z2	149.38	149.12	148.76
L3	Z3	127.39	128.03	128.67
L4	Z1, Z2	109.15	109.32	109.44
L4	Z3	101.92	102.72	103.50
L5	Z1, Z2	103.21	103.99	104.75
L5	Z3	90.44	91.04	91.62
Country		117.65	117.76	117.80

(Table 6-16 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: carbon gains in living biomass (gainCl,i) [t C ha^{-1} yr^{-1}]									
L1	Z1	3.66	3.66	3.66	3.66	3.66	3.66	3.34	3.34	3.34	3.34
L1	Z2	3.32	3.32	3.32	3.32	3.32	3.32	3.03	3.03	3.03	3.03
L1	Z3	2.08	2.08	2.08	2.08	2.08	2.08	1.80	1.80	1.80	1.80
L2	Z1	4.75	4.75	4.75	4.75	4.75	4.75	4.66	4.66	4.66	4.66
L2	Z2, Z3	4.66	4.66	4.66	4.66	4.66	4.66	4.52	4.52	4.52	4.52
L3	Z1, Z2	4.23	4.23	4.23	4.23	4.23	4.23	4.11	4.11	4.11	4.11
L3	Z3	2.49	2.49	2.49	2.49	2.49	2.49	2.50	2.50	2.50	2.50
L4	Z1, Z2	2.63	2.63	2.63	2.63	2.63	2.63	2.54	2.54	2.54	2.54
L4	Z3	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
L5	Z1, Z2	2.42	2.42	2.42	2.42	2.42	2.42	2.19	2.19	2.19	2.19
L5	Z3	1.65	1.65	1.65	1.65	1.65	1.65	1.78	1.78	1.78	1.78
Country		3.17	3.17	3.17	3.17	3.17	3.17	2.97	2.97	2.97	2.97

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: carbon gains in living biomass (gainCl,i) [t C ha^{-1} yr^{-1}]									
L1	Z1	3.34	3.34	3.34	3.34	3.34	3.34	3.50	3.50	3.50	3.50
L1	Z2	3.03	3.03	3.03	3.03	3.03	3.03	3.25	3.25	3.25	3.25
L1	Z3	1.80	1.80	1.80	1.80	1.80	1.80	2.02	2.02	2.02	2.02
L2	Z1	4.66	4.66	4.66	4.66	4.66	4.66	4.51	4.51	4.51	4.51
L2	Z2, Z3	4.52	4.52	4.52	4.52	4.52	4.52	4.74	4.74	4.74	4.74
L3	Z1, Z2	4.11	4.11	4.11	4.11	4.11	4.11	4.07	4.07	4.07	4.07
L3	Z3	2.50	2.50	2.50	2.50	2.50	2.50	2.41	2.41	2.41	2.41
L4	Z1, Z2	2.54	2.54	2.54	2.54	2.54	2.54	2.61	2.61	2.61	2.61
L4	Z3	1.91	1.91	1.91	1.91	1.91	1.91	2.06	2.06	2.06	2.06
L5	Z1, Z2	2.19	2.19	2.19	2.19	2.19	2.19	2.38	2.38	2.38	2.38
L5	Z3	1.78	1.78	1.78	1.78	1.78	1.78	1.90	1.90	1.90	1.90
Country		2.97	2.97	2.97	2.97	2.97	2.97	3.11	3.11	3.11	3.11

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC12: carbon gains in living biomass (gainCl,i) [t C ha^{-1} yr^{-1}]									
L1	Z1	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	2.77	2.77
L1	Z2	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	2.88	2.88
L1	Z3	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	1.89	1.89
L2	Z1	4.51	4.51	4.51	4.51	4.51	4.51	4.51	4.51	4.01	4.01
L2	Z2, Z3	4.74	4.74	4.74	4.74	4.74	4.74	4.74	4.74	4.53	4.53
L3	Z1, Z2	4.07	4.07	4.07	4.07	4.07	4.07	4.07	4.07	3.85	3.85
L3	Z3	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.20	2.20
L4	Z1, Z2	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.61	2.48	2.48
L4	Z3	2.06	2.06	2.06	2.06	2.06	2.06	2.06	2.06	2.10	2.10
L5	Z1, Z2	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.38	2.12	2.12
L5	Z3	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	2.00	2.00
Country		3.11	3.11	3.11	3.11	3.11	3.11	3.11	3.11	2.86	2.86

NFI	Elev.	2020	2021	2022
		CC12: carbon gains in living biomass (gainCl,i) [t C ha^{-1} yr^{-1}]		
L1	Z1	2.77	2.77	2.77
L1	Z2	2.88	2.88	2.88
L1	Z3	1.89	1.89	1.89
L2	Z1	4.01	4.01	4.01
L2	Z2, Z3	4.53	4.53	4.53
L3	Z1, Z2	3.85	3.85	3.85
L3	Z3	2.20	2.20	2.20
L4	Z1, Z2	2.48	2.48	2.48
L4	Z3	2.10	2.10	2.10
L5	Z1, Z2	2.12	2.12	2.12
L5	Z3	2.00	2.00	2.00
Country		2.86	2.86	2.86

(Table 6-16 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: carbon losses in living biomass (lossCl,i) [t C ha^{-1} yr^{-1}]									
L1	Z1	-2.71	-2.27	-2.35	-2.32	-2.37	-2.45	-3.56	-3.73	-4.10	-3.99
L1	Z2	-2.76	-2.13	-2.13	-2.09	-2.19	-2.23	-2.13	-2.26	-2.46	-2.40
L1	Z3	-1.70	-1.22	-1.17	-1.14	-1.22	-1.23	-0.97	-1.03	-1.11	-1.09
L2	Z1	-4.72	-3.65	-3.67	-3.61	-3.76	-3.84	-4.24	-4.54	-4.96	-4.84
L2	Z2, Z3	-4.48	-3.41	-3.40	-3.33	-3.49	-3.56	-4.04	-4.35	-4.73	-4.63
L3	Z1, Z2	-3.58	-2.71	-2.67	-2.61	-2.75	-2.79	-3.14	-3.39	-3.66	-3.59
L3	Z3	-2.56	-1.95	-1.88	-1.85	-1.95	-1.95	-2.02	-2.14	-2.24	-2.22
L4	Z1, Z2	-2.14	-1.72	-1.71	-1.68	-1.75	-1.77	-1.29	-1.36	-1.45	-1.43
L4	Z3	-1.94	-1.48	-1.43	-1.40	-1.48	-1.48	-1.01	-1.08	-1.14	-1.13
L5	Z1, Z2	-1.00	-0.93	-0.97	-0.96	-0.96	-0.99	-0.83	-0.84	-0.86	-0.85
L5	Z3	-0.61	-0.55	-0.54	-0.54	-0.55	-0.55	-0.41	-0.43	-0.44	-0.44
Country		-2.77	-2.15	-2.14	-2.10	-2.19	-2.23	-2.13	-2.27	-2.45	-2.41

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: carbon losses in living biomass (lossCl,i) [t C ha^{-1} yr^{-1}]									
L1	Z1	-5.95	-4.08	-3.52	-3.73	-3.77	-4.08	-3.46	-3.48	-3.38	-3.25
L1	Z2	-3.85	-2.61	-2.22	-2.40	-2.42	-2.53	-3.23	-3.23	-3.03	-2.85
L1	Z3	-1.79	-1.22	-1.05	-1.13	-1.14	-1.17	-1.81	-1.80	-1.67	-1.56
L2	Z1	-8.28	-5.43	-4.56	-4.98	-5.02	-5.21	-5.31	-5.32	-5.02	-4.72
L2	Z2, Z3	-8.23	-5.35	-4.46	-4.91	-4.94	-5.06	-5.45	-5.44	-5.09	-4.77
L3	Z1, Z2	-6.45	-4.22	-3.53	-3.89	-3.91	-3.96	-4.40	-4.38	-4.05	-3.76
L3	Z3	-3.54	-2.55	-2.24	-2.42	-2.42	-2.41	-1.99	-1.97	-1.80	-1.67
L4	Z1, Z2	-2.22	-1.57	-1.37	-1.47	-1.48	-1.52	-2.34	-2.34	-2.24	-2.14
L4	Z3	-1.95	-1.33	-1.14	-1.25	-1.26	-1.25	-1.21	-1.20	-1.12	-1.05
L5	Z1, Z2	-0.92	-0.83	-0.80	-0.80	-0.81	-0.84	-1.18	-1.18	-1.18	-1.17
L5	Z3	-0.62	-0.48	-0.44	-0.46	-0.47	-0.47	-0.74	-0.73	-0.70	-0.68
Country		-4.04	-2.72	-2.31	-2.51	-2.53	-2.60	-2.92	-2.92	-2.74	-2.58

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC12: carbon losses in living biomass (lossCl,i) [t C ha^{-1} yr^{-1}]									
L1	Z1	-3.40	-3.41	-3.22	-3.33	-3.41	-3.25	-3.20	-3.29	-4.05	-3.79
L1	Z2	-2.98	-2.96	-2.75	-2.82	-2.89	-2.71	-2.66	-2.77	-3.62	-3.33
L1	Z3	-1.62	-1.59	-1.48	-1.50	-1.54	-1.44	-1.42	-1.48	-1.93	-1.76
L2	Z1	-4.95	-4.93	-4.57	-4.71	-4.84	-4.53	-4.45	-4.64	-4.85	-4.41
L2	Z2, Z3	-4.99	-4.96	-4.60	-4.71	-4.83	-4.52	-4.44	-4.64	-4.98	-4.50
L3	Z1, Z2	-3.93	-3.88	-3.58	-3.65	-3.74	-3.48	-3.42	-3.58	-4.26	-3.89
L3	Z3	-1.73	-1.69	-1.57	-1.58	-1.61	-1.51	-1.48	-1.55	-1.59	-1.47
L4	Z1, Z2	-2.21	-2.20	-2.09	-2.13	-2.17	-2.07	-2.05	-2.10	-2.38	-2.22
L4	Z3	-1.08	-1.06	-1.01	-1.01	-1.02	-0.97	-0.96	-0.99	-1.20	-1.12
L5	Z1, Z2	-1.19	-1.19	-1.17	-1.19	-1.20	-1.18	-1.17	-1.18	-1.32	-1.30
L5	Z3	-0.69	-0.68	-0.66	-0.66	-0.67	-0.65	-0.64	-0.66	-1.27	-1.19
Country		-2.69	-2.67	-2.49	-2.54	-2.60	-2.45	-2.41	-2.50	-2.81	-2.59

NFI	Elev.	2020	2021	2022
		CC12: carbon losses in living biomass (lossCl,i) [t C ha^{-1} yr^{-1}]		
L1	Z1	-3.82	-3.96	-4.12
L1	Z2	-3.39	-3.52	-3.66
L1	Z3	-1.82	-1.87	-1.92
L2	Z1	-4.50	-4.69	-4.92
L2	Z2, Z3	-4.63	-4.82	-5.01
L3	Z1, Z2	-4.01	-4.13	-4.25
L3	Z3	-1.52	-1.55	-1.55
L4	Z1, Z2	-2.27	-2.33	-2.38
L4	Z3	-1.16	-1.17	-1.18
L5	Z1, Z2	-1.30	-1.31	-1.32
L5	Z3	-1.23	-1.24	-1.25
Country		-2.65	-2.73	-2.82

6.4.2.3. Productive forest: carbon stocks and carbon stock changes in dead wood, litter, mineral soil and organic soil

The NFI is the source of carbon inputs and the description of a (possible) state change for each sample tree between two consecutive inventories (i.e., (1) alive in both inventories, (2) alive in the first and dead or removed in the second inventory, (3) present in the second inventory only). The tree state in two consecutive NFIs determines the type and quantity of carbon inputs. Turnover rates reflecting the longevity of leaves and needles, seeds and fruits, fine roots, and small branches were used to estimate carbon inputs that were produced annually. Stemwood, including tree top and stump, large branches, and coarse roots were assumed to accrue only as the result of mortality. Depending on the cause of mortality (natural or timber harvesting) either the total mass of the latter tree elements or only the non-merchantable fraction (coarse root, stump, top, and small branches) was considered for carbon inputs. Consistent with the estimation procedure for living biomass, the model was applied on sample plots common to two consecutive NFIs (chp. 6.4.2.1.1; Table 6-14; for a detailed description, see Didion 2023).

6.4.2.3.1. Carbon stocks in dead wood

Carbon stocks in dead wood were obtained from simulations with Yasso20 and a separation of the total simulated annual carbon stocks based on the source of carbon inputs, including (1) stemwood of trees with DBH ≥12 cm, (2) large branches ≥ ca. 7 cm in diameter, and (3) dead coarse roots > ca. 5 mm in diameter. These tree elements were estimated according to Didion (2023: Table 3). Data are given in Table 6-17.

6.4.2.3.2. Carbon stocks in litter

Carbon stocks in litter were derived from Yasso20 simulations of carbon inputs of the tree elements small branches and twigs < ca. 7 cm in diameter, bark of the tree bole, foliage (Didion 2023: Table 3), seeds and fruits (based on published allometries; see Didion and Zell 2019), and fine roots < ca. 5 mm (estimated as fraction of coarse roots; Perruchoud et al. 1999). Data are given in Table 6-17.

6.4.2.3.3. Carbon stocks in mineral soil

Carbon stocks in mineral soil were not taken from Yasso20 simulations. Due to the incomplete knowledge of the origin of the high carbon stocks in mineral soils, particularly pyrogenic carbon in the mountainous soils of Southern Switzerland (Eckmeier et al. 2010; Nussbaum et al. 2014; Zanelli et al. 2006), they cannot be reproduced by models yet. Hence, soil carbon stocks were taken from Nussbaum and Burgos (2021), a spatial statistical analysis of soil profile data using the machine learning approach "random forest" (Baltensweiler et al. 2021). The sample material was taken from the soil sample archive (pedothek) maintained at the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) (n = 1033 sites). Additional 1060 sites either sampled by WSL or in the course of cantonal projects were used. The soil samples were collected over the past 50 years, by far the most between 1990 and 2015, and distributed over different forest types throughout Switzerland. Because of the distribution of sampling over a long time span, it is not possible to attribute the carbon stocks estimates in mineral forest soils to one single year. A combination of these carbon stocks and the carbon stock changes derived from the

Yasso20 model (see chp. 6.4.2.3.7) would not result in a consistent time series for soil carbon stocks. Thus, it was assumed that the values from Nussbaum and Burgos (2021) are representative of mineral soil in land-use category productive forest for the whole inventory period and were considered constant. Data are given in Table 6-4.

6.4.2.3.4. Carbon stocks in organic soil

The mean soil organic carbon stock (0–30 cm) for organic soil in the land-use category productive forest is 145.6±24.1 t C ha^{-1} (Wüst-Galley et al. 2016) (Table 6-4).

Table 6-17 Carbon stocks in dead wood (stockC_d) and in litter (stockC_h) for the land-use category productive forest (CC12) stratified for NFI production region (NFI) and elevation zone (Elev.). Highlighted data for 1990 are displayed in Table 6-4.

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: carbon stock in dead wood (stockCd,i) [t C ha^{-1}]									
L1	Z1	5.57	5.62	5.59	5.61	5.55	5.53	5.90	6.23	6.49	6.66
L1	Z2	6.34	6.37	6.35	6.37	6.32	6.31	6.38	6.45	6.52	6.52
L1	Z3	6.01	5.97	5.91	5.88	5.80	5.76	5.54	5.42	5.34	5.23
L2	Z1	9.12	9.18	9.14	9.17	9.07	9.03	9.39	9.70	9.94	10.05
L2	Z2, Z3	9.05	9.09	9.05	9.06	8.96	8.94	9.29	9.62	9.90	10.06
L3	Z1, Z2	8.92	9.00	9.02	9.08	9.03	9.07	9.55	9.92	10.26	10.50
L3	Z3	7.71	7.71	7.69	7.71	7.65	7.65	7.48	7.52	7.59	7.61
L4	Z1, Z2	6.45	6.52	6.55	6.62	6.62	6.68	6.57	6.56	6.55	6.50
L4	Z3	7.11	7.21	7.26	7.35	7.39	7.47	7.23	7.21	7.20	7.16
L5	Z1, Z2	2.14	2.19	2.23	2.28	2.30	2.34	2.21	2.16	2.11	2.06
L5	Z3	2.25	2.27	2.27	2.29	2.28	2.31	2.17	2.16	2.15	2.14
Country		6.97	7.03	7.03	7.08	7.04	7.07	7.10	7.23	7.34	7.38

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: carbon stock in dead wood (stockCd,i) [t C ha^{-1}]									
L1	Z1	6.87	7.02	7.16	7.36	7.55	7.74	7.67	7.70	7.78	7.82
L1	Z2	6.56	6.57	6.58	6.62	6.68	6.74	6.83	7.00	7.19	7.33
L1	Z3	5.13	5.04	4.96	4.86	4.82	4.78	4.64	4.68	4.72	4.74
L2	Z1	10.21	10.31	10.42	10.60	10.79	10.97	10.86	10.88	10.96	11.00
L2	Z2, Z3	10.24	10.38	10.53	10.69	10.90	11.11	11.09	11.14	11.25	11.30
L3	Z1, Z2	10.75	10.97	11.16	11.32	11.58	11.80	11.72	11.77	11.87	11.91
L3	Z3	7.64	7.67	7.69	7.67	7.74	7.79	7.30	7.23	7.19	7.12
L4	Z1, Z2	6.46	6.44	6.40	6.38	6.41	6.45	6.32	6.53	6.72	6.88
L4	Z3	7.12	7.10	7.07	7.04	7.07	7.10	6.62	6.62	6.62	6.61
L5	Z1, Z2	2.02	1.99	1.95	1.93	1.91	1.92	1.93	2.01	2.08	2.14
L5	Z3	2.13	2.12	2.11	2.10	2.10	2.12	1.97	2.04	2.11	2.16
Country		7.45	7.50	7.54	7.59	7.69	7.79	7.50	7.56	7.64	7.69

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC12: carbon stock in dead wood (stockCd,i) [t C ha^{-1}]									
L1	Z1	7.93	7.99	7.97	8.02	8.04	8.10	8.11	8.14	9.04	9.15
L1	Z2	7.53	7.65	7.72	7.83	7.91	7.99	8.06	8.14	8.37	8.58
L1	Z3	4.80	4.81	4.81	4.82	4.83	4.81	4.81	4.81	4.38	4.59
L2	Z1	11.13	11.20	11.18	11.23	11.24	11.28	11.26	11.29	11.08	11.12
L2	Z2, Z3	11.46	11.54	11.53	11.59	11.61	11.64	11.64	11.67	12.22	12.25
L3	Z1, Z2	12.04	12.06	12.06	12.13	12.13	12.12	12.13	12.13	11.60	11.83
L3	Z3	7.11	7.03	6.96	6.93	6.88	6.80	6.76	6.71	5.79	5.82
L4	Z1, Z2	7.08	7.20	7.29	7.43	7.52	7.59	7.67	7.73	7.78	7.89
L4	Z3	6.64	6.62	6.59	6.60	6.59	6.56	6.56	6.54	6.40	6.38
L5	Z1, Z2	2.21	2.26	2.30	2.35	2.38	2.42	2.47	2.50	2.38	2.33
L5	Z3	2.22	2.27	2.30	2.35	2.38	2.41	2.45	2.48	2.74	2.90
Country		7.79	7.83	7.84	7.89	7.90	7.92	7.94	7.96	7.90	7.98

NFI	Elev.	2020	2021	2022
		CC12: carbon stock in dead wood (stockCd,i) [t C ha^{-1}]		
L1	Z1	9.26	9.36	9.46
L1	Z2	8.77	8.99	9.15
L1	Z3	4.79	5.00	5.14
L2	Z1	11.18	11.25	11.32
L2	Z2, Z3	12.28	12.37	12.41
L3	Z1, Z2	12.04	12.30	12.46
L3	Z3	5.86	5.92	5.93
L4	Z1, Z2	8.02	8.18	8.31
L4	Z3	6.39	6.42	6.43
L5	Z1, Z2	2.30	2.29	2.27
L5	Z3	3.06	3.22	3.38
Country		8.07	8.18	8.26

(Table 6-17 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: carbon stock in litter (stockCh,i) [t C ha^{-1}]									
L1	Z1	13.81	13.99	13.78	13.88	13.51	13.38	13.77	13.90	13.90	13.65
L1	Z2	15.06	15.25	15.09	15.21	14.88	14.83	15.25	15.37	15.49	15.34
L1	Z3	13.80	13.74	13.53	13.53	13.20	13.16	13.00	13.02	13.16	13.10
L2	Z1	14.18	14.36	14.19	14.24	13.85	13.75	14.11	14.25	14.24	13.97
L2	Z2, Z3	15.62	15.79	15.63	15.71	15.33	15.28	15.63	15.72	15.76	15.53
L3	Z1, Z2	17.20	17.39	17.29	17.40	17.04	17.08	17.51	17.58	17.70	17.56
L3	Z3	18.43	18.55	18.47	18.62	18.30	18.40	18.17	18.20	18.43	18.40
L4	Z1, Z2	13.50	13.64	13.59	13.70	13.53	13.60	13.70	13.87	14.05	13.94
L4	Z3	18.26	18.45	18.46	18.66	18.51	18.70	18.46	18.67	18.91	18.84
L5	Z1, Z2	9.40	9.49	9.56	9.65	9.54	9.72	9.96	10.20	10.41	10.53
L5	Z3	12.25	12.37	12.42	12.55	12.40	12.65	12.44	12.71	12.96	13.13
Country		15.42	15.58	15.50	15.62	15.35	15.40	15.55	15.70	15.84	15.73

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: carbon stock in litter (stockCh,i) [t C ha^{-1}]									
L1	Z1	13.67	13.52	13.41	13.63	13.82	13.99	13.53	13.41	13.43	13.34
L1	Z2	15.40	15.34	15.28	15.35	15.57	15.78	15.38	15.39	15.56	15.57
L1	Z3	13.10	13.09	13.09	12.96	13.17	13.35	12.82	12.96	13.20	13.25
L2	Z1	13.91	13.74	13.63	13.80	13.98	14.14	13.48	13.29	13.27	13.15
L2	Z2, Z3	15.47	15.34	15.26	15.31	15.55	15.73	15.28	15.12	15.13	15.00
L3	Z1, Z2	17.54	17.50	17.42	17.31	17.59	17.74	17.21	17.13	17.19	17.05
L3	Z3	18.45	18.47	18.47	18.24	18.55	18.75	17.69	17.65	17.76	17.62
L4	Z1, Z2	13.94	13.98	13.91	13.97	14.27	14.51	13.74	13.80	13.90	13.93
L4	Z3	18.82	18.92	18.89	18.94	19.29	19.60	18.31	18.41	18.49	18.55
L5	Z1, Z2	10.58	10.77	10.78	10.92	11.11	11.51	10.97	11.12	11.15	11.13
L5	Z3	13.21	13.41	13.46	13.56	13.82	14.33	12.52	12.74	12.85	12.89
Country		15.73	15.73	15.68	15.72	15.99	16.23	15.42	15.43	15.50	15.47

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC12: carbon stock in litter (stockCh,i) [t C ha^{-1}]									
L1	Z1	13.51	13.49	13.22	13.23	13.14	13.20	13.09	13.10	12.46	12.46
L1	Z2	15.91	15.85	15.65	15.71	15.65	15.60	15.56	15.61	15.07	15.08
L1	Z3	13.61	13.54	13.46	13.55	13.54	13.41	13.40	13.42	12.68	12.73
L2	Z1	13.31	13.30	13.06	13.06	12.94	12.95	12.80	12.79	12.56	12.51
L2	Z2, Z3	15.21	15.15	14.91	14.92	14.76	14.71	14.59	14.55	14.73	14.72
L3	Z1, Z2	17.26	17.06	16.87	16.95	16.76	16.58	16.52	16.42	15.67	15.81
L3	Z3	17.89	17.61	17.43	17.51	17.37	17.12	17.08	16.96	17.83	17.92
L4	Z1, Z2	14.22	14.15	14.04	14.17	14.09	14.00	14.02	13.94	13.35	13.40
L4	Z3	18.88	18.81	18.66	18.79	18.76	18.64	18.70	18.63	17.50	17.59
L5	Z1, Z2	11.33	11.35	11.32	11.39	11.29	11.29	11.34	11.31	10.68	10.85
L5	Z3	13.15	13.16	13.13	13.23	13.21	13.18	13.25	13.23	12.58	12.76
Country		15.73	15.65	15.49	15.56	15.47	15.39	15.37	15.32	14.82	14.88

NFI	Elev.	2020	2021	2022
		CC12: carbon stock in litter (stockCh,i) [t C ha^{-1}]		
L1	Z1	12.46	12.46	12.51
L1	Z2	15.11	15.26	15.25
L1	Z3	12.79	13.03	12.93
L2	Z1	12.48	12.51	12.54
L2	Z2, Z3	14.70	14.81	14.81
L3	Z1, Z2	15.94	16.23	16.25
L3	Z3	18.06	18.40	18.31
L4	Z1, Z2	13.52	13.76	13.89
L4	Z3	17.82	18.18	18.41
L5	Z1, Z2	11.08	11.39	11.68
L5	Z3	13.02	13.40	13.73
Country		15.00	15.24	15.35

6.4.2.3.5. Carbon stock changes in dead wood

Annual stratified values of carbon stock changes for dead wood were calculated from the simulated annual stocks (chp. 6.4.2.3.1). Results are given in Table 6-18.

The carbon stock change in the dead wood pool is to a large extend driven by the increase in dead wood volume in Swiss forests since the mid-1990s (Brändli 2010). Dead wood accumulation as a consequence of the two storms Vivian (1990) and, in particular, Lothar (1999), strongly affects the results of the change analysis for dead wood volume in the period NFI2 to NFI3 (1996–2005). Although the majority of the wind thrown trees were removed from the forest, the dead wood stock increased significantly. As particularly the larger-sized felled trees decay slowly (Didion et al. 2014a), the increased dead wood stock acts as a sustained carbon sink (Figure 6-8: $changeC_d$; see also Figure 6-7 bottom panel). The trend of decreasing harvesting rates for several years after NFI3 (2004–2006; see Table 6-15) further sustained the carbon sink of dead wood as mature trees, which could be harvested, remain in the forest and potentially contribute to the dead wood pool. The increased mortality in more recent years (Allgaier Leuch and Fischer 2023; FOEN 2023g) results in further accumulation of dead wood in Swiss forests.

6.4.2.3.6. Carbon stock changes in in litter

Annual stratified values of carbon stock changes for litter were calculated from the simulated annual stocks (chp. 6.4.2.3.2). Results are given in Table 6-18.

Carbon stock changes in litter are higher and more erratic than those in the dead wood and soil pools (Figure 6-8: $changeC_h$; see also Figure 6-7 bottom panel). This is expected since non-woody material decomposes faster than dead wood (Tuomi et al. 2011) and its decomposition is more sensitive to interannual changes in temperature and precipitation (Liski et al. 2003).

6.4.2.3.7. Carbon stock changes in mineral soil

Annual stratified values of carbon stock changes for mineral soil were calculated from the simulated annual stocks. Results are given in Table 6-18.

Carbon stock changes in the soil pool are small compared to those in dead wood and litter (Figure 6-8: $changeC_{s\_m}$; see also Figure 6-7 bottom panel). Despite limitations to reproduce the comparably high carbon stocks in mineral soils in Swiss forests (see chp. 6.4.2.3.3), the carbon stock changes derived from simulated stocks can be expected to be accurate because (1) the pyrogenic carbon which is found particularly in the soils of the Southern Alps is very stable (Eckmeier et al. 2010), and (2) the simulated carbon stock changes including standard error are less than the minimum detection limit of repeated soil carbon stock measurements (see chp. 6.4.4.4). Furthermore, simulated soil carbon stocks were highly variable and did not show a clear correlation to environmental variables such as elevation. This is consistent with results from a study in the Bernese Alps by Hoffmann et al. (2014) who found a large unexplained variability in SOC stocks not correlated with environmental variables.

Table 6-18 Net carbon stock change in dead wood (changeC_d), in litter (changeC_h) and in mineral soil (changeC_s) for the land-use category productive forest (CC12) stratified for NFI production region (NFI) and elevation zone (Elev.). Highlighted data for 1990 are displayed in Table 6-4. Positive values refer to gains in carbon stock, negative values refer to losses in carbon stock.

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: net change in dead wood (changeCd,i) [t C ha^{-1} yr^{-1}]									
L1	Z1	-0.02	0.04	-0.03	0.02	-0.06	-0.03	0.44	0.33	0.26	0.17
L1	Z2	-0.02	0.04	-0.02	0.02	-0.06	-0.01	0.15	0.07	0.06	0.01
L1	Z3	-0.07	-0.04	-0.06	-0.03	-0.08	-0.03	-0.06	-0.11	-0.09	-0.11
L2	Z1	-0.05	0.06	-0.04	0.02	-0.10	-0.03	0.42	0.32	0.23	0.12
L2	Z2, Z3	-0.05	0.04	-0.04	0.01	-0.10	-0.03	0.45	0.33	0.28	0.16
L3	Z1, Z2	0.02	0.08	0.02	0.06	-0.04	0.03	0.50	0.37	0.34	0.24
L3	Z3	-0.03	0.01	-0.03	0.02	-0.06	0.01	0.13	0.04	0.07	0.03
L4	Z1, Z2	0.04	0.07	0.03	0.06	0.01	0.05	0.04	-0.01	-0.01	-0.05
L4	Z3	0.08	0.09	0.06	0.09	0.03	0.08	0.02	-0.02	0.00	-0.05
L5	Z1, Z2	0.05	0.05	0.04	0.04	0.02	0.05	-0.05	-0.06	-0.05	-0.05
L5	Z3	0.01	0.01	0.01	0.01	-0.01	0.02	0.00	-0.01	-0.01	-0.01
Country		0.01	0.06	0.01	0.04	-0.03	0.02	0.20	0.12	0.11	0.05

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: net change in dead wood (changeCd,i) [t C ha^{-1} yr^{-1}]									
L1	Z1	0.21	0.15	0.14	0.20	0.19	0.19	-0.04	0.03	0.08	0.04
L1	Z2	0.04	0.01	0.01	0.03	0.06	0.07	0.14	0.17	0.19	0.14
L1	Z3	-0.10	-0.09	-0.08	-0.10	-0.05	-0.04	0.01	0.03	0.05	0.02
L2	Z1	0.16	0.10	0.11	0.18	0.19	0.19	-0.03	0.02	0.08	0.03
L2	Z2, Z3	0.18	0.14	0.14	0.17	0.21	0.21	0.00	0.06	0.11	0.05
L3	Z1, Z2	0.25	0.22	0.19	0.16	0.26	0.23	-0.01	0.05	0.10	0.03
L3	Z3	0.03	0.03	0.02	-0.02	0.07	0.05	-0.12	-0.07	-0.04	-0.07
L4	Z1, Z2	-0.04	-0.02	-0.04	-0.02	0.03	0.03	0.23	0.21	0.19	0.16
L4	Z3	-0.04	-0.02	-0.03	-0.02	0.03	0.03	-0.01	0.00	0.00	-0.01
L5	Z1, Z2	-0.05	-0.03	-0.04	-0.02	-0.02	0.00	0.09	0.08	0.07	0.06
L5	Z3	-0.02	-0.01	-0.01	-0.01	0.00	0.02	0.08	0.08	0.06	0.05
Country		0.06	0.05	0.04	0.05	0.10	0.10	0.03	0.06	0.08	0.05

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC12: net change in dead wood (changeCd,i) [t C ha^{-1} yr^{-1}]									
L1	Z1	0.11	0.06	-0.02	0.05	0.02	0.06	0.01	0.03	0.08	0.11
L1	Z2	0.20	0.12	0.07	0.11	0.08	0.08	0.07	0.08	0.19	0.20
L1	Z3	0.06	0.00	0.00	0.02	0.01	-0.02	0.00	0.00	0.23	0.22
L2	Z1	0.13	0.07	-0.02	0.05	0.01	0.05	-0.02	0.02	0.03	0.04
L2	Z2, Z3	0.16	0.07	0.00	0.06	0.01	0.04	0.00	0.02	0.01	0.03
L3	Z1, Z2	0.13	0.02	0.00	0.07	0.00	-0.01	0.02	0.00	0.25	0.23
L3	Z3	0.00	-0.08	-0.07	-0.03	-0.06	-0.07	-0.04	-0.05	0.03	0.03
L4	Z1, Z2	0.20	0.12	0.09	0.14	0.09	0.07	0.09	0.06	0.10	0.11
L4	Z3	0.03	-0.02	-0.03	0.01	-0.01	-0.02	0.00	-0.02	-0.03	-0.02
L5	Z1, Z2	0.07	0.05	0.04	0.05	0.03	0.04	0.04	0.03	-0.05	-0.05
L5	Z3	0.06	0.05	0.04	0.04	0.03	0.03	0.04	0.03	0.17	0.16
Country		0.10	0.04	0.01	0.05	0.02	0.02	0.02	0.02	0.07	0.08

NFI	Elev.	2020	2021	2022
		CC12: net change in dead wood (changeCd,i) [t C ha^{-1} yr^{-1}]		
L1	Z1	0.11	0.10	0.10
L1	Z2	0.19	0.22	0.16
L1	Z3	0.20	0.21	0.14
L2	Z1	0.05	0.07	0.07
L2	Z2, Z3	0.03	0.08	0.04
L3	Z1, Z2	0.21	0.26	0.16
L3	Z3	0.04	0.06	0.01
L4	Z1, Z2	0.13	0.16	0.13
L4	Z3	0.01	0.03	0.02
L5	Z1, Z2	-0.03	-0.01	-0.01
L5	Z3	0.16	0.16	0.16
Country		0.09	0.11	0.08

(Table 6-18 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: net change in litter (changeCh,i) [t C ha^{-1} yr^{-1}]									
L1	Z1	-0.22	0.18	-0.21	0.10	-0.37	-0.13	0.53	0.14	0.00	-0.26
L1	Z2	-0.17	0.18	-0.15	0.12	-0.34	-0.04	0.58	0.12	0.12	-0.15
L1	Z3	-0.29	-0.06	-0.21	0.00	-0.34	-0.04	0.44	0.02	0.13	-0.05
L2	Z1	-0.25	0.18	-0.17	0.05	-0.39	-0.10	0.46	0.14	-0.01	-0.27
L2	Z2, Z3	-0.23	0.17	-0.16	0.07	-0.38	-0.05	0.47	0.09	0.05	-0.23
L3	Z1, Z2	-0.15	0.19	-0.10	0.11	-0.35	0.04	0.56	0.07	0.13	-0.14
L3	Z3	-0.12	0.13	-0.09	0.15	-0.32	0.09	0.58	0.03	0.22	-0.03
L4	Z1, Z2	-0.06	0.14	-0.05	0.11	-0.17	0.08	0.49	0.17	0.17	-0.11
L4	Z3	0.07	0.20	0.01	0.20	-0.14	0.19	0.50	0.21	0.24	-0.07
L5	Z1, Z2	0.09	0.08	0.08	0.09	-0.12	0.18	0.49	0.24	0.20	0.13
L5	Z3	0.13	0.12	0.05	0.12	-0.14	0.24	0.56	0.27	0.26	0.17
Country		-0.09	0.16	-0.08	0.12	-0.27	0.06	0.52	0.15	0.15	-0.11

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: net change in litter (changeCh,i) [t C ha^{-1} yr^{-1}]									
L1	Z1	0.02	-0.14	-0.11	0.22	0.18	0.17	-0.41	-0.12	0.02	-0.09
L1	Z2	0.06	-0.06	-0.06	0.07	0.22	0.21	-0.25	0.01	0.18	0.01
L1	Z3	0.00	-0.01	0.00	-0.14	0.21	0.18	-0.07	0.14	0.23	0.05
L2	Z1	-0.06	-0.18	-0.10	0.16	0.18	0.17	-0.39	-0.19	-0.02	-0.12
L2	Z2, Z3	-0.06	-0.13	-0.08	0.06	0.23	0.18	-0.40	-0.16	0.01	-0.13
L3	Z1, Z2	-0.02	-0.05	-0.08	-0.11	0.28	0.15	-0.31	-0.08	0.07	-0.15
L3	Z3	0.06	0.02	0.00	-0.23	0.31	0.19	-0.32	-0.03	0.11	-0.14
L4	Z1, Z2	0.00	0.04	-0.07	0.06	0.30	0.24	0.04	0.06	0.10	0.03
L4	Z3	-0.02	0.10	-0.03	0.05	0.35	0.31	0.07	0.10	0.08	0.06
L5	Z1, Z2	0.05	0.19	0.00	0.14	0.19	0.40	0.15	0.14	0.04	-0.02
L5	Z3	0.08	0.20	0.05	0.10	0.26	0.51	0.19	0.23	0.11	0.04
Country		0.00	0.00	-0.05	0.04	0.27	0.25	-0.14	0.00	0.07	-0.03

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC12: net change in litter (changeCh,i) [t C ha^{-1} yr^{-1}]									
L1	Z1	0.16	-0.01	-0.28	0.01	-0.09	0.07	-0.11	0.00	-0.17	0.00
L1	Z2	0.34	-0.05	-0.21	0.06	-0.06	-0.05	-0.04	0.04	-0.20	0.01
L1	Z3	0.36	-0.06	-0.09	0.09	-0.01	-0.14	0.00	0.02	-0.10	0.05
L2	Z1	0.16	-0.01	-0.23	0.00	-0.12	0.01	-0.15	-0.01	-0.10	-0.05
L2	Z2, Z3	0.21	-0.06	-0.24	0.01	-0.15	-0.05	-0.12	-0.04	-0.07	-0.01
L3	Z1, Z2	0.21	-0.20	-0.19	0.08	-0.19	-0.19	-0.05	-0.11	0.13	0.15
L3	Z3	0.27	-0.28	-0.17	0.07	-0.14	-0.25	-0.04	-0.12	0.04	0.08
L4	Z1, Z2	0.29	-0.07	-0.11	0.13	-0.08	-0.09	0.02	-0.08	-0.04	0.05
L4	Z3	0.33	-0.08	-0.14	0.12	-0.03	-0.12	0.06	-0.07	0.04	0.09
L5	Z1, Z2	0.19	0.03	-0.03	0.06	-0.09	-0.01	0.06	-0.03	0.22	0.17
L5	Z3	0.26	0.01	-0.03	0.10	-0.02	-0.04	0.08	-0.02	0.19	0.17
Country		0.26	-0.08	-0.16	0.07	-0.09	-0.09	-0.02	-0.05	0.00	0.07

NFI	Elev.	2020	2021	2022
		CC12: net change in litter (changeCh,i) [t C ha^{-1} yr^{-1}]		
L1	Z1	0.01	0.00	0.05
L1	Z2	0.03	0.15	-0.01
L1	Z3	0.06	0.24	-0.10
L2	Z1	-0.03	0.03	0.03
L2	Z2, Z3	-0.03	0.11	0.00
L3	Z1, Z2	0.12	0.30	0.01
L3	Z3	0.15	0.34	-0.09
L4	Z1, Z2	0.13	0.23	0.13
L4	Z3	0.23	0.36	0.23
L5	Z1, Z2	0.23	0.31	0.30
L5	Z3	0.26	0.38	0.33
Country		0.12	0.24	0.10

(Table 6-18 continued)

NFI	Elev.	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
		CC12: net change in mineral soil (changeCs,i) [t C ha^{-1} yr^{-1}]									
L1	Z1	0.009	-0.001	0.008	0.002	0.009	0.008	-0.002	0.004	0.010	0.018
L1	Z2	0.011	0.002	0.010	0.006	0.011	0.009	0.000	0.008	0.009	0.016
L1	Z3	0.002	-0.003	0.000	-0.003	0.000	-0.003	-0.010	-0.004	-0.005	-0.001
L2	Z1	0.008	-0.003	0.004	0.002	0.007	0.005	-0.005	0.000	0.005	0.014
L2	Z2, Z3	0.009	-0.002	0.005	0.003	0.008	0.005	-0.003	0.003	0.005	0.015
L3	Z1, Z2	0.016	0.008	0.014	0.012	0.017	0.013	0.007	0.015	0.015	0.024
L3	Z3	0.017	0.012	0.015	0.012	0.019	0.013	0.006	0.015	0.012	0.019
L4	Z1, Z2	0.018	0.014	0.018	0.016	0.019	0.016	0.011	0.016	0.017	0.025
L4	Z3	0.015	0.012	0.016	0.014	0.019	0.014	0.009	0.013	0.013	0.022
L5	Z1, Z2	0.019	0.019	0.020	0.021	0.023	0.018	0.020	0.024	0.025	0.028
L5	Z3	0.014	0.014	0.016	0.016	0.019	0.012	0.013	0.017	0.018	0.021
Country		0.013	0.007	0.012	0.010	0.015	0.011	0.005	0.011	0.012	0.020

NFI	Elev.	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
		CC12: net change in mineral soil (changeCs,i) [t C ha^{-1} yr^{-1}]									
L1	Z1	0.007	0.015	0.014	-0.006	0.007	0.007	0.017	0.011	0.007	0.007
L1	Z2	0.009	0.014	0.013	0.001	0.007	0.006	0.017	0.013	0.010	0.011
L1	Z3	-0.004	-0.002	-0.004	-0.008	-0.007	-0.007	-0.002	-0.004	-0.005	-0.004
L2	Z1	0.005	0.012	0.008	-0.009	0.002	0.002	0.009	0.006	0.001	0.001
L2	Z2, Z3	0.007	0.013	0.010	-0.005	0.003	0.004	0.012	0.009	0.005	0.005
L3	Z1, Z2	0.018	0.022	0.022	0.015	0.014	0.018	0.022	0.019	0.015	0.018
L3	Z3	0.014	0.017	0.017	0.016	0.010	0.014	0.015	0.011	0.007	0.011
L4	Z1, Z2	0.020	0.021	0.023	0.013	0.013	0.015	0.017	0.020	0.020	0.019
L4	Z3	0.019	0.017	0.020	0.012	0.010	0.011	0.013	0.014	0.016	0.014
L5	Z1, Z2	0.029	0.025	0.030	0.021	0.025	0.019	0.027	0.027	0.032	0.032
L5	Z3	0.023	0.020	0.023	0.018	0.018	0.011	0.016	0.016	0.020	0.021
Country		0.015	0.017	0.017	0.007	0.010	0.010	0.015	0.014	0.013	0.013

NFI	Elev.	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
		CC12: net change in mineral soil (changeCs,i) [t C ha^{-1} yr^{-1}]									
L1	Z1	0.005	0.003	0.015	0.008	0.007	-0.002	0.009	0.003	0.000	0.000
L1	Z2	0.007	0.012	0.020	0.015	0.014	0.010	0.015	0.010	0.013	0.011
L1	Z3	-0.007	-0.003	0.002	-0.001	-0.002	-0.002	-0.002	-0.004	-0.006	-0.006
L2	Z1	-0.002	-0.003	0.007	0.002	0.002	-0.007	0.004	-0.004	-0.008	-0.004
L2	Z2, Z3	0.001	0.001	0.011	0.006	0.007	-0.002	0.007	0.001	-0.001	0.003
L3	Z1, Z2	0.014	0.018	0.021	0.016	0.020	0.015	0.016	0.016	0.007	0.011
L3	Z3	0.005	0.012	0.012	0.007	0.010	0.009	0.007	0.008	0.010	0.011
L4	Z1, Z2	0.017	0.022	0.026	0.020	0.025	0.022	0.022	0.024	0.020	0.021
L4	Z3	0.011	0.016	0.020	0.014	0.016	0.015	0.014	0.016	0.016	0.016
L5	Z1, Z2	0.029	0.030	0.032	0.031	0.035	0.030	0.030	0.031	0.026	0.029
L5	Z3	0.018	0.020	0.023	0.020	0.023	0.020	0.020	0.021	0.021	0.023
Country		0.010	0.013	0.018	0.013	0.015	0.011	0.014	0.012	0.010	0.012

NFI	Elev.	2020	2021	2022
		CC12: net change in mineral soil (changeCs,i) [t C ha^{-1} yr^{-1}]		
L1	Z1	-0.001	0.007	-0.008
L1	Z2	0.010	0.014	0.006
L1	Z3	-0.007	-0.005	-0.007
L2	Z1	-0.005	0.000	-0.014
L2	Z2, Z3	0.003	0.006	-0.005
L3	Z1, Z2	0.013	0.014	0.010
L3	Z3	0.010	0.010	0.010
L4	Z1, Z2	0.019	0.019	0.013
L4	Z3	0.012	0.012	0.007
L5	Z1, Z2	0.028	0.027	0.021
L5	Z3	0.021	0.020	0.015
Country		0.010	0.012	0.005

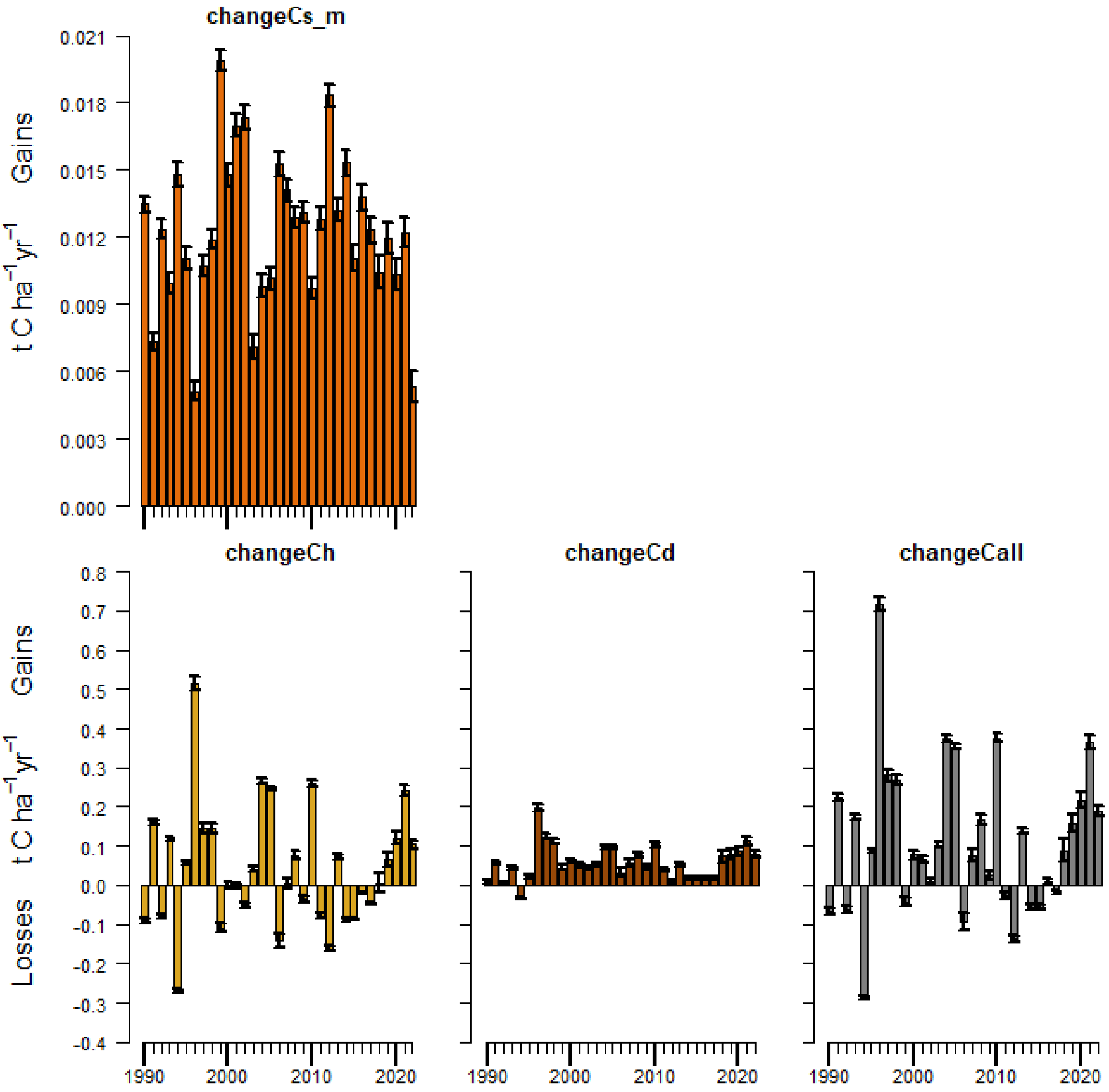

Figure 6-8 Mean carbon stock changes (changeC) over the inventory period for three pools mineral soil (s_m, 0–100 cm), litter (h), dead wood (d) and their sum (all) in t C ha^{-1} yr^{-1}. Note the difference of the y-axis scale between changeCs_m and changeCh, changeCd and changeCall, respectively. Negative values indicate losses in carbon stock, positive values gains in carbon stock. The error bars indicate the double standard error.

6.4.2.3.8. Carbon stock changes in organic soil

Drainage of forests is not a permitted practice in Switzerland (Swiss Confederation 1991). However, it is possible that parts of the Swiss forest were drained before 1990 or were established on drained areas. Abegg (2017) estimated the amount of drained organic soil by comparing information on drainage from NFI plots with spatial data of organic soil in Switzerland produced by Wüst-Galley et al. (2015): 3 % of organic soil on Forest land appeared to be subject to drainage.

For the calculation of carbon stock changes in organic soil, the default emission factor of 2.6 t C ha^{-1} yr^{-1} was applied for the land-use category productive forest (CC12; Table 6-4) according to the Wetlands Supplement (IPCC 2014a: Table 2.1).

6.4.2.4. Unproductive forest

6.4.2.4.1. Carbon stocks in living biomass

- Brush forest: Brush forests in Switzerland mainly consist of *Alnus viridis*, horizontal *Pinus mugo var. prostrata* with a percentage cover of 65 % and 16 %, respectively (Düggelin and Abegg 2011: Table 1). Following the NFI definition, brush forests are dominated by more than two thirds by shrubs. In a case study, Düggelin and Abegg (2011) analysed the carbon stock of living biomass of woody shrub species in Swiss brush forests and found an average value of 20.45 t C ha^{-1}.
- Inaccessible stands: Inaccessible stands are considered the same as brush forest regarding biomass and carbon stock. Their area is determined based on land cover ”tree vegetation” in typically remote and high-elevation land uses such as avalanche chutes (NOLU04 403 and 422; Table 6-6).
- Unproductive forests not covered by NFI: These forests are mainly associated with extensively pastured land where sparse tree vegetation (NOLC04 44 and 47; Table 6-6) is found. As those forests are assumed to grow preferably on bad site conditions, an average growing stock (>7 cm diameter) of 150 m^3 ha^{-1} was assumed. Multiplied by the mean BCEF of 0.69 (i.e., weighted mean based on the quotient of stemwood volume and total tree biomass of coniferous and broadleaved trees as described in Thürig and Herold 2013), an average biomass for these forests of 102.75 t ha^{-1} was estimated, which corresponds to 51.38 t C ha^{-1} (using a carbon content of 50 %; see chp. 6.4.2.1.3).

The carbon stock of living biomass (C_l) in unproductive forest (CC13) was calculated as a weighted average of brush forest, inaccessible stands and unproductive forest not covered by NFI per spatial stratum:

$$stockC_{l,i,CC13} = F_i * stockC_{l,i,CC13bi} + (1- F_i) * stockC_{l,i,CC13u}$$

where:

- F_i is the fraction of the brush and inaccessible forest per spatial stratum i;
- $stockC_{l,i,CC13bi}$ is the carbon stock in brush and inaccessible forest (20.45 t C ha^{-1});
- $stockC_{l,i,CC13u}$ is the carbon stock in unproductive forest not covered by NFI (51.38 t C ha^{-1}).

Table 6-19 shows the resulting carbon stocks in living biomass of the land-use category unproductive forest per spatial stratum in t C ha^{-1}. The data was transferred to Table 6-4.

Table 6-19 Area of brush forest, inaccessible forest and unproductive forest not covered by NFI, their areal fractions (F_i: fraction of brush and inaccessible forest per stratum i) and the resulting weighted carbon stocks in living biomass (t C ha^{-1}) for the land-use category unproductive forest (CC13) specified for all spatial strata ($stockC_{l,i,CC13}$).

NFI region	Elevation [m]	Brush forest [ha]	Inacessessible forest [ha]	Forest not covered by NFI [ha]	Fraction of brush and inaccessible forest (F_i)	Fraction of forest not covered by NFI ($1-F_i$)	Carbon stock in living biomass ($stockC_{l,i,CC13}$) [t C ha^{-1}]
1	<601	49	0	69	0.42	0.58	38.53
	601-1200	44	0	4'841	0.01	0.99	51.10
	>1200	6	0	4'648	0.00	1.00	51.34
2	<601	188	0	0	1.00	0.00	20.45
	601-1200	94	0	93	0.50	0.50	35.83
	>1200	1	0	633	0.00	1.00	51.33
3	<601	11	0	0	1.00	0.00	20.45
	601-1200	172	0	1'210	0.12	0.88	47.53
	>1200	3'486	5	8'482	0.29	0.71	42.36
4	<601	26	0	1	0.96	0.04	21.60
	601-1200	1'058	5	589	0.64	0.36	31.48
	>1200	42'795	50	18'808	0.69	0.31	29.88
5	<601	243	1	3	0.99	0.01	20.83
	601-1200	2'249	0	275	0.89	0.11	23.82
	>1200	17'776	7	2'568	0.87	0.13	24.35

6.4.2.4.2. Carbon stocks in dead wood

Carbon stocks in dead wood, litter and mineral soil under unproductive forest reveal a high spatial heterogeneity, and specific data are not available.

Dead wood on unproductive forest stands was assumed to be zero (Table 6-4).

6.4.2.4.3. Carbon stocks in litter

Carbon stocks in litter in the land-use category unproductive forest were assigned to the mean value of the modelled CC12 litter stocks for the inventory period 1990–2021 (see FOEN 2023: chp. 6.4.2.4.4). Data is given in Table 6-4.

6.4.2.4.4. Carbon stocks in mineral soil

Carbon stocks in mineral soil in the land-use category unproductive forest were taken from Nussbaum and Burgos (2021) (compare description in chp. 6.4.2.3.3). Data is given in Table 6-4.

6.4.2.4.5. Carbon stocks in organic soil

The mean soil organic carbon stock (0–30 cm) for organic soil in the land-use category unproductive forest is 145.6±24.1 t C ha^{-1} (Wüst-Galley et al. 2016) (Table 6 4).

6.4.2.4.6. Carbon stock changes in living biomass

For unproductive forests not covered by NFI and inaccessible stands no NFI data are available. For brush forests there are only few case studies and, similar to mountainous neighbouring countries, only incomprehensive forest inventory data available. As no harvesting is conducted in unproductive forests, gross growth and cut and mortality of these forest were assumed to be in equilibrium (Tier 1 approach). This approach is transcribed into “gains ($gainC_{l,i,13}$) = losses ($lossC_{l,i,13}$) = 0” and reported as NA in Table 6-4 and CRT Table4.A.

6.4.2.4.7. Carbon stock changes in dead wood, litter and mineral soil

Applying a Tier 1 approach, carbon stock changes in dead wood, litter, and mineral soil were assumed to be in equilibrium for unproductive forest. This approach is transcribed into “$changeC_{d,i,13}$= $changeC_{h,i,13}$ = $changeC_{s,I,13}$ = 0” and reported as NA in Table 6-4 and CRT Table4.A.

6.4.2.4.8. Carbon stock changes in organic soil

3 % of organic soil on Forest land is assumed to be subject to drainage (see chp. 6.4.2.3.8). For the calculation of carbon stock changes in organic soil, the default emission factor of 2.6 t C ha^{-1} yr^{-1} was applied for the land-use category unproductive forest (Table 6-4) according to the Wetlands Supplement (IPCC 2014a: Table 2.1).

6.4.2.5. Land-use change

In the case of land-use change, the net carbon stock changes in biomass and soils of land-use categories productive forest and unproductive forest were calculated as described in chp. 6.1.3.

6.4.2.6. Non-CO_2 emissions from Forest land

6.4.2.6.1. Direct N_2O emissions from N inputs to managed soils

Fertilisation of forests is prohibited by the Federal Act on Forest and the adherent ordinance (Swiss Confederation 1991, 1992). The Federal Act on Forest (Art. 18) states: “The use of environmentally hazardous substances in the forest is prohibited” with a direct reference to the Federal Act on the Protection of the Environment (Swiss Confederation 1983). Details of the Federal Act on Forest Art. 18 had initially been regulated in the Ordinance on Forest (Art. 27). Since 2005, the Chemical Risk Reduction Ordinance (Swiss Confederation 2005: Art. 4) prohibits the application of fertilisers, including liming, in forests. Hence, the application of fertilisers, including liming in forests was prohibited since 1991 in Switzerland. Furthermore, these management practices have never been common practice in Swiss forestry. There is thus considerable evidence to justify the assumption that this situation is valid since 1990. Additionally, the reporting of N_2O emissions from fertiliser application in the Agriculture sector encompasses all fertilisers applied in Switzerland. Therefore, no emissions were reported in category A in CRT Table4(I) (notation key NO).

6.4.2.6.2. N_2O and CH_4 emissions from drainage of organic soil

N_2O emissions from drainage of organic soil was calculated for Forest land with an emission factor of 2.8 kg N_2O-N ha^{-1} for 3 % of the area of organic soil (see chp. 6.4.2.3.8 and chp. 6.4.2.4.8) and reported in category A in CRT Table4(II). The emission factor used is the default value given in the Wetlands Supplement (IPCC 2014a: Table 2.5) for temperate forest land.

CH_4 emissions were not estimated (notation key NE) in 4(II) as reporting is not mandatory for this category.

6.4.2.6.3. Direct and indirect N_2O emissions from mineral soils

The calculations of direct and indirect N_2O emissions from nitrogen mineralisation in mineral soil (category 4(III)A) in Forest land are described in chp. A5.4.

6.4.2.6.4. CH_4 and N_2O emissions from biomass burning

6.4.2.6.4.1. Controlled burning

Emissions from controlled burning on Forest land covers the burning of harvest residues only since controlled burning of whole forest stands is not allowed in Switzerland.

The amount of natural residues burnt openly was estimated by INFRAS (2014). Open burning of such residues is regulated in the Ordinance on Air Pollution Control OAPC (Swiss Confederation 1985: Art. 26b). In Switzerland cantonal authorities are responsible for the enforcement of the OAPC regulations. For INFRAS (2014), an inquiry of some cantonal authorities was performed in order to assess the activity data for these processes.

CH_4 and N_2O emissions were calculated by a Tier 2b approach based on chp. 5.2. in Volume 5 of IPCC (2006). The emissions of burning of residues in forestry were calculated by multiplying the annual estimate of residues burnt (in kt, see FOEN 2024b: chp. 7.3) by emission factors as documented in EMIS 2024/5C2: 6.8 kg t^{-1} for CH_4 and 0.180 kg t^{-1} for N_2O.

CO_2 emissions from controlled burning were noted IE in the CRT Table4(IV) and are encompassed in the data in CRT Table4.A since carbon losses in living biomass are reflected in the NFI data set.

The emission factors of CH_4 and N_2O of burning of residues from forestry were calculated based on the EMEP/EEA guidebook (EMEP/EEA 2019), see also documentation in EMIS 2024/5C2 and EMIS 2024/4VA1 Abfallverbrennung in der Land- und Forstwirtschaft.

6.4.2.6.4.2. Wildfires

Data on wildfires affecting Forest land were obtained from cantonal authorities and were compiled by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL, Swissfire database). These data are updated regularly based on analysing data from cantonal archives (Pezzatti et al. 2019). Table 6-20 shows the time series of affected areas and associated CH_4 and N_2O emissions.

As controlled burning of forest stands is not allowed in Switzerland all fires in forests were considered wildfires. All fires were assigned to the land-use category productive forest. This approach reflects reality quite well, since fires in land-use category unproductive forest are rather unlikely to occur because the available fuel is small since tree cover is not very dense and there is very little dead woody material on the surface which can catch fire (Zumbrunnen et al. 2012). Moreover, in remote areas the cause of fire is restricted to lightning strikes.

CO_2 emissions from wildfires were noted IE in CRT Table4(IV) and are encompassed in the data in CRT Table4.A. Carbon losses in living biomass are reflected in the NFI data set. Carbon changes in dead wood, litter and mineral soil calculated with Yasso20 also cover the influence of forest fires and other disturbances by using NFI data as an input (see Didion 2023: chp. 2.4.2).

CH_4 and N_2O emissions from wildfires (Table 6-20) were calculated using equation 2.27 in Volume 4 of IPCC (2019) with the following parameters:

- For CH_4 the default emission factor of 4.7 g kg-1 dry matter burnt and for N_2O, the default emission factor of 0.26 g kg-1 dry matter burnt were applied (IPCC 2019, Volume 4, Table 2.5).
- The mass of available fuel encompasses carbon stocks in living biomass, dead wood, and litter. A continous time series of the mass of available fuel was derived from NFI data for living biomass (see chp. 6.4.2.2.1) and from Yasso20 modelled data for dead wood and litter (see chp. 6.4.2.3.1 and chp. 6.4.2.3.2).
- The fraction of the biomass combusted was 0.45 (IPCC 2019, Volume 4, Table 2.6).

CH_4 and N_2O emissions caused by wildfires are reported in category A1 in CRT Table4(IV), because it is not known which fires occur on Forest land remaining forest land and which on Land converted to forest land. Consequently, category 4(IV)A2 is labelled as IE.

Table 6-20 Forest land affected by wildfires (WSL, Swissfire database) and resulting CH_4 and N_2O emissions.

Forest land	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Area burnt	ha	1'067	363	47	41	26
CH_4	t	613	216	28	25	16
N_2O	t	33.9	11.9	1.6	1.4	0.9

Forest land	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Area burnt	ha	24	43	45	256	106	55	16	11	26	267
CH_4	t	15	26	27	154	63	33	10	6	16	159
N_2O	t	0.8	1.4	1.5	8.5	3.5	1.8	0.5	0.4	0.9	8.8

6.4.2.6.5. Precursor gas emissions (NO_x, CO, NMVOC)

CRT Table4 presents emissions of NO_x, CO and NMVOC from burning of residues in forestry and from wildfires on 4A Forest land as described by FOEN (2024b: chp. 7.3). In addition, CRT Table4 includes the annual biogenic emissions of NMVOC from the forest stands as shown in FOEN (2024b: chp. 7.4).

The biogenic NMVOC emissions from forest stands were calculated for the years 1900–2022 and 2050 on the basis of monthly maps for the parameters temperature, vegetation period and for 12 different tree species (Meteotest 2019a and EMIS 2024/11C Wald). This corresponds to the simplified method according to chp. 11C in the EMEP/EEA guidebook (EMEP/EEA 2019).

In 1990, NMVOC emissions from forest stands were 60.83 kt; from 1990 to 2022 these emissions increased on average by 0.66 % per year. The emissions from burning of residues in forestry and from wildfires (FOEN 2024b: chp. 7.3) are much smaller; they fluctuated between 0.02 and 0.74 kt over the same period.

6.4.3. Uncertainties and time-series consistency for 4A

6.4.3.1. Uncertainties

Detailed results of approach 1 and approach 2 uncertainty analyses are given in Annex A2.2 and Annex A2.3, respectively. Note that in this submission the four categories according to the CRF nomenclature 4(II), 4(III), 4(IV) and 4(V) are still used.

6.4.3.1.1. Activity data

Uncertainties of activity data of category 4A Forest land are described in chp. 6.3.1.3.1.

6.4.3.1.2. Carbon stock change factors

Uncertainties were estimated for the pools living biomass, dead wood, litter and soil. One source of uncertainty common to all pools is the error resulting from the estimates of changes in the pools between two NFIs based on shifting samples of sample plots common to NFI3 and five-year NFI4 subsets (see chp. 6.4.2.1.1.2), i.e. 2009–2011 (GHG inventory submission 2013), 2009–2012 (GHG inventory submission 2014), 2009–2013 (GHG inventory submissions 2015 and 2016), 2011–2015 (GHG inventory submissions 2017 and 2018), and 2013–2017 (GHG inventory submissions 2019 and 2020). This was taken into account to obtain a multi-annual uncertainty estimate.

Living biomass

Sources of uncertainty (relative uncertainty, 2 SE) considered are:

- NFI sampling between NFIs 3 and 5-year NFI4 subsets: 30.2 %
- Carbon content in solid wood: 2 % based on 2 % relative standard deviation (RSD) in Monni et al. (2007), and 4-8 % RSD in Lamlom and Savidge (2003)
- Biomass expansion function (for Forest land in the Swiss GHG inventory, allometric functions for individual trees were applied) and conversion into mass with wood density: 21.2 % sampling uncertainty and 22.2 % model uncertainty; based on Lehtonen and Heikkinen (2016).

Thus, the total uncertainty of net carbon stock change in living biomass ($U_{liv.biom}$) in terms of carbon per unit area can be calculated following equation 3.1 in chp. "'Quantifying Uncertainties" (Volume 1 of IPCC 2006):

$$U_{liv.biom} = \sqrt{30.2^2+2^2+21.2^2+22.2^2} = 43.1\ \%$$

Dead wood, litter, soil

In the Monte Carlo simulation approach described in Didion (2020a: chp. 2.3) the following sources of uncertainty were considered:

- NFI sampling between NFIs 3 and 5-year NFI4 subsets
- carbon input estimates obtained from the NFI (measurement errors, allometries, etc.)
- decomposition parameters used in the Yasso07 model.

The resulting relative uncertainties are:

- U_{Soil} = 37.0 %
- U_{Litter} = 96.7 %
- $U_{Dead\ wood}$ = 16.6 %.

Overall uncertainty categories 4A1 and 4A2

The total uncertainty associated with carbon stock change in all four pools was estimated using equation 3.2 in chp. “Quantifying Uncertainties” (IPCC 2006, Volume 1):

$$U_{tot} = \frac{\sqrt{(U_{\mathrm{liv.biom}} * X_{\mathrm{liv.biom}})^2 + (U_{soil} * X_{soil})^2 + (U_{Litter} * X_{Litter})^2 + (U_{Deadwood} * X_{Deadwd})^2}}{|X_{\mathrm{liv.biom}} + X_{soil} + X_{Litter} + X_{Deadwood}|}$$

with long-term mean carbon stock changes based on Didion et al. (2023) and Didion (2023) in

- living biomass ($X_{liv.biom}$): 0.474 t C ha^{-1} yr^{-1}
- soil (X_{Soil}): 0.012 t C ha^{-1} yr^{-1}
- litter (X_{Litter}): 0.042 t C ha^{-1} yr^{-1}
- dead wood ($X_{Deadwood}$): 0.058 t C ha^{-1} yr^{-1}

where positive values refer to gains in carbon stock and negative values refer to losses in carbon stock.

The resulting relative uncertainty of the total carbon stock change for Forest land is 34.9 %. This value is used for categories 4A1 and 4A2 for the whole inventory period (see Table 6-5).

Drainage of organic soil (CO_2; pool organic soil in CRT Table4.A)

The CO_2 emissions from drained organic forest soils are very small (<0.1 % of category 4A total) and were neglected in the uncertainty calculation.

6.4.3.1.3. Uncertainties in category 4(II) Drainage of organic soil (N_2O)

The contribution of Forest land to N_2O emissions from drained organic soil (category 4(II)A) is small (around 5 %). Its uncertainty was included in the uncertainty calculation for Wetlands (see chp. 6.7.3.1).

6.4.3.1.4. Uncertainties in category 4(V) Biomass burning (CH_4, N_2O)

The emission factor uncertainty for category 4(V) (biomass burning, wildfires) is 70 %. It is derived from the uncertainty of the combustion factor from IPCC (2006, Volume 4, Table 2.6: mean = 0.45, 2SE = 0.32). The activity data uncertainty for wildfires is 30 % (see chp. 6.3.1.3.3).

6.4.3.2. Time-series consistency

Consistent time series of annual carbon stocks in living biomass were calculated forward starting from the growing stock in 1985 (see chp. 6.4.2.2.3).

Consistent time series of annual carbon stocks in dead wood and litter were calculated with the model Yasso20 (see chp. 6.4.2.3.1 and chp. 6.4.2.3.2).

6.4.4. Category-specific QA/QC and verification for 4A

The general QA/QC measures are described in chp. 1.5.

6.4.4.1. Living biomass – omission of trees <12 cm DBH and of non-tree understory vegetation

In Forest land, trees with DBH <12 cm and non-tree understory vegetation are not considered (see chp. 6.4.2.1.1.3). The omission is justified because of their negligible effect on carbon stocks and carbon stock changes of living biomass, dead wood, litter, and soil in productive forests in Switzerland (justification in response to UNFCCC 2022, ID#L.4). In detail:

- Trees with DBH <12 cm contribute only little to total forest biomass and carbon stock (Peichl and Arain 2006). Dunger et al. (2012) estimated this contribution to 1–2 % for forests with similar forest structure as common in Switzerland. Their contribution to annual litter production and hence to carbon stock changes in dead wood, litter, and soil is small compared to mature trees with larger diameters (He et al. 2012).
- Carbon gains in biomass of trees with BDH <12 cm are implicitly accounted for in the trees above this threshold as the cumulative carbon uptake. This is a statistically valid and accurate approach, particularly for the gain/loss approach applied by Switzerland ensuring that carbon stock change factors are neither over- nor underestimated.
- Biomass of non-tree understory vegetation presents <1 % of the above ground biomass carbon pool in the Swiss NFI (Didion 2020b), and thus has a negligible contribution to annual litter production. Consistent with the inventory guidelines (IPCC 2006, Volume 4, Annex 4A.1), it can therefore be excluded from the inventory.

6.4.4.2. Carbon stocks in mineral soil

The trend of a minor increase in soil carbon stocks since 1990, based on the Yasso20 simulations (chp. 6.4.2.3.7), supports the assumption that carbon stocks from Nussbaum and Burgos (2021) are representative of mineral soil in the land-use category productive forest and can be considered constant for the whole inventory period (chp. 6.4.2.3.3).

6.4.4.3. Carbon balance of two mountain forest ecosystems in Switzerland – Net ecosystem exchange and soil respiration

Measurements of the net ecosystem exchange (NEE) and of soil respiration were conducted at a montane mixed forest over 5 years (Lägeren; 2005–2009; NFI production region 2), and at a subalpine coniferous forest over 12 years (Davos; 1997–2009; Swiss Plateau, NFI production region 4).

(1) Etzold et al. (2011) determined the NEE by eddy covariance (EC) measurements. EC measurements as well as biometric estimates indicate that both sites with two different mountain forest types were significant carbon sinks in the respective periods. NEE of the Lägeren forest ranged from -366 to -662 g C m^{-2} yr^{-1} (mean: -415 g C m^{-2} yr^{-1}), and of the Davos forest from -47 to -274 g C m^{-2} yr^{-1} (mean: -154 g C m^{-2} yr^{-1}).

(2) Rühr and Eugster (2009) measured soil respiration rates at these two Swiss forest sites. Modelled changes in soil carbon storage with the dynamic soil carbon model Yasso07 gave comparable results with measured soil respiration. Rühr and Eugster (2009) found that soils at the alpine site Davos acted as a significant carbon sink. Soils at the Lägeren site were neither a significant carbon sink nor a significant carbon source. This domestic study confirms the broadly spread knowledge that it is very difficult to detect short term changes in soil carbon stocks, since the uncertainty of the measurement is often higher than the actual change of the annual estimates (e.g. Falloon and Smith 2003).

6.4.4.4. Carbon stock changes in mineral soil – Soil organic carbon (SOC) data set of the Swiss Soil Monitoring Network

The objective of the Swiss Soil Monitoring Network (http://www.nabo.ch; NABO) is to assess soil quality in the long term, such as concentrations of harmful substances, organic carbon, the microbiology, and its development over time (Gross et al. 2024). NABO operates about 110 long-term monitoring sites throughout Switzerland covering all relevant land uses, such as cropland, grassland, and forest. Most of the monitoring sites were sampled for the first time between 1985 and 1989 and resampled every five years ever since (SAEFL 1993, 2000a; Meuli et al. 2014; Gubler et al. 2015; Gross et al. 2024).

At each site, four replicate bulked soil samples from the upper soil layer 0–20 cm are taken within an area of 10m*10m. Each bulked sample consists of 25 single cores taken according to a stratified random sampling scheme. Further details are provided by SAEFL (2000a) and Gubler et al. (2015). Currently, results of sampling campaigns 1 to 7 are available for the cultivation types forest, grassland and cropland (Gross et al. 2024).

The spatial variation of bulk density was included in calculating the carbon stocks. Bulk density and soil skeleton (fragments >2 mm) were measured repeatedly for all monitoring sites at the occasion of sampling campaigns 4 to 7 (2000–2019), but not in the previous campaigns. The mass of fine earth (<2 mm; M_{FE}) per total soil volume (V_{tot}, including skeleton and pores) was determined for four volumetric samples 0–20 cm per site and campaign to derive the so-called apparent density of fine earth ($D = M_{FE} / V_{tot}$). Subsequently, SOC stocks (t C / ha) in 0–20 cm depth were calculated as D (g/cm^3) * SOC (%) * 20 (cm). For each site, the site-specific apparent density was used; repeated apparent density measurements per site were used to account for the variability of the bulk density.

The data presented here are based on samples collected from 1985 to 2019 at 28 forest sites (NABO 2021). SOC stocks for the top 20 cm of forest soils ranged from 41 to 149 t C

ha^{-1} with a mean of 72 t C ha^{-1}. Few sites have stocks higher than 90 t C ha^{-1} (Figure 6-9 top panel). There were no significant changes in SOC stocks over time except for the periods between the second and third, and the third and fourth sampling campaigns due to the exceptionally high SOC stocks in the third campaign (Figure 6-9 bottom panel). Previous NABO studies showed that the elevated SOC stocks for the third sampling campaign must be considered as artefact, induced by sub-optimal conditions during field work (Meuli et al. 2014; Gubler et al. 2015). These samples were collected earlier in the year and, thus, soils were moister. It is known that soil carbon has a high natural variation which may be pronounced if soil moisture differences are high. For instance, six resamplings within three years at two forest sites revealed short-term variation of SOC contents between ±1.8 % and ±0.6 % (single standard errors; Keller et al. 2006).

The monitoring scheme applied by NABO is able to detect relative changes in SOC contents of roughly 2.5 % per 10 years for mineral forest soils (minimum detectable change for 30 monitoring sites including three or more sampling campaigns). Regarding the measured SOC stocks (mean 72 t ha^{-1}), this corresponds to a minimum detectable change of roughly 0.18 t C ha^{-1} yr^{-1} for SOC stocks. In comparison, the mean change in SOC stocks obtained with Yasso07 for the period 1991–2010 was -0.00075±0.00053 t C ha^{-1} yr^{-1} (2SE; based on data in Didion and Thürig 2017). This value is several orders of magnitude smaller than the minimum detectable change that can be identified in the NABO monitoring scheme.

In conclusion, NABO data indicate that mineral soils on Forest land acted neither as a significant net source nor as a significant net sink of carbon when considered over the entire 34-year period.

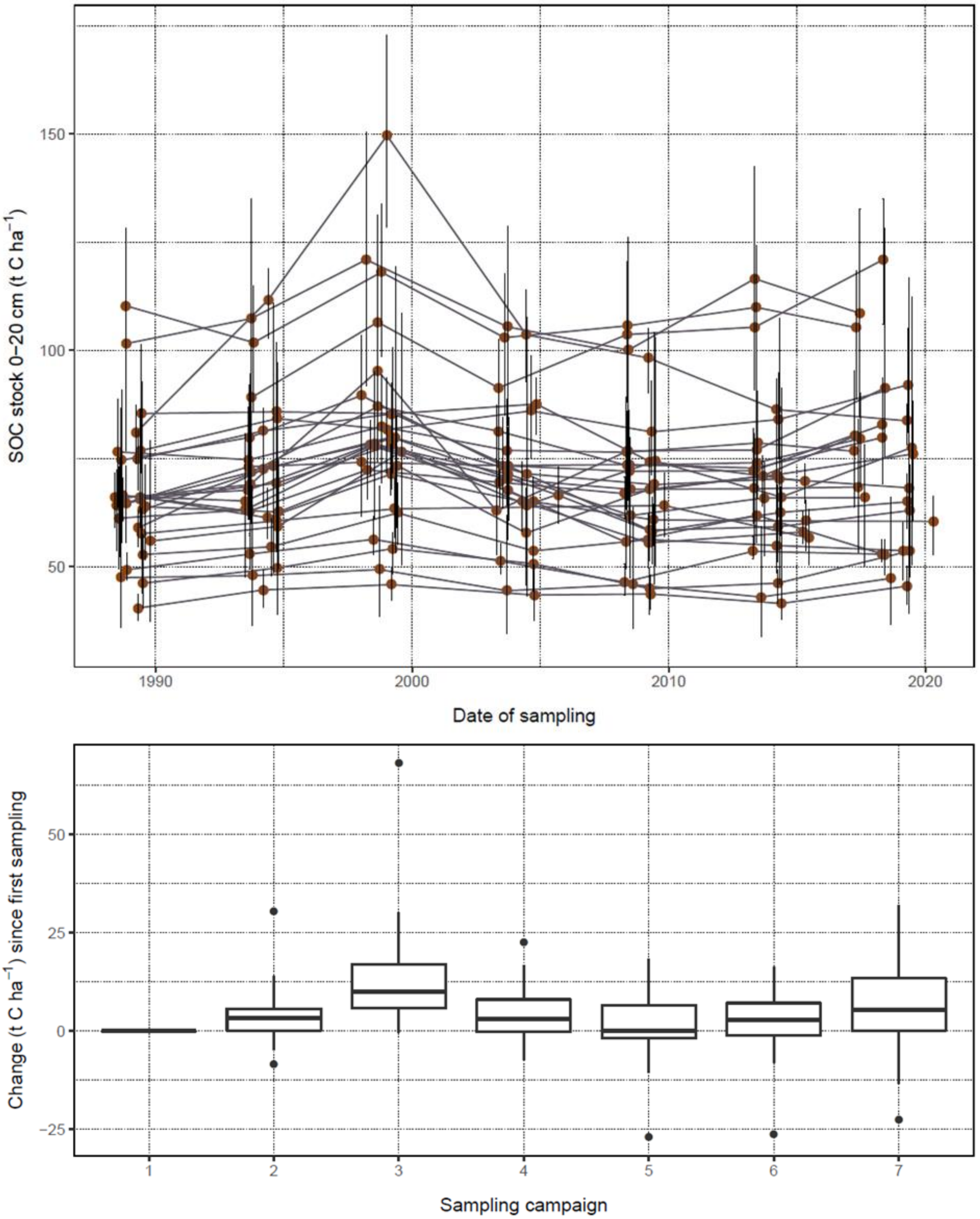

Figure 6-9 Measured SOC stocks for topsoils (0–20 cm) and their changes for 28 NABO long-term monitoring sites in forest during the time period 1985–2019. The elevation of the sites ranges from 383 to 1690 m a.s.l. Top panel: SOC stocks 0–20 cm per site and sampling; the dots indicate the mean and the bars the range of 5 % and 95 % percentiles of bootstrap samples taking into account the variability in SOC content of the individual replicates per site and sampling as well as the variations of the bulk density. Bottom panel: boxplot of changes in SOC stocks in each case related to the first sampling (boxes indicate the lower und the upper quartiles with the median indicated; lines include all observations inside the range of 1.5 times the interquartile distance, observations beyond that range are indicated as dots).

6.4.4.5. Uncertainty estimates

The double standard errors for the dead wood, litter and mineral soil carbon are 16.6 %, 96.7 %, and 37.0 %, respectively (chp. 6.4.3.1.2). The total uncertainty of the carbon stock change in DOM and mineral soil was estimated as 17.1 % (Didion 2023: chp. 3.1.4). This is in the range of uncertainty estimates of parties where the older version of the soil carbon model (Yasso07) was applied. For example, Norway reported an uncertainty of 15.5 %, which applied to both the DOM and mineral soil pools (Norwegian Environment Agency 2023: chp. 6.4.1.2), and Finland reported an uncertainty of 31.5 % in the net carbon stock changes in DOM and mineral soil (Lehtonen and Heikkinen 2016; Statistics Finland 2023: chp. 6.4.3.2).

6.4.5. Category-specific recalculations for 4A

The following recalculations were implemented. Major recalculations which contribute significantly to the differences in net emissions and net removals of sector 4A between the latest and the previous submissions are additionally presented in chp. 10.1.2.4.

- 4A: Activity data (areas) 2013–2021 were updated (see chp. 6.3.1.5). The inclusion of most recent data from the AREA5 survey led to small recalculations (Table 6-11).
- 4A: Organic soil: The dataset defining the geographical distribution of organic soils in Switzerland was updated (see chp. 6.3.1.5). The total area of organic soil in 1990 on Forest land increased from 3.8. to 5.4 kha (Figure 6-6 and Table 6-7).
- 4A: Data of the first 5 years of the NFI5, comprising the measurements in the period 2018 to 2022, provided the first occasion to derive robust estimates of carbon gains and losses between NFI4 and NFI5. This allowed to conclude the period between NFI3 and NFI4, which was the basis of data in previous submissions (see Didion et al. 2020). This in turn provided the opportunity to consistently derive data for the entire time series since 1990, i.e. including data from the periods NFI12 and NFI23, which were last derived for the submission in 2014 (FOEN 2014; Thürig and Herold 2013), and thereby taking account of
  - minor corrections and updates in the NFI database;
  - revised allometry for coarse roots; and
  - aggregation of spatial strata with the start of the NFI4 (see chp. 6.4.2.1.2);
  - annualisation of fellings only, i.e., the fraction affected by natural mortality is no longer annualised (see chp. 6.4.2.2.2);
  - inclusion of the harvest statistics data for 2022 in the derivation of annual values of carbon losses (see chp. 6.4.2.2.2).
- 4A: For the first time, Yasso20 was applied and replaced the previously used version Yasso07 (see chp. 6.4.2.1.4).
- 4(IV)A: The time series of CH_4 and N_2O emissions from wildfires 1990–2021 were recalculated for specific years due to updated activity data in the Swissfire database. Negligible changes resulted for the years 2015 and 2021 (see chp. 6.4.2.6.4.2). Further, the mass of available fuel was no longer calculated as an average stock, but was replaced by a continuous time series encompassing living biomass, dead wood and litter (chp. 6.4.2.6.4.2).

6.4.6. Category-specific planned improvements for 4A

6.4.6.1. Living biomass

6.4.6.1.1. Productive forest

As a result of the continuous monitoring of the Swiss Forests, new NFI data will be available regularly (see chp. 6.4.2.1.1.2). The adoption of new NFI data (based on a shifting five-year window) can affect the estimates of all reported pools as well as the calculation of the available fuel for wildfires in forests.

6.4.6.1.2. Unproductive forest

For the submission 2026 data to compare the changes in growing stock of brush forest between NFIs 4 and 5 will be available. Carbon stocks change factors for brush forest will be derived based on conversion factors to biomass and carbon and backcasting for the entire time series since the base year.

6.4.6.2. Dead wood, litter, and mineral soil

The implementation of the soil carbon model Yasso20 to improve the accuracy in the estimates of temporal changes in soil carbon, litter and dead wood is continuously developed. Depending on the availability of relevant data and studies, planned improvements include:

- Improving the uncertainty estimates for litter production by revising allometries and by estimating tree compartments using a Monte Carlo approach. This is expected to improve the accuracy of the estimates of carbon stocks and carbon stock changes.
- Taking advantage of further Yasso20 development arising from national and international projects, particularly in the context of the EU-Horizon project Pathfinder (https://pathfinder-heu.eu/) and the contribution by WSL to task 3.3 "Modelling carbon flux among pools".

6.5. Category 4B – Cropland

6.5.1. Description

Table 6-21 Key categories in category 4B Cropland. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	**IPCC category**	**Gas**	**Identification criteria**
4B1	Cropland remaining cropland	CO2	L1, L2, T1, T2
4B2	Land converted to cropland	CO2	L2

Swiss croplands belong to the cold temperate wet climatic zone. Croplands (CC21) include annual crops and leys in arable rotations (see Table 6-2 and Table 6-6).

In the inventory period, total net emissions of category 4B1 Cropland remaining cropland range from 87 kt CO_2 in 2009 to 865 kt CO_2 in 2014 (average 448 kt CO_2; Figure 6-10).

Annual fluctuations are mainly due to climatic influences on carbon stocks in living biomass and in mineral soil. In contrast, high stable carbon losses in organic soil characterise the net figures in 4B1 (although organic soil accounts only for 2.8 % of cropland area in Switzerland; Table 6-7). Carbon stocks in living biomass increased, whereas those in mineral soil decreased over the inventory period (see upper panels in Figure 6-11 and Figure 6-12).

Category 4B2 Land converted to cropland acts as a very small net sink in all years (average -8 kt CO_2; Figure 6-10) due to new soil formation and re-vegetation on former landfills and gravel pits under category 4B2.4 Settlements converted to cropland.

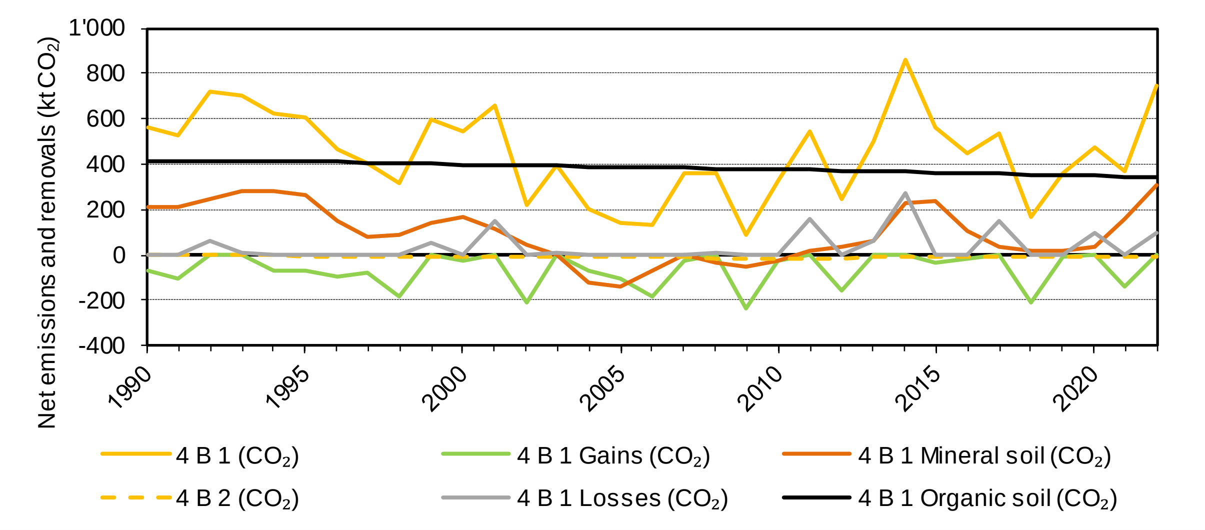

Figure 6-10 Net CO_2 emissions (positive values) and removals (negative values) from categories 4B1 and 4B2. Category 4B1 is broken down by gains in living biomass, losses in living biomass, net carbon stock changes in mineral soil, and net carbon stock changes in organic soil.

6.5.2. Methodological issues

Carbon stocks in living biomass as well as carbon stocks in mineral soil were estimated with a Tier 3 approach. The results were integrated in category 4B by calculating area-weighted (using the relative surface of crops) average values per elevation zone. The differences in carbon stocks (calculated as five-year moving average except for the previous and latest inventory years) between two consecutive years were reported as net changes for living biomass and for mineral soil.

6.5.2.1. Carbon stocks

6.5.2.1.1. Carbon stocks in living biomass

Annual carbon stocks in living biomass per elevation zone (see chp. 6.2.2.2) were calculated as area-weighted means of harvested biomass for the 19 most important annual crops (barley, broad beans ("Ackerbohnen"), fallow, fodder beet, maize (grain), oat, peas ("Eiweisserbsen"), potatoes, rape (cooking oil), rye, sugar beet, silage and green corn, sun flowers (cooking oil), soybean, spelt, triticale, vegetables, wheat) and as cumulated annual harvested biomass for clover-grass (leys).

Annual values 1990–2021 for harvested yields (dt ha^{-1}) were published by the Swiss Farmers Union (SBV 2022 and previous editions). Values for 2022 were calculated using the yield averages of the previous 5 years. The same allometric equation as used for soil organic carbon modelling was applied to estimate total biomass including roots (Wüst-Galley et al. 2020). A carbon fraction of 0.45 was assumed based on Bolinder et al. (2007).

Carbon stocks and carbon stock changes in living biomass were reported as moving averages over five years (from year-2 to year+2, e.g. 1988–1992 for the year 1990; the previous and latest inventory years were reported as four-year (year-2 to year+1) and three-year (year-2 to latest inventory year) moving averages, respectively). Data are shown in Table 6-22 and in Figure 6-11.

The rationale for this smoothing is that due to stockpiling, the consumption (and thus oxidation) of the biomass is levelled out between individual years (see Figure 6-11 upper panel). The resulting area-weighted (across the three elevation zones) mean carbon stock in living biomass for Cropland over the inventory time period was 6.85 t C ha^{-1}.

Table 6-22 Area-weighted (using the relative surface of crops per elevation zone) carbon stocks (t C ha^{-1}) and net carbon stock changes (t C ha^{-1} yr^{-1}) in living biomass of arable crops for land-use category Cropland (CC21), stratified for elevation zone (Elev.: Elevation Z1 = <601 m, Z2 = 601-1200 m, Z3 = >1200 m; see chp. 6.2.2.2). Highlighted data for 1990 are displayed in Table 6-4.

Living		**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
biomass	**Elev.**	CC21: carbon stock [t C ha^{-1}] and net change in living biomass [t C ha^{-1} yr^{-1}]									
Stock	Z1	6.38	6.46	6.41	6.41	6.45	6.50	6.56	6.61	6.73	6.69
Stock	Z2	6.39	6.45	6.41	6.41	6.45	6.50	6.57	6.63	6.76	6.74
Stock	Z3	6.07	6.15	6.13	6.10	6.12	6.11	6.21	6.32	6.48	6.56
Net change	Z1	0.05	0.07	-0.04	-0.01	0.05	0.05	0.06	0.05	0.12	-0.05
Net change	Z2	0.04	0.06	-0.04	0.00	0.05	0.04	0.07	0.06	0.13	-0.02
Net change	Z3	0.08	0.08	-0.02	-0.02	0.02	-0.01	0.10	0.10	0.16	0.08

Living		**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
biomass	**Elev.**	CC21: carbon stock [t C ha^{-1}] and net change in living biomass [t C ha^{-1} yr^{-1}]									
Stock	Z1	6.70	6.60	6.75	6.74	6.79	6.86	7.00	7.02	7.01	7.19
Stock	Z2	6.76	6.67	6.81	6.81	6.86	6.94	7.06	7.07	7.06	7.21
Stock	Z3	6.63	6.59	6.73	6.78	6.87	7.02	7.12	7.15	7.12	7.21
Net change	Z1	0.02	-0.11	0.15	0.00	0.05	0.07	0.13	0.02	-0.01	0.19
Net change	Z2	0.02	-0.09	0.14	0.00	0.05	0.08	0.12	0.02	-0.01	0.15
Net change	Z3	0.07	-0.04	0.14	0.05	0.09	0.15	0.10	0.02	-0.03	0.09

Living		**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
biomass	**Elev.**	CC21: carbon stock [t C ha^{-1}] and net change in living biomass [t C ha^{-1} yr^{-1}]									
Stock	Z1	7.22	7.11	7.23	7.19	6.97	7.00	7.02	6.90	7.06	7.07
Stock	Z2	7.23	7.11	7.22	7.15	6.97	7.00	7.00	6.89	7.08	7.08
Stock	Z3	7.19	7.05	7.15	7.01	6.89	6.88	6.85	6.78	7.02	7.01
Net change	Z1	0.03	-0.11	0.12	-0.04	-0.21	0.03	0.02	-0.12	0.16	0.01
Net change	Z2	0.01	-0.12	0.12	-0.07	-0.18	0.02	0.00	-0.11	0.19	0.00
Net change	Z3	-0.02	-0.14	0.10	-0.13	-0.12	-0.01	-0.03	-0.07	0.24	-0.01

Living		**2020**	**2021**	**2022**
biomass	**Elev.**	CC21: carbon stock [t C ha^{-1}] and net change in living biomass [t C ha^{-1} yr^{-1}]		
Stock	Z1	6.99	7.09	7.04
Stock	Z2	7.01	7.13	7.08
Stock	Z3	6.97	7.14	7.08
Net change	Z1	-0.08	0.10	-0.07
Net change	Z2	-0.07	0.13	-0.08
Net change	Z3	-0.05	0.17	-0.10

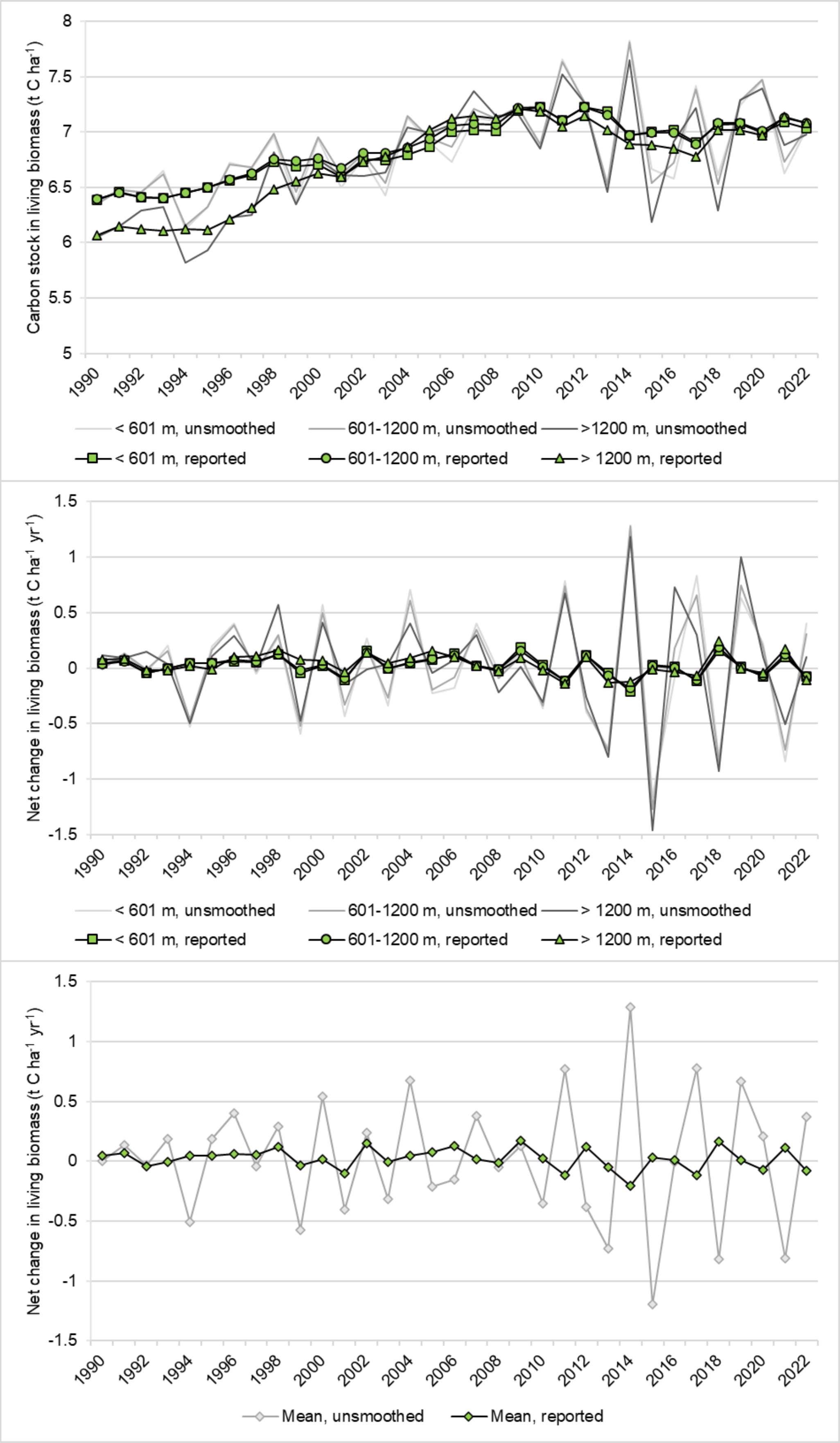

Figure 6-11 Reported carbon stocks (t C ha^{-1}) and net carbon changes (t C ha^{-1} yr^{-1}) in living biomass of Cropland and underlying unsmoothed data (shown for transparency reasons), stratified for elevation zone (upper and middle panel) and area-weighted means (across three elevation zones; lower panel). Upper and lower confidence intervals are too small to be distinguished from the mean. Elevation zone >1200 m is less important as it covers only 0.1 % of the total cropland area (see Table 6-7).

6.5.2.1.2. Carbon stocks in dead organic matter

Carbon stocks in dead organic matter were assumed to be zero.

6.5.2.1.3. Carbon stocks in soil

6.5.2.1.3.1. Mineral soil

Initial carbon stocks

Initial carbon stocks in mineral soil under Cropland were calculated using a digital soil mapping approach, as described in Stumpf et al. (2023). In this approach, a regression model describing the statistical relationship between a soil property (e.g., carbon concentration) measured at many points and continuous variables that influence soil properties (e.g., climate relief or parent rock material) is estimated. This relationship is then applied to those continuous variables to predict that soil property for the whole surface of interest.

Stumpf et al. (2023) estimated soil organic carbon stocks for individual points using the following equation:

$$SOC_{stock} = SOC_{conc} \times BD \times (1 - CF) \times D$$

where SOC_{stock} is the carbon stock (kg m^{-2}) in the upper 30 cm of soil, SOC_{conc} is the carbon concentration (%), BD is the bulk density of soil (g cm^{-3}), CF is the proportion of coarse fragments in the soil and D is the thickness of the sample (here, 30 cm).

Soil carbon concentration measurements were available for 10'258 points (of which 4'815 were from cropland; obtained from the national soil information system database (NABODAT, https://www.nabodat.ch); mean sample density for cropland: 1.3 samples per km^2). Bulk density measurements were available for 10 % of these soil samples. For the remaining 90 %, bulk density was estimated using a pedotransfer function, describing bulk density as a function of: soil carbon concentration, soil cover, climate, vegetation or land use, relief and parent rock material. This function was estimated using a regression forest model. The proportion of coarse fragments was derived from the nationwide soil suitability map (Bodeneignungskarte; SFSO 2000a).

To estimate the nation-wide carbon stocks, Stumpf et al. (2023) then estimated the statistical relationship between the above-mentioned carbon stock point information and 668 continuous variables related to climate, land use, relief, parent rock material, and a ‘bare soil map’ derived from satellite data. The statistical relationship was derived using a regression forest method.

The products of this mapping are raster data sets of 30 m resolution showing soil carbon stocks for the upper 30 cm of cropland soils, per year, for the period 1995–2020. An average of the estimates of carbon stocks for the years 1995 to 2000 was used to represent the initial soils carbon stocks for 1987 in the RothC modelling for each of the regions simulated (see below). No earlier SOC stock estimates are available. The mean initial soil organic carbon stock (0–30 cm) for Cropland is 59.1 t C ha^{-1} (standard deviation = 10.5 t C ha^{-1}).

Simulation of carbon stocks through time

Switzerland used the soil carbon model RothC (Coleman et al. 1997; Coleman and Jenkinson 1999) to estimate carbon stocks in mineral soil (0–30 cm) under Cropland for the inventory period. The implementation of RothC in LULUCF reporting is described in detail in Wüst-Galley et al. (2020) and Wüst-Galley et al. (2019: p. 71, the up-scaling to elevation zone). In contrast to Wüst-Galley et al. (2020), the years 1975–1986 (referred to as “historic simulations”, see p. 63) are no longer included in the current simulations, because the new SOC stocks are already influenced by recent agricultural management. The first simulated year is 1987, allowing a five-year average for the carbon stock change for 1990 (calculated as difference between 1989 and 1990) to be calculated.

RothC is a model for the turnover of organic carbon in mineral soil, implementing four active carbon pools each associated with their own decomposition rates. In addition, there is a small carbon pool that is considered to be stable (inert). The model runs and calculates soil carbon stocks on a monthly basis. The decomposition rates are altered by temperature, moisture, soil cover and the soil’s clay content. RothC requires information on climate (monthly precipitation, temperature and evapotranspiration), monthly carbon inputs (from organic manures and from plants, including above- and below ground harvest residues and root exudates) and soil (clay content, monthly soil cover). Testing and validation of RothC are described in Wüst-Galley et al. (2020).

Input data

Gridded climate data were obtained from the Federal Office of Meteorology and Climatology (MeteoSwiss 2021), including monthly average temperature and monthly (total) precipitation. Monthly evapotranspiration was calculated with the Priestley-Taylor method using these two data sets as well as monthly surface incoming short wave radiation (SIS), also obtained from MeteoSwiss. The most important 19 crops (as introduced in chp. 6.5.2.1.1, covering over 99 % of Swiss cropland area) were considered. Annual crop yields (dt ha^{-1}) were obtained from the Swiss Farmers Union (SBV 2022 and previous editions). Based on yield data from crops, plant carbon inputs to the soil from crop residues, roots and rhizodeposition were estimated using an allometric function adapted from Bolinder et al. (2007), as described in Wüst-Galley et al. (2020). Annual carbon inputs from organic manures to different types of crops or grasslands were calculated based on: (1) organic manure production, calculated as a function of excretion rate of volatile solids, using the method described in chp. 5.3.2.2.1; (2) animal herd size, described in chp. 5.3.2.5.1; (3) the share of manure management systems, described in chp. 5.3.2.2.4 (using the data for volatile solids); (4) the tendency of farmers to apply different types of manure onto four different crop / grass categories, using information obtained from the Swiss ammonium model AGRAMMON (Kupper et al. 2022); (5) the different fertilisation needs of individual crops or grasslands of differing management intensities (obtained from the “Principles of Fertilisation of Agricultural Crops in Switzerland" (GRUD; Richner and Sinaj 2017); (6) straw production, using annual values published by the Swiss Farmers Union (SBV 2022 and previous editions); (7) the amount of manure digested anaerobically in biogas plants, as described in chp. 5.3.2.2.3; (8) the amount of liquid and solid digestates, as described in chp. 5.5.2.2.2; and (9) the number of livestock units moving annually to the summer pasture regions, using annual data (1999 to present, prior years using extrapolation) that are collected for the calculation of subsides for this summer grazing (“Sömmerungsbeiträge”), from the Federal Office for Agriculture. Soil cover and the distribution of plant inputs throughout the year were determined using sowing and harvest dates from various agricultural guidelines, as described in Wüst-Galley et al. (2020).

Information on the clay content was estimated using a digital soil mapping approach, as detailed in Stumpf et al. (2023a).

Up-scaling

The RothC modelling was carried out for 4'560 different combinations (19 crops x 240 regions) representing similar climate, crop type, management systems and clay content, as described in Wüst-Galley et al. (2020). Based on the estimate of clay content (see previous paragraph), 10 clay classes were derived (2.5 % to 42.5 %, in 5 % increments, and > 45 %). An average initial soil organic carbon stock was calculated for the cropland area in each of the 240 regions. The simulated carbon stocks were then upscaled using the proportion of different crop types within each region, as well as the surface of each region, to calculate weighted means (Wüst-Galley et al. 2020).

Reporting

Carbon stocks in mineral soil were integrated in category 4B by calculating area-weighted (using the relative surface of crops) average values per elevation zone. The results were reported as moving averages over five years (from year-2 to year+2, e.g. 1988–1992 for the year 1990; the previous and latest inventory years were reported as four-year (year-2 to year+1) and three-year (year-2 to latest inventory year) moving averages, respectively). Data are shown in Table 6-23 and in Figure 6-12 upper panel.

Unsmoothed data mainly reflect effects of climatic conditions, whereas long-term trends related to e.g. changes in agricultural management are better visible when the data are smoothed. The resulting area-weighted (across the three elevation zones) mean carbon stock in mineral cropland soil over the inventory period was 57.53 t C ha^{-1}.

Table 6-23 Area-weighted (using the relative surface of crops per elevation zone) carbon stocks (t C ha^{-1}) and net carbon stock changes (t C ha^{-1} yr^{-1}) in mineral soil (0-30 cm) for land-use category Cropland (CC21), stratified for elevation zone (Elev: Elevation Z1 = <601 m, Z2 = 601-1200 m, Z3 = >1200 m; see chp. 6.2.2.2). Highlighted data for 1990 are displayed in Table 6-4.

Mineral		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
soil	Elev.	CC21: carbon stock [t C ha^{-1}] and net change in mineral soil [t C ha^{-1} yr^{-1}]									
Stock	Z1	58.25	58.12	57.95	57.74	57.54	57.34	57.23	57.18	57.11	57.01
Stock	Z2	59.82	59.67	59.50	59.33	59.16	59.00	58.90	58.85	58.80	58.70
Stock	Z3	51.91	51.99	52.03	52.04	52.03	52.03	52.05	52.14	52.29	52.46
Net change	Z1	-0.14	-0.14	-0.17	-0.20	-0.21	-0.19	-0.11	-0.05	-0.07	-0.11
Net change	Z2	-0.16	-0.15	-0.16	-0.18	-0.17	-0.16	-0.10	-0.05	-0.06	-0.10
Net change	Z3	0.07	0.07	0.04	0.01	-0.01	-0.01	0.03	0.08	0.15	0.17

Mineral		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
soil	Elev.	CC21: carbon stock [t C ha^{-1}] and net change in mineral soil [t C ha^{-1} yr^{-1}]									
Stock	Z1	56.88	56.80	56.78	56.79	56.89	57.01	57.06	57.05	57.07	57.11
Stock	Z2	58.59	58.50	58.45	58.43	58.50	58.58	58.63	58.65	58.68	58.73
Stock	Z3	52.60	52.85	53.19	53.55	53.96	54.34	54.60	54.75	54.85	54.88
Net change	Z1	-0.13	-0.08	-0.02	0.01	0.10	0.12	0.05	-0.01	0.02	0.04
Net change	Z2	-0.11	-0.09	-0.05	-0.02	0.06	0.08	0.06	0.02	0.04	0.04
Net change	Z3	0.15	0.25	0.33	0.36	0.41	0.39	0.25	0.15	0.10	0.03

Mineral		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
soil	Elev.	CC21: carbon stock [t C ha^{-1}] and net change in mineral soil [t C ha^{-1} yr^{-1}]									
Stock	Z1	57.12	57.11	57.09	57.05	56.87	56.67	56.60	56.60	56.60	56.61
Stock	Z2	58.74	58.71	58.68	58.62	58.45	58.28	58.17	58.09	58.03	57.98
Stock	Z3	54.86	54.81	54.72	54.59	54.44	54.26	54.21	54.25	54.33	54.40
Net change	Z1	0.02	-0.01	-0.03	-0.04	-0.18	-0.19	-0.07	0.00	0.00	0.01
Net change	Z2	0.01	-0.02	-0.03	-0.06	-0.17	-0.18	-0.11	-0.08	-0.06	-0.06
Net change	Z3	-0.01	-0.06	-0.09	-0.13	-0.15	-0.18	-0.05	0.04	0.08	0.07

Mineral		2020	2021	2022
soil	Elev.	CC21: carbon stock [t C ha^{-1}] and net change in mineral soil [t C ha^{-1} yr^{-1}]		
Stock	Z1	56.60	56.58	56.46
Stock	Z2	57.92	57.88	57.78
Stock	Z3	54.58	54.65	54.65
Net change	Z1	-0.01	-0.13	-0.27
Net change	Z2	-0.06	-0.14	-0.23
Net change	Z3	0.18	0.11	0.02

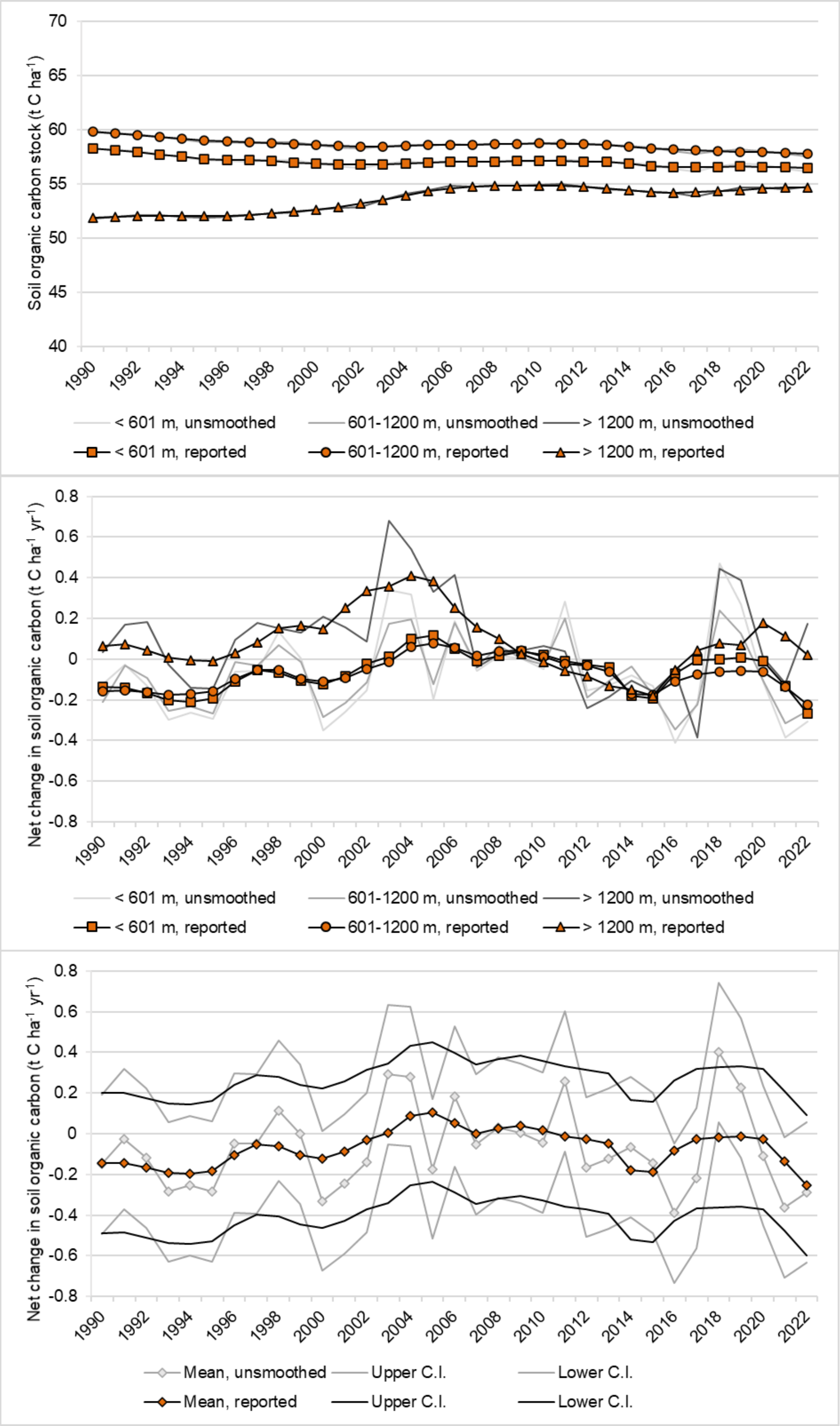

Figure 6-12 Reported carbon stocks (t C ha^{-1}) and net carbon changes (t C ha^{-1} yr^{-1}) in Cropland mineral soil (0–30 cm) and underlying unsmoothed data (shown for transparency reasons), stratified for elevation zone (upper and middle panel) and area-weighted means (across three elevation zones; lower panel) plus upper and lower confidence intervals (C.I.; see chp. 6.5.3.1.2). Elevation zone >1200 m is less important as it covers only 0.1 % of the total cropland area.

6.5.2.1.3.2. Organic soil

Soil carbon stocks in organic soil under Cropland were calculated based on Leifeld et al. (2003, 2005). The approach used measured carbon stocks in Swiss organic soils. The mean soil organic carbon stock (0–30 cm) of cultivated organic soil was 240±48 t C ha^{-1} (uncertainty 20 %).

6.5.2.2. Changes in carbon stocks

6.5.2.2.1. Carbon stock changes in living biomass

The difference in biomass carbon stock (five-year moving average, see chp. 6.5.2.1.1) between two consecutive years was reported as net carbon stock change (gain or loss) (see Table 6-22 and Figure 6-11 middle panel). For transparency reasons, unsmoothed changes in carbon stocks were also displayed in Figure 6-11. The mean area-weighted carbon stock change across all elevation zones was 0.021 t C ha^{-1} yr^{-1} for the inventory time period.

6.5.2.2.2. Carbon stock changes in dead organic matter

Applying a Tier 1 approach, carbon stock changes in dead organic matter were assumed to be in equilibrium for Cropland remaining cropland.

6.5.2.2.3. Carbon stock changes in soil

6.5.2.2.3.1. Mineral soil

The difference in carbon stock (five-year moving average, see chp. 6.5.2.1.3.1) between two consecutive years was reported as net carbon stock change (gain or loss) in Cropland mineral soil (see Table 6-23 and Figure 6-12 middle panel). For transparency reasons, unsmoothed changes in carbon stocks were also displayed in Figure 6-12.

The mean carbon stock change in the inventory period for elevation zone 1 was -0.066 t C ha^{-1} yr^{-1} and for elevation zone 2 -0.074 t C ha^{-1} yr^{-1} (elevation zone 3 is less important as it covers 0.1 % of Cropland; see Table 6-7). The mean area-weighted carbon stock change across all elevation zones was -0.068 t C ha^{-1} yr^{-1}.

6.5.2.2.3.2. Organic soil

The annual net carbon stock change in organic soil was estimated to -9.52 t C ha^{-1} according to measurements in Europe including Switzerland as compiled by Leifeld et al. (2003, 2005) and verified by ART (2009b) and Paul and Alewell (2018).

6.5.2.2.4. Land-use change

In the case of land-use change, the net carbon stock changes in biomass and soils were calculated as described in chp. 6.1.3.

6.5.2.3. Non-CO_2 emissions from Cropland

6.5.2.3.1. N_2O and CH_4 emissions from drainage of organic soil

N_2O emissions from drainage of organic soil (category 4(II)) in Cropland were reported in the Agriculture sector (category 3D1f Cultivation of organic soils; see chp. 5.5.1).

CH_4 emissions were not estimated (notation key NE) in 4(II) as reporting is not mandatory for this category.

6.5.2.3.2. Direct and indirect N_2O emissions from mineral soils

The calculations of direct and indirect N_2O emissions from nitrogen mineralisation in mineral soil are described in Annex A5.4.

Direct and indirect N_2O emissions from Cropland remaining cropland were included in the Agriculture sector in category 3D1e Mineralisation (see chp.5.5.1), whereas those from Lands converted to cropland (category 4(III)B2) were reported under LULUCF.

6.5.2.3.3. CH_4 and N_2O emissions from biomass burning

CH_4 emissions and N_2O emissions from biomass burning in Cropland (category 4(IV)B) were not occurring (notation key NO).

6.5.3. Uncertainties and time-series consistency for 4B

6.5.3.1. Uncertainties

Detailed results of approach 1 and approach 2 uncertainty analyses are given in Annex A2.2 and Annex A2.3, respectively. Note that in this submission the four categories according to the CRF nomenclature 4(II), 4(III), 4(IV) and 4(V) are still used.

6.5.3.1.1. Activity data

Uncertainties of activity data of category 4B Cropland are described in chp. 6.3.1.3.1.

6.5.3.1.2. Overall uncertainties of carbon stock changes and emission factors

For calculating the overall uncertainty of category 4B, all emissions and removals from living biomass, dead organic matter, mineral soil and organic soil were considered. The uncertainties of carbon stock change factors and emission factors were calculated for 1990 and the reporting year (see overview in Table 6-5).

Living biomass

The relative uncertainty in yield determination was estimated as 13 % for biomass carbon from agricultural land (Leifeld and Fuhrer 2005).

Dead organic matter

Emissions from the dead organic matter pool occur only by land-use changes from Forest land to Cropland as the carbon stock of dead organic matter is assumed to be zero in the non-forest land-use categories. Thus, the uncertainty of these emissions corresponds to the uncertainty of carbon stocks in litter and dead wood on Forest land. Based on the results of the Yasso20 model supplied by Didion (2023), a relative uncertainty of 0.5 % was calculated for the total carbon stock in litter and dead wood (Meteotest 2024).

Mineral soil

The absolute uncertainty of 0.344 t C ha^{-1} yr^{-1} was used for annual carbon stock changes in categories 4B1 and 4B2, as calculated by a Monte Carlo analysis (Wüst-Galley et al. 2020). That uncertainty analysis considered variation in the following input parameters: carbon inputs from farmyard manure and plants, the extent of summer pastures, and monthly temperature, precipitation and evapotranspiration. For the Monte Carlo analysis it was assumed that the extent of variation in input parameters is unchanged from one year to the next. By comparison, the range of annual SOC changes identified for 71 different treatments of Swiss agricultural long-term experiments is 1.87 t C ha^{-1} (Keel et al. 2019), suggesting that the calculated uncertainty might have been underestimated (Wüst-Galley et al. 2020).

The resulting relative uncertainty in 2022, calculated with the implied carbon stock change factors of mineral soil, is 135.9 % for category 4B1 and 450.1 % for category 4B2.

Organic soil

The uncertainty of the carbon stock change (emission factor) in organic soil is 23 % as reported by Leifeld et al. (2003: 56) and the uncertainty of the activity data (area of organic soil) is 37.3 % (see chp. 6.3.1.3.2).

Overall uncertainties categories 4B1 and 4B2

Using the detailed input uncertainties as described above, the uncertainty propagation for categories 4B1 and 4B2 was computed using Monte Carlo simulations (see chp. 1.6.2). The resulting overall uncertainties of approach 2 for categories 4B1 and 4B2 emissions and removals in 2022 are (-60, +59 %) and (-696, +693 %), respectively (see Annex A2.3).

6.5.3.2. Time-series consistency

Time series for category 4B Cropland are all considered consistent; they were calculated based on consistent methods and homogenous databases (Wüst-Galley et al. 2020). Small inconsistencies in the input data for the RothC model (related to livestock husbandry, chp. 5.2.3) are barely relevant for the overall results.

6.5.4. Category-specific QA/QC and verification for 4B

The general QA/QC measures are described in chp. 1.5.

6.5.4.1. Carbon stocks in living biomass

The crop yield data for the reporting year are available always in the most recent Swiss Farmers' Union's annual report. Since this report is usually not available in time, the inventory is prepared with a provisional value for the reporting year. The correction of this provisional value in the following submission leads by default to a recalculation for the year in question and also affects the neighbouring years due to the moving average approach (see chp. 6.5.2.1.1).

6.5.4.2. Carbon stocks in mineral soil

The initial SOC stocks for the latest submission are based on newly available digital soil maps (Stumpf et al. 2023, 2023a). The new approach explains the changes in soil carbon stocks and also in stock changes as described in chp. 10.1.2.4. The initial SOC stocks for the three elevation zones are (for 0–30 cm): 58.8 t C ha^{-1} (Z1), 60.4 t C ha^{-1} (Z2), 51.8 t C ha^{-1} (Z3). In the previous submission, the initial SOC stocks were substantially lower at all elevations: 49.5 t C ha^{-1} (Z1), 49.2 t C ha^{-1} (Z2), 37.5 t C ha^{-1} (Z3). Compared to the method used for previous submissions, the model applied for digital soil mapping was calibrated and validated using a much larger number of data points for carbon and clay content and fourteen times more points for carbon stocks. Furthermore, the complexity of the model is much higher, including a lot more parameters covering a wider range of biophysical processes.

6.5.4.3. Carbon stock changes in mineral soil

6.5.4.3.1. RothC

RothC, used to model SOC stock changes, is a relatively simple model that does not represent certain soil processes such as feedback due to microbial processes or consider other nutrient cycles. It was however the best-performing model given the available data for Switzerland, considering also temporal resolution (Wüst-Galley et al. 2020). The calibration of the allometric equations (for deriving carbon inputs from crop yields), as well as a comparison of simulated SOC stock changes with measured values from field experiments is described in Wüst-Galley et al. (2020). A sensitivity analysis of the RothC simulations and of the system used to upscale these simulations to the national scale was completed (Wüst-Galley et al. 2021).

In 2003 and 2018 mean area-weighted unsmoothed increases in SOC stocks are exceptionally high (see Figure 6-12 lower panel). The peak carbon stock changes might be explained by strongly reduced SOC decomposition in RothC caused by high soil moisture deficits (these summers were exceptionally warm and dry in Switzerland leading to high evapotranspiration relative to precipitation). Such model behaviour in RothC was also identified by Falloon et al. (2011). Recent model experiments for potato and maize in the most important cropping region of Switzerland support this explanation by showing reduced SOC stocks with irrigation. In 2003 and 2018, peak SOC values were obtained for cropland but not for permanent grassland (see Figure 6-16). This can be explained by the distribution of these two land-use types: Cropland is concentrated in regions prone to high topsoil moisture deficit (lowlands), whereas permanent grassland is distributed more evenly across the country, including wetter and cooler (upland) regions.

The recalculations related to newly available soil information described in detail in chp. 10.1.2.4 have an influence on the carbon stock changes of Cropland. For the majority of years, the mean stock change is negative (i.e., SOC was lost; Figure 6-12 lower panel). This trend is dominated by the results for the two lower elevation zones (Z1 and Z2; Figure 6-12 middle panel). However due to high uncertainties, mean stock changes across all elevation zones are not statistically significant for any year (see confidence intervals in Figure 6-12 lower panel).

The negative mean SOC stock change for the entire inventory period (-0.068 t C ha^{-1} yr^{-1}) agrees with the European-scale decline in SOC content that was estimated by De Rosa et al. (2024) for cropland remaining cropland based on data from the Land Use/Land Cover Area Frame Survey (LUCAS) for the years 2009–2018. If only stock changes for the identical time span (i.e., 2009–2018) are compared, the direction of change still agrees (-0.052 t C ha^{-1} yr^{-1}; Figure 6-12 lower panel). Quantitative comparisons, however, are not possible because different metrics were used.

The patterns of year-to-year changes in SOC stocks are similar to previous submissions (e.g. FOEN 2023: Figure 6-11), because they are mainly driven by weather conditions that remained unchanged. Overall, the changes induced by these recalculations suggest that trends in SOC changes are strongly affected by initial SOC stocks whereas year-to-year variability in SOC changes are controlled by weather conditions.

6.5.4.3.2. Swiss Soil Monitoring Network (NABO)

The SOC stocks measured at 30 cropland monitoring sites of the NABO (NABO 2021a; see chp. 6.4.4.4) featuring mineral soils indicate no significant changes from 1990 to 2019. The apparent decline of SOC stocks from the first to the sixth sampling campaign (see Figure 6-13 bottom panel) was identified as artefact induced by the date of sampling. In the first campaign, samplings were conducted substantially later in the year compared with the remaining campaigns, which induced higher SOC contents and, thus, SOC stocks. Changes in SOC stocks over time are less pronounced when compared to the second sampling campaign, as shown in Gubler et al. (2019). The range of the calculated SOC stocks in 0–20 cm depth was large (20–87 t C ha^{-1}) with a mean of 47 t C ha^{-1} (Figure 6-13 top panel). Minor changes in SOC stocks occurred only on single cropland sites, and could be assigned to changed amounts of farmyard manure applications (Gubler et al. 2019).

The monitoring scheme applied by NABO is able to detect relative changes in SOC contents of roughly 3.5 % per 10 years for mineral cropland soils (minimum detectable change for 30 monitoring sites including three or more sampling campaigns; Gubler et al. 2019). Regarding the measured SOC stocks (mean 47 t ha^{-1}) this corresponds to a minimum detectable change of roughly 0.16 t C ha^{-1} yr^{-1} for SOC stocks.

The mean change in SOC which was calculated with RothC for the years 1990–2022 was -0.068±0.344 t C ha^{-1} yr^{-1} (area-weighted mean across three elevation zones ± absolute uncertainty based on a Monte Carlo analysis; see Figure 6-12 lower panel and chp. 6.5.3.1.2). In comparison, the modelled net carbon change is clearly smaller than the detectable change by NABO and suggests that modelled SOC stock changes agree with the repeated soil inventories in the NABO network.

In conclusion, the NABO data indicate that Cropland mineral soils acted neither as a significant net source nor as a significant net sink of carbon when considered over the entire

34-year period. Gubler et al. (2019) concluded that SOC contents in cropland sites of the NABO have approached a steady-state at sites where agricultural management and crop rotation have remained relatively constant.

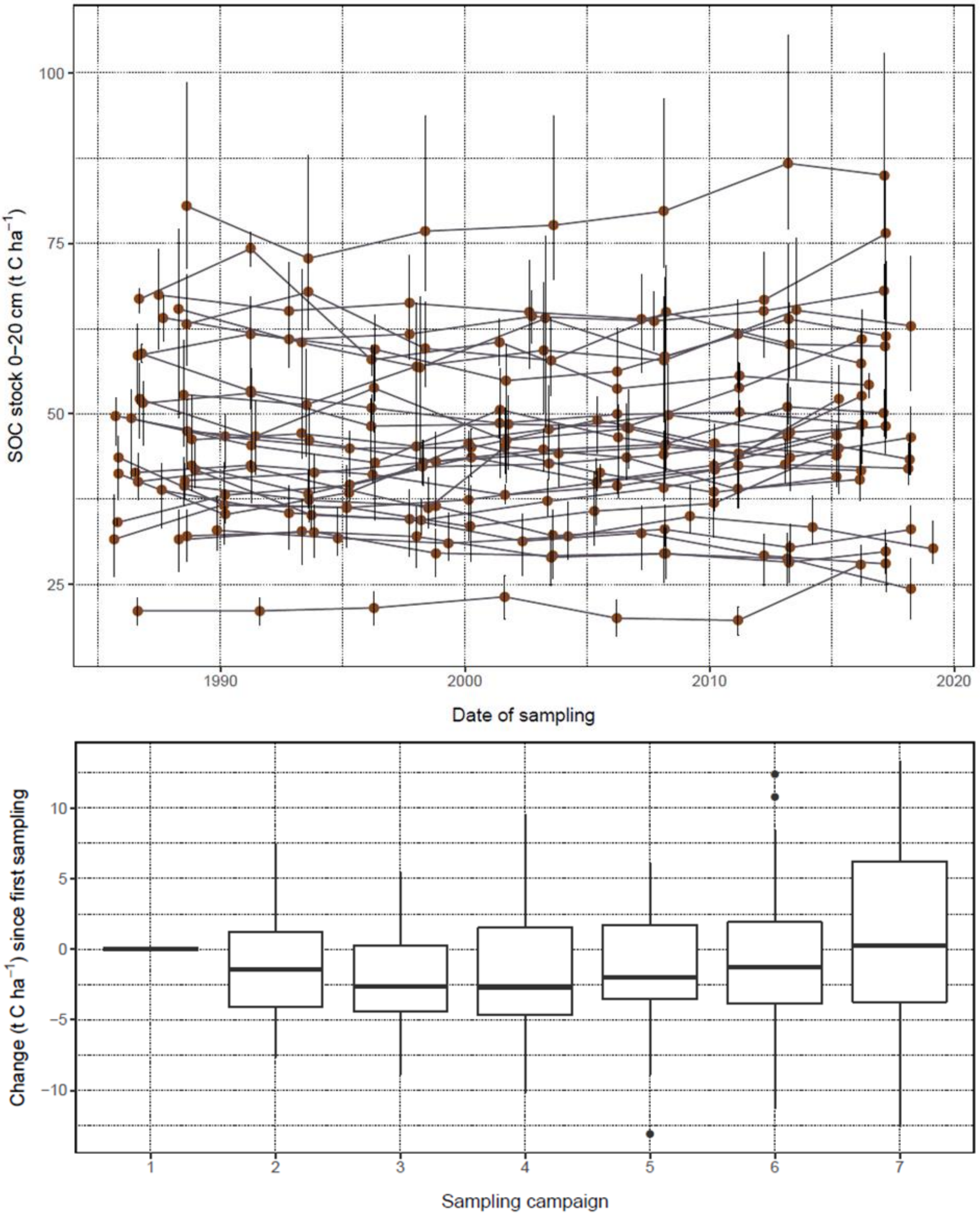

Figure 6-13 Measured SOC stocks for topsoils (0–20 cm) and their changes for 30 NABO long-term monitoring sites used as cropland during the time period 1985–2019. The elevation of the sites ranges from 324 to 945 m a.s.l. Top panel: SOC stocks 0–20 cm per site and sampling; the dots indicate the mean and the bars the range of 5 % and 95 % percentiles of bootstrap samples taking into account the variability in SOC content of the individual replicates per site and sampling as well as the variations of the bulk density. Bottom panel: boxplot of changes in SOC stocks in each case related to the first sampling (boxes indicate the lower und the upper quartiles with the median indicated; lines include all observations inside the range of 1.5 times the interquartile distance, observations beyond that range are indicated as dots).

6.5.4.4. Short-term land-use changes in arable rotations

Short-term land-use changes between apparent Grassland and Cropland are to be expected for leys in arable rotations. However, leys were allocated to Cropland by the Swiss Land Use Statistics (AREA) and were thus not considered grasslands in the usual sense (i.e. permanent grassland). Since only long-term land-use changes are registered by the Swiss Land Use Statistics (AREA), carbon stock changes in soils associated with land-use changes between Cropland and Grassland and vice versa were adequately reported in the GHG inventory.

6.5.5. Category-specific recalculations for 4B

The following recalculations were implemented. Major recalculations which contribute significantly to the differences in net emissions and net removals of sector 4B between the latest and the previous submissions are additionally presented in chp. 10.1.2.4.

- 4B: Activity data (areas) 2013–2021 were updated (see chp. 6.3.1.5). The inclusion of most recent data from the AREA5 survey led to small recalculations (Table 6-11).
- 4B: Organic soil: The dataset defining the geographical distribution of organic soils in Switzerland was updated (see chp. 6.3.1.5). The total area of organic soil in 1990 on Cropland increased from 11.7 to 12.2 kha (Figure 6-6 and Table 6-7).
- 4B: Carbon stock changes in living biomass were recalculated for 2021, based on newly available data (SBV 2022).
- 4B: Carbon stocks and carbon stock changes in mineral soil were recalculated for the whole inventory period, applying
  - new soil information (initial soil carbon stocks and clay content classes), following newly available estimates (described in chp. 6.5.2.1.3.1). The effect of this is that the direction of the mean carbon stock change for Cropland soil changes from 0.006 t C ha^{-1} yr^{-1} in the previous submission to -0.068 t C ha^{-1} yr^{-1} in the latest submission. However, it is important to note that uncertainties are high and carbon stock changes are not statistically significant for any of the inventory years.
  - updated information used for the calculation of organic amendments for the year 2021 (animal numbers, straw production and the amount of manure going to biogas plants), following the availability of new data (SBV 2022). This recalculation had a negligible effect on mineral soil carbon changes;
  - updated yield data for 2021, based on the newly available data (SBV 2022). This recalculation had a negligible effect on mineral soil carbon changes.
  - A small mistake in a function that is used to prepare the input data for modelling with RothC was corrected. The belowground harvest residues for rye and spelt were estimated using a yield-dependent function instead of a constant value that is used for all cereals. This recalculation had a very small influence on the results.

6.5.6. Category-specific planned improvements for 4B

6.5.6.1. Living biomass

Price et al. (2017) created a nationwide model for above ground tree biomass in Switzerland (both inside and outside of forest), using structural information available from airborne laser scanning. The model offers significant opportunity for improved estimates of carbon stocks in living biomass on land-use categories where tree biomass has either not been included or only roughly estimated until now. The tree biomass model of Price et al. (2017) was calibrated and evaluated based on reference plots from the NFI. The model showed promising results at the Tier 3 level. However, further improvement could be achieved if additionally specific reference data from non-Forest land would be available. In a pioneering study, 62 felled urban reference trees with actual above ground tree biomass as well as many detailed predictor variables were surveyed (Mathys et al. 2019; Kükenbrink et al. 2021). To account for the detected differences in tree geometry and associated biomass pattern a nationwide non-Forest land field survey of above ground tree biomass at the plot level was initiated by FOEN (aiming for 1’500 reference plots within the project duration 2018–2024). The overall objective is to calculate a wall-to-wall above ground tree biomass database and map for Switzerland, using the LiDAR survey 2017–2023 of the Federal Office of Topography (see https://www.swisstopo.admin.ch/en/lidar-data-swisstopo). The field work has now been completed and the biomass model is being calibrated with the final set of LiDAR data. The planned continuation of the LiDAR survey will allow the data to be tested for its suitability to derive carbon stock changes of tree biomass in non-Forest land.

6.5.6.2. Mineral soil

Activities at the Competence Center for Soils (CCSoils) address the shortcomings of the lack of comprehensive, nationwide soil information in Switzerland. The results of a digital soil mapping project (Stumpf et al. 2023, 2023a) were used for the first time in this submission. It can be viewed as a first step towards a switch to grid-based SOC modelling with RothC for Cropland. Further steps are planned for the following years.

Additionally, the predicted soil carbon stocks from 1995–2000 are currently used to derive the initial soil carbon stocks, as these are the earliest years for which data are available. The initial soil carbon stock estimate might be improved however by using predicted soil carbon stocks from an earlier period, e.g. 1990–1995, if these become available.

6.6. Category 4C – Grassland

6.6.1. Description

Table 6-24 Key categories in category 4C Grassland. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
4C1	Grassland remaining grassland	CO2	L1, L2, T1, T2
4C2	Land converted to grassland	CO2	L1, L2, T1

Swiss grasslands belong to the cold temperate wet climatic zone.

Grasslands were subdivided into permanent grassland (CC31), shrub vegetation (CC32), vineyards, low-stem orchards (‘Niederstammobst’) and tree nurseries (CC33), copse (CC34), orchards (‘Hochstammobst’; CC35), stony grassland (CC36), and unproductive grassland (CC37) (see Table 6-2 and Table 6-6). In category 2 in CRT Table4.C, the land-use types

CC32, CC33, CC34 and CC35 were merged under the notation ‘woody’ and CC36 and CC37 were merged under ‘unproductive’ (see Table 6-2).

In the inventory period, total net emissions of category 4C1 Grassland remaining grassland range from -1170 kt CO_2 in 1990 to 214 kt CO_2 in 2017 (average -226 kt CO_2; Figure 6-14). Whereas annual carbon stocks and carbon stock changes in living biomass and in mineral soil were calculated for permanent grassland (CC31) (however, five-year averages were reported, see below), for the remaining land-use categories CC32–CC37 carbon stocks in living biomass and in mineral soil were assumed to be in equilibrium (i.e. no carbon stock changes occur if the land use does not change; changes of grassland land-use categories among themselves, however, do contribute to net emissions and removals in category 4C1). High stable carbon losses in organic soil (especially under permanent grassland) characterise the net figures in 4C1, although only 0.8 % of permanent grassland soils are organic soil (Table 6-7). Contributions of other Grassland remaining grassland land-use categories (CC32–CC37) were of minor importance except for a noticeable gain in living biomass for shrub vegetation (CC32) which can be explained mainly by the conversion of abandoned alpine and jurassic pastures (i.e., summer pastures, which belonged to CC31; well above 1 kha in many years, see also Table 6-9) to this latter land-use category.

Carbon stocks in living biomass of the two lower elevation zones in category 4C1 decreased significantly over the inventory period, while the 1990 level in the highest elevation zone remained the same (Figure 6-15 upper panel). Carbon stocks in mineral soil in the two lower elevation zones decreased moderately (< 601 m) or remained largely stable (601–1200 m), while in the highest elevation zone the stock increased significantly (Figure 6-16 upper panel).

Category 4C2 Land converted to grassland acted as a net source in all years (average 286 kt CO_2; Figure 6-14). The highest individual contribution came consistently from category 4C2.1 Forest land converted to grassland. Most of this source was due to net changes in living biomass from deforestation. In contrast, the categories 4C2.3 to 4C2.5 acted as net sinks mainly due to sequestration of CO_2 in mineral soil in the course of the conversion to grassland.

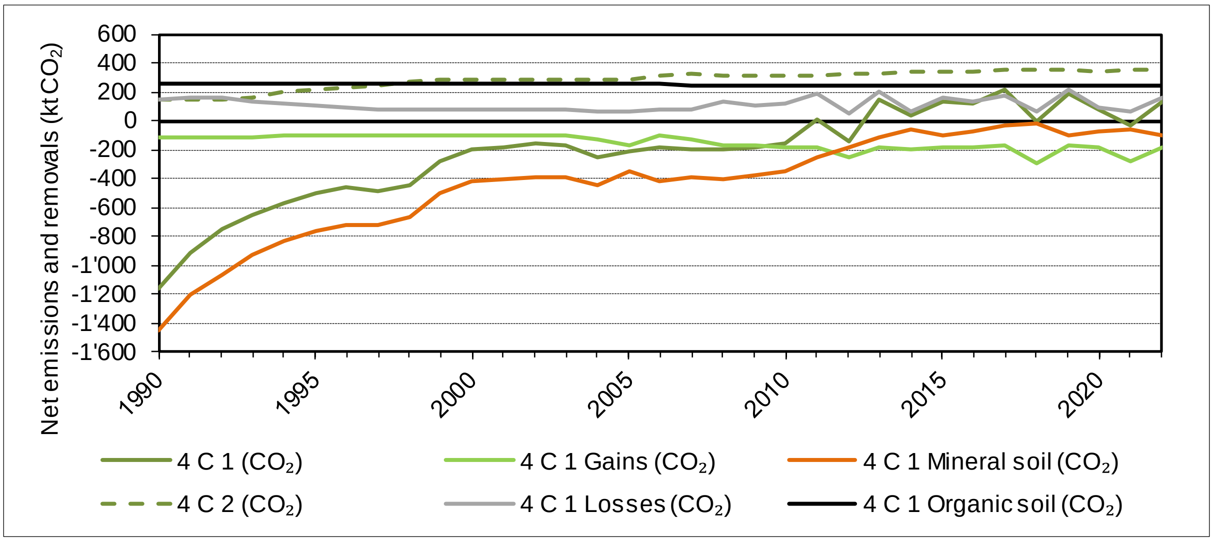

Figure 6-14 Net CO_2 emissions (positive values) and removals (negative values) from categories 4C1 and 4C2. Category 4C1 is broken down by gains in living biomass, losses in living biomass, net carbon stock changes in mineral soil, and net carbon stock changes in organic soil.

6.6.2. Methodological issues

For permanent grassland (CC31), carbon stocks in living biomass as well as carbon stocks in mineral soil were estimated with a Tier 3 approach. The results were integrated in category 4C by calculating area-weighted (using the relative surface of the six grassland types) average values per elevation zone. The differences in carbon stocks (calculated as five-year moving average except for the previous and latest inventory years) between two consecutive years were reported as net changes for living biomass and for mineral soil. For the remaining Grassland land-use categories CC32–CC37, constant carbon stocks in living biomass and in mineral soil were assumed (see Table 6-4).

6.6.2.1. Carbon stocks

6.6.2.1.1. Carbon stocks in living biomass

6.6.2.1.1.1. Permanent grassland (CC31)

Permanent grasslands range in elevation from <300 m to 3000 m above sea level. Because both biomass productivity and soil carbon dynamics rely on the prevailing climatic and pedogenic conditions, grassland stocks were calculated separately for three elevation zones (see chp. 6.2.2.2).

Standing biomass for permanent grasslands (t C ha^{-1}) was calculated as the annual cumulative yield of six differentially managed grasslands for three elevation zones. Total harvested biomass for the years 1990–2021 was adopted from annual statistics of the Swiss Farmers Union (SBV 2022 and previous editions) and allocated to the below listed different grassland types and elevation zones based on standard yields from Richner and Sinaj (2017) and area data from the Farm Structure Survey (SFSO 2016g):

- extensive meadow
- less intensive meadow
- intensive meadow
- extensive pasture
- intensive pasture
- summer pasture

Values for 2022 were calculated using the yield averages of the previous 5 years. A carbon fraction of 0.45 was assumed (Bolinder et al. 2007). For grassland, yield was assumed to be equal to above ground biomass. Root biomass was estimated based on an allometric function as described in Wüst-Galley et al. (2020).

Carbon stocks and carbon stock changes in living biomass were reported as moving averages over five years (from year-2 to year+2, e.g. 1988–1992 for the year 1990; the previous and latest inventory years were reported as four-year (year-2 to year+1) and three-year (year-2 to latest inventory year) moving averages, respectively). Data are shown in Table 6-25 and in Figure 6-15.

The rationale for this smoothing is that due to stockpiling the consumption (and thus oxidation) of the biomass is levelled out between individual years (due to the unsmoothed curve progressions, however, to a lesser extent than with Cropland; compare Figure 6-15 upper panel with Figure 6-11 upper panel). Year-to-year variability for unsmoothed data is higher in recent years compared to earlier years, because since 2007 yields are reported annually, whereas prior to that they were reported only every five years.

The resulting area-weighted (across the three elevation zones) mean carbon stock in living biomass for permanent grassland over the inventory time period was 4.31 t C ha^{-1}.

Table 6-25 Area-weighted (using the relative surface of the six grassland types) carbon stocks (t C ha^{-1}) and net carbon stock changes (t C ha^{-1} yr^{-1}) in living biomass (including roots) of land-use category permanent grassland (CC31), stratified for elevation zone (Elev: Elevation Z1 = <601 m, Z2 = 601-1200 m, Z3 = >1200 m; see chp. 6.2.2.2). Highlighted data for 1990 are displayed in Table 6-4. Please note: Associated data in CRT Table4.C.1 also include land-use changes within the Grassland land-use categories CC31–CC37 and therefore differ from the data shown here (see also chp. 6.1.3.4).

Living biomass	**Elev.**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
		CC31: carbon stock [t C ha^{-1}] and net change in living biomass [t C ha^{-1} yr^{-1}]									
Stock	Z1	5.78	5.72	5.66	5.62	5.59	5.56	5.53	5.51	5.50	5.48
Stock	Z2	5.30	5.25	5.20	5.17	5.14	5.12	5.10	5.09	5.09	5.08
Stock	Z3	3.34	3.33	3.33	3.32	3.32	3.32	3.32	3.33	3.33	3.34
Net change	Z1	-0.05	-0.06	-0.06	-0.04	-0.03	-0.03	-0.02	-0.02	-0.01	-0.02
Net change	Z2	-0.04	-0.05	-0.05	-0.03	-0.03	-0.02	-0.02	-0.01	0.00	0.00
Net change	Z3	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.01	0.01	0.01

Living biomass	**Elev.**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
		CC31: carbon stock [t C ha^{-1}] and net change in living biomass [t C ha^{-1} yr^{-1}]									
Stock	Z1	5.47	5.45	5.43	5.42	5.42	5.44	5.42	5.40	5.36	5.32
Stock	Z2	5.08	5.08	5.07	5.07	5.09	5.12	5.11	5.10	5.06	5.04
Stock	Z3	3.35	3.35	3.36	3.36	3.37	3.39	3.39	3.39	3.38	3.37
Net change	Z1	-0.02	-0.02	-0.02	-0.02	0.00	0.02	-0.02	-0.02	-0.04	-0.03
Net change	Z2	0.00	0.00	0.00	0.00	0.01	0.03	-0.01	-0.01	-0.03	-0.02
Net change	Z3	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00	-0.01	-0.01

Living biomass	**Elev.**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
		CC31: carbon stock [t C ha^{-1}] and net change in living biomass [t C ha^{-1} yr^{-1}]									
Stock	Z1	5.28	5.20	5.23	5.15	5.15	5.09	5.05	4.98	5.03	4.95
Stock	Z2	5.01	4.95	4.98	4.92	4.93	4.88	4.85	4.80	4.85	4.78
Stock	Z3	3.36	3.34	3.36	3.34	3.34	3.33	3.32	3.30	3.33	3.30
Net change	Z1	-0.04	-0.07	0.02	-0.08	0.00	-0.06	-0.04	-0.07	0.04	-0.08
Net change	Z2	-0.03	-0.06	0.03	-0.06	0.01	-0.05	-0.03	-0.05	0.05	-0.07
Net change	Z3	-0.01	-0.02	0.01	-0.02	0.01	-0.01	-0.01	-0.02	0.02	-0.02

Living biomass	**Elev.**	**2020**	**2021**	**2022**
		CC31: carbon stock [t C ha^{-1}] and net change in living biomass [t C ha^{-1} yr^{-1}]		
Stock	Z1	4.93	4.98	4.94
Stock	Z2	4.76	4.81	4.77
Stock	Z3	3.30	3.32	3.31
Net change	Z1	-0.02	0.04	-0.06
Net change	Z2	-0.01	0.05	-0.05
Net change	Z3	0.00	0.02	-0.02

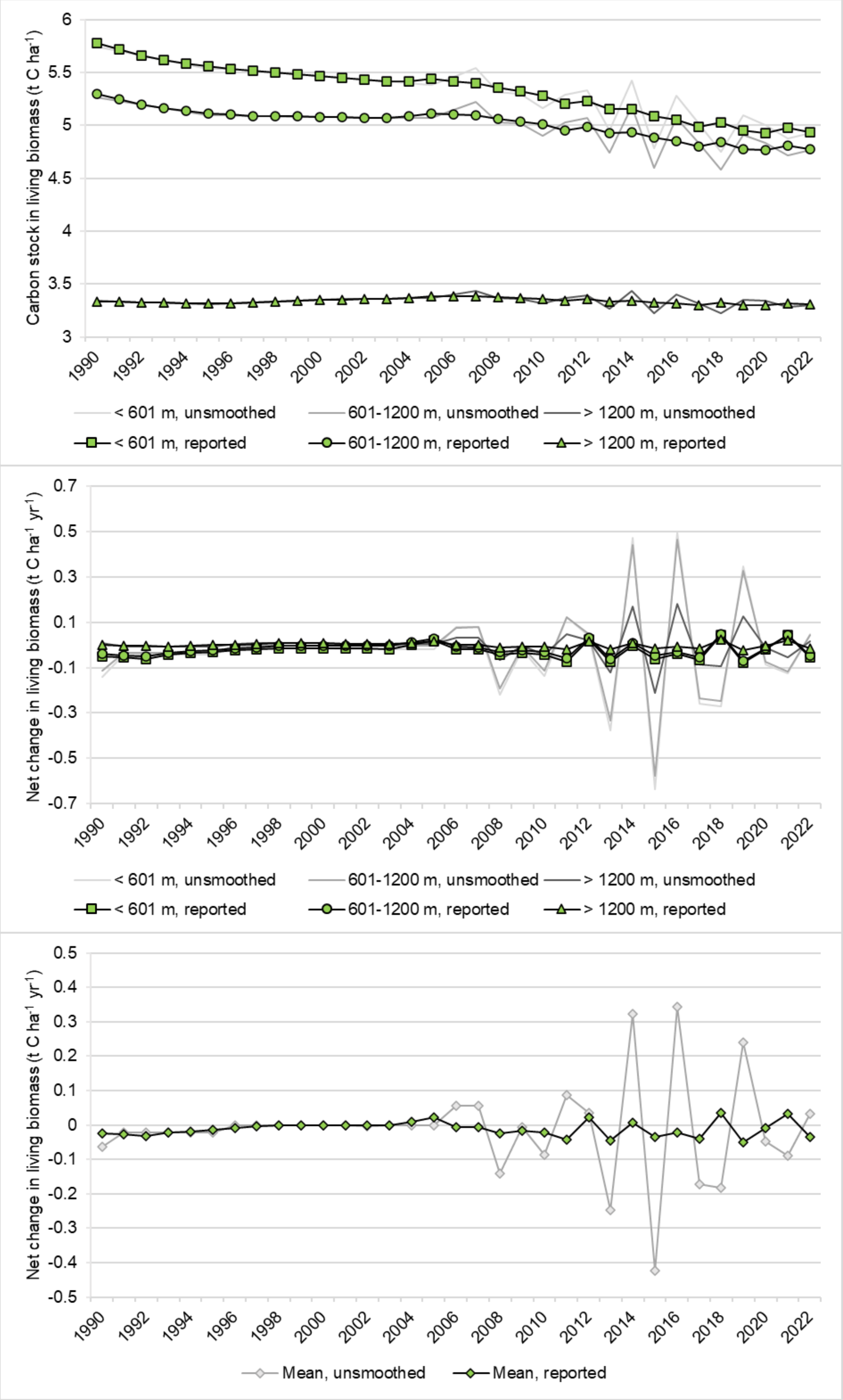

Figure 6-15 Reported carbon stocks (t C ha^{-1}) and net carbon changes (t C ha^{-1} yr^{-1}) in living biomass of permanent grassland (CC31) and underlying unsmoothed data (shown for transparency reasons), stratified for elevation zone (upper and middle panel) and area-weighted means (across three elevation zones; lower panel). Upper and lower confidence intervals are too small to be distinguished from the mean.

6.6.2.1.1.2. Shrub vegetation (CC32) and Copse (CC34)

Due to the lack of accurate data, the living biomass of shrub vegetation and copse was assumed to be equal to the living biomass of brush forest as described in chp. 6.4.2.4.1, where brush forest is assumed to contain 20.45 t C ha^{-1} (Düggelin and Abegg 2011).

6.6.2.1.1.3. Vineyards, low-stem orchards and tree nurseries (CC33)

Low-stem orchards are small fruit trees distinguished from CC35 (orchards) by a maximum stem height of 1 m and a much higher stand density. Only low-stem orchards and vineyards are considered in the following because no stand densities for tree nurseries are available. This is justified because tree nurseries comprise only ca. 8 % (1’378 ha tree nurseries, SFSO 2002) of the total area of CC33, i.e., 17’054 ha, 15’436 ha are vineyards (SFSO 2005) and 240 ha are low-stem orchards (Widmer 2006).

The standing carbon stock of living biomass per ha (Cl) for CC33 was therefore calculated as:

$$Cl = \left[\left(Cl_{vineyards} * area_{vineyards}\right) + \left(Cl_{low-stem\ orchards} * area_{low-stem\ orchards}\right)\right] \\ /\left(area_{vineyards} + area_{low-stem\ orchards}\right)$$

Cl of vineyards (5.35 t C ha^{-1}) was calculated as the sum of the woody biomass (3.61 t C ha^{-1}) and the biomass in the grass layer (1.74 t C ha^{-1}).

Woody biomass for vineyards was calculated based on the mean stand density (5’556 vines ha^{-1}) and the mean carbon content in the woody biomass of one plant including roots (0.65 kg C; Ruffner 2005).

The mean carbon stock of the grass layer in vineyards was calculated using the following information and assumptions: (1) Most vineyards in Canton Valais (around 5'000 ha) have no grass layer, in the other cantons the share of vineyards with grass understorey is very high (95 %). Thus, it can be assumed that on the average 65 % of the Swiss vineyards exhibit a grass layer. (2) The grass layer between the vine rows has a lower carbon stock than permanent grassland. It is assumed that it is 50 % less than the carbon stock of CC31 (elevation <600 m, average of the period 1990–2020 as reported in FOEN 2023: chp. 6.6.2.1.1.3).

Cl of low-stem orchards (14.93 t C ha^{-1}) was calculated as the sum of the woody biomass (12.25 t C ha^{-1}) and the biomass in the grass layer (2.68 t C ha^{-1}).

For small fruit trees on low-stem orchards, no literature value was found for biomass expansion factors. Therefore, the following assumptions were made: Diameter at breast height (DBH) of such trees was assumed to be 10 cm and the stem height was assumed to be 1 m. The bole shape of low-stem apple trees can be approximated by a cylinder shape.

Stem wood volume = $r^2 * \pi *$ height = $(5\text{ cm})^2 * 3.1 * 100\text{ cm} = 7.75\text{ dm}^3$

Based on expert knowledge (Kaufmann 2005), the percentage of branches was estimated as 100 %, and the percentage of roots was estimated as 30 % of the stem wood volume. This results in a BEF of 2.3. A wood density of 0.55 kg dm^{-3} (Vorreiter 1949) and the default IPCC carbon content of 50 % (IPCC 2006, Volume 4, chp. 5.2.2.2) were assumed. With these assumptions the carbon stock of a tree of the type low-stem (‘Niederstamm’) was calculated as follows:

C low-stem = stem wood volume * BEF * wood density * carbon content

= 7.75 dm^3 * 2.3 * 0.55 kg/dm^3 * 0.5 = 4.9 kg C

The mean stand density of low-stem orchards was estimated as 2500 ha^{-1} (Widmer 2006), resulting in a Cl of 12.25 t C ha^{-1} in woody biomass.

The mean carbon stock of the grass layer in low-stem orchards was calculated using the following information and assumptions: (1) All low-stem orchards have a grass layer. (2) The grass layer between the tree rows has a lower carbon stock than permanent grassland. It is assumed that it is 50 % less than the carbon stock of CC31 (elevation <600 m, average of the period 1990–2020 as reported in FOEN 2023: chp. 6.6.2.1.1.3).

The resulting carbon stock in living biomass (Cl) for land-use category CC33 is 5.5 t C ha^{-1}.

6.6.2.1.1.4. Orchards (CC35)

Orchards consists of larger fruit trees (‘Hochstammobst’) planted at a low density with grass understory. Cl of orchards trees was calculated as:

Cl biomass = (carbon per fruit tree [t C] * number of fruit trees / area orchards [ha])
+ carbon in grass [t C ha^{-1}]

The carbon stock of a large fruit tree with a DBH of 25–35 cm was calculated as follows:

C (Hochstamm) = Stem wood volume * KE-Factor = 225 kg C

where:

- Stem wood volume of an apple tree assuming a cylindrical stem with mean DBH of 30 cm and a stem height of 7 m amounts to 0.5 m^3, and
- KE-Factor [t C m^{-3}] = BEF * Density * carbon content = 0.45
(Wirth et al. 2004: p. 68, Table 16).

From the total fruit-growing area of 41’480 ha (SFSO 2005), the area of low-stem trees (240 ha, see CC33) was subtracted, and the remaining area of 41’240 ha was divided by the number of large fruit trees calculated as the mean of the counts in 1991 (3’616’301 trees) and 2001 (2’900’000 trees; SFSO 2002). This resulted in a mean stand density of 79 trees ha^{-1}. The resulting carbon stock in woody biomass of CC35 is thus 17.78 t C ha^{-1}. Because orchards typically have a grass understory, the biomass of CC31 was added to the woody biomass. In FOEN (2023: chp. 6.6.2.1.1.4), the average biomass 1990–2020 of CC31 was weighted with the area of CC35 in the three elevation zones, resulting in 5.29 t C ha^{-1}. The value was left unchanged for this submission and added to the woody biomass to obtain a total carbon stock of 23.1 t C ha^{-1} for land-use category CC35.

6.6.2.1.1.5. Stony grassland (CC36)

Approximately 35 % of the surface of land-use category CC36 (herbs and shrubs on stony surfaces) is covered by vegetation. No accurate data were available for this category. Therefore, the carbon stock of brush forest (20.45 t C ha^{-1}; see chp. 6.4.2.4; Düggelin and Abegg 2011) was multiplied by 0.35 to account for the 35 % vegetation coverage. This results in a carbon stock for stony grassland of 7.2 t C ha^{-1}.

6.6.2.1.1.6. Unproductive grassland (CC37)

Land-use category CC37 includes grass and herbaceous plants at watersides of lakes and rivers including dams and other flood protection structures, constructions to protect against avalanches and rock slides, and alpine infrastructure (e.g. for skiing). For none of these land-use types are biomass data currently available. Therefore, the CC37-area-weighted mean (see Table 6-7) of carbon stocks of permanent grasslands (CC31; average 1990–2020 as reported in FOEN 2023: chp. 6.6.2.1.1.6) in the three elevation zones was assumed to be representative of the carbon stock on unproductive grassland. Carbon stock in living biomass in unproductive grassland appeared to be 3.5 t C ha^{-1}.

6.6.2.1.2. Carbon stocks in dead organic matter

Carbon stocks in dead organic matter were assumed to be zero.

6.6.2.1.3. Carbon stocks in soil

6.6.2.1.3.1. Permanent grassland (CC31)

Mineral soil

Initial carbon stocks in mineral soil under Grassland were calculated using a digital soil mapping approach (Stumpf et al. 2023, 2023a), as described in chp. 6.5.2.1.3.1. The mean initial soil organic carbon stock (0–30 cm) for permanent grassland is 53.0 t C ha^{-1} (standard deviation = 12.3 t C ha^{-1}). The mean carbon stock of each of the 240 regions simulated was used to initialise the RothC simulations.

Switzerland used the soil carbon model RothC to estimate carbon stocks in mineral soil (0–30 cm) under permanent grassland, as described in chp. 6.5.2.1.3.1, in Wüst-Galley et al. (2020) and in Wüst-Galley et al. (2019: p. 71, the upscaling to elevation zone). Six differently managed permanent grassland types (as listed in chp. 6.6.2.1.1.1, covering over 99 % of Swiss permanent grassland) were considered. Plant carbon inputs into the soil from grasslands were assumed to be constant, in accordance to the approach in Franko et al. (2011) and as detailed in Wüst-Galley et al. (2020).

Carbon stocks in mineral soil were integrated in category 4C by calculating area-weighted (using the relative surface of the six grassland types) average values per elevation zone. The results were reported as moving averages over five years (from year-2 to year+2, e.g. 1988–1992 for the year 1990; the previous and latest inventory years were reported as four-year (year-2 to year+1) and three-year (year-2 to latest inventory year) moving averages, respectively). Data are shown in Table 6-26 and in Figure 6-16 upper panel.

Unsmoothed data mainly reflect effects of climatic conditions, whereas long-term trends related to e.g. changes in agricultural management are better visible when the data are smoothed. The resulting area-weighted (across the three elevation zones) mean carbon stock in mineral soil for permanent grassland over the inventory period was 56.02 t C ha^{-1}.

Table 6-26 Area-weighted (using the relative surface of the six grassland types) carbon stocks (t C ha^{-1}) and net carbon stock changes (t C ha^{-1} yr^{-1}) in mineral soil (0-30 cm) for land-use category permanent grassland (CC31), stratified for elevation zone (Elev: Elevation Z1 = <601 m, Z2 = 601-1200 m, Z3 = >1200 m; see chp. 6.2.2.2). Highlighted data for 1990 are displayed in Table 6-4. Please note: Associated data in CRT Table4.C.1 also include land-use changes within the grassland land-use categories CC31–CC37 and therefore differ from the data shown here (see also chp. 6.1.3.4).

Mineral		**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
soil	**Elev.**	CC31: carbon stock [t C ha^{-1}] and net change in mineral soil [t C ha^{-1} yr^{-1}]									
Stock	Z1	63.02	62.95	62.85	62.72	62.58	62.41	62.27	62.14	62.01	61.83
Stock	Z2	58.99	59.13	59.23	59.30	59.35	59.38	59.41	59.45	59.48	59.47
Stock	Z3	46.22	46.83	47.40	47.92	48.41	48.87	49.30	49.72	50.12	50.47
Net change	Z1	-0.03	-0.07	-0.10	-0.13	-0.14	-0.17	-0.15	-0.13	-0.13	-0.18
Net change	Z2	0.21	0.14	0.10	0.07	0.05	0.03	0.03	0.04	0.04	-0.01
Net change	Z3	0.71	0.62	0.57	0.52	0.49	0.46	0.43	0.42	0.40	0.35

Mineral		**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
soil	**Elev.**	CC31: carbon stock [t C ha^{-1}] and net change in mineral soil [t C ha^{-1} yr^{-1}]									
Stock	Z1	61.63	61.47	61.37	61.27	61.23	61.20	61.13	61.00	60.88	60.75
Stock	Z2	59.43	59.39	59.35	59.32	59.31	59.28	59.29	59.28	59.28	59.26
Stock	Z3	50.79	51.09	51.36	51.63	51.88	52.10	52.34	52.58	52.81	53.03
Net change	Z1	-0.20	-0.15	-0.10	-0.10	-0.04	-0.04	-0.07	-0.13	-0.11	-0.14
Net change	Z2	-0.04	-0.04	-0.04	-0.03	0.00	-0.03	0.00	0.00	0.00	-0.02
Net change	Z3	0.32	0.30	0.27	0.27	0.26	0.22	0.24	0.24	0.23	0.22

Mineral		**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
soil	**Elev.**	CC31: carbon stock [t C ha^{-1}] and net change in mineral soil [t C ha^{-1} yr^{-1}]									
Stock	Z1	60.59	60.42	60.22	60.01	59.80	59.60	59.43	59.31	59.16	59.02
Stock	Z2	59.24	59.19	59.12	59.03	58.93	58.83	58.72	58.60	58.49	58.40
Stock	Z3	53.23	53.39	53.55	53.67	53.76	53.87	53.96	54.02	54.08	54.16
Net change	Z1	-0.15	-0.17	-0.20	-0.20	-0.21	-0.20	-0.17	-0.12	-0.15	-0.14
Net change	Z2	-0.02	-0.04	-0.07	-0.09	-0.10	-0.10	-0.12	-0.12	-0.12	-0.09
Net change	Z3	0.20	0.16	0.15	0.12	0.10	0.11	0.09	0.06	0.06	0.08

Mineral		**2020**	**2021**	**2022**
soil	**Elev.**	CC31: carbon stock [t C ha^{-1}] and net change in mineral soil [t C ha^{-1} yr^{-1}]		
Stock	Z1	58.88	58.79	58.68
Stock	Z2	58.31	58.26	58.22
Stock	Z3	54.24	54.26	54.31
Net change	Z1	-0.14	-0.18	-0.21
Net change	Z2	-0.09	-0.09	-0.06
Net change	Z3	0.07	0.07	0.09

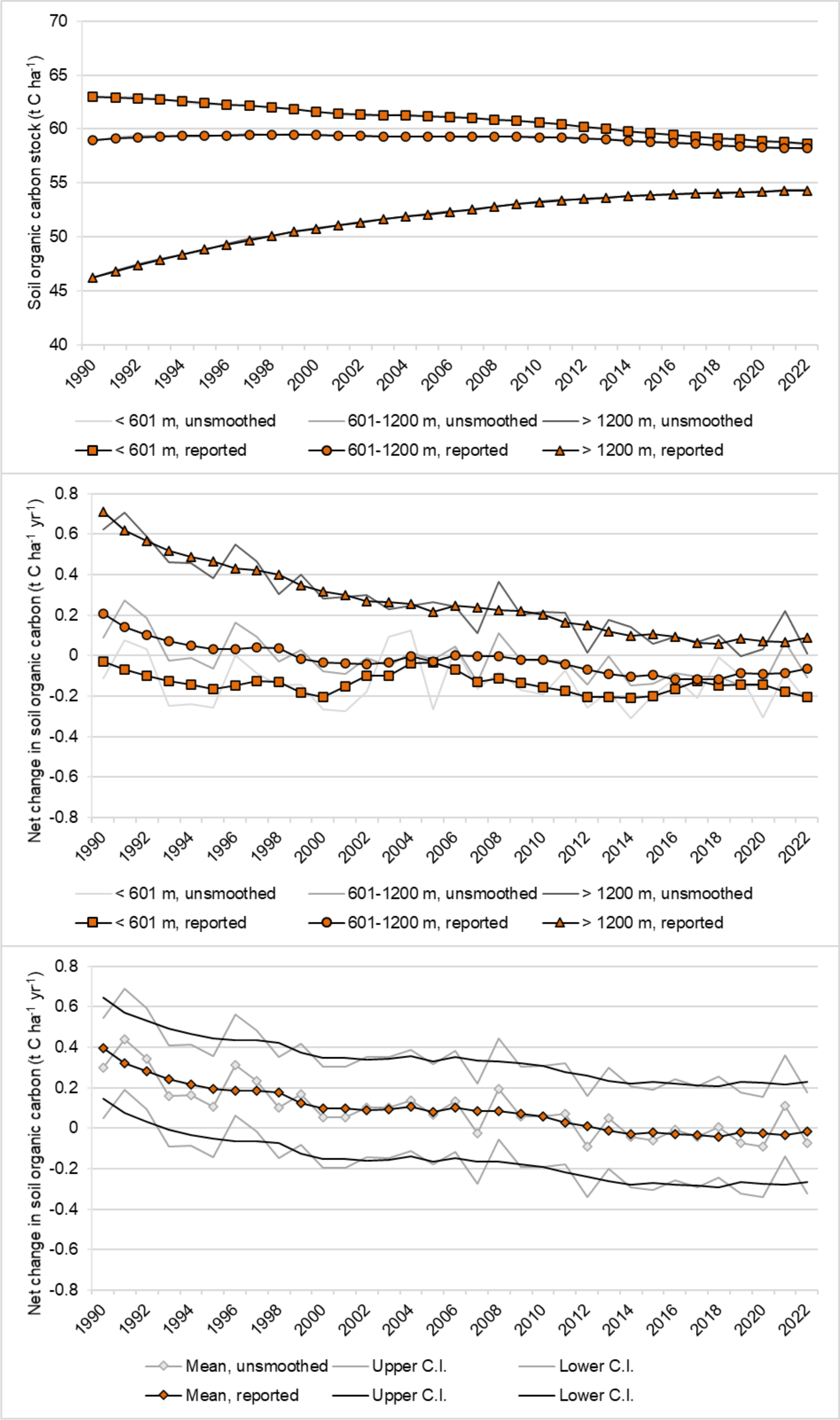

Figure 6-16 Reported carbon stocks (t C ha^{-1}) and net carbon changes (t C ha^{-1} yr^{-1}) in permanent grassland mineral soil (0–30 cm) and underlying unsmoothed data (shown for transparency reasons), stratified for elevation zone (upper and middle panel) and area-weighted means (across three elevation zones; lower panel) plus upper and lower confidence intervals (C.I.; see chp. 6.6.3.1.2).

Organic soil

Soil carbon stocks in organic soil under permanent grassland were calculated based on Leifeld et al. (2003, 2005). The approach used measured carbon stocks in Swiss organic soils without differentiation between Cropland and Grassland. The mean soil organic carbon stock (0–30 cm) in organic soil is 240±48 t C ha^{-1} (uncertainty 20 %).

6.6.2.1.3.2. Shrub vegetation (CC32) and Copse (CC34)

Due to the lack of specific data, for mineral soil in land-use categories CC32 and CC34 the average carbon stocks of CC31 for each elevation zone in the period 1990–2020 (as reported in FOEN 2023: chp. 6.6.2.1.3.2) were used:

- Elevation zone 1 (<601 m a.s.l.): 58.3 t C ha^{-1}
- Elevation zone 2 (601-1200 m a.s.l.): 63.8 t C ha^{-1}
- Elevation zone 3 (>1200 m a.s.l.): 64.5 t C ha^{-1}.

The mean soil organic carbon stock (0–30 cm) in organic soil is 240 t C ha^{-1}.

6.6.2.1.3.3. Vineyards, low-stem orchards and tree nurseries (CC33)

No specific value for mineral soil in land-use category CC33 was available. As CC33 is only partially covered by grass understorey the average soil carbon stock of Cropland (CC21) for the period 1990–2020 was taken, weighted with the area of CC33 per elevation zone: 49.9 t C ha^{-1} (0–30 cm); as reported in FOEN (2023: chp. 6.6.2.1.3.3).

The mean soil organic carbon stock (0–30 cm) in organic soil is 240 t C ha^{-1}.

6.6.2.1.3.4. Orchards (CC35)

No specific value for mineral soil in land-use category CC35 was available. As most orchard areas have grass understorey the average soil carbon stock of permanent grassland (CC31) for the period 1990–2020 was taken, weighted with the area of CC35 per elevation zone: 59.4 t C ha^{-1} (0–30 cm); as reported in FOEN (2023: chp. 6.6.2.1.3.4).

The mean soil organic carbon stock (0–30 cm) in organic soil is 240 t C ha^{-1}.

6.6.2.1.3.5. Stony grassland (CC36)

Carbon stock in mineral soil under herbs and shrubs on stony surfaces in the land-use category CC36 was calculated according to the procedure described in chp. 6.6.2.1.1.5, i.e. it was assumed that not more than 35 % of the area of CC36 is covered with vegetation and thus only 35 % of the area bears a mineral soil while the remainder is bare rock. Land use in this category is mainly located at elevations above 1200 m a.s.l. The soil carbon stock of CC36 was calculated as average soil carbon stock of permanent grassland (CC31) for the period 1990–2020, weighted with the area of CC36 per elevation zone, considering a 35 % coverage: 22.6 t C ha^{-1} (0–30 cm); as reported in FOEN (2023: chp. 6.6.2.1.3.5).

The mean soil organic carbon stock (0–30 cm) in organic soil is 240 t C ha^{-1}. It was assumed that the small area covered by organic soil in CC36 (see Table 6-7), albeit entitled ‘stony grassland’, does not contain significant contributions from stones because bogs are free of stones as a matter of nature and fens usually contain, if any, only fine mineral sediments.

6.6.2.1.3.6. Unproductive grassland (CC37)

The land-use category CC37 includes grass and herbaceous plants at watersides of lakes and rivers including dams and other flood protection structures, constructions to protect against avalanches and rock slides, and alpine infrastructure (e.g. for skiing). For none of these land-use types, soil carbon stock data are currently available. Therefore, the carbon stock in mineral soil was calculated as average soil carbon stock of permanent grassland (CC31) for the period 1990–2020, weighted with the area of CC37 per elevation zone: 64.2 t C ha^{-1} (0–30 cm); as reported in FOEN (2023: chp. 6.6.2.1.3.6).

The mean soil organic carbon stock (0–30 cm) in organic soil is 240 t C ha^{-1}.

6.6.2.2. Changes in carbon stocks

6.6.2.2.1. Carbon stock changes in living biomass

For permanent grassland (CC31), the difference in carbon stock in living biomass (five-year moving average, see chp. 6.6.2.1.1.1 Permanent grassland) between two consecutive years was reported as net carbon stock change (gain or loss) (see Table 6-25 and Figure 6-15 middle panel). For transparency reasons, unsmoothed changes in carbon stocks were also displayed in Figure 6-15. The mean area-weighted carbon stock change across all elevation zones was -0.012 t C ha^{-1} yr^{-1} for the inventory time period.

Applying a Tier 1 approach, carbon stock changes in living biomass were assumed to be in equilibrium for Grassland remaining grassland in the other land-use categories CC32–CC37.

6.6.2.2.2. Carbon stock changes in dead organic matter

Applying a Tier 1 approach, carbon stock changes in dead organic matter were assumed to be in equilibrium for Grassland remaining grassland.

6.6.2.2.3. Carbon stock changes in soil

6.6.2.2.3.1. Mineral soil: Permanent grassland (CC31)

The difference in carbon stock (five-year moving average, see chp. 6.6.2.1.3.1) between two consecutive years was reported as net carbon stock change (gain or loss) in permanent grassland mineral soil (see Table 6-26 and Figure 6-16 middle panel). For transparency reasons, unsmoothed changes in carbon stocks were also displayed in Figure 6-16.

The mean carbon stock change in the inventory period for elevation zone 1 was -0.138 t C ha^{-1} yr^{-1}, for elevation zone 2 -0.019 t C ha^{-1} yr^{-1} and for elevation zone 3 0.269 t C ha^{-1} yr^{-1}. The mean area-weighted carbon stock change across all elevation zones was 0.092 t C ha^{-1} yr^{-1}.

6.6.2.2.3.2. Mineral soil: Remaining grassland land-use categories (CC32–37)

A Tier 1 approach (changes in soil carbon stocks are in equilibrium) was assumed for carbon stock changes in mineral soil in the land-use categories CC32–37.

6.6.2.2.3.3. Organic soil

The annual net carbon stock change in organic soil on managed grassland (CC31, CC33, CC35) was estimated as -9.52 t C ha^{-1} according to measurements in Europe including Switzerland as compiled by Leifeld et al. (2003, 2005) and verified by ART (2009b) and Paul and Alewell (2018). For extensively managed grasslands (CC32, CC34, CC36, CC37) the emission from organic soil was estimated as 5.30 t C ha^{-1} yr^{-1} according to available domestic data (ART 2011b; Paul and Alewell 2018; Paul et al. 2021).

6.6.2.2.4. Land-use change

In the case of land-use change, the net carbon stock changes in biomass and soils of land-use categories CC31, CC32, CC33, CC34, CC35, CC36, and CC37 were calculated as described in chp. 6.1.3.

6.6.2.3. Non-CO_2 emissions from Grassland

6.6.2.3.1. N_2O and CH_4 emissions from drainage of organic soil

N_2O emissions from drainage of organic soil (category 4(II)) in Grassland were reported in the Agriculture sector (category 3D1f Cultivation of organic soils; see chp. 5.5.1).

CH_4 emissions were not estimated (notation key NE) in 4(II) as reporting is not mandatory for this category.

6.6.2.3.2. Direct and indirect N_2O emissions from mineral soils

The calculations of direct and indirect N_2O emissions from nitrogen mineralisation in mineral soil are described in Annex A5.4.

Direct and indirect N_2O emissions from Grasslands remaining grasslands (category 4(III)C1) were included in the Agriculture sector in category 3D1e Mineralisation (see chp. 5.5.1), whereas those from Lands converted to grasslands (category 4(III)C2) were reported under LULUCF.

6.6.2.3.3. CH_4 and N_2O emissions from biomass burning

Data on wildfires affecting Grassland are obtained from cantonal authorities and were compiled by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL, Swissfire database, http://www.wsl.ch/swissfire; Pezzatti et al. 2019). Table 6-27 shows the time series 1990 to 2022 of affected areas and associated emissions. The Swissfire database differentiates between 'grassland' and 'unproductive land'. As 'unproductive land' can partially cover the Grassland land-use categories CC32, CC34, CC36 and CC37 the sum of both categories was reported. Controlled burning is not a common practice in

Switzerland. Therefore, all fires were assigned to wildfires, and controlled burning was reported as not occurring (NO).

The CH_4 and N_2O emissions were calculated using equation 2.27 in Volume 4 of IPCC (2019) with the following parameters:

- The mass of available fuel encompasses the carbon stock of living biomass (litter and dead wood carbon stocks were assumed to be zero for Grassland). On average, the amount of living biomass amounted to 16.44 t biomass ha^{-1} (7.4 t C ha^{-1}). This value was derived from the carbon stocks (average 1990–2020) of all grassland land-use categories (CC31–CC37) as an area-weighted mean using the geographical extensions in 1990 (using raw data from FOEN 2023). A carbon fraction of 0.45 was applied.
- The fraction of the biomass combusted was assumed to be 0.74 (IPCC 2019, Volume 4, Table 2.6, Savanna grasslands).
- For CH_4 the default emission factor of 2.3 g (kg combusted dry biomass)$^{-1}$ and for N_2O, the default emission factor of 0.21 g (kg combusted dry biomass)$^{-1}$ was applied (IPCC 2019, Volume 4, Table 2.5, Savanna and Grassland).

The resulting annual CH_4 and N_2O emissions on burnt areas in category 4C Grassland are shown in Table 6-27 and are reported in CRT Table4(IV).

Table 6-27 Grassland affected by wildfires (WSL, Swissfire database) and resulting CH_4 and N_2O emissions.

Grassland	Unit	1990	1995	2000	2005	2010
Area burnt	ha	637	82	22	20	1.3
CH_4	t	17.8	2.3	0.6	0.5	0.0
N_2O	t	1.63	0.21	0.06	0.05	0.00

Grassland	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Area burnt	ha	3.6	2.6	8.0	212	38	29	16	30	9.9	63
CH_4	t	0.1	0.1	0.2	5.9	1.1	0.8	0.5	0.9	0.3	1.8
N_2O	t	0.01	0.01	0.02	0.54	0.10	0.07	0.04	0.08	0.03	0.16

6.6.2.3.4. Precursor gas emissions (NO_x, CO, NMVOC)

CRT Table4 presents annual emissions of NO_x, CO and NMVOC from grassland wildfires as described by FOEN (2024b: chp. 7.3). In addition, CRT Table4 includes an estimate for the biogenic emissions of NMVOC on unproductive grassland that is not included in the sector agriculture. Based on SAEFL (1996a), a value of 0.51 kt yr^{-1} was used over the entire time series (FOEN 2024b: chp. 7.4).

6.6.3. Uncertainties and time-series consistency for 4C

6.6.3.1. Uncertainties

Detailed results of approach 1 and approach 2 uncertainty analyses are given in Annex A2.2 and Annex A2.3, respectively. Note that in this submission the four categories according to the CRF nomenclature 4(II), 4(III), 4(IV) and 4(V) are still used.

6.6.3.1.1. Activity data

Uncertainties of activity data of category 4C Grassland are described in chp. 6.3.1.3.1.

6.6.3.1.2. Overall uncertainties of carbon stock changes and emission factors

For calculating the overall uncertainty of category 4C, the relevant emissions and removals from living biomass, dead organic matter, mineral soil and organic soil were considered. The uncertainties of carbon stock change factors and emission factors were calculated for 1990 and the reporting year (see overview in Table 6-5).

Living biomass

The relative uncertainty in yield determination was estimated as 13 % for biomass carbon from both Cropland and Grassland (Leifeld and Fuhrer 2005). Data on biomass yields for different elevations and management intensities were derived from many agricultural field experiments and have a high reliability (SBV 2022; Richner and Sinaj 2017).

Dead organic matter

Emissions from the dead organic matter pool occur only by land-use changes from Forest land to Grassland as the carbon stock of dead organic matter is assumed to be zero in the non-forest land-use categories. Thus, the uncertainty of these emissions corresponds to the uncertainty of carbon stocks in litter and dead wood on Forest land. Based on the results of the NFI4 and the Yasso20 model presented by Didion (2023), a relative uncertainty of 0.5 % was calculated for the total carbon stock in litter and dead wood (Meteotest 2024).

Mineral soil

The absolute uncertainty of 0.249 t C ha^{-1} yr^{-1} was used for annual carbon stock changes in categories 4C1 and 4C2. This value was calculated by a Monte Carlo analysis (Wüst-Galley et al. 2020), see chp. 6.5.3.1.2. By comparison, the range of annual SOC changes identified for 9 different treatments of Swiss agricultural long-term experiments is 0.51 t C ha^{-1} yr^{-1} (Keel et al. 2019), indicating that the calculated uncertainty is plausible.

The resulting relative uncertainty in 2022, calculated with the implied carbon stock change factors of mineral soil, is 1'108.0 % for category 4C1 and 107.8 % for category 4C2.

Organic soil

The uncertainty of the carbon stock change (emission factor) in organic soil is 23 % as reported by Leifeld et al. (2003: 56) and the uncertainty of the activity data (area of organic soil) is 68.6 % (see chp. 6.3.1.3.2).

Overall uncertainties categories 4C1 and 4C2

Using the detailed input uncertainties as described above, the uncertainty propagation for categories 4C1 and 4C2 was computed using Monte Carlo simulations (see chp. 1.6.2). The resulting overall uncertainties of approach 2 for categories 4C1 and 4C2 emissions and removals in 2022 are (-912, +916 %) and (-30, +30 %), respectively (see Annex A2.3).

6.6.3.1.3. Uncertainties in category 4(V) Biomass burning, Wildfires (CH_4, N_2O)

For wildfires, the emission factor uncertainties of CH_4 and N_2O were set to 70 % (same as in Forest land, see chp. 6.4.3.1). The activity data uncertainty is 30 % (see chp. 6.3.1.3.3).

6.6.3.2. Time-series consistency

Time series for category 4C Grassland are all considered consistent; they were calculated based on consistent methods and homogenous databases (Wüst-Galley et al. 2020). Small inconsistencies in the input data for the RothC model (related to livestock husbandry, compare chp. 5.2.3 and chp. 5.3.3) are barely relevant for the overall results.

6.6.4. Category-specific QA/QC and verification for 4C

The general QA/QC measures are described in chp. 1.5.

6.6.4.1. Carbon stocks in living biomass

The grassland yield data for the reporting year are available always in the most recent Swiss Farmers' Union's annual report. Since this report is usually not available in time, the inventory is prepared with a provisional value for the reporting year. The correction of this provisional value in the following submission leads by default to a recalculation for the year in question and also affects the neighbouring years due to the moving average approach (see chp. 6.6.2.1.1.16.5.2.1.1).

6.6.4.2. Carbon stocks in mineral soil

The initial SOC stocks for the latest submission are based on newly available digital soil maps (Stumpf et al. 2023, 2023a). The new approach explains the changes in soil carbon stocks and also in stock changes as described in chp. 10.1.2.4. The initial SOC stocks for permanent grassland for the three elevation zones are (for 0–30 cm): 63.2 t C ha^{-1} (Z1), 58.3 t C ha^{-1} (Z2), 44.0 t C ha^{-1} (Z3). In the previous submission, the initial SOC stocks were slightly lower for Z1 and clearly higher for Z2 and Z3: 61.0 t C ha^{-1} (Z1), 65.3 t C ha^{-1} (Z2), 57.1 t C ha^{-1} (Z3). Compared to the method used for previous submissions, the model applied for digital soil mapping was calibrated and validated using a much larger number of data points for carbon and clay content and fourteen times more points for carbon stocks. Furthermore, the complexity of the model is much higher, including a lot more parameters covering a wider range of biophysical processes.

6.6.4.3. Carbon stock changes in mineral soil

6.6.4.3.1. RothC

RothC, used to model SOC stock changes, is a relatively simple model that does not represent certain soil processes such as feedback due to microbial processes or consider other nutrient cycles. It was however the best-performing model given the available data for Switzerland, considering also temporal resolution (Wüst-Galley et al. 2020). The calibration of the allometric equations (for deriving carbon inputs from the cumulative yield of six differentially managed grasslands), as well as a comparison of simulated SOC stock changes with measured values from field experiments is described in Wüst-Galley et al. (2020). A sensitivity analysis of the RothC simulations and of the system used to upscale these simulations to the national scale was completed (Wüst-Galley et al. 2021). The model performance is evaluated on an ongoing basis.

The recalculations related to newly available soil information described in detail in chp. 10.1.2.4 have a strong influence on the carbon stock changes of permanent grassland. For the years 1990–2012 stock changes are consistently above zero with a clear decreasing trend until about 2014 (Figure 6-16 lower panel). This trend is dominated by the results for the highest elevation zone (Z3), but are also visible during the first six years for the two lower elevation zones (Figure 6-16 middle panel). However, due to high uncertainties mean stock changes across all elevation zones are only statistically significant for the first three years (i.e., lower confidence interval in Figure 6-16 lower panel is above zero).

The positive mean SOC stock change for the entire inventory period (0.092 t C ha^{-1} yr^{-1}) agrees with the European-scale increase in SOC content that was estimated by De Rosa et al. (2024) for grassland remaining grassland based on data from the Land Use/Land Cover Area Frame Survey (LUCAS) for the years 2009–2018. If only stock changes for identical years (i.e., 2009–2018) are compared, the direction of change no longer agrees, because there is no change in the inventory data (-0.001 t C ha^{-1} yr^{-1}; Figure 6-16 lower panel). Quantitative comparisons, however, are not possible because different metrics were used.

The patterns of year-to-year changes in SOC stocks are similar to previous submissions (e.g. FOEN 2023: Figure 6-15), because they are mainly driven by weather conditions that remained unchanged. Overall, the changes induced by these recalculations suggest that trends in SOC changes are strongly affected by initial SOC stocks whereas year-to-year variability in SOC changes are controlled by weather conditions.

6.6.4.3.2. Swiss Soil Monitoring Network (NABO)

NABO provides data from 33 monitoring sites identified as grassland (NABO 2021b; see chp. 6.4.4.4) according to the land-use categorisation used for LULUCF (see chp. 6.2). The selected sites include 26 meadows and pastures, but also 4 vineyards and 3 orchards. SOC stocks for the top 20 cm of these soils ranged from 25 to 144 t C ha^{-1} with a mean of 75 t C ha^{-1} (Figure 6-17 top panel). The highest carbon stocks were found for alpine pastures at high elevation. On average, a slight increase during the period 1985 to 2000 (sampling campaigns 1 to 3) and a slight decrease thereafter (campaigns 3 to 4) were observed (Figure 6-17 bottom panel). However, these minor changes were statistically non-significant. In addition, previous studies showed that the elevated SOC stocks for the third sampling campaign must be considered as an artefact, induced by sub-optimal conditions during field work (Meuli et al. 2014; Gubler et al. 2015). From sampling campaigns 4 to 7, SOC stocks remained stable.

The monitoring scheme applied by NABO is able to detect relative changes in SOC contents of roughly 2.5 % per 10 years for mineral grassland soils (minimum detectable change for 30 monitoring sites including three or more sampling campaigns). Regarding the measured SOC stocks (mean 75 t ha^{-1}) this corresponds to a minimum detectable change of roughly 0.19 t C ha^{-1} yr^{-1} for SOC stocks.

The mean change in SOC which was calculated with RothC for the years 1990–2022 was 0.092±0.249 t C ha^{-1} yr^{-1} (area-weighted mean across three elevation zones ± the absolute uncertainty based on a Monte Carlo analysis; see Figure 6-16 lower panel and chp. 6.6.3.1.2). In comparison, the modelled net carbon change is clearly smaller than the detectable change by NABO and suggests that modelled SOC stock changes agree with the repeated soil inventories in the NABO network.

In conclusion, NABO data provide evidence that Grassland mineral soils acted neither as a significant net source nor as a significant net sink of carbon when considered over the entire 34-year period (see also Moll-Mielewczik et al. 2023).

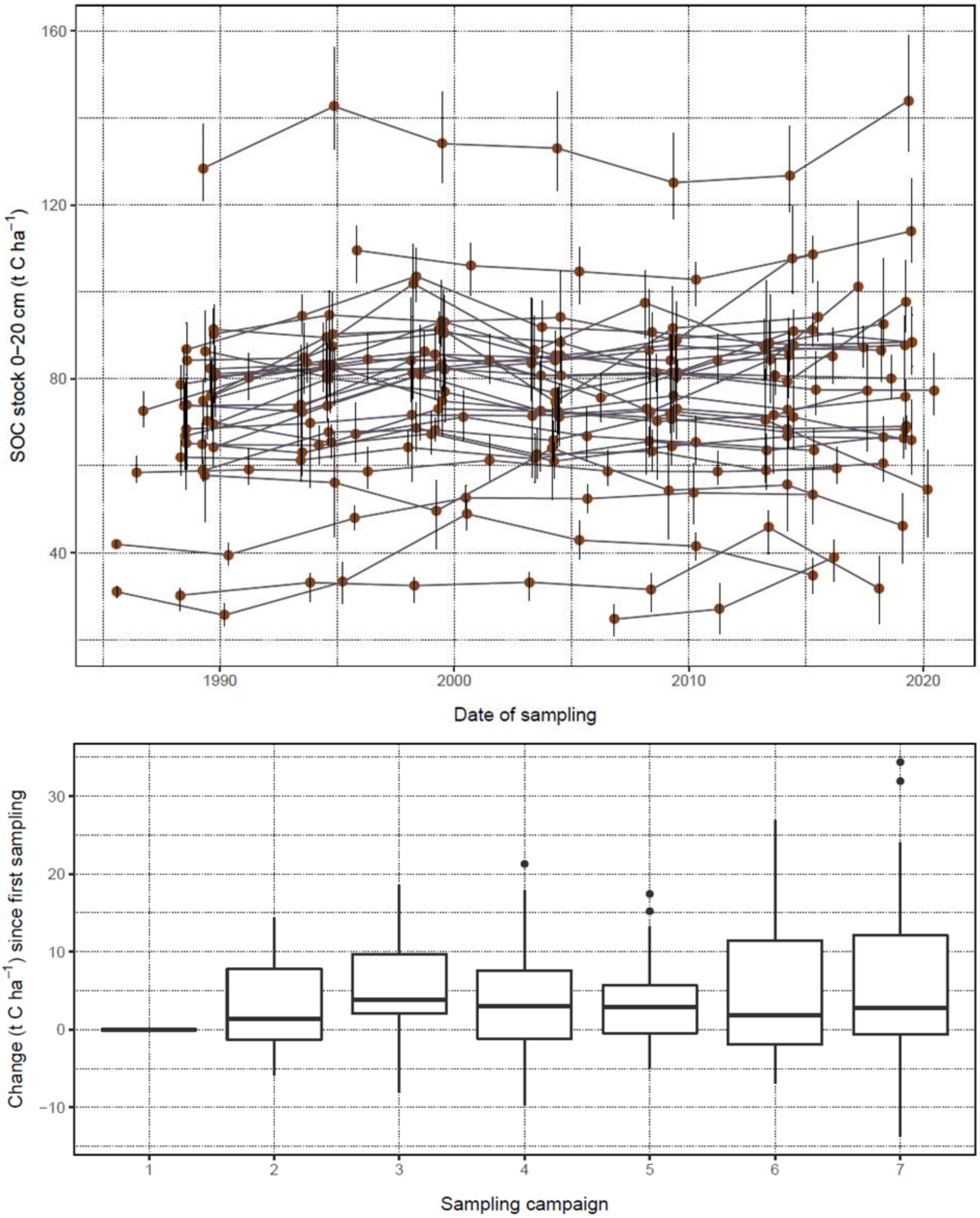

Figure 6-17 Measured SOC stocks for topsoils (0–20 cm) and their changes for 33 NABO long-term monitoring sites used as grassland during the time period 1985–2019. The elevation of the sites ranges from 265 to 2400 m a.s.l. Top panel: SOC stocks 0–20 cm per site and sampling; the dots indicate the mean and the bars the range of 5 % and 95 % percentiles of bootstrap samples taking into account the variability in SOC content of the individual replicates per site and sampling as well as the variations of the bulk density. Bottom panel: boxplot of changes in SOC stocks in each case related to the first sampling (boxes indicate the lower und the upper quartiles with the median indicated; lines include all observations inside the range of 1.5 times the interquartile distance, observations beyond that range are indicated as dots).

6.6.4.4. Short-term land-use changes between Grassland and Cropland

See chp. 6.5.4.4.

6.6.5. Category-specific recalculations for 4C

The following recalculations were implemented. Major recalculations which contribute significantly to the differences in net emissions and net removals of sector 4C between the latest and the previous submissions are additionally presented in chp. 10.1.2.4.

- 4C: Activity data (areas) 2013–2021 were updated (see chp. 6.3.1.5). The inclusion of most recent data from the AREA5 survey led to small recalculations (Table 6-11).
- 4C: Organic soil: The dataset defining the geographical distribution of organic soils in Switzerland was updated (see chp. 6.3.1.5). The total area of organic soil in 1990 on Grassland increased from 6.3 to 8.2 kha (Figure 6-6 and Table 6-7).
- 4C: permanent grassland (CC31): Carbon stocks and carbon stock changes in mineral soil were recalculated for the whole inventory period, applying
  - new soil information (initial soil carbon stocks and clay content classes), following newly available estimates (described in chp. 6.5.2.1.3.1 and chp. 6.6.2.1.3.1). The effects of this are that the direction of the mean carbon stock change for permanent grassland soil changes from -0.054 t C ha^{-1} yr^{-1} in the previous submission to 0.092 t C ha^{-1} yr^{-1} in the latest submission. However, it is important to note that uncertainties are high and carbon stock changes are only statistically significant for the first three inventory years.
  - updated information used for the calculation of organic amendments for the year 2021 (animal numbers, straw production and the amount of manure going to biogas plants), following the availability of new data (SBV 2022). This recalculation had a negligible effect on mineral soil carbon changes.
- 4(IV)C: CH_4 and N_2O emissions from wildfires 1990–2021 were recalculated based on an updated mass of available fuel: 7.4 t C ha^{-1} (chp. 6.6.2.3.3). It was calculated as area-weighted average biomass 1990–2020 of all grassland categories CC31–CC37 as reported in FOEN (2023) for the year 1990. The former value was 7.46 t C ha^{-1}. Very small changes resulted from this recalculation.

6.6.6. Category-specific planned improvements for 4C

6.6.6.1. Living biomass

The project process to achieve a sound wall-to-wall above ground tree biomass database and map for Switzerland is described in chp. 6.5.6.1. The suitability of the methodology for reporting in category 4C is subject to ongoing evaluation.

6.6.6.2. Mineral soil

The information in chp. 6.5.6.2 on the switch to grid-based SOC modelling with RothC and on the potential for improvement using predicted soil carbon stocks from an earlier period also applies to permanent grassland mineral soil. The progress of digital soil modelling at CCSoils will also be used to improve estimates soil carbon stocks in the remaining Grassland land-use categories.

6.7. Category 4D – Wetlands

6.7.1. Description

Table 6-28 Key categories in category 4D Wetlands. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	**IPCC category**	**Gas**	**Identification criteria**
4D1	Wetland remaining wetland	CO2	L2

Wetlands were subdivided into surface water (CC41) and unproductive wetland such as shore vegetation, fens or (raised) bogs (CC42) (see Table 6-2 and Table 6-6).

Figure 6-18 shows the time series of net CO_2 emissions and net CO_2 removals from categories 4D1 Wetlands remaining wetlands and 4D2 Land converted to wetlands. Emissions from organic soil largely dominate category 4D1 alone. Net emissions from category 4D2 more than double over the inventory period (with losses in living biomass from Forest land converted to other wetlands as both most important and driving process). Total net emissions from category 4D Wetlands range between 136 and 164 kt CO_2 (in 1990 and in 2019, respectively; not shown).

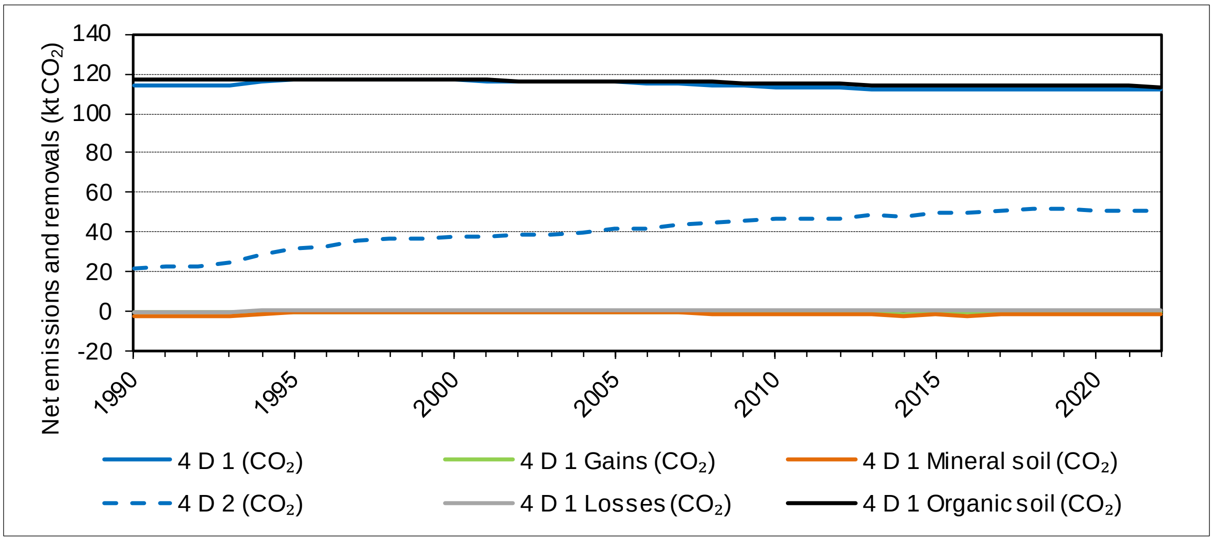

Figure 6-18 Net CO_2 emissions (positive values) and removals (negative values) from categories 4D1 and 4D2. Category 4D1 is broken down by gains in living biomass, losses in living biomass, net carbon stock changes in mineral soil, and net carbon stock changes in organic soil. Gains and losses in living biomass are too small to be distinguished from the zero line.

6.7.2. Methodological issues

6.7.2.1. Carbon stocks

6.7.2.1.1. Carbon stocks in living biomass

6.7.2.1.1.1. Surface waters (CC41)

Surface waters have no carbon stocks by definition.

6.7.2.1.1.2. Unproductive wetland (CC42)

CC42 consists of (very) extensively managed grassland, bushes or tree groups. The carbon stock of living biomass was estimated as 6.5 t C ha^{-1} (Mathys and Thürig 2010: Table 7).

6.7.2.1.2. Carbon stocks in dead organic matter

Carbon stocks in dead organic matter were assumed to be zero.

6.7.2.1.3. Carbon stocks in soil

6.7.2.1.3.1. Surface waters (CC41)

The mineral soil carbon stock for surface waters (CC41) is zero.

For CC41 situated in areas with organic soil (see chp. 6.2.2.1 and Table 6-7), a soil carbon stock of 240 t C ha^{-1} (0–30 cm) was assumed. These surface waters were assumed to be shallow ponds as integrated parts of fens or bogs.

6.7.2.1.3.2. Unproductive wetland (CC42)

Land cover in CC42 includes (raised) bogs and fens protected by Federal Legislation (Swiss Confederation 1991a, 1994) as well as reed. Nearly 25 % of the unproductive wetland are located on organic soil (see Table 6-7). In this case the soil carbon stock is 240 t C ha^{-1} (0–30 cm).

No specific soil data are available for CC42 on mineral soil. As a first estimate, it was assumed that the carbon stock in unproductive wetland mineral soil is similar to that of permanent grassland (CC31). In FOEN (2023: chp. 6.7.2.1.3.2), the averages 1990–2020 of CC31 were calculated and weighted with the area per elevation zone of CC42, resulting in 63.1 t C ha^{-1} (0–30 cm). This value was left unchanged for this submission.

6.7.2.2. Changes in carbon stocks

6.7.2.2.1. Carbon stock changes in living biomass, dead organic matter, and mineral soil

Applying a Tier 1 approach, carbon stock changes in living biomass, dead organic matter, and mineral soil were assumed to be in equilibrium for Wetlands remaining wetlands.

6.7.2.2.2. Carbon stock changes in organic soil

Carbon losses in organic soil in land-use category CC41 were assumed to be zero because the respective areas are not drained.

Carbon losses in organic soil in land-use category CC42 were estimated to be 5.30 t C ha^{-1} yr^{-1} according to domestic data (ART 2011b; Paul and Alewell 2018). This value was used for weakly managed ecosystems such as fens and (very) extensively managed ecosystems such as raised bogs. Most bogs and fens are protected by Federal Ordinances (Swiss Confederation 1991a, 1994) and drainage is not allowed any more. However, the impact of old drainages constructed before 1990 still triggers certain emissions.

6.7.2.2.3. Land-use change

In the case of land-use change, the net carbon stock changes in biomass and soils of both land-use categories CC41 and CC42 were calculated as described in chp. 6.1.3.

For land converted to unproductive wetland (CC42) a conversion time of one year was chosen for the carbon stock change in living biomass and in dead organic matter (see Table 6-3). For carbon stock changes in mineral soil the conversion time is 20 years.

6.7.2.3. Non-CO_2 emissions from Wetlands

6.7.2.3.1. Direct N_2O emissions from N inputs to managed soils

No emissions were reported in category D in CRT Table4(I) (notation key NO). Input of nitrogen fertilisers to land-use category unproductive wetlands (CC42) is very unlikely as these areas represent mostly nature conservation areas (raised bogs, fens) protected by legislation (Swiss Confederation 1991a, 1994), where fertilising is prohibited.

6.7.2.3.2. N_2O and CH_4 emissions from drainage of organic soil

N_2O emissions from drainage of organic soil was calculated for unproductive wetland (CC42) and reported in category D.1c Other wetlands remaining other wetlands in CRT Table4(II) (labelled as “WL drained”). Activity data correspond to the total area of organic soil for all subdivisions "unprod wetland" (CC42) in CRT Table4.D. The emission factor of 1.6 kg N_2O-N ha^{-1} used is the default value given in the IPCC Wetlands Supplement (IPCC 2014a: Table 2.5) for shallow-drained, nutrient-rich grassland.

An estimate of 0.4 kt CH_4 yr^{-1} emitted by reservoirs (flooded lands) was given by Hiller et al. (2014). The estimate encompasses 97 artificial lakes covering a total area of 10.6 kha. This emission is reported in category D.1b Flooded land remaining flooded land in CRT Table4(II).

For category D.1c Other wetlands remaining other wetlands in CRT Table4(II), CH_4 emissions were not estimated (notation key NE) as reporting is not mandatory for this category.

6.7.2.3.3. Direct and indirect N_2O emissions from mineral soils

The calculations of direct and indirect N_2O emissions from nitrogen mineralisation in mineral soil (category 4(III)D) in Wetlands are described in Annex A5.4.

6.7.2.3.4. CH_4 and N_2O emissions from biomass burning

CH_4 emissions and N_2O emissions from biomass burning in Wetlands (category 4(IV)D) were not occurring (notation key NO).

6.7.3. Uncertainties and time-series consistency for 4D

6.7.3.1. Uncertainties

Detailed results of approach 1 and approach 2 uncertainty analyses are given in Annex A2.2 and Annex A2.3, respectively. Note that in this submission the four categories according to the CRF nomenclature 4(II), 4(III), 4(IV) and 4(V) are still used.

6.7.3.1.1. Activity data

Uncertainties of activity data of category 4D Wetlands are described in chp. 6.3.1.3.1.

6.7.3.1.2. Overall uncertainties of carbon stock changes and emission factors

6.7.3.1.2.1. Category 4D1 Wetlands remaining wetlands

For calculating the overall uncertainty of category 4D1, only the relevant emissions from organic soil were considered (see Table 6-5).

The uncertainty of the carbon stock change factor in organic soil is 72.2 % both for 1990 and 2022. It was calculated on the basis of measurement data compiled by ART (2011b). The uncertainty of the activity data (area of organic soil) is 90.8 % (see chp. 6.3.1.3.2 and Table 6-5).

6.7.3.1.2.2. Category 4D2 Land converted to wetlands

For calculating the overall uncertainty of category 4D2, the relevant emissions and removals from living biomass, dead organic matter, mineral soil and organic soil were considered (see overview in Table 6-5).

Living biomass

The relative uncertainty in yield determination was estimated as 13 % for biomass carbon from both Cropland and Grassland (Leifeld and Fuhrer 2005).

Dead organic matter

Emissions from the dead organic matter pool occur only by land-use changes from Forest land to Wetlands as the carbon stock of dead organic matter is assumed to be zero in the non-forest land-use categories. Thus, the uncertainty of these emissions corresponds to the uncertainty of the carbon stock in litter and dead wood on Forest land. Based on the results of the NFI4 and the Yasso20 model presented by Didion (2023), a relative uncertainty of 0.5 % was calculated for the total carbon stock of litter and dead wood (Meteotest 2024).

Mineral soil

Based on expert judgement, an uncertainty of 50 % was chosen for the carbon stock changes calculated with the stock-difference approach in category 4D2.

Organic soil

The uncertainty of the carbon stock change factor in organic soil is 72.2 % calculated on the basis of measurement data compiled in ART (2011b) and the uncertainty of the activity data (area of organic soil) is 90.8 % (see chp. 6.3.1.3.2).

Overall uncertainty category 4D2

Using the detailed input uncertainties as described above, the uncertainty propagation for category 4D2 was computed using Monte Carlo simulations (see chp. 1.6.2). The resulting overall uncertainty of approach 2 for 4D2 emissions in 2022 is 21 % (see Annex A2.3).

6.7.3.1.3. Uncertainties in category 4(II) Flooded lands (CH_4)

The emission factor uncertainty for CH_4 emitted by flooded lands can be very high (IPCC 2006, Volume 4, Appendix 3). As a best guess, a value of 70 % was chosen for the CH_4 emission factor of category 4(II)D2 (Table 6-5). The activity data uncertainty of flooded lands was set to 10 % based on an expert judgment considering the methods used by Hiller et al. (2014) for estimating the area of reservoirs/flooded land.

6.7.3.1.4. Uncertainties in category 4(II) Drainage of organic soil (N_2O)

For N_2O emissions from drainage of organic soil (category 4(II)), the emission factor uncertainty for shallow-drained, nutrient-rich grassland given in the Wetlands Supplement Guidelines (IPCC 2014a: Table 2.5) was used. It was calculated as arithmetic mean of the lower and upper bound uncertainty (66.9 %; see Table 6-5). The respective activity data uncertainty is 50.8 % (Meteotest 2024). It was calculated by area-weighting and combining the uncertainties of the areas of organic soil for Forest land (35.3 %) and for Wetlands (90.8 %) (see chp. 6.3.1.3.2).

6.7.3.2. Time-series consistency

Time series for category 4D Wetlands are all considered consistent; they were calculated based on consistent methods and homogenous databases.

6.7.4. Category-specific QA/QC and verification for 4D

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

6.7.5. Category-specific recalculations for 4D

The following recalculations were implemented:

- 4D: Activity data (areas) 2013–2021 were updated (see chp. 6.3.1.5). The inclusion of most recent data from the AREA5 survey led to very small recalculations (Table 6-11).
- 4D: Organic soil: The dataset defining the geographical distribution of organic soils in Switzerland was updated (see chp. 6.3.1.5). The total area of organic soil in 1990 on unproductive wetland (CC42) increased from 3.7 to 6.2 kha (Figure 6-6 and Table 6-7). Figure 10-10 illustrates the resulting increase in CO_2 emissions of around 47-48 kt.

The resulting differences of both recalculations in net emissions and removals between the latest and the previous submissions for category 4D are shown in Figure 10-9. They range from 47.0 kt CO_2 eq in 2012 to 51.0 kt CO_2 eq in 2018 and are almost completely controlled by the change in the area of organic soils.

6.7.6. Category-specific planned improvements for 4D

6.7.6.1. Living biomass

The project process to achieve a sound wall-to-wall above ground tree biomass database and map for Switzerland is described in chp. 6.5.6.1. The suitability of the methodology for reporting in category 4D is subject to ongoing evaluation.

6.7.6.2. Mineral soil

The progress of digital soil modelling at CCSoils mentioned in chp. 6.5.6.2 will also be used to improve estimates of carbon stock in unproductive wetland mineral soil.

6.8. Category 4E – Settlements

6.8.1. Description

Table 6-29 Key categories in category 4E Settlements. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	**IPCC category**	**Gas**	**Identification criteria**
4E2	Land converted to settlements	CO2	L1, L2

Settlements were subdivided into buildings/constructions (CC51), herbaceous biomass in settlements (CC52), shrubs in settlements (CC53), and trees in settlements (CC54) (see Table 6-2 and Table 6-6).

Figure 6-19 shows the time series of net CO_2 emissions and net CO_2 removals. Category 4E1 Settlements remaining settlements consistently acts as a small CO_2 sink, with a weak minimum formed in the middle of the inventory period. Between 2004 and 2014, net emissions in category 4E2 Land converted to settlements declined to a 15 % lower level. Forest land converted to settlements and Grassland converted to settlements together are the most important land-use changes. Total net emissions from category 4E Settlements range between 164 and 244 kt CO_2 (in 2022 and in 1998, respectively; not shown).

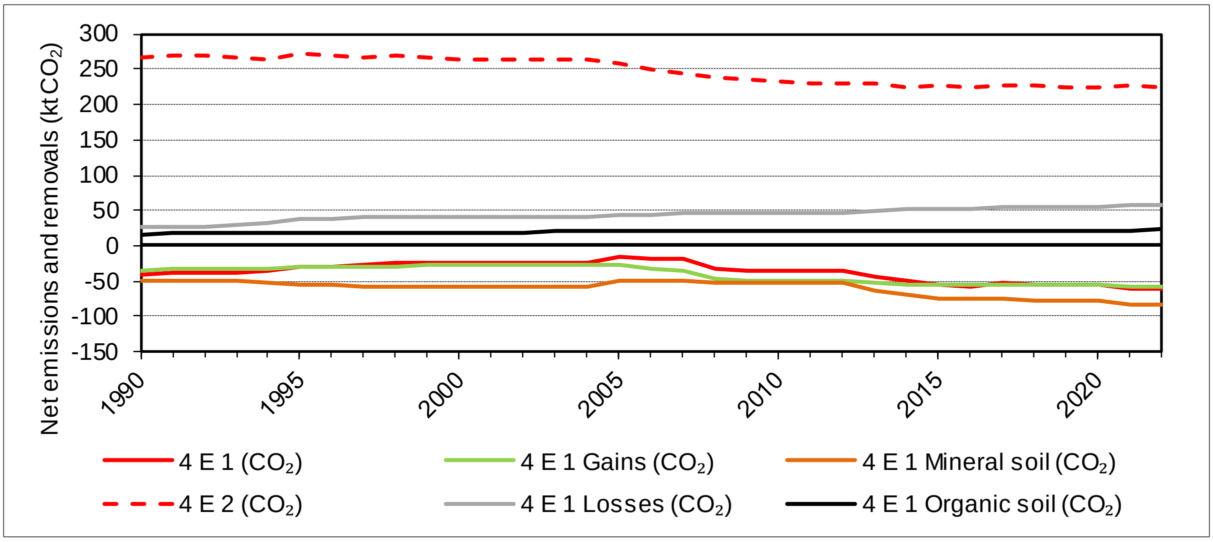

Figure 6-19 Net CO_2 emissions (positive values) and removals (negative values) from categories 4E1 and 4E2. Category 4E1 is broken down by gains in living biomass, losses in living biomass, net carbon stock changes in mineral soil, and net carbon stock changes in organic soil.

6.8.2. Methodological issues

6.8.2.1. Carbon stocks

6.8.2.1.1. Carbon stocks in living biomass

6.8.2.1.1.1. Buildings and constructions (CC51)

By default, buildings/constructions have no carbon stocks.

6.8.2.1.1.2. Herbaceous biomass, shrubs and trees in settlements (CC52, CC53, CC54)

Carbon stocks in living biomass are: 9.54 t C ha^{-1} for CC52, 15.43 t C ha^{-1} for CC53, and 20.72 t C ha^{-1} for CC54 (Mathys and Thürig 2010: Table 7).

6.8.2.1.2. Carbon stocks in dead organic matter

Carbon stocks in dead organic matter were assumed to be zero.

6.8.2.1.3. Carbon stocks in soil

6.8.2.1.3.1. Buildings and constructions (CC51)

The carbon stocks in mineral and in organic soil for CC51 were assumed to be zero.

6.8.2.1.3.2. Herbaceous biomass, shrubs and trees in settlements (CC52, CC53, CC54)

The carbon stocks in mineral soil for CC52, CC53, and CC54 are 49.7 t C ha^{-1} (0–30 cm). In FOEN (2023: chp. 6.8.2.1.3.2), this value was calculated as average soil carbon stock of Cropland for the period 1990–2020, weighted with the area of Settlements per elevation zone. It was left unchanged for this submission.

For organic soil, a carbon stock of 240 t C ha^{-1} (0–30 cm) was assumed for CC52, CC53, and CC54 (see chp. 6.5.2.1.3.2).

6.8.2.2. Changes in carbon stocks

6.8.2.2.1. Carbon stock changes in living biomass, dead organic matter, and mineral soil

Applying a Tier 1 approach, carbon stock changes in living biomass, dead organic matter, and mineral soil were assumed to be in equilibrium for Settlements remaining settlements.

6.8.2.2.2. Carbon stock changes in organic soil

On organic soil, the following carbon stock change factors were applied:

- As CC51 has no carbon stock, carbon stock changes in organic soil were assumed to be zero (labelled as NA in Table 6-4).

- 9.52 t C ha^{-1} yr^{-1} for CC52. This corresponds to the value used for Cropland because CC52 areas are managed (gardens, parks) (Leifeld et al. 2003, 2005 and verified by ART 2009b and Paul and Alewell 2018).
- 5.30 t C ha^{-1} yr^{-1} for CC53 and CC54. This corresponds to the value used for extensively managed grasslands (ART 2011b; Paul and Alewell 2018).

6.8.2.2.3. Land-use change

In case of land-use changes from non-CC51 to CC51 on mineral or on organic soil a loss of 20 % of the initial carbon stock was reported following IPCC 2006 (Volume 4, chp. 8.3.3.2). The reason for this is that 20 % of the soil organic matter is assumed to be lost as a result of disturbance, removal or relocation on these areas being sealed. This assumption is supported by paragraph 7 of the federal "Ordinance against deterioration of soils" (Swiss Confederation 1998) stating that the soil material excavated on a construction site must be treated in such a way that it can be used as a soil again. When the material is re-used (e.g. for re-cultivations) the fertility of the soil must not be affected. This regulation ensures that a large part of the soil organic matter is preserved on land converted to CC51.

Thus, equation 6.8 presented in chp. 6.1.3.2 was adjusted as follows if a=CC51:

$$\mathrm{deltaC}_{s,i,b51} = [\ 0.2 * (0 - \mathrm{stockC}_{s,i,b}\ ) \ /\ \mathrm{CT}\ ] * A_{i,b51}$$

where:

$\mathrm{stockC}_{s,i,b}$	carbon stock in soil (t C ha^{-1})
b	land-use category before conversion (CC = b ≠ 51)
b51	land use conversion from b to CC51
i	spatial stratum
$A_{i,b51}$	area of land (ha) converted from b to CC51 in the spatial stratum i (the sum of the areas converted within the last 20 years)
CT	conversion time (20 years; see Table 6-3).

In case of land-use changes from land-use category CC51 to non-CC51 land-use categories, the regular stock-difference approach and gain-loss approach, respectively, according to chp. 6.1.3.2 and Table 6-3 were applied.

In the case of land-use change from or to land-use categories CC52, CC53, and CC54, the net carbon stock changes in biomass and soils of CC52, CC53, and CC54 were calculated as described in chp. 6.1.3.2.

6.8.2.3. Non-CO_2 emissions from Settlements

6.8.2.3.1. Direct N_2O emissions from N inputs to managed soils

Direct N_2O emissions from N inputs to managed soils in Settlements (category 4(I)E) were included in the Agriculture sector (categories 3D1a Inorganic N fertilisers and 3D1g Other, see chp. 5.5.1) (notation key IE).

6.8.2.3.2. Direct and indirect N_2O emissions from mineral soils

The calculations of direct and indirect N_2O emissions from nitrogen mineralisation in mineral soil (category 4(III)E) in Settlements are described in Annex A5.4.

6.8.2.3.3. CH_4 and N_2O emissions from biomass burning

CH_4 emissions and N_2O emissions from biomass burning in Settlements (category 4(IV)E) were not occurring (notation key NO).

6.8.3. Uncertainties and time-series consistency for 4E

6.8.3.1. Uncertainties

Uncertainties of activity data of category 4E Settlements are described in chp. 6.3.1.3.1.

Based on expert judgement, a value of 50 % was chosen for the carbon stock change factor uncertainty in category 4E (Table 6-5).

Detailed results of approach 1 and approach 2 uncertainty analyses are given in Annex A2.2 and Annex A2.3, respectively. Note that in this submission the four categories according to the CRF nomenclature 4(II), 4(III), 4(IV) and 4(V) are still used.

6.8.3.2. Time-series consistency

Time series for category 4E Settlements are all considered consistent; they were calculated based on consistent methods and homogenous databases.

6.8.4. Category-specific QA/QC and verification for 4E

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

6.8.5. Category-specific recalculations for 4E

The following recalculations were implemented:

- 4E: Activity data (areas) 2013–2021 were updated (see chp. 6.3.1.5). The inclusion of most recent data from the AREA5 survey led to small recalculations (Table 6-11).
- 4E: Organic soil: The dataset defining the geographical distribution of organic soils in Switzerland was updated (see chp. 6.3.1.5). The total area of organic soil in 1990 in Settlements increased from 1.8 to 2.0 kha (Figure 6-6 and Table 6-7). Figure 10-10 illustrates the resulting small increase in CO_2 emissions of around 4–5 kt.

In addition to these two recalculations, the newly calculated mineral soil data on Cropland (chp. 6.5.5) and on Grassland (chp. 6.6.5) had a particular impact when calculating the carbon stock changes in category 4E2 (partly mutually reinforcing, partly offsetting). The resulting differences in net emissions and removals between the latest and the previous submissions for category 4E are shown in Figure 10-9. They are small and range from 0.0 kt CO_2 eq in 2021 to 14.7 kt CO_2 eq in 1995.

6.8.6. Category-specific planned improvements for 4E

6.8.6.1. Living biomass

The project process to achieve a sound wall-to-wall above ground tree biomass database and map for Switzerland is described in chp. 6.5.6.1. The suitability of the methodology for reporting in category 4E is subject to ongoing evaluation (Gardi et al. 2016).

6.8.6.2. Mineral soil

The progress of digital soil modelling at CCSoils mentioned in chp. 6.5.6.2 will also be used to improve estimates of carbon stocks in Settlements mineral soil.

6.9. Category 4F – Other land

6.9.1. Description

Table 6-30 Key categories in category 4F Other land. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
4F2	Land converted to other land	CO2	L1, L2

As shown in Table 6-2 and in Table 6-6 Other land (CC61) covers unmanaged, non-vegetated areas such as glaciers, rocks, screes and shores.

The area of Land converted to other land has increased since 1990 from 361 ha yr^{-1} to 536 ha yr^{-1} in 2022 (see change matrices in Table 6-9). Primarily the conversions of Forest land and Grassland to Other land led to CO_2 emissions caused by the loss of biomass and soil organic carbon. Mudflows, erosion, landslides, and dynamic changes in stream beds were identified as the main processes causing the land-use changes. The trigger for the altered morphodynamics is not known, but a connection with climate change can be assumed.

Another phenomenon strongly linked to climate change, namely the shift of vegetation zones in mountainous regions (as especially expressed in category 4C2.5 Other land converted to stony grassland (CC36), see Table 6-9), however, has a higher rate of land-use change. As a consequence, the total area of Other land has decreased by 4 % over the inventory period (Table 6-8).

In category 4F1 Other land remaining other land, only areas are reported. Figure 6-20 shows the time series of CO_2 emissions from category 4F2 Land converted to other land. They have increased almost steadily over the inventory period from 84 kt CO_2 (1990) to 126 kt CO_2 (2019). Forest land converted to other land and Grassland converted to other land together are the most important land-use changes.

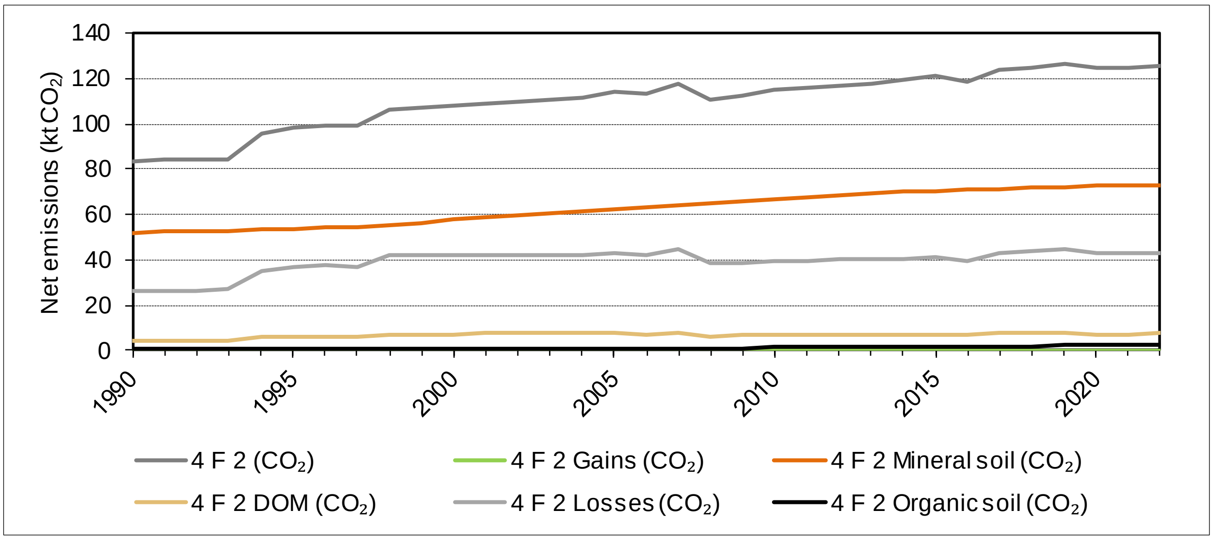

Figure 6-20 CO_2 emissions from category 4F2 Land converted to other land, broken down by gains in living biomass, losses in living biomass, net carbon stock changes in dead organic matter (DOM), net carbon stock changes in mineral soil, and net carbon stock changes in organic soil. Gains in living biomass are not occurring and changes in organic soil are too small to be distinguished from the zero line.

6.9.2. Methodological issues

By definition, Other land has no carbon stocks. Coherently, carbon stock changes in living biomass, dead organic matter, mineral and organic soil were assumed to be zero for Other land remaining other land (see Table 6-4).

In the case of land converted to other land, the net carbon changes in biomass and soils were calculated as described in chp. 6.1.3.

The calculations of direct and indirect N_2O emissions from nitrogen mineralisation in mineral soil (category 4(III)F) in Other land are described in chp. A5.4.

6.9.3. Uncertainties and time-series consistency for 4F

6.9.3.1. Uncertainties

Uncertainties of activity data of category 4F Other Land are described in chp. 6.3.1.3.1.

Based on expert judgement, a value of 50 % was chosen for the carbon stock change factor uncertainty in category 4F2 (Table 6-5).

Detailed results of approach 1 and approach 2 uncertainty analyses are given in Annex A2.2 and Annex A2.3, respectively.

6.9.3.2. Time-series consistency

Time series for category 4F Other land are all considered consistent; they were calculated based on consistent methods and homogenous databases.

6.9.4. Category-specific QA/QC and verification for 4F

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

6.9.5. Category-specific recalculations for 4F

The following recalculations were implemented:

- 4F: Activity data (areas) 2013–2021 were updated (see chp. 6.3.1.5). The inclusion of most recent data from the AREA5 survey led to small recalculations (Table 6-11).
- 4F: Organic soil: The dataset defining the geographical distribution of organic soils in Switzerland was updated (see chp. 6.3.1.5). The total area of organic soil in 1990 in 4F2 increased slightly from 0.023 to 0.025 kha (see also Figure 6-6 and Table 6-7 for category 4F as a whole).

The resulting differences of both recalculations between the latest and the previous submissions for category 4F are insignificantly small (see Figure 10-10 for organic soil). The recalculations for biomass on Forest land (chp. 6.4.5) and for mineral soil on Grassland (chp. 6.6.5) had a greater impact when calculating the carbon stock changes in category 4F2 according to Table 6-3. The overall impact, as shown in Figure 10-9, is still very small, and ranges from -5.7 kt CO_2 eq in 2021 to -3.4 kt CO_2 eq in 2016.

6.9.6. Category-specific planned improvements for 4F

No category-specific improvements are planned.

6.10. Category 4G – Harvested wood products

6.10.1. Description

Table 6-31 Key categories in category 4G Harvested wood products. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
4G	HWP Harvested Wood Products	CO2	T1, T2

Estimates of net emissions and removals from Harvested wood products (HWP) due to losses and gains of carbon, respectively, were reported. Gains refer to annual carbon inflow to the HWP pool, whereas losses refer to annual carbon outflow from the HWP pool.

The approach to calculate carbon stock changes in HWP corresponds to a production approach as described in chp. 12, Volume 4 of IPCC (2019). Changes in carbon stocks in Swiss forests are presented in chp. 6.4. The estimate covers all wood products originating from trees harvested in Switzerland (sawnwood, wood panels, and paper and paperboard) that are processed in Switzerland and that are used for material (i.e. not for energetic) purposes.

The HWP pool includes products made from domestic harvest that were exported and are in use in other countries. Imported HWP are not included in the HWP pool.

To calculate carbon stock changes in HWP, product categories and half-lives were used following the methodologies described in IPCC (2014) and IPCC (2019). Further details and result evaluations are presented in FOEN (2024e).

The resulting CO_2 emissions and removals per product category are listed in Table 6-32 and shown in Figure 6-21.

Table 6-32 CO_2 emissions and removals from Harvested wood products derived from sawnwood ($changeC_{HWP-sawnwood}$), panels ($changeC_{HWP-panels}$), and paper and paperboard ($changeC_{HWP-paper\ and\ paperboard}$) in kt CO_2 (positive values refer to emissions, negative values refer to removals).

	Unit	1990	1995	2000	2005	2010
HWP	kt CO_2	-1'119	-443	-700	-690	-426
$changeC_{HWP-sawnwood}$	kt CO_2	-633	-228	-348	-274	-124
$changeC_{HWP-panels}$	kt CO_2	-450	-222	-378	-402	-318
$changeC_{HWP-paper\ and\ paperboard}$	kt CO_2	-35	7.7	26	-14	16

	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
HWP	kt CO_2	76	-90	-70	-27	7.0	-54	83	24	-132	-35
$changeC_{HWP-sawnwood}$	kt CO_2	148	51	46	52	98	52	53	20	-62	-62
$changeC_{HWP-panels}$	kt CO_2	-115	-136	-131	-100	-104	-122	16	-29	-93	-28
$changeC_{HWP-paper\ and\ paperboard}$	kt CO_2	43	-4.3	16	20	13	15	14	33	22	55

Fluctuations in the HWP pool are mainly caused by changes in the production of sawnwood and wood panels. The share of paper and paperboard is relatively small (see Table 6-32). Because of the strong reduction in the production of sawnwood since 2011, the relative contribution of panels and paper and paperboard to the HWP pool considerably increased (see Figure 6-21). In 2019, the production of wood panels decreased by almost 25 % and, as a consequence, HWP became a net CO_2 source in 2019 and 2020 (next to 2013 and 2017).

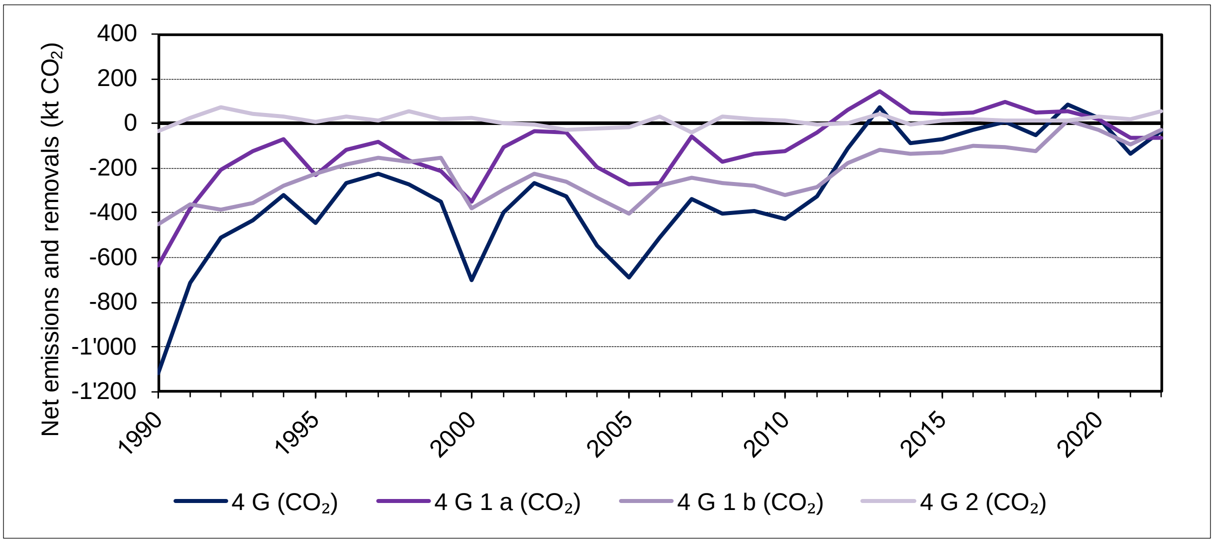

Figure 6-21 Net CO_2 emissions (positive values) and removals (negative values) from category 4G broken down by 4G1a Sawnwood, 4G1b Wood panels, and 4G2 Paper and paperboard.

6.10.2. Methodological issues

6.10.2.1. Approach

Switzerland decided to continue the HWP reporting according to the production approach that had been used under the Kyoto Protocol, including minor modifications. For the estimation of carbon stocks and carbon stock changes, the equations described in IPCC (2014: chp. 2.8) were used. A Tier 2 approach, first order decay, was applied for the product categories sawnwood, wood panels, and paper and paperboard according to equation 2.8.5 in IPCC (2014).

- The starting year used to estimate the delayed emissions from the existing pools is 1900.
- Emissions from wood harvested for energy purposes were accounted for on the basis of instantaneous oxidation (FOEN 2024e).
- HWP going to solid waste disposals were not included in the HWP pool for LULUCF, i.e. instantaneous oxidation is assumed. Information on wood in solid waste disposals is given in the waste sector, see chp. 7.2.2.
- Imported HWP were not included in the HWP pool.
- Exported HWP were included in the HWP pool.
- The share of industrial roundwood (f_{IRW}) used for calculating the domestic production of HWP originating from domestic forests was derived according to equation 2.8.1 in IPCC (2014). f_{IRW} was applied in the period 1961–2020. For 2021–2022, national surveys of the production including the domestic shares were available (FOEN 2024e).
- For estimating the domestic HWP contribution of paper and paperboard, the feedstock factors f_{IRW} and f_{PULP} (see equation 2.8.2 in IPCC 2014) were applied according to equation 2.8.4 in IPCC (2014). f_{IRW} and f_{PULP} were applied in the period 1961–2020. For 2021–2022, national surveys of the production including the domestic shares were available (FOEN 2024e).
- For estimating the HWP contribution of paper and paperboard, the recovered wood pulp from recovered paper was excluded from the feedstock. For this purpose, the net consumption of recovered pulp was calculated from FAO data on production, export and import of recovered fibre pulp in the period 1961–2020. For 2021–2022, the share of recovered pulp was taken from national surveys (FOEN 2024e).
- The change in HWP carbon stocks was estimated separately for each product category and differentiating HWP from deforestation (biomass losses in categories 4B2.1 to 4F2.1 Forest land converted to X) and from Forest land (category 4A) by applying equation 2.8.4 in IPCC (2014). Instantaneous oxidation was assumed for HWP originating from deforestation.

6.10.2.2. Activity data

The time series is shown in CRT Table4.Gs2. The activity data are described in detail in FOEN (2024e):

- Production data for all product categories (sawnwood, wood panels, paper and paperboard, and recovered fibre pulp) were retrieved from FAOSTAT for the years 1961–2020 (http://www.fao.org/faostat/en/#data/FO, Forestry Production and Trade).
- In order to estimate the share of industrial roundwood and the share of fibre pulp originating from domestic forests as feedstock for HWP production, data from national wood processing statistics and foreign trade statistics (import and export) available from FAOSTAT 1961–2020 were used.

- For the years 2021–2022, the following data sources were used: National statistics provided data on production and domestic share of sawnwood (FSO 2023k) and of paper/paperboard (RPK 2023). Surveys on the enterprise level provided production data and domestic share of wood panels (FOEN 2023d).

In order to estimate carbon stocks in each HWP category, default carbon conversion factors were taken from IPCC (2014: Table 2.8.1) for wood panels.

For sawnwood, country-specific wood density values measured by the wood industry and checked against the values published by the National Forest Inventory (Werner 2019a) were adopted:

- Coniferous sawnwood: 0.41 t dry mass / m^3
- Non-coniferous sawnwood: 0.59 t dry mass / m^3

The IPCC (2019) default carbon fraction of 0.5 was used for sawnwood.

6.10.2.3. Carbon stock change factors

Carbon stock change factors for specific product categories were calculated following equation 2.8.5 in IPCC (2014) using default half-lives of 25 years for wood panels, 35 years for sawnwood and 2 years for paper products (IPCC 2014: Tab. 2.8.2).

6.10.3. Uncertainties and time-series consistency for 4G

6.10.3.1. Uncertainties

For category 4G HWP, the following information on relative uncertainty was used:

6.10.3.1.1. Activity data

A mean uncertainty of 11.2 % (Table 6-5) was estimated based on the following expert judgements considering the type and reliability of data source:

- Roundwood harvest: 5 % (national activity data from the Swiss Forestry Statistics, annual complete survey)
- Sawnwood production: 5 % (national activity from survey on wood processing in sawmills, combined survey)
- Wood Panels production: 5 % (national activity from survey in the wood industry)
- Paper and Paperboard production: 5 % (activity data from FAOSTAT)
- Share of domestic wood used in the production of sawnwood, panels and paper: 10 % (based on foreign trade statistics in the FAO database)

$$U_{HWP}AD = \sqrt{5^2 + 10^2} = 11.2\ \%\text{, for each product category.}$$

6.10.3.1.2. Conversion factors (carbon stock change factors)

The uncertainties of conversion factors used to calculate emission factors were based on the following sources:

- Wood density: 20 %; a preliminary uncertainty assessment based on expert judgement results in medium to high uncertainty for the country-specific measurements of the wood industry. According to Werner (2019a), the main source of uncertainty is the water content of the HWP.
- Carbon contents in wood products: 10 % (Lamlom and Savidge 2003, assessment of carbon content in wood; IPCC 2006, Volume 4, Table 12.6).
- Half-lives: 50 % (default from IPCC 2006, Volume 4, Table 12.6).

The resulting uncertainty of the carbon stock change factors (CSCF) for HWP amounts to 54.8 % (Table 6-5):

$$U_{HWP}CSCF = \sqrt{20^2 + 10^2 + 50^2} = 54.8\ \%$$

6.10.3.1.3. *Overall uncertainty 4G*

The overall relative uncertainty of HWP was thus calculated as:

$$U_{HWP}Combined = \sqrt{11.2^2 + 54.8^2} = 55.9\ \%$$

Detailed results of approach 1 and approach 2 uncertainty analyses are given in Annex A2.2 and Annex A2.3, respectively.

6.10.3.2. Time-series consistency

Time series for category 4G Harvested wood products are all considered consistent; they were calculated based on consistent methods and homogenous databases.

The inclusion of national statistics for the years 2021–2022 instead of FAO statistics, which were used in the years preceding 2020, is an improvement of quality (availability, transparency). It does not lead to inconsistencies as in principle both sources should provide the same information.

6.10.4. Category-specific QA/QC and verification for 4G

The general QA/QC measures are described in chp. 1.5.

In 2019, methods and calculations were reviewed by an external expert (Werner 2019a). Based on the review, the calculation procedure for HWP was thoroughly restructured and several improvements and recalculations were made in the course of inventory preparation for the submission 2020 (FOEN 2020).

For the latest submission, production data 2021–2022 were taken directly from national surveys (see chp. 6.10.2.2). This is a more transparent and reliable way than using the FAO statistics. Furthermore, the share of domestic wood used in the production is also provided by the national surveys, thus, the export/import data of FAOSTAT is not required for calculating the domestic shares. For practical reasons, this procedure could not be applied so far for years before 2021.

6.10.5. Category-specific recalculations for 4G

The following recalculations were implemented:

- 4G: Activity data (areas) 2013–2021 were updated (see chp. 6.3.1.5). The inclusion of most recent data from the AREA5 survey led to small recalculations (Table 6-11) related to the split between harvests on Forest land and on deforestations.
- 4G: 1990–2021: The split between HWP from deforestations and from Forest land was recalculated. In previous submissions, the biomass loss on all deforested area was considered. In the latest submission, only the biomass loss on deforested areas in categories 4B2.1, 4C2.1 and 4E2.1 were considered because it is very unlikely that wood from Forest land converted to wetlands (4D2.1) or Forest land converted to other land (4F2.1) can be used for HWP.
- 4G, 2018: Import and production of non-coniferous sawnwood were updated in FAOSTAT.
- 4G, 2019: Export and production of particle board OSB, as well as import of non-coniferous sawnwood were updated in FAOSTAT.
- 4G, 2020: Export and Import of industrial roundwood (coniferous and non-coniferous), paper, wood pulp, recovered fibre pulp, and of all types of wood panels were updated in FAOSTAT.
- 4G, 2020: The production of industrial roundwood (coniferous and non-coniferous) and particle boards were updated in FAOSTAT.
- 4G, 2021: Instead of FAOSTAT, national surveys were used as data source of production and domestic shares for all products. Thus, export and import data were not used for calculating the domestic shares.

The resulting differences of all recalculations between the latest and the previous submissions for category 4G are shown in Figure 10-9. Their absolute values are clearly smaller than 10 kt CO_2 except for the years 2018 (20.9 kt CO_2), 2020 (52.3 kt CO_2), 2021 (-93.1 kt CO_2). The course of net CO_2 emissions and removals in category 4G as shown in Figure 6-21 is therefore largely the same as in the previous submission.

6.10.6. Category-specific planned improvements for 4G

Further improvement could be achieved if plant-specific activity data could also be used for the years before 2021 instead of exclusively FAO statistics, e.g. for the share of domestic wood used for producing wood panel and sawnwood. The availability of such data for reporting in category 4G is subject to ongoing evaluation.

7. Waste

Responsibilities for sector Waste	
Overall responsibility	Daiana Leuenberger (FOEN)
Method updates & authors	Michael Bock (FOEN, 5D), Daiana Leuenberger (FOEN)
EMIS database operation	Myriam Guillevic (FOEN), Daiana Leuenberger (FOEN)
Annual updates (NID text, tables, figures)	Dominik Eggli (Meteotest), Beat Rihm (Meteotest)
Quality control NID (annual updates)	Dominik Eggli (Meteotest), Myriam Guillevic (FOEN), Daiana Leuenberger (FOEN), Adrian Schilt (FOEN)
Internal review	Adrian Schilt (FOEN)

7.1. Overview

7.1.1. Greenhouse gas emissions

Within sector 5 Waste, emissions from five source categories are considered (Figure 7-1):

- 5A Solid waste disposal
- 5B Biological treatment of solid waste
- 5C Incineration and open burning of waste
- 5D Wastewater treatment and discharge
- 5E Other (no direct GHG emissions, but indirect GHG emissions included in CRT Table6 as documented in chp. 9)

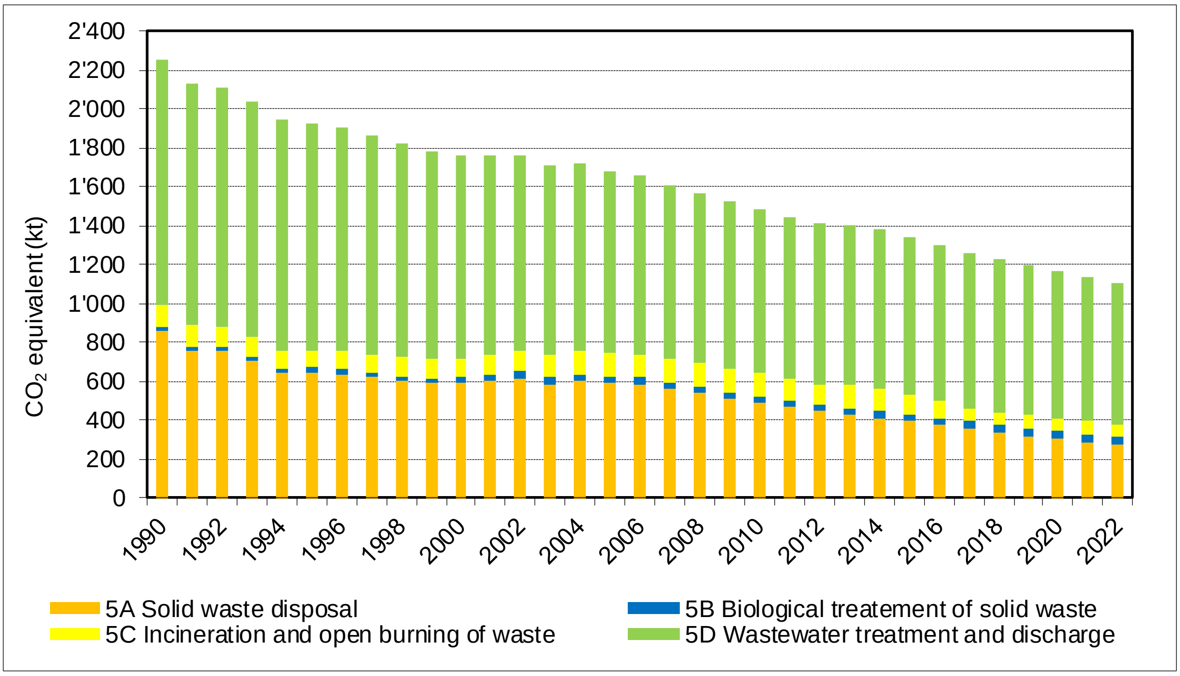

Figure 7-1 Switzerland's greenhouse gas emissions from sector 5 Waste. There are no direct greenhouse gas emissions from sector 5E Other.

The total greenhouse gas emissions from sector 5 Waste show a decrease within the reporting period (Figure 7-1 and Table 7-1). 5A Solid waste disposal and 5D Wastewater treatment and discharge are the two dominant source categories, both showing decreasing greenhouse gas emissions.

Table 7-1 Trend of total GHG emissions from sector 5 Waste in Switzerland.

Gas	**1990**	**1995**	**2000**	**2005**	**2010**
	CO_2 equivalent (kt)				
CO_2	40	22	17	12	11
CH_4	1'084	861	802	805	713
N_2O	1'127	1'048	946	868	759
Sum	2'251	1'931	1'764	1'685	1'484

Gas	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	CO_2 equivalent (kt)									
CO_2	10	10	9.9	9.9	9.6	9.3	9.1	8.9	8.7	8.1
CH_4	661	648	632	621	607	590	576	562	549	537
N_2O	733	722	696	669	640	625	614	600	584	565
Sum	1'404	1'380	1'338	1'300	1'256	1'224	1'199	1'171	1'142	1'110

CH_4 and N_2O are dominant and of similar importance in sector 5 Waste over the entire reporting period. Overall, these two gases show a decreasing trend. CO_2 is of low importance (<2 %) in sector 5 Waste (Table 7-1). The relative trends of all greenhouse gases are shown in Figure 7-2.

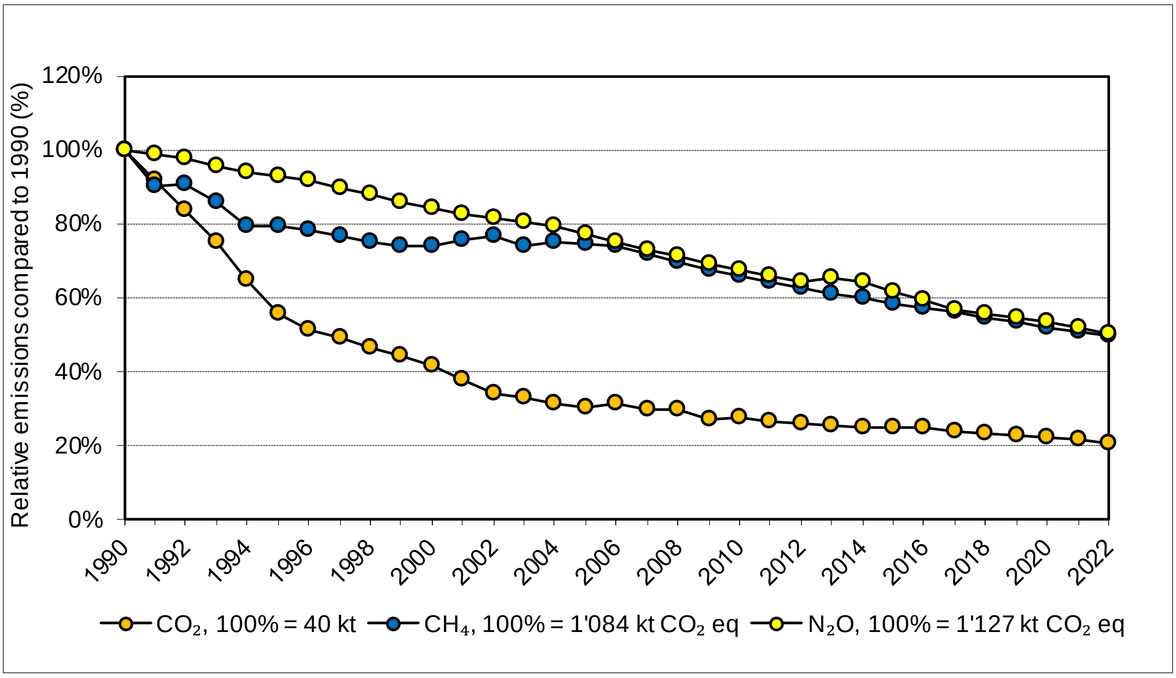

Figure 7-2 Relative trends of greenhouse gas emissions from sector 5 Waste. The base year 1990 represents 100 %.

According to the 2006 IPCC Guidelines (IPCC 2006) all emissions from waste-to-energy, i. e. emissions resulting when waste material is used directly as fuel or converted into a fuel, are reported under sector 1 Energy (see also Figure 7-5). Therefore, the largest share of waste-related emissions in Switzerland is not reported under sector 5 Waste. This is illustrated in Figure 7-3 which provides an overview of all waste-related GHG emissions in Switzerland reported in chp. 7 and elsewhere in the NID.

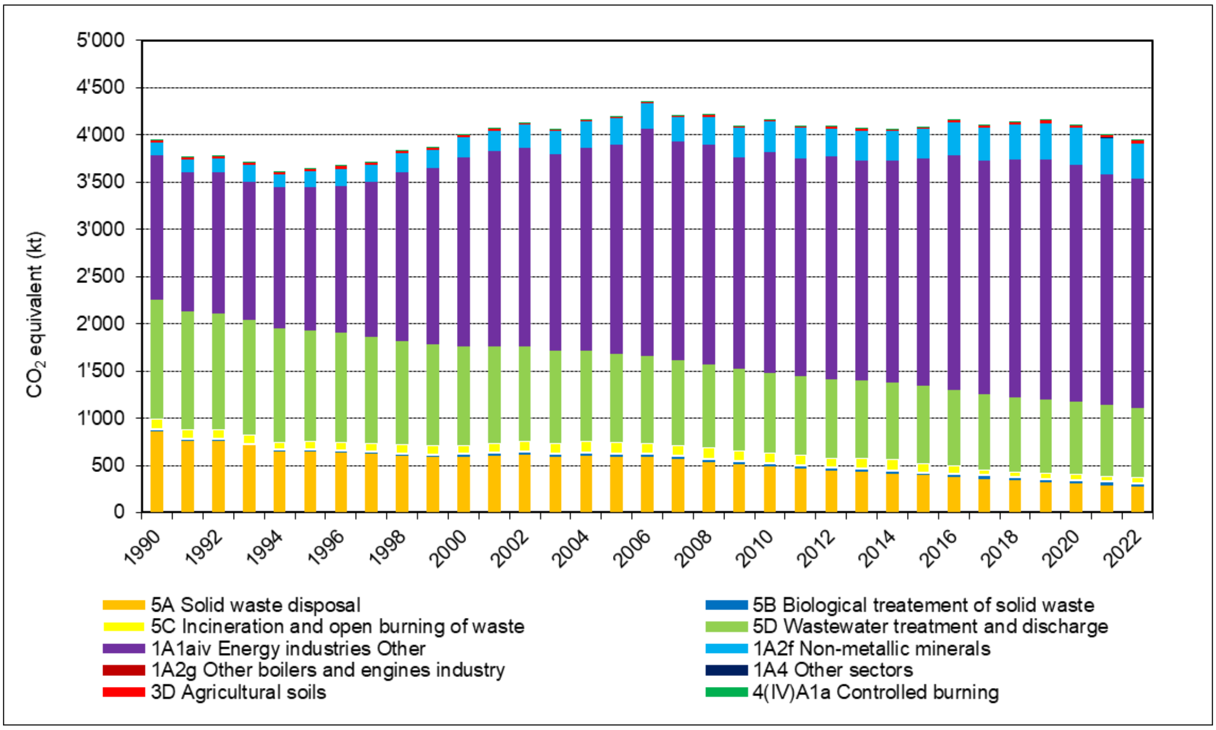

Figure 7-3 Total waste-related GHG emissions, reported in different sectors. The energetic use of waste-related biomass is not considered in this figure, as it predominantly leads to emissions of biogenic CO_2 (and only very minor emission of CH_4 and N_2O).

For sector 5 Waste, there is a total of four identified key categories, emitting CH_4 and N_2O (see Figure 7-4).

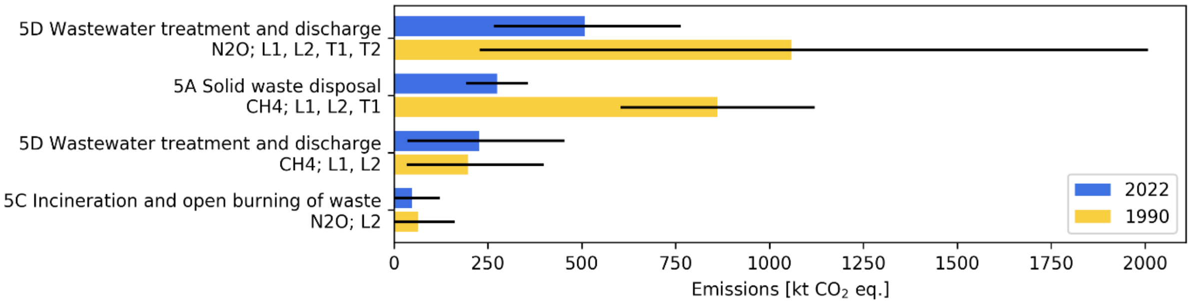

Figure 7-4 Key categories in the Swiss GHG inventory from sector 5 Waste determined by the key category analyses, approaches 1 and 2. Categories are set out in order of decreasing emissions in 2022. L1: key category according to approach 1 level in 2022; L2: same for approach 2; T1: key category according to approach 1 trend 1990–2022; T2: same for approach 2. Black uncertainty bars represent the narrowest 95 % confidence interval obtained by Monte Carlo simulations (see chp. 1.6 for details).

7.1.2. Overview of waste management in Switzerland

Goals and principles regarding waste management in Switzerland are stated in the Guidelines on Swiss Waste Management (BUS 1986), in the Waste Concept for Switzerland (SAEFL 1992) and in the Ordinance on the Avoidance and the Disposal of Waste (Swiss Confederation 2015).

The four principles are:

- The generation of waste shall be avoided as far as possible.
- Pollutants from manufacturing processes and in products shall be reduced as far as possible.
- Waste shall be recycled wherever this is environmentally beneficial and economically feasible.
- Waste shall be treated in an environmentally sound way. In the long term only materials of final storage quality shall be disposed of in landfills.

Figure 7-5 gives a general overview of the type of treatment and amounts of waste treated in the respective sectors in Switzerland, including waste imports and waste exports. Only waste fractions that are relevant for emissions are shown. The figure further illustrates where the processes related to the waste management system are reported in the NID. The following details can be provided regarding the different sectors:

- **1 Energy:** In accordance with the IPCC Guidelines (IPCC 2006) emissions from waste-to-energy activities, where waste is used as an alternative fuel for energy production, are reported in 1A Fuel combustion. This applies to municipal solid waste incineration plants and special waste incineration plants, where energy is recovered (1A1a). Municipal solid waste incineration plants treat burnable municipal solid waste as well as sewage sludge, burnable construction waste and some special wastes. Cement industry uses conventional fossil fuels but also alternative fuels, which are special waste, dried sewage sludge, biomass as well as plastics collected separately or segregated from solid waste streams (1A2fi). The digestion of biomass in agricultural and industrial biogas facilities and of sewage sludge in wastewater treatment plants as well as the use of landfill gas are also reported in sector 1 Energy (source categories 1A1a, 1A2gviii and 1A4ci), as such biogas and sewage gas are used for combined heat and power generation. The energy production from renewable goods, such as the use of wood waste in wood-fired power stations, is reported under 1A1a, 1A2, 1A4ai and 1A4bi and 1A4ci.
- **3 Agriculture:** Since 2003 it is forbidden in Switzerland to use sewage sludge as a fertiliser. As of 2006, this prohibition has been made effective for all agricultural areas with a transition period to 2008. Since 2009, sewage sludge has no longer been applied; however, the use of 3D1biii Other organic fertilisers applied to soils has increased and includes nitrogen inputs from compost, liquid and solid digestates from industrial biogas plants, co-substrates from agricultural biogas plants and decentralised wastewater streams (see chp. 5.5.2.2 Direct N_2O emissions from managed soils, Table 5-24).
- **5 Waste:** Only emissions from waste management activities not used for energy production are reported under sector 5 Waste. Solid waste disposal is no longer practiced in Switzerland as incineration has been mandatory for the disposal of combustible waste since 2000. Emissions from composting are described under 5B1. Emissions related to digestion, but not directly related to energy production (such as the storage of digested biomass), are reported under 5B2. 5C Waste incineration and open burning of waste accounts for a small fraction only, consisting of illegal waste incineration, sewage sludge incineration, burning of residues in agriculture and private households as well as cremations. Special waste incineration without energy recovery, such as cable

incineration or hospital waste incineration plants, no longer takes place in Switzerland and is thus crossed out in the figure. These waste fractions are nowadays incinerated in municipal solid waste incineration plants and are therefore reported under sector 1 Energy. Emissions related to wastewater treatment are reported under 5D.

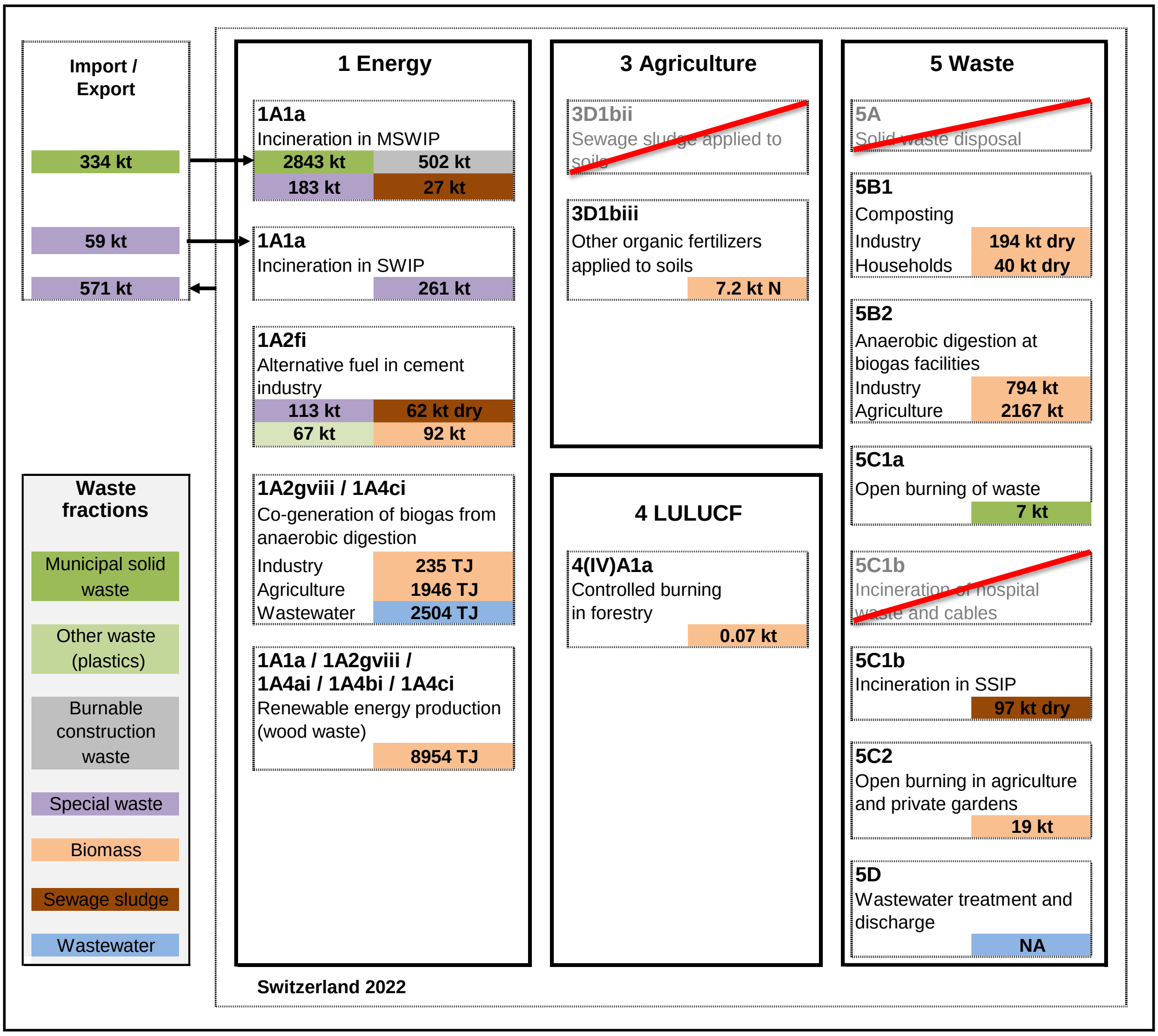

Figure 7-5 Overview on the type of treatment and amounts of waste treated in the respective sectors in Switzerland in 2022. Abbreviations: MSWIP: Municipal Solid Waste Incineration Plant, SWIP: Special Waste Incineration Plant, SSIP: Sewage Sludge Incineration Plant.

Regarding the treatment and amounts of relevant waste types the following details can be provided (recycled amounts are not shown in Figure 7-5 because they are not relevant for emissions):

- **Municipal solid waste:** In Switzerland more than 50 % of the municipal solid waste is collected separately and recycled (FOEN 2023h). The amount of waste incinerated includes imported municipal solid waste, mainly from neighbouring countries such as Germany, France, Austria and Italy. The import of waste into Switzerland needs to be authorized by the Federal Office for the Environment. A part of the separately collected plastic fractions from households and industry which cannot be recycled is used as an alternative fuel in the cement industry.
- **Construction waste:** More than 50 % of the construction waste is recycled. About half of the recycling takes place at the construction sites, e. g. by reusing material left after

breaking up the road cover. The other half is separated at the construction sites and recycled individually, e. g. used glass, metals, concrete etc. A minor amount of combustible construction waste is incinerated in municipal solid waste incineration plants. The remaining, inert construction waste is disposed of in landfills for inert waste (ERM 2016; Wüest & Partner 2015).

- **Special waste:** Special waste refers to a highly diverse waste fraction encompassing hospital wastes, batteries, electronic waste, hazardous industrial sludge, contaminated soils, solvents, chemicals etc. Special waste is either recycled, biologically treated, landfilled, burnt or exported for landfilling in foreign countries (FOEN 2023h). Only the amount of incinerated special waste is relevant for emissions (EMIS 2024/1A1a Kehrichtverbrennungsanlagen and EMIS 2024/1A1a Sondermüllverbrennungsanlagen). Some special waste is also used as an alternative fuel in the cement production (EMIS 2024/1A2f i Zementwerke Feuerung).
- **Sewage sludge:** Since 2009 sewage sludge has not been used anymore as a fertiliser in agriculture. Such use has been prohibited due to the content of organic contaminants, heavy metals and other substances (see chp. 5.5.2.2.2). Therefore, all sewage sludge is incinerated, either in municipal solid waste incineration plants or in sewage sludge incineration plants without energy recovery (internal information provided by the waste section of FOEN). Dried sewage sludge is also used as an alternative fuel in the cement industry (EMIS 2024/1A2fi Zementwerke Feuerung).
- **Biomass:** The term biomass refers to a broad range of materials such as garden waste, grass, wood waste, liquid manure and production remains e. g. from the food industry. Biomass from agriculture, forestry and private gardens are burnt without energy recovery (EMIS 2024/5C2 & 4VA1 Abfallverbrennung Land- und Forstwirtschaft). Biomass is also digested or composted (in large-scale composting facilities or backyards). Quantities of biomass refer to dry matter. Biomass such as used wood or animal fat is used as an alternative fuel in the cement industry (EMIS 2024/1A2fi Zementwerke Feuerung). Compost is used as a fertiliser and quantities refer to dry matter (see Table 5-24 “Other organic fertilisers”).

7.2. Source category 5A – Solid waste disposal

7.2.1. Source category description

Table 7-2 Key categories of 5A Solid waste disposal. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
5A	Solid waste disposal	CH4	L1, L2, T1

Source category 5A1 Managed waste disposal sites comprise all emissions from managed solid waste landfill sites. As incineration has been mandatory for combustible waste since 2000, inputs into managed solid waste landfill sites have dropped to zero. Remaining emissions thus originate from landfilling before 2000. Emissions from source category 5A2 Unmanaged waste disposal sites are included in source category 5A1 Managed waste disposal sites. This is motivated by the fact that in Switzerland to date no official unmanaged waste disposal sites exist. Although no reliable data is available, the effective quantity of waste not properly treated in landfills is estimated to be very small.

In Switzerland, less than four managed biogenically active landfill sites were equipped to recover landfill gas from 2018 onwards (SFOE 2023a). While some landfill gas is used to generate heat only, the landfill gas is generally used in co-generation plants in order to produce electricity and heat. A small amount of the landfill gas is flared (Consaba 2016).

Emissions from the usage of landfill gas in combined heat and power units are reported in sector 1 Energy in source category 1A1a Public electricity and heat production (see Figure 3-18).

Table 7-3 Specification of source category 5A Solid waste disposal in Switzerland.

5A	Source category	Specification
5A1	Managed waste disposal sites	Emissions from managed solid waste landfill sites.
5A2	Unmanaged waste disposal sites	Officially no unmanaged waste disposal sites exist (included in 5A1)
5A3	Uncategorized waste disposal sites	Not ocurring in Switzerland

7.2.2. Methodological issues

Methodology (5A)

Emissions are calculated by a Tier 2 method based on the decision tree in the IPCC Guidelines (IPCC 2006, vol. 5, chp. 3, Fig. 3.1). The spreadsheet for the First Order Decay (FOD) model provided by IPCC (2006) has been applied and parametrised for Swiss conditions (FOEN 2024c).

The values for the parameter degradable organic carbon are provided for each waste fraction (Table 7-4). For all waste types the IPCC (2006) default values are used, except for industrial waste. For industrial waste the default value for wood and straw is used, as most of the industrial waste deposited in Switzerland is assumed to be wood waste.

Table 7-4 Degradable organic carbon values for fractions of different waste compositions (weight fraction, wet basis).

Waste composition	IPCC default value		Values used in Switzerland	
(weight fraction, wet basis)	Range	Default	Value	Reference and remarks
Food waste	0.08 - 0.20	0.15	0.15	IPCC default value
Garden	0.18 - 0.22	0.2	0.2	IPCC default value
Paper	0.36 - 0.45	0.4	0.4	IPCC default value
Wood and straw	0.39 - 0.46	0.43	0.43	IPCC default value
Textiles	0.20 - 0.40	0.24	0.24	IPCC default value
Disposable nappies	0.18 - 0.32	0.24	NO	Not relevant / no activity data
Sewage sludge	0.04 - 0.05	0.05	0.05	IPCC default value
Industrial waste	0.00 - 0.54	0.15	0.43	Same as wood and straw

The methane generation rate [1/yr] is chosen according to wet temperate conditions (Table 7-5). For all waste types the IPCC (2006) default values are used, except for industrial waste. For industrial waste the default value for wood and straw is used, again based on the fact that most of it is assumed to be wood waste.

Table 7-5 Methane generation rate [1/yr] according to waste by composition for wet temperature conditions.

Waste composition (weight fraction, wet basis)	**IPCC default value** Range	 Default	**Values used in Switzerland** Value	 Reference and remarks
Food waste	0.10 - 0.20	0.185	0.185	IPCC default value
Garden	0.06 - 0.10	0.1	0.1	IPCC default value
Paper	0.05 - 0.07	0.06	0.06	IPCC default value
Wood and straw	0.02 - 0.04	0.03	0.03	IPCC default value
Textiles	0.05 - 0.07	0.06	0.06	IPCC default value
Disposable nappies	0.06 - 0.10	0.1	NO	Not relevant / no activity data
Sewage sludge	0.10 - 0.20	0.185	0.185	IPCC default value
Industrial waste	0.08 - 0.10	0.09	0.03	Same as wood and straw

The general parameters are set as follows:

- DOCf (fraction of degradable organic carbon dissimilated) = 0.5 (IPCC (2006) default value)
- Delay time (months) = 6 (IPCC (2006) default value)
- Fraction of methane (F) in developed landfill gas = 0.5 (IPCC (2006) default value)
- Conversion factor, C to CH_4 = 1.33 (IPCC (2006) default value)
- Oxidation factor (OX) = 0.1

The oxidation factor has been set to 0.1 according to the 2006 IPCC Guidelines (IPCC 2006, vol. 5, chp. 3), since it is standard practice in Switzerland to cover the landfills, e. g. with soil.

For the methane correction factors (MCF) for the different solid waste disposal site types IPCC default values are used. Between 1990 and 2015 (the IPCC spreadsheet has to be parametrised from 1950 to 2030/2050) waste distribution to the following three solid waste disposal site types has taken place (for both municipal solid waste and industrial waste):

- Methane correction factor for unmanaged, shallow solid waste disposal sites (SWDS) = 0.4 (IPCC (2006) default value)
- Methane correction factor for unmanaged, deep solid waste disposal sites = 0.8 (IPCC (2006) default value)
- Methane correction factor for managed solid waste disposal sites = 1 (IPCC (2006) default value)
- The other two methane correction factor (managed, semi-aerobic and uncategorised) are not relevant because such solid waste disposal sites are not occurring in Switzerland, i. e. no waste has been distributed to such sites.

As shown in Table 7-6, the composition of municipal solid waste deposited has changed during the last 60 years.

Table 7-6 Composition of municipal solid waste going to solid waste disposal sites (BUS 1978, BUS 1984, FOEN 2014o).

Waste fraction	1950–1979	1980–1989	1990–1999	2000–2009	since 2010
Food	20.0%	26.5%	21.4%	26.6%	31.5%
Garden	8.0%	2.9%	1.6%	1.4%	1.7%
Paper	36.0%	30.6%	28.0%	21.0%	17.2%
Wood	4.0%	4.3%	5.0%	2.0%	1.8%
Textile	4.0%	3.1%	3.0%	3.0%	3.2%
Nappies	0.0%	0.0%	0.0%	0.0%	0.0%
Plastics, other inert	28.0%	32.6%	41.0%	46.0%	44.6%

With these parametrisations and the activity data for municipal solid waste, industrial waste and sewage sludge the amount of CH_4 generated in landfills is calculated. The amount of CH_4 recovered and used as fuel for combined heat and power generation or flared is then subtracted.

For combined heat and power generation and flaring, the emissions of other gases are considered to be proportional to the amount of CH_4 burnt (Table 7-7).

Long-term storage of carbon in waste disposal sites, annual change in total long-term storage of carbon and annual change in total long-term storage of carbon in harvested wood products has been calculated with the parametrised spreadsheet model provided by IPCC (2006) as well and is reported in CRT Table5 as memo item. As incineration has been mandatory for combustible waste since 2000 in Switzerland and solid waste disposal activities have ceased there is no annual change since 2007.

Emission factors (5A)

Emission factors for CO_2, CH_4, CO, NMVOC and SO_2 are country-specific based on measurements and expert estimates, as documented in EMIS 2024/1A1 & 5A Kehrichtdeponien. The emission factor of NMVOC from flaring has been introduced based on a study on emissions from landfill gas installations (Butz 2003) suggesting emissions of 82.15 grams of NMVOC per tonne of CH_4 flared with an uncertainty of ±10 %. CO_2 emissions from non-biogenic waste are included, while CO_2 emissions from biogenic waste are excluded from total emissions. Table 7-7 presents the emission factors used in 5A1.

Table 7-7 Emission factors for 5A1 Managed waste disposal sites in 2022.

5A1 Managed waste disposal sites	Unit	CO_2 biogen	CO_2 fossil	CH_4	NO_x	CO	NMVOC	SO_2
Direct emissions from landfill	t / t CH_4 produced	3	NA	1	NA	NA	0.013	NA
Flaring	kg / t CH_4 burned	2750	NA	NA	1	17	0.082	NA
Open burning	kg / t waste burned	569	521	6	2.5	50	16	0.75

Activity data (5A)

There are three kinds of activity data for 5A1 Managed waste disposal sites: Waste quantities disposed on landfills, direct CH_4 emissions and CH_4 flared.

For the calculation of these three kinds of activity data, the amounts of municipal solid waste, construction waste and sewage sludge (deposited on managed waste disposal sites) are relevant.

Table 7-8 Activity data in 5A1: Waste disposed on managed waste disposal sites since 1950 (documented in EMIS 2024/1A1a & 5A Kehrichtdeponien).

5A1 Managed waste disposal sites	**Unit**	**1950**	**1960**	**1970**	**1980**	**1990**	**1995**	**2000**	**2005**	**2010 - 2021**
Municipal solid waste (MSW)	kt	570	675	864	532	650	540	292	14	NO
Construction waste (CW)	kt	9.9	11	36	85	150	60	54	1.4	NO
Sewage sludge (SS)	kt (dry)	NO	NO	3.2	30	60	28	4.2	0.98	NO
Open burned waste	kt	299	294	226	97	NO	NO	NO	NO	NO
Total waste quantity	kt	879	980	1129	744	860	628	350	16	NO

Table 7-8 documents the amounts of municipal solid waste, construction waste and sewage sludge disposed of on managed waste disposal sites since 1950 (as documented in EMIS 2024/1A1a & 5A Kehrichtdeponien). An increase of waste landfilled until 1970 can be observed. The decline of waste amounts landfilled afterwards is due to changes in the legislative framework, making incineration mandatory for disposal of combustible waste and banning the disposal of combustible waste on landfills from 1 January 2000. The amounts of combustible waste disposed of on managed waste disposal sites reached zero in 2009. While open burning of waste on managed waste disposal sites occurred in the distant past it is assumed that, by reason of legal requirements and regulations, open burning has not taken place since 1990 anymore (Consaba 2016) and is therefore NO in Table 7-8.

With these primary activity data total CH_4 emissions generated are calculated using the spreadsheet first order decay model provided by IPCC (2006). For the calculation of direct CH_4 emissions, CH_4 flared and used in co-generation units is determined and subtracted from total CH_4 emissions (Table 7-9). The landfill gas recovered and used as fuel for co-generation units is reported under 1A1 Energy in accordance with the 2006 IPCC Guidelines (IPCC 2006). The sum of landfill gas flared and landfill gas used in co-generation units is reported as being recovered in CRT Table5.A.

The amount of CH_4 used in co-generation is taken from the Swiss statistics of renewable energies (SFOE 2023a). The amount of landfill gas flared has been assessed in a separate investigation (Consaba 2016). The CH_4 flared has been estimated as follows:

- A list of all managed waste disposal sites that are still operated or have been closed since 1990 was compiled.
- Their technical equipment was assessed and deduced (motors, torches, gas drainage, etc.).
- Four types of managed landfill sites according to their equipment and CH_4 management were distinguished:
  - landfills with gas recovery in combined heat and power generation, boiler and torch; category a);
  - landfills with gas recovery or thermal treatment (boiler, torch, non-catalytic oxidation, flameless oxidation; category b);
  - landfill gas recovery without methane elimination (bio filter, aerobiosation); category c);
  - landfills without gas treatment (direct release); category d).

- A survey was conducted in 14 managed waste disposal sites and data on their operation mode has been collected.
- With these data the amounts flared in managed waste disposal sites categories a) and b) were estimated.
- The amount flared on all managed waste disposal sites has been extrapolated considering the waste amounts deposited.
- A time series for the amount of methane torched relative to the total amount of CH_4 estimated with the Swiss first order decay IPCC 2006 model (managed and unmanaged sites) has been calculated.

The amount flared is expressed as a percentage of CH_4 produced in all managed waste disposal sites in Switzerland. The percentage flared varies between 5 and 15 % since 1990.

Table 7-9 Activity data in 5A1: Direct CH_4 emissions, CH_4 flared and CH_4 used in combined heat and power units (as documented in EMIS 2024/1A1a & 5A Kehrichtdeponien).

5A1 Managed waste disposal sites	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
CH_4 direct emissions	kt	31	23	21	21	18	15	15	14	13	13	12	11	11	10	10
CH_4 flared	kt	1.8	5.3	5.6	3.4	2.4	1.6	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3
CH_4 used in co-generation units (reported under 1A1a)	kt	4.9	12	11	4.1	1.0	0.77	0.63	0.43	0.25	0.13	0.12	0.17	0.079	0.079	0.17

Waste quantities disposed in landfills started to decrease in the early 1990s and have ceased completely from 2009 onwards. The continuous decrease of CH_4 generated by decaying waste over time, in combination with the relative increase of CH_4 recovery from 1990 until 2017 yields a pronounced trend of CH_4 emissions from source category 5A.

7.2.3. Uncertainties and time-series consistency for 5A

Uncertainty in CH_4 emissions from 5A Solid waste disposal

For lack of a detailed uncertainty analysis with the first order decay model, a combined uncertainty of 30 % is assumed for the CH_4 emissions (EMIS 2024/1A1a & 5A Kehrichtdeponien).

Consistency: Time series for 5A Solid waste disposal are all considered consistent.

7.2.4. Category-specific QA/QC and verification for 5A

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

7.2.5. Category-specific recalculations for 5A

There were no recalculations implemented in submission 2024.

7.2.6. Category-specific planned improvements for 5A

No category-specific improvements are planned.

7.3. Source category 5B – Biological treatment of solid waste

7.3.1. Source category description

Table 7-10 Key categories of 5B – Biological treatment of solid waste. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Source category 5B – Biological treatment of solid waste is not a key category.

Source category 5B Biological treatment of solid waste comprises the process-related GHG emissions from composting and from digesting of organic waste.

Within 5B1 Composting two kinds of composting are distinguished, i. e. industrial composting and backyard composting. Industrial composting covers the emissions from centralized composting activities with a capacity of more than 100 tonnes of organic matter per year as well as the composting of organic material at the border of agricultural fields. Backyard composting in private households or communities is also common practice in Switzerland and therefore considered.

In 5B2 Anaerobic digestion at biogas facilities emissions occur from gas leakages as well as from digested matter (solid leftovers after completion of anaerobic microbial degradation of organic matter) which is being composted. The biogas is used for combined heat and power generation or is upgraded and used as fuel.

In 5B Biological treatment of solid waste the emissions from the composting of digested matter as well as the CH_4 losses from biogas facilities and emerging from biogas upgrading are included. Emissions related to the use of biogas for combined heat and power generation are reported in sector 1 Energy source categories 1A2gviii Other and 1A4ci Agriculture/forestry/fishing (see Figure 3-18). Emissions related to the use of upgraded biogas fed into the natural gas grid are reported in sector 1 Energy source categories 1A3bi-iii Road transportation and 1A4ai Commercial boilers (see Figure 3-18).

Table 7-11 Specification of source category 5B Biological treatment of solid waste.

5B	Source category	Specification
5B1	Composting	Process-related emissions from composting of organic waste
5B2	Anaerobic digestion at biogas facilities	Process-related emissions from digesting of organic waste

7.3.2. Methodological issues

7.3.2.1. Composting (5B1)

Methodology (5B1)

Emissions are calculated by a Tier 2 method based on the IPCC Guidelines (IPCC 2006, vol. 5, chp. 4.1.1 Biological treatment of solid waste).

Activity data and emission factors for industrial and backyard composting have been thoroughly reassessed in 2017 (Schleiss 2017), new data were gained and EMIS 2024/5B1 Kompostierung, which serves as basis for greenhouse gas emission estimates, has been revised accordingly.

Both activity data and emission factors are reported with reference to mass of dry matter as requested in CRT Table5.B. A transfer factor from wet to dry matter of 40.0 % has been suggested by Baier (2023).

Emission factors (5B1)

Emission factors used for source category 5B1 Composting are summarised in Table 7-12 and documented in detail in EMIS 2024/5B1 Kompostierung. Emission factors are country-specific and encompass CH_4, N_2O and NMVOC based on measured or estimated values reported in the literature. The emission factors are based on a recommendation by Schleiss (2017) based on Dinkel et al. (2012). They are based on measurements and taking into account the predominantly non-industrial (ban on refuse composting) origin of composted material in Switzerland resulting in a rotting process as aerobic as possible to produce compost of marketable quality. This yields a lower emission factor for CH_4 compared to reference values (IPCC 2006).

Activity data (5B1)

Activity data for source category 5B1 Composting are shown in Table 7-13 and documented in detail in EMIS 2024/5B1 Kompostierung.

Activity data for industrial composting are based on waste surveys (Schleiss 2017). For 2013 reliable data on waste quantities are available (FOEN 2016m). All cantons were addressed and data on the amounts of organic waste quantities, according to their respective treatment option, have been collected. Data on waste quantities are also available from surveys in 1989, 1993 and 2000. Activity data between these years were interpolated. The time series were validated with additional data sets from the years 2002 and 2010. After 1993 digesting of organic waste was also becoming a relevant treatment option and therefore respective amounts were subtracted. In addition, also waste wood quantities were subtracted, in order to get the amount of organic waste treated in industrial composting plants. As of 2014, activity data for industrial composting are adopted from the annual statistical reports by the inspectorate system for the composting and fermentation industry in Switzerland (CVIS) as recommended by Schleiss (2017). Since submission 2023 the annual statistical data have to be obtained from the presentation from the "Kantonstag des Vereins Inspektorat" as the association ceased to produce an annual report but presents the data during this annual meeting (CVIS 2023).

Activity data for backyard composting were reassessed in 2017 (Schleiss 2017). Basically, amounts of organic waste composted in backyards are based on expert assessments and are derived from data from a small number of cities and villages. The experts took into account different parameters affecting waste amounts composted in backyards over time, i.e.

urban or rural situation, communication e.g. by community authorities and incentive programmes, and on the availability of separate door-to-door collection of organic wastes. As of 2008, activity data for backyard composting are assumed to be constant as recommended by Schleiss (2017).

7.3.2.2. Anaerobic digestion at biogas facilities (5B2)

Methodology (5B2)

In source category 5B2 Anaerobic digestion at industrial and agricultural biogas facilities are considered. The produced biogas is used for combined heat and power generation or upgraded to natural gas quality. Accordingly, biogas upgrading is considered as a separate process in 5B2. However, emissions from the use of biogas as fuel for combined heat and power generation are reported under sector 1 Energy, in accordance with the IPCC Guidelines (IPCC 2006).

For the emissions from 5B2 Anaerobic digestion at biogas facilities, a Tier 2 method is used. While industrial and agricultural biogas facilities are separately considered, the same emission factors are used (see below). As mentioned above, emissions from biogas upgrading are estimated separately, based on the amount of biogas upgraded.

Emissions of greenhouse gases from industrial and agricultural biogas facilities are estimated using a constant emission factor for each biogas facility. This is based on an evaluation of measurement data for CH_4 losses that has shown that those losses are not dependent on the amount of substrate processed in a particular facility. Therefore, CH_4 emissions are calculated based on an emission factor per plant multiplied by the number of industrial and agricultural biogas facilities, respectively.

In contrast, emissions of air pollutants are calculated based on estimates from up to seven different process steps (such as pre-storage, primary and secondary digester, interim storage, maturing, handling of biogas etc.), as documented in EMIS 2024/1A1a & 5 B 2 Vergärung LW and EMIS 2024/1A1a & 5 B 2 Vergärung IG. However, as CH_4, CO and NMVOC emissions from source category 5B are of biogenic origin, no indirect CO_2 emissions from this source category are included in CRT Table6 as documented in chp. 9.

N_2O emissions from source category 5B2 are considered to be negligible according to the IPCC Guidelines (IPCC 2006, vol. 5, chp. 4.1.3), and are therefore set to zero.

Emission factors (5B2)

Table 7-12 presents the emission factors used in 5B2 Anaerobic digestion at biogas facilities. As documented in FOEN (2015n), the emission factor for CH_4 for anaerobic digestion at industrial and agricultural biogas facilities is based on investigations performed in the framework of the greenhouse gas emission compensation projects. Field measurements indicate that there is no correlation between the produced amount of biogas and the amount of biogas lost to the atmosphere. The investigated data show that on average each biogas facility loses 1.23 t CH_4 per year to the atmosphere. This value is used to estimate the emissions from industrial and agricultural biogas facilities in Switzerland.

The emission factor for losses of CH_4 from biogas upgrading is based on official regulations regarding maximal CH_4 leakage, as well as studies focussing on CH_4 emissions from biogas upgrading. Accordingly, regulations by the Swiss Gas and Water Association (SGWA 2016a) set an emission limit value for CH_4 losses from biogas upgrading. In 1990, such losses were allowed to be 5 % of the upgraded amount, in 2014 the limit was lowered to 2.5 %. Measurements in a few biogas upgrade installations in 2007, 2013 and 2014 showed the following losses: 2007 one plant: 2.6 %, 2013 one plant: 1 %, 2014 three plants: 1.3 %, 1.8 %, and 3.5 %. The measurements showed that the emission limits were respected (with the exception of one plant in 2014) and therefore Switzerland decided to set the losses from biogas upgrading to the emission limit value with the assumption of a linear improvement between the 1990 and the 2014 value. The continuous improvement seems plausible, as newer plants show fewer losses and values of less than 1 % to 2.5 % are state of the art.

Activity data (5B2)

Activity data for 5B2 Anaerobic digestion at biogas facilities, as shown in Table 7-13, are based on data from the Swiss renewable energy statistics (SFOE 2023a). Relevant are the number of industrial and agricultural biogas facilities, as well as the total amount of biogas upgraded.

Table 7-12 Emission factors for 5B Biological treatment of solid waste in 2022.

5B Biological treatment of solid waste	Unit	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Composting (industrial)	g/t composted waste	2'500	125	NA	NA	750	NA
Composting (backyard)	g/t composted waste	2'500	125	NA	NA	750	NA
Digestion (industrial biogas facilities)	t/facility	1.2	NA	NA	NA	NA	NA
Digestion (agricultural biogas facilities)	t/facility	1.2	NA	NA	NA	NA	NA
Biogas up-grade	g/GJ	500	NA	NA	NA	NA	NA

Table 7-13 Activity data in 5B Biological treatment of solid waste.

5B Biological treatment of solid waste	Unit	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Composting (industrial)	kt (dry)	96	144	208	210	212	214	191	172	201	196	190	218	209	219	194
Composting (backyard)	kt (dry)	44	62	72	68	48	40	40	40	40	40	40	40	40	40	40
Digestion (industrial biogas facilities)	number	NO	4.0	11	14	22	26	25	26	27	28	28	29	27	28	28
Digestion (agricultural biogas facilities)	number	102	76	68	72	72	97	98	99	98	106	111	112	119	121	126
Biogas up-grade	GJ	NO	NO	19'866	40'637	121'627	277'700	337'415	408'038	442'665	456'665	473'538	551'924	600'094	624'825	633'116

To improve transparency the CH_4 and N_2O emissions of source category 5B Biological treatment of solid waste are shown on a completely disaggregated level in Table 7-14.

Table 7-14 CH_4 and N_2O emissions of 5B Biological treatment of solid waste.

5B Biological treatment of solid waste	**Gas**	**Unit**	**1990**	**1995**	**2000**	**2005**	**2010**
Composting (industrial)	CH_4	t	240	360	519	526	530
	N_2O	t	12	18	26	26	26
Composting (backyard)	CH_4	t	110	155	180	170	120
	N_2O	t	5.5	8	9	9	6.0
Digestion (industrial)	CH_4	t	NO	4.9	14	17	27
Digestion (agricultural)	CH_4	t	125	93	84	89	89
Biogas up-grade	CH_4	t	NO	NO	16	28	71

5B Biological treatment of solid waste	**Gas**	**Unit**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Composting (industrial)	CH_4	t	536	478	430	503	490	475	544	523	548	484
	N_2O	t	27	24	21	25	24	24	27	26	27	24
Composting (backyard)	CH_4	t	100	100	100	100	100	100	100	100	100	100
	N_2O	t	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Digestion (industrial)	CH_4	t	32	31	32	33	34	34	36	33	34	34
Digestion (agricultural)	CH_4	t	119	121	122	121	130	137	138	146	149	155
Biogas up-grade	CH_4	t	145	169	204	221	228	237	276	300	312	317

7.3.3. Uncertainties and time-series consistency for 5B

Uncertainty in CH_4 and N_2O emissions from composting and digestion

The uncertainty of all emission factors in source category 5B1 Composting is estimated at 30 % for industrial composting and at 100 % for backyard composting. The uncertainty of the related activity data is estimated at 30 % for industrial composting and at 100 % for backyard composting (EMIS 2024/5B1 Kompostierung).

For 5B2 Anaerobic digestion at biogas facilities the uncertainty takes into account the different process steps on one hand and emission factors on the other hand (EMIS 2024/1A1a & 5 B 2 Vergärung LW and EMIS 2024/1A1a & 5 B 2 Vergärung IG).

The overall uncertainty for 5B Biological treatment of solid waste for activity data as well as for emission factor is 30 %.

Consistency: Time series for 5B Biological treatment of solid waste are all considered consistent.

7.3.4. Category-specific QA/QC and verification for 5B

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

7.3.5. Category-specific recalculations for 5B

The following recalculations were implemented in submission 2024.

- 5B Biological Treatment of Solid Waste: All input activity data for 1990-2021 have been updated because of harmonisation of rounding. This may cause changes in emissions of up to 10 %.
- 5B1 Composting (industrial and backyard): Both activity data and emission factors are reported with reference to mass of dry matter. A new transfer factor from wet to dry mass of 40.0 % has been suggested by Baier (2023) instead of the previously applied factor from CVIS (2019). Consequently, activity data for the years 1990–2021 have decreased by 27 % while emission factors for CH_4, N_2O and NMVOC have increased by 36 %. This leads to changes in emissions from 5B1 Composting of <1 % due to rounding.

7.3.6. Category-specific planned improvements for 5B

No category-specific improvements are planned.

7.4. Source category 5C – Incineration and open burning of waste

7.4.1. Source category description

Table 7-15 Key categories of 5C Incineration and open burning of waste. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	**IPCC category**	**Gas**	**Identification criteria**
5C	Incineration and open burning of waste	N2O	L2

There is a long tradition in Switzerland to incinerate waste. Since 1991, the incineration of waste has only been legally permitted in appropriate plants with a rated thermal input of at least 350 kW (Ordinance on Air Pollution Control (Swiss Confederation 1985)). Consequently, the open burning of waste has been prohibited. The heat generated during the incineration has to be recovered in accordance with the Ordinance on the Avoidance and the Disposal of Waste (Swiss Confederation 2015). Following the IPCC Guidelines (IPCC 2006) emissions from waste-to-energy activities are dealt with in 1A1a Public electricity and heat production.

5C1 encompasses incineration of hospital wastes, illegal waste incineration, incineration of insulation material from cables, of sewage sludge and cremations.

5C2 consists of emissions from open burning of branches in agriculture and gardening. Natural agricultural and gardening residues consist of fallen fruit trees, part of diseased residue which are cut up, collected and burnt off-site. Field burning of agricultural residues does not occur in Switzerland. Emissions from open burning of residues in forestry are reported in LULUCF sector 4IV (chp. 6.4.2.6.4.1).

Table 7-16 Overview of waste incineration sources reported under 5C.

5C	Source category	Specification
5C1	Hospital waste incineration	Emissions from incinerating hospital waste in hospital incinerators
	Municipal waste incineration (illegal)	Emissions from illegal incineration of municipal solid wastes at home. Emissions from waste incineration at construction sites (open burning)
	Industrial waste incineration	Emissions from incinerating cable insulation materials
	Sewage sludge incineration	Emissions from sewage sludge incineration plants
	Cremation	Emissions from the burning of bodies in crematoria
5C2	Open burning of natural residues in agriculture and private households	Open burning of branches in agriculture and gardening.

7.4.2. Methodological issues

Methodology (5C)

Emissions are calculated using Tier 2 methods based on the IPCC Guidelines (IPCC 2006, vol. 5, chp. 5.2). In general, the greenhouse gas emissions are calculated by multiplying the waste quantity incinerated by emission factors. For crematoria, the greenhouse gas emissions are calculated by multiplying the number of cremations by emission factors.

For sewage sludge incineration plants, the respective waste quantities are based on reliable statistical data. The emission factors are based on emission declarations from three incineration plants in 2002 and 2015, respectively that covered approximately one third of the Swiss capacities. Due to the lack of better or newer data these emission factors are kept constant since then and no improvement in flue gas cleaning standards is assumed.

For hospital waste incineration, municipal waste incineration (illegal) and industrial waste incineration (consists of cable insulation materials), the waste quantities used are based on expert estimates.

Emissions from burning of residues in agriculture and gardening are calculated using a Tier 1 method based on the IPCC Guidelines (IPCC 2006, vol. 5, chp. 5.2). Emission factors are taken from the EMEP/EEA guidebook (EMEP/EEA 2019, EMEP/EEA 2002).

Indirect CO_2 emissions resulting from fossil CH_4, CO and NMVOC emissions from hospital waste incineration, municipal waste incineration (illegal) and industrial waste incineration (consists of cable insulation materials) are included in CRT Table6 as documented in chp. 9.

Emission factors (5C)

Table 7-17 presents an overview of the emission factors for 5C for the latest inventory year. Documentation and sources are given in: EMIS 2024/5 C 1 (5 C 1 b iii UNECE)_Spital-abfallverbrennung, EMIS 2024/5 C 1 (5 C 1 a UNECE)_ Abfallverbrennung illegal, EMIS 2024/5 C 1 (5 C 1 b i UNECE)_Kabelabbrand, EMIS2024/5 C 1_(5 C 1 b iv UNECE)_Klärschlammverbrennung, EMIS2024/ 5 C 2_4 V A 1_Abfallverbrennung Land- und Forstwirtschaft and EMIS 2024/5 C 1 (5 C 1 b v UNECE)_Krematorien.

Table 7-17 Emission factors for 5C Waste incineration and open burning of waste in 2022.

5C Waste incineration and open burning of waste	**CO_2 fossil**	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**
	t/t		kg/t					
Hospital waste incineration	0.9	NA	NA	0.06	1.5	1.4	0.3	1.3
Municipal fossil waste incineration (illegal)	1.1	NA	6	0.15	2.5	50	16	0.75
Municipal biogenic waste incineration (illegal)	NA	1.1	6	0.15	2.5	50	16	0.75
Industrial waste incineration	1.3	NA	NA	NE	1.3	2.5	0.5	6
Sewage sludge incineration	NA	0.82	0.095	1.9	0.4	0.097	0.19	0.16
Open burning of natural residues in agriculture	NA	1.7	6.8	0.18	1.4	49	1.5	0.03
Open burning of natural residues in private households	NA	1.7	6.8	0.18	1.4	49	1.5	0.03

	CO_2 fossil	**CO_2 biog.**	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**
	kg/crem.							
Cremation	NA	NA	NA	NA	0.21	0.038	0.0059	NA

Comments on CO_2 emission factors:

- For all waste incineration categories, only CO_2 emissions from non-biogenic waste are taken into account.
- Hospital waste incineration: The waste is mainly of fossil origin. The default value for the CO_2 emission factor is taken from SAEFL (2000). Since 2002 no emissions from hospital waste incineration have occurred, as all hospital waste incinerator plants have been closed and hospital waste is incinerated in municipal solid waste incineration plants (accounted for in 1A1a).
- Municipal waste incineration (illegal): The CO_2 emission factor is estimated by using the same assumption as in case of municipal solid waste incineration: The C-content is based on the study by FOEN (2014l). See also chp. 3.2.5.2 and detailed information in EMIS 2024/1A1a Kehrichtverbrennungsanlagen (pp. 5–7).
- Industrial waste incineration (consists of cable insulation materials): The CO_2 emission factor is based on measurements of the flue gas treatment of a cable disassembling site where O_2 was measured in the flue gas. Assuming that the ratio of CO_2/O_2 is the same as in municipal solid waste incineration plants, a fraction of 7 % of CO_2 results. Based on these assumptions, an emission factor of 1.3 kg/kg cable can be derived. Since 1995 no emissions from incinerating cable insulation materials have occurred.
- Sewage sludge incineration plants: As sewage sludge is biogenic waste, the emission factor for CO_2 is zero. It is assumed that the share of fossil fuel used during the start-ups is negligible.

Additional information on emission factors of all other (non-CO_2) gases:

- Hospital waste incineration: All emission factors are taken from SAEFL (2000). Following IPCC (2006), no CH_4 emissions are estimated (see issue W.8 in UNFCCC 2023)
- Municipal waste incineration (illegal): The emission factor for N_2O is taken from the IPCC Guidelines (IPCC 2006, vol. 5), the emission factors for CH_4, NO_x, NMVOC and SO_2 from SAEFL (2000) and USEPA (1995a).
- Industrial waste incineration (consists of cable insulation materials): All emission factors are adopted from SAEFL (2000). Following IPCC (2006), no CH_4 emissions are estimated (see issue W.8 in UNFCCC 2023). Due to low relevance, and considering that the process ceased in 1995, no N_2O emission factor has been estimated for 1990–1994 (see issue W.9 in UNFCCC 2023).

- Sewage sludge incineration plants: For 1990, emission factors are taken from SAEFL (2000). From 2002 to 2015, constant emission factors are used, which are deduced from measurements (LHA 2004) taken at the largest sewage sludge incineration plant incinerating at that time roughly one third of Switzerland's sewage sludge. In 2015 new emission factors for all pollutants other than CO_2 and CH_4 have been deduced based on measurements on three sewage sludge incineration plants (EMIS 2024/5C1 Klärschlammverbrennung). Between 1990 and 2002 as well as between 2002 and 2015, the emission factors are interpolated. Emission factors for CH_4, NO_x, CO and SO_2 decrease due to gradual technical improvements. Emission factors for N_2O have been deduced differently (EMIS 2024/5C1 Klärschlammverbrennung): From 1990 to 2014, the evaluation of results from 7 emissions measurements over the years 2005–2013 on three sewage sludge incineration plants yielded an N_2O emission factor of 4.10 kg/t (Meyer 2016, Wunderlin 2013). No indications suggested changes in emissions reductions technology over this period. In 2015, one plant accounting for incinerating 30 % of the total sewage sludge in Switzerland applied a new emissions reduction technology resulting in N_2O emissions of only 0.03 kg/t (TBF 2021). By accounting for this improvement, the N_2O emission factor for 2015–2016 was reduced to 3.3 kg/t. TBF (2021) investigated that as of 2017 two additional sewage sludge incineration plants, accounting for the incineration of additional 30 % of Switzerland's sewage sludge, have implemented emissions reductions measures. This led to the implementation of a new N_2O emission factor of 1.85 kg/t from 2017 onwards.
- Crematoria: NMVOC and CO emissions were reduced by technical improvements. A large number of measurements were analysed (crematoria as well as other types of installations are obliged to monitor their emissions by the Swiss Federal Ordinance on Air Pollution Control (Swiss Confederation 1985) such that plant-specific emission factors are available for installations with retrofitted flue gas treatment as well as non-retrofitted installations. The emission factors are calculated as weighted averages of cremations taking place in retrofitted and non-retrofitted cremation plants (EMIS 2024/5C1 Krematorien). Following IPCC (2006), no CH_4 emissions are estimated. There is no methodology for N_2O emissions from cremation in the IPCC Guidelines (IPCC 2006). Hence, there is no explanation required according to the UNFCCC reporting guidelines (UNFCCC 2019, paragraph 30) and no N_2O emissions from cremation are estimated.
- The emission factors of burning of branches in agriculture and gardening are calculated based on the EMEP/EEA guidebook (EMEP/EEA 2019) except for CH_4 and N_2O for which emission factors are based on EMEP/CORINAIR (EMEP/EEA 2002), see also documentation in EMIS 2024/5C2 & 4VA1 Abfallverbrennung in der Land- und Forstwirtschaft.
- General remark: In years with no specific data for activity data or emission factors the respective data are interpolated.
- General remark: Indirect CO_2 emissions resulting from fossil CH_4, CO and NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9.

Activity data (5C)

The activity data for 5C Waste incineration are the quantities of waste incinerated, see Table 7-18. Activity data for open burning are split into open burning of natural residues in agriculture as well as into open burning of natural residues in private households, while respective activity data in CRT Table5.C are aggregated.

Table 7-18 Activity data for the different emission sources within source category 5C Waste incineration and open burning of waste.

5C Incineration and open burning of waste	Unit	1990	1995	2000	2005	2010
Hospital waste incineration	kt	15	8.8	2.5	NO	NO
Municipal fossil waste incineration (illegal)	kt	16	13	13	11	10
Municipal biogenic waste incineration (illegal)	kt	16	13	12	11	11
Industrial waste incineration	kt	7.5	NO	NO	NO	NO
Sewage sludge incineration	kt (dry)	57	50	64	95	90
Open burning of natural residues in agriculture	kt	16	15	14	13	12
Open burning of natural residues in private households	kt	6.1	4.9	3.6	2.4	1.2
Total	kt	134	105	109	132	124
Cremation	Numb.	37'513	40'968	44'821	48'169	52'813

5C Incineration and open burning of waste	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Hospital waste incineration	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Municipal fossil waste incineration (illegal)	kt	9.5	9.2	9.2	9.1	8.7	8.5	8.3	8.1	8.0	7.5
Municipal biogenic waste incineration (illegal)	kt	10	10	10	9.9	9.6	9.3	9.1	8.9	8.7	8.1
Industrial waste incineration	kt	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Sewage sludge incineration	kt (dry)	94	93	97	99	102	98	100	97	96	97
Open burning of natural residues in agriculture	kt	11	11	11	11	11	11	10	10	10	10
Open burning of natural residues in private households	kt	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Total	kt	126	124	129	130	132	128	129	126	125	124
Cremation	Numb.	53'205	55'616	59'664	54'634	57'694	54'842	57'746	68'148	64'106	65'688

Hospital waste incineration: Does not occur anymore in specific hospital waste incineration plants since 2002. Such waste is nowadays incinerated in municipal solid waste incineration plants and is therefore reported under sector 1 Energy. The amount of hospital waste burnt in 1990 stems from BUS (1988).

Municipal waste incineration (illegal): As waste incineration outside incineration plants is forbidden in Switzerland, no data is available. Illegal incineration of waste e.g. in wood stoves, garden fires, construction sites etc. is decreasing due to surveillance by authorities but also by citizens that would report open burning. However, there still are cases of illegal waste incineration. It is assumed that 1 % of all waste in Switzerland has been burnt illegally in 1990 and that this value linearly decreases to 0.25 % in 2030 (and then remains constant). The fossil carbon fraction is assumed equal to the value for municipal solid waste incineration and was determined by Rytec (2014). See also chp. 3.2.5.2 and detailed information in EMIS 2024/1A1a Kehrichtverbrennungsanlagen.

Industrial waste incineration (consists of cable insulation materials): Does not occur anymore since 1995. Such waste is nowadays incinerated in municipal solid waste incineration plants and is therefore reported under sector 1 Energy. The amount burnt in 1990 is estimated by the amount reported by a company that was supposed to burn approx. 1/3 of all cable insulation materials in Switzerland.

Sewage sludge incineration: Activity data for sewage sludge incineration for the years 1990, 1994, and 1999 are taken from Külling et al. (2002a). As of 2000 the total amount of sewage sludge produced in Switzerland is calculated by multiplying the sludge production per person and year as reported by VBSA (2017) with the total population. The per capita sewage sludge production for 2000, 2004, 2008, 2012, 2016 and 2017 (VBSA 2017) have been derived by compiling the respective amounts of sewage sludge incinerated in municipal solid waste incineration plants, sewage sludge incineration plants and used as alternative fuel in the cement industry and dividing it by the total population count (VBSA 2017). Per capita sludge productions for the intervening years were interpolated linearly. As of 2016, annual per capita sludge production amounted to 21.2 kg (VBSA 2017).

Open burning of natural residues: The quantity of natural residues burnt openly has been estimated in a study (INFRAS 2014) as briefly described in the following. Open burning of such residues is regulated in the Ordinance on Air Pollution Control (Swiss Confederation 1985), Article 26b. In Switzerland, cantonal authorities are responsible for the implementation of these regulations. Since there is no nationwide data available for the activity data of open burning of natural residues, cantonal authorities have been interviewed. Based on the available statistics for many cantons on the number of permitted fires and sanctions due to non-permitted fires, the amount of burnt material in those cantons has been quantified. Since there is also a significant number of unreported cases, it has been assumed that the actual amount of material burnt is three times as large as the amount approved by the authorities. Based on the evaluated numbers from the cantons, an extrapolation to the amount burnt in Switzerland has been made. For the extrapolation the statistics on the harvesting of wood has been used (FOEN 2012i). For the determination of a time series of natural residues burnt, senior experts with historical knowledge in agriculture and forestry have been interviewed. Furthermore, statistical data on agricultural and forestry activities has been used to estimate the potential of material available for burning at a certain time. With this approach a time series since 1900 has been compiled. Emissions from open burning of natural residues in forestry (5C2ii) are reported in LULUCF sector 4IV (chp. 6.4.2.6.4.1).

Cremations: Activity data are reported by the Swiss Cremation Association. These statistics are updated every year.

7.4.3. Uncertainties and time-series consistency for 5C

The uncertainty assessment, based on expert judgment, results in high combined uncertainties for CO_2, CH_4 and N_2O of 40 %, 60 % and 150 % of emission estimates, respectively (see Table 1-8 for quantification of “high”). In addition, the expert estimate for the activity data uncertainty is 50 % for CH_4 and 30 % for CO_2 and N_2O (see details in Annex A2.1).

Consistency: Time series for 5C Waste incineration and open burning of waste are all considered consistent.

7.4.4. Category-specific QA/QC and verification for 5C

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

7.4.5. Category-specific recalculations for 5C

The following recalculations were implemented in submission 2024.

- 5C1 incineration of waste / sewage sludge: Activity data of the amount of sewage sludge incineration has changed in 2016 and 2021 by -1 t and 100 t, respectively, due to rounding. This leads to changes in emissions of CH_4, N_2O and NMVOC by <1 % (2016 and 2021).

- 5C1a Illegal waste incineration: For practical reason, the activity data for illegal waste incineration in tons is now reported separately for the fossil and biogenic fractions, for the entire time series. The sum of the fossil and biogenic fractions has changed by less than 1 % compared to the previous values due to rounding issues.

7.4.6. Category-specific planned improvements for 5C

No category-specific improvements are planned.

7.5. Source category 5D – Wastewater treatment and discharge

7.5.1. Source category description

Table 7-19 Key categories of 5D Wastewater treatment and discharge. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	**IPCC category**	**Gas**	**Identification criteria**
5D	Wastewater treatment and discharge	CH4	L1, L2
5D	Wastewater treatment and discharge	N2O	L1, L2, T1, T2

Source category 5D1 Domestic wastewater comprises all emissions from liquid waste handling and sludge from housing and commercial sources (including grey water and night soil). Since submission 2023 emissions from decentralised wastewater treatment and since submission 2024 CH_4 emissions from effluents are estimated as well.

In Switzerland, municipal wastewater treatment (WWT) plants treat wastewater from single cities or several cities and municipalities together. Here, wastewater in general is treated in three steps:

- Mechanical treatment
- Biological treatment
- Chemical treatment

The treated wastewater flows into a receiving system (lake, river or stream). Pre-treated industrial effluents are also handled for final treatment in municipal wastewater treatment plants (see Figure 7-6). In the following, these are called "domestic wastewater treatment plants" according to the terminology of 5D1 Domestic wastewater.

Switzerland’s wastewater management infrastructure – comprising about 850 wastewater treatment plants and 40’000–50’000 km of public sewers – is practically complete today (FOEN 2017l). The vast majority of wastewater treatment plants apply an anaerobic sludge treatment with sewage gas recovery, and use the sewage gas for heat production. About 290 wastewater treatment plants also apply combined heat and power units. See also EMIS 2024/5D1 Wastewater Treatment Plants.

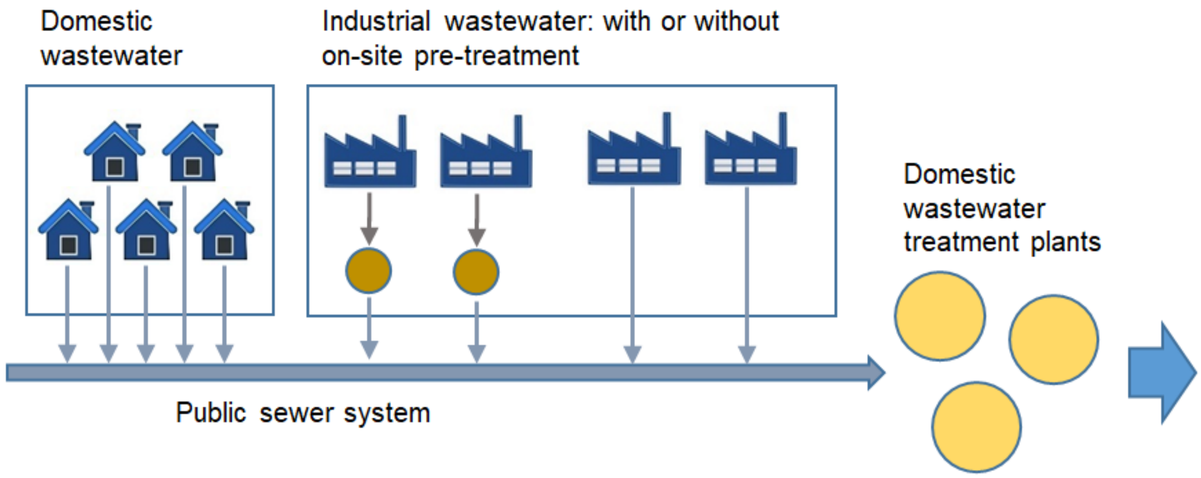

Figure 7-6 Graphical representation of domestic and industrial wastewater streams towards centralised wastewater treatment plants. Decentralised wastewater treatment is not shown here.

Source category 5D2 Industrial wastewater comprises all emissions from liquid waste handling and sludge from industrial processes such as food processing, textiles, car-washing places, electroplating plants, and pulp/paper production. These processes may result in effluents with a high load of organics. Depending on the contaminants, an on-site pre-treatment is necessary in order to reduce the load of pollutants in the wastewater to meet the regulatory standards (which are in place to preclude disruptions of the domestic wastewater treatment plants) and to reduce discharge fees. The on-site pre-treatment is generally anaerobic, in order to use the sewage gas as source for heat and power production. Currently, about 20 industrial wastewater treatment plants pre-treat wastewater before its discharge to the domestic sewage system, where the industrial wastewater is additionally treated together with domestic wastewater in domestic wastewater treatment plants (see Figure 7-6 and Figure 7-7). Due to this strong connection with domestic wastewater treatment, industrial wastewater is not identified as separate wastewater stream for the calculation of GHG emissions, but joined to the domestic wastewater treatment. For the calculation of emissions of other gases (NO_x, CO, NMVOC, SO_2), domestic and industrial wastewater streams are distinguished (i. e. different emission factors are applied, see below). See also EMIS 2024/5D2 Kläranlagen industriell (Luftschadstoffe).

Table 7-20 Specification of source category 5D Wastewater treatment and discharge.

5D	**Source category**	**Specification**
5D1	Domestic wastewater	Emissions from liquid waste handling and sludge from housing and commercial sources
5D2	Industrial wastewater	Emissions of precursors from handling of liquid wastes and sludge from industrial processes (emissions of CH_4 and N_2O are implemented in 5D1)
5D3	Other	Not occurring in Switzerland

Category 5D contains all direct emissions from wastewater handling, including direct emissions of sewage gas (leakage), torching and upgrading of sewage gas to natural gas quality (to be fed into the natural gas network and/or used as fuel). Emissions from the usage of sewage gas in combined heat and power (CHP) units and boilers (only heat production) are reported in sector 1 Energy in source category 1A2gviii Other (see Figure 3-18).

Wastewater treatment also leads to emissions reported in other categories, as illustrated in Figure 7-7. Emissions associated with sewage sludge drying are assumed to be negligible. The discharge of sewage sludge from centralised wastewater treatment plants on agricultural soils has been phased out since 2003 and is generally forbidden since 2009. Therefore, this process is crossed out in Figure 7-7. The same applies to solid waste disposal sites (5A). All sewage sludge is incinerated either in municipal solid waste incineration plants (1A1a), sewage sludge incineration plants (5C) or used as alternative fuel in the cement industry (1A2f).

According to legislation (Swiss Confederation 1992b and 1998b) and as stated in Vuna (2023) the pathway mentioned above is also applied to all sludge from on-site wastewater treatment in small scale wastewater treatment plants. On-site wastewater management is here defined as a solution for the collection, treatment and/or disposal of wastewater at or near its point of generation, without the connection to a public sewer network. On-site wastewater management systems are often called decentralised or small-scale sanitation systems. CH_4 and N_2O emissions from such systems are estimated according to a desk study (Vuna 2023).

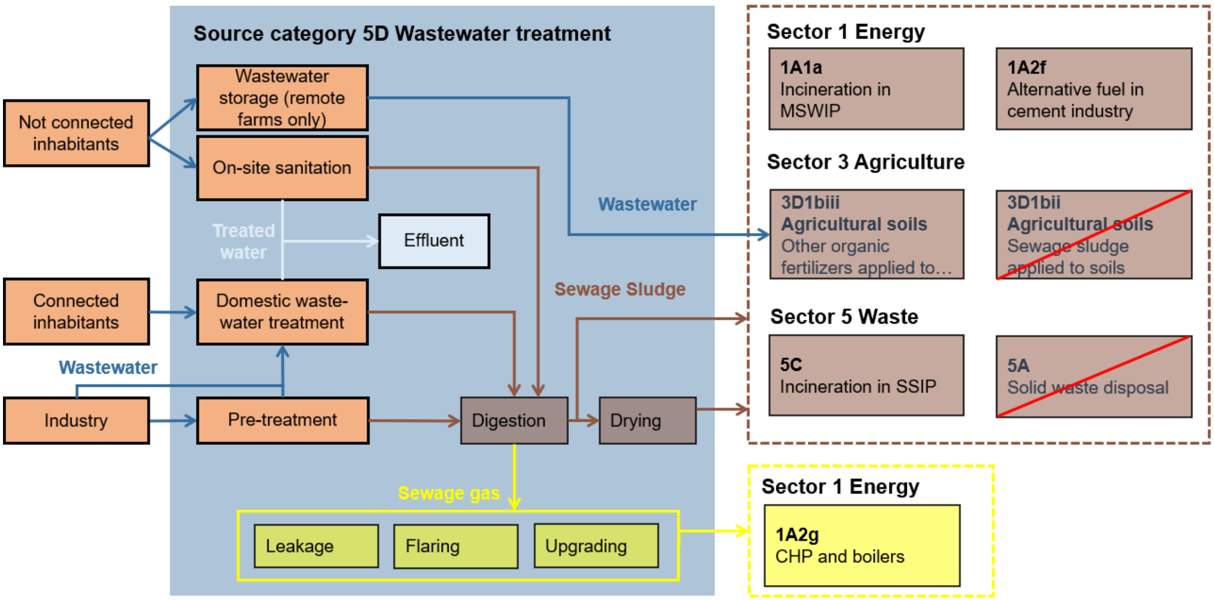

Figure 7-7 System boundaries of processes related to wastewater treatment. CHP = Combined heat and power generation. MSWIP = Municipal solid waste incineration plant. SSIP = Sewage sludge incineration plant.

7.5.2. Methodological issues

Emissions from wastewater treatment are estimated according to Gruber et al. (2021) for the centralised system and according to Vuna (2023) for decentralised wastewater management.

Centralised CH_4 emissions (treatment and discharge) are calculated by applying a Tier 2 method based on the decision trees of the IPCC Guidelines (IPCC 2006, vol. 5, chp. 6, Fig. 6.2 and Fig. 6.3 and IPCC 2019, vol. 5, chp. 6, Fig. 6.2). N_2O emissions are calculated using a country-specific method according to IPCC (2006). According to IPCC (2019) N_2O emissions are calculated by a Tier 2 method concerning treatment and by a Tier 1 method concerning discharge (IPCC 2019, vo. 5. Chp. 6, Fig. 6.4). Details regarding the calculation of CH_4 and N_2O emissions are provided in the following.

In Switzerland, 90 % of all inhabitants (urban and rural) were connected to wastewater treatment plants in 1990. This share reached 97 % in 2007 and is assumed to be at 97.3 % since 2011 (FOEN 2021m). Hence, about 2.7 % of the population are currently not connected to public sewer networks and can be distinguished as follows:

- Farms which cannot be connected to public sewer networks and hold at least eight cows or pigs are entitled to connect their domestic wastewater to the liquid manure (slurry) tank and to dispose of the manure and sewage by land application.
- Residents that cannot be connected to public networks and rely on on-site or decentralised sanitation solutions, such as septic tanks, holding tanks or small-scale wastewater treatment plants.

An overview concerning emissions from wastewater treatment via manure tanks on the one hand and on-site sanitation systems (including their characteristics and rough estimates on their penetration rates in Switzerland) on the other hand is presented in a desk study (Vuna 2023). Therein, Table 2 provides an overview of the on-site sanitation technologies applied in Switzerland. However, it is stated that not all the technologies are relevant in terms of CH_4 or N_2O emissions, either because they are rare or because their emission potential is negligible. Table 4 thus compiles the relevant technologies, taking into account their occurrence in Switzerland and their emission potentials (Vuna 2023).

Finally, it is assumed that residents whose principal residence is connected to the sewer system are on occasion spending time in rural areas. Vuna (2023) takes this into account for two reasons. Firstly, people connected to the centralised wastewater treatment system should neither be overlooked nor double counted if they temporarily use on-site sanitation systems. It is thus assumed that the wastewater of an estimated 0.7 % of the Swiss population is actually managed in decentralised systems, despite the fact that these residents are connected to sewers most of the time (Vuna 2023). Secondly, the emission factors for on-site sanitation systems are higher than for well-managed centralised wastewater treatment plants. Emission estimates for CH_4 and N_2O for the entire time series take these considerations into account. See Vuna (2023) for a detailed presentation of the corresponding calculations. Notably, Table 7-21 displays population numbers for the centralised and decentralised sanitation systems adjusted for the mentioned 0.7 % of total population using both systems.

Accordingly, an overview of the relevant numbers of persons, the implied emission factors and emission estimates of CH_4 and N_2O from the various wastewater treatment pathways for source category 5D Wastewater treatment and discharge is given in Table 7-21. Detailed information is given in EMIS 2024/5D1 5D2 Abwasserbehandlung GHG.

Table 7-21 Country-specific implied emission factors (IEF) for CH_4 and N_2O for source category 5D Wastewater treatment and discharge in 2022. The IEF from wastewater treatment in centralised plants is derived from four sources of emissions: 1) the sewer system, 2) the wastewater treatment plant, 3) gas losses, 4) the effluent. Numbers in the column named “Relevant population” reflect the fact that a fraction of the population is connected to the centralised system but using decentralised sanitation systems from time to time (see text). Numbers in the last row represent total population and corresponding values as given in the reporting tables.

5D Wastewater treatment and discharge	**Relevant population**	**IEF CH_4**	**EM CH_4**	**IEF N_2O**	**EM N_2O**
	persons	g/person	kt/yr	g/person	kt/yr
Centralised WWTP	8'443'526				
Sewer		140	1.2		
Plant		515	4.3	198	1.7
Gas losses (upgrading)		105	0.89		
Effluent (all types of receiving waters)		56	0.48	19	0.16
Decentralised (on-site SSWWTP)	169'632				
SSWWTP including effluent		6725	1.1	480	0.081
Wastewater storage on remote farms	125'842				
Wastewater storage (excl. manure application)		606	0.076	27	0.0035
Total (Wastewater treatment 5D)	8'739'000	927	8.1	220	1.9

7.5.2.1. CH_4 emissions

7.5.2.1.1. Methodology for centralised wastewater treatment (5D, CH_4)

CH_4 emission estimates from centralised wastewater treatment and discharge take into account emissions from the degradation of organically degradable material in wastewater and emissions related to sewage gas production (and recovery) from sewage sludge (in domestic as well as industrial installations). Accordingly, the contribution of industrial wastewater is taken into account in the calculation of CH_4 emissions from domestic wastewater by means of a correction factor for additional industrial chemical oxygen demand (COD) discharged into the domestic sewer system. Considering COD discharged to effluents, emissions from different receiving waters are estimated. Industries handling wastewater with high chemical oxygen demand usually use anaerobic digesters to produce sewage gas. The emissions related to sewage gas production (and recovery) during industrial pre-treatment of wastewater are also taken into account in the calculation of emissions from domestic wastewater treatment plants, because the underlying Swiss renewable energy statistics (see below) does not differentiate between sewage gas production in domestic and industrial wastewater treatment plants. Four pathways for CH_4 emissions are characterised according to Gruber et al. (2021, see chapter 4.2.1 in the report) and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2019) and summed up, namely emissions from:

- The sewer system ($CH_{4,\ SEWER}$)
- Wastewater treatment (water line and sludge line) ($CH_{4,\ WWTP}$)
- Sewage gas (leakage losses, treatment/upgrading, torches) ($CH_{4,\ SEWAGE\ GAS}$)
- Effluent ($CH_{4,\ EFFLUENT}$)

In short, $CH_{4,SEWER}$ is calculated by multiplying total organically degradable material in the sewer (TOW_{SEWER}) with an emission factor for the sewer system ($EF_{CH4,\ SEWER}$).

CH_4 emissions from wastewater treatment is calculated by multiplying TOW_{SEWER} with an emission factor for entire wastewater treatment plants ($EF_{CH4,\ WWTP}$).

The CH_4 emissions resulting from sewage gas treatment (aiming at stabilizing the sewage sludge and producing sewage gas) are calculated based on a country-specific implied emission factor ($EF_{CH4,\ sewage\ gas}$, see below), which is normalized with population (P).

Since submission 2024, the CH_4 emissions from effluents ($CH_{4,\ EFFLUENT}$) are calculated by multiplying remaining organically degradable material discharged ($TOW_{DISCHARGED}$) with distinguished emissions factors ($EF_{CH4,effluent,river}$, $EF_{CH4,effluent,lake}$) for receiving waters (IPCC 2019).

Emission factors (centralised 5D, CH_4)

Emission factors for CH_4 are chosen according to chp. 3.2.2. in Gruber et al. (2021) and IPCC (2019).

Sewer system

For the sewer system, a CH_4 emission factor ($EF_{CH4,\ SEWER}$) is chosen that represents the average of different assessments: 0.00255 kg CH_4 / kg COD (Gruber 2021).

Wastewater treatment (water line and sludge line)

Gruber et al. (2021) discuss different CH_4 emission factors for the water line and sludge line and conclude that an emission factor representing whole plant measurements is most appropriate ($EF_{CH4,\ WWTP}$). Hence, the median value according to Gruber et al. (2021) is used: 0.0094 kg CH_4 / kg COD.

Sewage gas

To calculate the country-specific implied emission factor $EF_{CH4,\ sewage\ gas}$ for CH_4 emissions from sewage gas treatment the total sewage gas production (in domestic and industrial systems) is taken into account based on detailed Swiss renewable energy statistics (SFOE 2023a). These statistics provide the amount of sewage gas used in furnaces and combined heat and power installations, as well as the amount of sewage gas upgraded to natural gas quality. It is assumed that 2 % of the total amount of sewage gas is flared and 0.75 % of the total amount is leaking. It is further assumed that the leakage of upgraded gas linearly decreases from 5 % in 1990 to 2.5 % in 2014, remaining constant thereafter. The implied emission factor $EF_{CH4,\ sewage\ gas}$ is adapted on a yearly basis due to the respective annual changes in population and the total production of sewage gas.

Effluent

According to VSA/SVKI (2023) different types of receiving waters can be distinguished. Accordingly, Tier 2 emission factors from IPCC (2019, Volume 5 Waste, Chapter 6 Wastewater Treatment and Discharge, Table 6.3) are applied to estimate CH_4 emissions from effluents for rivers ($EF_{CH4,effluent,river}$= 0.009 kg CH_4/(kg COD)) and for lakes ($EF_{CH4,effluent,lake}$= 0.048 kg CH_4/(kg COD)).

Values of emission factors referred to the number of inhabitants

The implied CH_4 emission factors for 5D Wastewater treatment and discharge in centralised wastewater treatment plants are summarised in Table 7-21.

Activity data (centralised 5D, CH_4)

Activity data for CH_4 are specified according to chp. 2.2.2. in Gruber et al. (2021) and Dominguez (2023).

Sewer system and wastewater treatment (water line and sludge line)

Total organically degradable material (TOW) is used as activity data for emissions from both, sewers and wastewater treatment plants. TOW is calculated by multiplying the number of persons, connection rate to sewer system, per capita load of organically degradable material, and a correction factor (I = 1.25 (default IPCC 2006)) for additional industrial COD discharged into sewers (Gruber 2021, p. 14).

Sewage gas

As elaborated above, a per capita implied emission factor ($EF_{CH4,\ sewage\ gas}$) is calculated for CH_4 emissions from separate sewage sludge treatment, and the respective activity data are total population.

Effluent

Since submission 2024, the CH_4 emissions from effluents ($CH_{4,\ EFFLUENT}$) are calculated based on data presented in VSA/SVKI (2023). From COD measurements in the discharge from wastewater treatment plants that are attributable to a known number of connected persons, an average for chemical oxygen demand (COD) of 10.24 g COD/(person*day) of treated water discharged is derived (Dominguez 2023). From the same data base (VSA/SVKI 2023), different types of receiving waters can be attributed to and weighted with the number of connected persons. As a result, 84.5 % of treated water is fed to rivers and 15.5 % is fed to lakes (Dominguez 2023).

7.5.2.1.2. Methodology for decentralised wastewater treatment (5D, CH_4)

Concerning CH_4 emissions from decentralised wastewater treatment two pathways are considered: storage in manure tanks on remote farms and other housing with on-site sanitation systems with anaerobic primary treatment stages are relevant (Vuna 2023). Since submission 2024 also CH_4 emissions from effluents of on-site systems are considered (IPCC 2019).

- CH_4 emissions from remote farms (via manure handling) are estimated to occur due to storage of wastewater in manure tanks. Resulting emissions are calculated within the agricultural model (Agroscope 2024) according to the methodologies for 3B manure management (see chp. 5.3.2.2). The IEF in Table 7-21 is estimated based on the per capita excretion of volatile solids (VS, see below under “activity data”) and the CH_4 emissions per kg of VS (see below under “emission factor”). VS is equivalent to the total organic carbon (TOC).

- CH_4 emissions from on-site sanitation systems are estimated by multiplying total organically degradable material (TOW) by emission factors for primary only or primary and secondary treatments.
- CH_4 emissions from effluents of on-site sanitation systems are estimated by multiplying remaining, discharged organic matter ($TOW_{DISCHARGED}$) by $EF_{CH4,effluent,river}$ (IPCC, 2019).

Furthermore, Vuna (2023) confirms that it is valid to assume that all sludge of unconnected inhabitants which is not discharged on farm land after storage in manure tanks, is transported to large-scale, centralised wastewater treatment plants. There, the sludge is typically fed into the sludge thickener or digester for treatment together with the primary and secondary sludge of the plant.

Emission factors (decentralised 5D, CH_4)

CH_4 emissions for wastewater storage in manure tanks on remote farms are estimated based on IPCC equation 10.23 (IPCC 2019) as described under 3B Manure management (chp. 5.3). For the maximum methane producing capacity (B_0), the same value for humans as for swine (i. e. 0.45 m^3 kg^{-1}, IPCC 2019) is adopted due to the similarities of the respective digestive systems. It is assumed that all wastewater is handled in liquid/slurry systems. The respective methane conversion factor (MCF) is assessed as described under chp. 5.3.2.2.3. Average CH_4 emissions per kg of volatile solids (VS, corresponding to total organic carbon, TOC) are thus 0.042 kg and range from 0.041 to 0.045 according to fluctuations of the MCF.

For primary and secondary treatments in different on-site sanitation systems, CH_4 emission factors are used according to IPCC Guidelines (IPCC 2006, 2014a, 2019) as described in Vuna (2023, chp. 3.3.3 Emission factors of SSWWTPs, and in particular also Table 7).

According to Dominguez (2023) all small-scale wastewater treatment plants in Switzerland discharge into streams. Accordingly, the Tier 2 emission factor from IPCC (2019, Volume 5 Waste, Chapter 6 Wastewater Treatment and Discharge, Table 6.3) for rivers is used to estimate CH_4 emissions from effluents ($EF_{CH4,effluent,river}$= 0.009 kg CH_4/(kg COD)).

Activity data (decentralised 5D, CH_4)

According to Vuna (2023) about 1.44 % of the Swiss population's wastewater is treated via manure tanks on remote farms today. Based on this fraction and the chemical oxygen demand (COD) per person (chp. 2.2.2. in Gruber et al. (2021)) multiplied by a conversion factor (TOC = 1/3 * COD, according to Metcalf and Eddy (2003) and Dominguez (2023)), quantities of total organic carbon (TOC) in wastewater going to manure tanks are estimated. It is assumed that the TOC corresponds to the volatile solids (VS) as used for emission calculations during manure management (equation 10.23, IPCC 2019). The per capita excretion of VS is thus 0.04 kg $person^{-1}$ day^{-1}.

According to Vuna (2023) about 1.26 % of the Swiss population's wastewater is treated in on-site sanitation systems today. Based on this fraction and the chemical oxygen demand (COD) per person (chp. 2.2.2. in Gruber et al. (2021)) quantities of total organic degradable material (TOW) in wastewater going to on-site sanitation systems are estimated. Relevant on-site technologies in terms of CH_4 are listed in Table 4 of Vuna (2023) and fractions for secondary treatment techniques are quantified in Figure 3 of Vuna (2023). Hereof only constructed wetlands (according to IPCC 2014a) are considered relevant for CH_4 emissions.

The ratio of the two given fractions is assumed to be constant over the time series as no data is available (Vuna 2023). Together with time series for total population and the share of people not connected to the centralised system, the ratio is used to calculate the number of people living on remote farms or using on-site sanitation systems.

Concerning CH_4 emissions from effluents ($CH_{4,\ EFFLUENT}$), the remaining organically degradable material in the outflow of small-scale wastewater treatment plants (SSWWTPs) is estimated via the reduction potential for organics in wastewater of such systems in Switzerland: TOW reduction in primary treatment amounts to 30 % (Dominguez 2023, Vuna 2023). Furthermore, it is required by Federal legislation that COD is reduced by 80 % in SSWWTPs with primary and secondary treatments (Swiss Confederation 1998b). The carbon removal rate of individual SSWWTP is regularly controlled by cantonal authorities and therefore considered plausible. Also, these numbers compare well to default values given in IPCC (2019, Volume 5 Waste, Chapter 6 Wastewater Treatment and Discharge, Table 6.6).

7.5.2.2. N_2O emissions

7.5.2.2.1. Methodology for centralised wastewater treatment (5D, N_2O)

Direct N_2O emissions from centralized wastewater treatment plants and N_2O emissions from wastewater effluent are calculated using a country-specific method in accordance with the IPCC Guidelines (IPCC 2006).

The method is described in detail in Gruber et al. (2021) and Gruber (2022). Therein, two pathways for N_2O emissions are characterised (see chapter 4.1.1 in Gruber et al. (2021)) and summed up, namely emissions from:

- Wastewater treatment plants (N_2O_{PLANT})
- Effluent ($N_2O_{EFFLUENT\text{-}WATERBODY}$)

In short, N_2O emissions from wastewater treatment plants (N_2O_{PLANT}) are calculated by multiplying nitrogen load in the influent ($N_{INFLUENT}$) by an emission factor ($EF_{N2O,\ PLANT}$). N_2O emissions from the effluent are calculated by multiplying nitrogen load in the effluent ($N_{EFFLUENT}$) by an emission factor ($EF_{N2O,\ EFFLUENT\text{-}WATERBODY}$).

Emission factors (centralised 5D, N_2O)

Wastewater treatment plants ($EF_{N2O,\ PLANT}$)

Gruber et al. (2021) selected a suite of wastewater treatment plants representative for Switzerland. They then set up an off-gas monitoring system and measured N_2O emissions from each selected plant throughout the year. The latter is important as it was shown that seasonal emission patterns are evident. The authors assessed emission factors evaluating 14 monitoring campaigns. Accordingly, three emission factors from wastewater treatment plants were derived, corresponding to three different nutrient removal categories: (a) carbon removal, (b) nitrification only, (c) year-round nitrogen removal (see Table 3 of Gruber et al. (2021)). It is generally assumed that a lower nitrogen removal results in higher N_2O emissions. The estimation of the country-wide emission factor ($EF_{N2O,\ PLANT}$) is calculated by multiplying the respective share of nitrogen load treated in wastewater treatment plants belonging to a nutrient removal category by the respective emission factor. The categorization used is described in a written communication by Gruber (2022) updating Figure 9 of Gruber et al. (2021). As such, technical development over the time series is reflected with increasing nitrogen removal from 1990 to today.

In addition, N_2O emissions from unaerated process stages are considered. Gruber et al. (2021) assume that the respective share of emissions ($F_{N2O,UNAERATED}$) corresponds to 25 % of the emission from aerated processes (calculated with $EF_{N2O,\ PLANT}$, see above). The authors assume a constant share over the whole reporting period.

Effluent ($EF_{N2O,EFFLUENT}$)

Following Gruber et al. (2021) the emission factor for N_2O emitted from nitrogen in the effluent of wastewater treatment plants is kept at the default value given in the IPCC Guidelines (IPCC 2006): $EF_{N2O,\ EFFLUENT}$ = 0.005 kg N_2O-N/kg N.

Activity data (centralised 5D, N_2O)

Nitrogen loads for wastewater treatment plants are interpolated linearly following references and data presented in Table 1 of Gruber et al. (2021). Influent nitrogen load to wastewater treatment plants ($N_{INFLUENT}$) is then calculated by multiplying population, nitrogen load (kg/person/year) and connection rate (T_{PLANT}).

An average nitrogen removal rate ($r_{NITROGEN\ REMOVAL\ RATE}$) is calculated based on Table 1 of Gruber et al. (2021) and is used to calculate nitrogen load in the effluent
($N_{EFFLUENT} = N_{INFLUENT} * (1 – r_{NITROGEN\ REMOVAL\ RATE}$).

7.5.2.2.2. Methodology for decentralised wastewater treatment (5D, N_2O)

Concerning N_2O emissions from decentralised wastewater treatment two relevant pathways are considered: 1) handling via manure tanks on remote farms and 2) other housing with on-site sanitation systems with secondary treatment stages (Vuna 2023).

N_2O emissions from wastewater storage on remote farms (via manure handling) are estimated within the agricultural model (Agroscope 2024) according to the methodologies for 3B manure management (see chp. 5.3.2). The IEF in Table 7-21 is estimated based on the per capita nitrogen load (see below under “activity data”) and the cumulated direct and indirect N_2O emissions per kg of nitrogen (see below under “emission factor”).

According to Vuna (2023) and references therein N_2O emissions from on-site sanitation systems are estimated as follows:

- Nitrogen influent to on-site sanitation systems is calculated by multiplying the number of persons served by on-site sanitation with nitrogen load per person (as in chp. 7.5.2.2.1) in accordance with Gruber et al. (2021).
- Nitrogen removed in primary treatment is subtracted (5 %) to receive nitrogen influent to secondary treatments.
- Several secondary treatment technologies are differentiated for different small scale wastewater treatment plants leading to different N_2O emission strengths.
- Nitrogen removal in secondary treatment is set to 25 % as a weighted average of the various relevant treatment technologies.

- A constant emission factor for N_2O from effluents is assumed (as in chp. 7.5.2.2.1), based on the IPCC Guidelines (2006) and in accordance with Gruber et al. (2021), and multiplied with residual nitrogen in effluent to yield in N_2O emissions from effluents.

Emission factors (decentralised 5D, N_2O)

N_2O emissions for wastewater storage in manure tanks on remote farms is estimated based on IPCC equations 10.25, 10.26 and 10.28 (IPCC 2019). It is assumed that all wastewater is handled in liquid/slurry systems. For direct N_2O emissions a nitrogen loss rate (EF_3) of 0.2 % is assumed based on IPCC (2019). For indirect N_2O emissions, the amount of nitrogen volatilised as NH_3 and NO_x during storage must be estimated. Loss rates of NH_3 during liquid storage are estimated based on the respective loss rates of cattle manure in the AGRAMMON model (Kupper et al. 2022) corrected for the higher content of total ammoniacal nitrogen (TAN) in human excretions (TAN-content of 55 % and 70 % for cattle and swine/human excreta respectively, Kupper et al. 2022). Losses of NO_x are 0.2 % according to van Bruggen et al. (2014). Subsequently, indirect N_2O emissions are estimated by multiplying the amount of nitrogen volatilised by EF_4 (see chp. 5.3.2.4). Average N_2O emissions per kg of nitrogen are thus 3.0 g.

No N_2O is emitted from primary treatments of on-site sanitation systems (IPCC 2019, Vuna 2023).

For different on-site technologies using secondary treatments and for effluents, N_2O emission factors are used according to IPCC Guidelines (IPCC 2006, 2014a, 2019) as described in Vuna (2023, chp. 3.3.3 Emission factors of SSWWTPs, and in particular also Table 7).

Activity data (decentralised 5D, N_2O)

According to Vuna (2023) about 1.44 % of the Swiss population’s wastewater is treated via manure tanks on remote farms today. Based on this fraction and the per capita nitrogen load (5.33 to 7.04 kg person^{-1} year^{-1}, Gruber et al. (2021), Table 1), estimates for total nitrogen loads going to manure tanks are established.

According to Vuna (2023) about 1.26 % of the Swiss population’s wastewater is treated in on-site sanitation systems today. Relevant on-site technologies in terms of N_2O are listed in Table 4 of Vuna (2023) and fractions for secondary treatment techniques are quantified in Figure 3 of Vuna (2023).

The ratio of the two given fractions is assumed to be constant over the time series as no data is available (Vuna 2023). Together with time series for total population and the share of people not connected to the centralised system, the ratio is used to calculate the number of people living in remote farms or using on-site sanitation systems.

7.5.2.3. Other gases

The sewage gas production generates emissions of further gases from flaring: CO_2 (biogenic), NO_x, CO, NMVOC, and SO_2. The emissions are calculated by multiplying population (as activity data, see Table 7-21) with country-specific emission factors based on measurements and expert estimates, documented in EMIS 2024/5D1 Wastewater Treatment

Plants and EMIS 2024/5D2 Pre-treatment of industrial wastewater. The emission factors used are summarised in Table 7-22.

Table 7-22 Emission factors of CO_2 (biogenic), CH_4, N_2O, NO_x, CO, NMVOC and SO_2 for 5D Wastewater treatment and discharge in 2022.

5D Wastewater treatment and discharge	**CO_2 fossil**	**CO_2 biog.**	**N_2O**	**CH_4**	**NO_x**	**CO**	**NMVOC**	**SO_2**
	kg/person		g/person					
5D1 Domestic wastewater	NA	0.44	220	927	0.59	0.29	0.012	0.0030
5D2 Industrial wastewater	NA	0.10	IE	IE	0.15	0.073	0.0029	0.00073

7.5.3. Uncertainties and time-series consistency for 5D

Uncertainty in CH_4 and N_2O emissions from 5D

Uncertainty input data (see Annex A2.1) has been estimated as follows:

- According to Gruber et al. (2021) for centralised wastewater treatment for both gases.
- According to Vuna (2023) for on-site sanitation for both gases.
- According to the EMEP/EEA guidebook (EMEP/EEA 2019, part A, chp. 5, Table 2-2) and expert judgement for wastewater storage on remote farms for both gases.
- According to given ranges of methane conversion factors (MCF) in IPCC (2019, vol. 5, chp. 6, Tab. 6.3) for CH_4 from receiving waters.

7.5.3.1. CH_4 emissions

Combined uncertainty input for CH_4 for relative uncertainties for wastewater treatment in the centralised system (106 %), in on-site sanitation systems (200 %), for wastewater storage on remote farms (200 %) and for effluents (100 %) has been weighted by the respective shares of population, leading to a rounded value of 100 %. For the assumption of a gamma distribution the uncertainty analyses resulted in a combined uncertainty U(Em CH_4) of -74 % to +122 % for approach 1 and of -84 % to +100 % for approach 2 (see Annexes A2.2 and A2.3).

7.5.3.2. N_2O emissions

Combined uncertainty input for N_2O for relative uncertainties for wastewater treatment in the centralised system (54 %), in on-site sanitation systems (200 %) and for wastewater storage on remote farms (200 %) has been weighted by the respective shares of population, leading to a rounded value of 50 %. For the assumption of a gamma distribution the uncertainty analyses resulted in a combined uncertainty U(Em N_2O) of -44 % to +56 % for approach 1 and of -48 % to +50 % for approach 2 (see Annexes A2.2 and A2.3).

Consistency: Time series for 5D Wastewater treatment and discharge are all considered consistent.

7.5.4. Category-specific QA/QC and verification for 5D

The general QA/QC measures are described in chp. 1.5.

Following IPCC (2019), emission estimates for CH_4 from receiving waters have been included in submission 2024.

7.5.5. Category-specific recalculations for 5D

The following recalculations were implemented in submission 2024. Major recalculations which contribute significantly to the total differences emissions of sector 5D between the latest and the previous submissions are presented also in chp. 10.1.2.5.

In 5D1 Domestic wastewater treatment, several adjustments have been made to the country-specific approaches to estimate CH_4 and N_2O emissions:

- Activity data and emission factors of CH_4 1990–2021: Emissions from the effluents of both centralised and decentralised on-site wastewater treatment have been newly estimated based on country-specific per capita TOW quantities in the system outflows (activity data), shares of receiving waters and emission factors based on IPCC (2019).
- Activity data of CH_4 1990–2021: CH_4 Emissions are calculated based on activity data of total organically degradable material in wastewater (TOW). Previous figures of DC in CRT Table5.D reported values from centralised wastewater treatment only. As of the current submission, TOW from decentralised primary and secondary wastewater treatment are included for 1990–2021 as well, leading to an increase in activity data (1990 +4.7 %, 2021 +1.6 %) and thus emissions, though with a decreasing trend.
- Emission factor CH_4 1990–2021: A wrongly rounded emission factor to estimate CH_4 emissions from public sewer systems has been applied in the previous submission. The correct emission factor is lower by 2 % (0.00255 kg CH_4 / kg COD instead of 0.0026 kg CH_4 / kg COD) yielding lower annual per capita CH_4 emissions.
- Emission factors CH_4 and N_2O 1990–2021: Reduced emission factors for CH_4 and N_2O for wastewater storage in decentralised wastewater on remote farms have been derived in 5D (CH_4: 1990 -76 %, 2021 -87 %; N_2O: 1990 -84 %, 2021 -87 %). The reduction for CH_4 emissions is due to a low conversion factor for TOC in the agriculture model according to literature (Metcalf and Eddy (2003) and Dominguez (2023)). The reduction of N_2O emissions is mainly due to the fact that emissions from the spreading of this wastewater are now allocated to sector 3D1biii Other organic fertilizers applied to soils while in the previous submission, they have been accounted to 5D.

The combined changes for N_2O and CH_4 lead to the following changes in emissions of 5D1 Domestic wastewater treatment:

- Emissions N_2O 1990: -1.6 % (-0.063 kt)
- Emissions N_2O 2021: -1.2 % (-0.023 kt)
- Emissions CH_4 1990: -5.3 % (-0.4 kt)
- Emissions CH_4 2021: +2.6 % (+0.2 kt)

7.5.6. Category-specific planned improvements for 5D

No category-specific improvements are planned.

7.6. Source category 5E – Other

7.6.1. Source category description

Table 7-23 Key categories of 5E Other. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Source category 5E Other is not a key category.

The source category 5E Other comprises NMVOC and CO emissions from car shredding stemming from residues of fuels (gasoline, diesel oil) and motor oil in the tanks and motors of the shredded vehicles. Direct GHG emissions do not occur.

Table 7-24 Specification of source category 5E Other (car shredding)

5E	Source category	Specification
5E	Car shredding plants	Emissions from car shredding plants

7.6.2. Methodological issues

Methodology (5E)

For the emissions from car shredding a Tier 1 method is used.

Indirect CO_2 emissions resulting from fossil CO and NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9.

Emission factors (5E)

An emission factor of 100 g NMVOC per tonne of shredded vehicle is applied for the period 1990–1995. From 2000 onward, 200 g/t are used. Between 1995 and 2000 the values are linearly interpolated. The NMVOC emission factor are based on measurements at four plants in the years from 2002 to 2008 (EMIS 2024/5E Shredder Anlagen). For CO a constant emission factor is applied over the entire reporting period.

Table 7-25 CO and NMVOC emission factors for 5E Other (car shredding) in 2022.

5E Other waste	Unit	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Shredding	g/t scrap	NA	NA	NA	5	200	NA

Activity data (5E)

The waste quantities from 1990 to 1999 are provided by the Swiss Shredding Association. The data from 2000 to 2007 are taken from Swiss waste statistics. From then onwards the quantities are assumed to remain constant due to the lack of data (see also EMIS 2024/5E Shredder Anlagen).

Table 7-26 Activity data 5E Other (car shredding).

5E Other waste	Unit	1990	1995	2000	2005	2010
Shredding	kt	280	300	300	300	300

5E Other waste	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Shredding	kt	300	300	300	300	300	300	300	300	300	300

7.6.3. Uncertainties and time-series consistency for 5E

Uncertainties of CO and NMVOC emissions are documented in Switzerland’s Informative Inventory Report 2024 (FOEN 2024b). The uncertainties of the emission factors are partly based on values provided by the EMEP/EEA guidebook (EMEP/EEA 2019, part A, chp. 5, Table 2-2) and expert judgements (see detailed input uncertainties in Annex A2.1).

Consistency: Time series for 5E Other are all considered consistent.

7.6.4. Category-specific QA/QC and verification for 5E

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

7.6.5. Category-specific recalculations for 5E

There were no recalculations implemented in submission 2024.

7.6.6. Category-specific planned improvements for 5E

No category-specific improvements are planned.

8. Other

Responsibilities for chapter Other	
Overall responsibility	Myriam Guillevic (FOEN)
Authors	Michael Bock (FOEN), Myriam Guillevic (FOEN), Daiana Leuenberger (FOEN)
EMIS data base operation	Myriam Guillevic (FOEN), Daiana Leuenberger (FOEN)
Annual updates (NID text, tables, figures)	Beat Rihm (Meteotest)
Quality control (NID annual updates)	Michael Bock (FOEN), Dominik Eggli (Meteotest), Adrian Schilt (FOEN)
Internal review	Daiana Leuenberger (FOEN), Adrian Schilt (FOEN)

8.1. Overview

Within the sector 6 Other emissions from two sources are considered:

- Fire damage buildings
- Fire damage motor vehicles

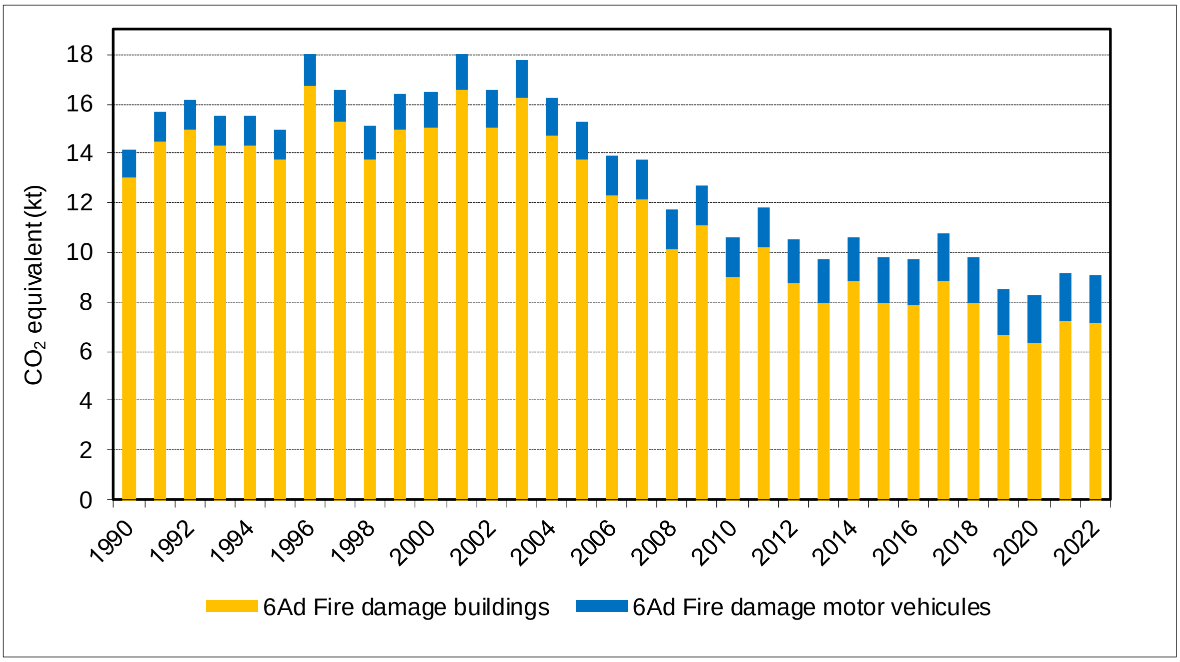

Figure 8-1 Switzerland's greenhouse gas emissions in sector 6 Other.

Gas	1990	1995	2000	2005	2010
	CO_2 equivalent (kt)				
CO_2	13	14	15	14	9.7
CH_4	0.83	0.81	0.84	0.78	0.55
N_2O	0.60	0.58	0.60	0.55	0.36
Sum	14	15	16	15	11

Gas	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	CO_2 equivalent (kt)									
CO_2	8.9	9.7	9.0	8.9	9.8	9.0	7.8	7.6	8.4	8.3
CH_4	0.50	0.55	0.51	0.50	0.55	0.51	0.44	0.43	0.48	0.47
N_2O	0.32	0.35	0.32	0.31	0.35	0.31	0.26	0.25	0.29	0.28
Sum	9.7	11	9.8	9.7	11	9.8	8.5	8.3	9.2	9.1

Table 8-1 Trend of total GHG emissions from sector 6 Other in Switzerland.

In sector 6 Other, Fire damage buildings account for most of the emissions, the rest originates from Fire damage motor vehicles. The emission trend is generally decreasing since 2004, mostly due to a gradually decreasing number of building fires per year. The total greenhouse gas emissions of this sector show emissions of less than 20 kt CO_2 eq in each year during the reporting period. Consequently, sector 6 Other is an emission source of minor importance for the national total.

8.2. Source category 6A – Other

8.2.1. Source category description

Table 8-2 Key categories of 6A – Other. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Source category 6A – Other is not a key category.

The sources reported in source category 6A Other are shown in Table 8-3.

Table 8-3 Specification of source category 6A Other.

6A	Source category	Specification
6Ad	Fire damage buildings	Emissions from fires in buildings.
6Ad	Fire damage motor vehicles	Emissions from fires in motor vehicles.

8.2.2. Methodological issues

Methodology (6A Other)

CO_2, CH_4 and N_2O emissions are calculated by a Tier 1 method based on the decision tree of the IPCC Guidelines (IPCC 2006, vol. 5, chp. 5, Fig. 5.1 and Fig. 5.2). Emission factors are country-specific.

Emission factors (6A Other)

a) Fire damage buildings

Emission factors for CO_2, CO, NO_x and SO_2 are country-specific, based on measurements and expert estimates originally gained for illegal waste incineration. It is assumed that for fire damage in buildings, emission factors are the same as for illegal waste incineration (chp. 7.4.1 and EMIS 2024/6A Immobilienbrände).

Emission factors for CH_4 and N_2O are estimated based on data in FM Global (2010).

Indirect CO_2 emissions resulting from fossil CH_4, CO and NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9.

b) Fire damage motor vehicles

Emission factors for CO_2, NO_x, CO and SO_2 are country-specific, based on measurements obtained by car fire experiments (Lönnermark and Blomqvist 2006, ADEME 2013, INERIS 2019), EMIS 2024/6A Fahrzeugbrände).

The emission factor for CH_4 from fire damage in motor vehicles is based on USEPA (1992). It is of the same order of magnitude but slightly higher than the value published in INERIS 2019 (5 t/kt vs 3 t/kt burnt material, respectively).

N_2O emissions have not been estimated for this source category.

It is assumed that the emission factor for NMVOC is the same as for illegal waste incineration (chp. 7.4.1 and EMIS 2024/6A Fahrzeugbrände).

Indirect CO_2 emissions resulting from fossil CH_4, CO and NMVOC emissions in this source category are included in CRT Table6 as documented in chp. 9.

Table 8-4 Emission factors for fire damages in 2022 (EMIS 2024/6Ad).

6A Other	**Unit**	**CO_2 biogenic**	**CO_2 fossil**	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**
6Ad Fire damage buildings	t / kt burnt good	1'900	1'900	3	0.25	3	100	16	1
6Ad Fire damage motor vehicles	t / kt burnt good	NO	2'295	5	NE	4.5	52	2	5

Activity data (6A Other)

a) Fire damage buildings

Activity data are estimated yearly based on the number of building fires reported to insurance companies for the given year. This information is annually published by the fire insurance association of the cantons (Vereinigung kantonaler Feuerversicherungen, VKF).

VKF publishes the number of fire incidents in buildings each year and the total sum of monetary damage. Using the data from 1992 to 2001, the average damage sum per fire incident in buildings amounts to approximately CHF 16’000. This corresponds – based on the assumption of typical damage costs of CHF 20’000 per 1’000 kg of burnt material – to 800 kg of flammable material per case. It is further assumed that on average 50 % of the flammable material gets destroyed during an incident because of the intervention of the fire brigade, yet without actually being set on fire. Thus, an average amount of 400 kg of burnt material per fire case is estimated and held constant throughout the time series. This is the same order of magnitude as the range of 272–417 kg of burnt material estimated based on a test fire as published in FM Global (2010). With these assumptions, the amount of burnt material for each year can be estimated using the total number of building fires published by VKF (EMIS 2024/6A Immobilienbrände), multiplied by the burnt material (400 kg) per fire incident. The resulting value of 9 kt burnt goods is used for the year 1990.

The fraction of fossil material burnt is assumed to be 20 % from 1900 until 1950. It is then assumed to increase linearly until 2000, when it reaches a fraction of 80 %, and to remain constant at a fraction of 80 % afterwards.

b) Fire damage motor vehicles

Activity data are estimated yearly based on the vehicle number published annually by the Federal Statistical Office FSO (EMIS 2024/6A Fahrzeugbrände).

Based on data from a Swiss insurance company with 25 % market share in 2002, the number of reported cases of fire damage to vehicles was extrapolated to the total vehicle number in Switzerland. This results in one fire case per 790 vehicles for the year 2002. It is assumed that this ratio has remained constant during the reporting period. By applying this ratio to the actual vehicle number published annually by the FSO, the total number of vehicles with fire damages in Switzerland can be calculated for each year.

During a car fire incident, a car burns down only partially. It is assumed that approximately 100 kg of material burns down during a car fire. With these assumptions, the total mass of material burnt is calculated from the total number of car fire incidents in Switzerland.

It is assumed that the burnt material is entirely of fossil origin.

Table 8-5 Activity data of burnt goods (documented in EMIS 2024/6Ad).

6A	Unit	1990	1995	2000	2005	2010
6Ad Fire damage buildings (fossil)	kt	6.1	6.5	7.2	6.6	4.3
6Ad Fire damage buildings (biog.)	kt	2.9	2.3	1.8	1.6	1.1
6Ad Fire damage motor vehicles	kt	0.48	0.52	0.58	0.64	0.68

6A	Unit	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
6Ad Fire damage buildings (fossil)	kt	3.8	4.2	3.8	3.8	4.2	3.8	3.2	3.0	3.5	3.4
6Ad Fire damage buildings (biog.)	kt	0.95	1.1	0.95	0.94	1.1	0.95	0.79	0.76	0.87	0.85
6Ad Fire damage motor vehicles	kt	0.72	0.73	0.75	0.76	0.77	0.77	0.78	0.79	0.80	0.81

8.2.3. Uncertainties and time series consistency for 6A

For building fires, the assigned uncertainty value for the total amount of burnt good is 50 %. This results in an uncertainty of 50 % for the activity data for CH_4 and N_2O. For CO_2, the uncertainty of the fossil fraction increases the uncertainty of the activity data to 60 %. For car fires, the assigned uncertainty for the activity data (amount of burnt material) for all gases is 50 %.

For building fires and car fires, the uncertainty assigned to the emission factors is 100 % for CH_4, 120 % for CO_2 and 150 % for N_2O (see also Table A – 2).

Consistency: Time series for 6Ad Fire damages are all considered consistent.

8.2.4. Category-specific QA/QC and verification for 6A

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

8.2.5. Category-specific recalculations for 6A

The following recalculation was implemented in submission 2024:

- 6Ad Fire damages buildings: The activity data for the number of building fires has been reassessed for the time period 1990–2021. The activity data are now based on the number of fires per year instead of the total costs of fires. This reassessment causes emissions changes from +10 % in 1990 to -45 % in 2021, for CO_2 fossil, CH_4, N_2O.
- 6Ad Fire damages motor vehicles: The emission factor for source category 6Ad Other for CO_2 fossil emitted during accidental car fires has been reassessed. It is now based on the average of several car fire experiments reported in the literature. This causes an increase in emissions for the time period 1990–2021 by 53 %.

8.2.6. Category-specific planned improvements for 6A

No category-specific improvements are planned.

9. Indirect CO_2 and N_2O emissions

Responsibilities for chapter Indirect CO_2 and N_2O emissions	
Overall responsibility	Adrian Schilt (FOEN)
Authors	Adrian Schilt (FOEN) and sector experts
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Quality control (NID annual updates)	Dominik Eggli (Meteotest), Adrian Schilt (FOEN)
Internal review	Anouk-Aimée Bass (FOEN), Daniel Bretscher (Agroscope), Myriam Guillevic (FOEN), Daiana Leuenberger (FOEN), Sabine Schenker (FOEN), Adrian Schilt (FOEN)

9.1. Overview

In this chapter, indirect CO_2 emissions that result from the atmospheric oxidation of CH_4, CO and NMVOC as well as indirect N_2O emissions that are induced by the deposition of NO_x and NH_3 are documented. While indirect CO_2 emissions of fossil origin reported in this chapter are accounted for in the national total, indirect N_2O emissions are not.

Indirect emissions of CO_2 and N_2O are shown in CRT Table6, together with the emissions of the precursor gases CH_4, CO, NMVOC, NO_x and NH_3. While all emissions of precursor gases are shown in both CRT Table6 and in the respective sectors, the indirect emissions of CO_2 and N_2O shown in CRT Table6 only represent emissions not already included in direct emissions in other sectors (in order to avoid double counting). Further, in the case of indirect CO_2 emissions, only carbon of fossil origin is considered. Accordingly, while CH_4, CO and NMVOC of biogenic origin are shown as precursor gases in CRT Table6, they are not included for the calculation of indirect CO_2 emissions. Consequently, the implied emission factors may vary from sector to sector and also from year to year.

Chapter 9.2 explains in detail the methodological issues to derive indirect CO_2 and N_2O emissions based on the emissions of the precursor gases CH_4, CO and NMVOC as well as NO_x and NH_3 from the different sectors. As an overview, the resulting indirect CO_2 emissions are shown in Table 9-1, as well as in Figure 9-1 and Figure 9-2. The resulting indirect N_2O emissions are shown in Table 9-2, as well as in Figure 9-3 and Figure 9-4.

To provide further details with regard to the CH_4, CO and NMVOC emissions relevant for the indirect CO_2 emissions as shown in CRT Table6, the emissions of these precursor gases are shown for each sector, disaggregated by source category, in Table 9-3 (for sector 1 Energy), in Table 9-4 (for sector 2 Industrial processes and product use), in Table 9-5 (for sector 5 Waste) and in Table 9-6 (for sector 6 Other). In these tables, the percentages provided in parentheses reflect the share of emissions of precursor gases that are relevant for indirect CO_2 emissions, i.e. the share of fossil emissions of precursor gases not already considered under the direct CO_2 emissions. This information – together with the factors for the stoichiometric conversion of CH_4, CO and NMVOC to indirect CO_2 as provided in chp. 9.2.1 – allows for an interpretation of the implied emission factors.

Indirect CO_2 emissions are considered for both the uncertainty analysis (see chp. 1.6) and the key category analysis (see chp. 1.4). Indirect N_2O emissions are neither considered for the uncertainty analysis (see chp. 1.6), nor for the key category analysis (see chp. 1.4).

Table 9-1 Indirect fossil CO$_2$ emissions.

Indirect fossil CO$_2$ emissions by source category	**1990**	**1995**	**2000**	**2005**	**2010**
	kt CO$_2$				
1 Energy	**55**	**45**	**32**	**24**	**20**
1B Fugitive emissions from fuels	55	45	32	24	20
2 Industrial processes and product use	**334**	**236**	**170**	**117**	**110**
2A Mineral industry	0.15	0.12	0.11	0.11	0.12
2B Chemical industry	8.0	6.8	8.4	7.3	8.1
2C Metal industry	3.4	2.4	2.2	1.3	0.93
2D Non-energy products from fuels and solvent use	194	127	92	51	49
2G Other product manufacture and use	126	97	65	57	50
2H Other	2.8	2.0	1.9	1.3	2.3
5 Waste	**2.2**	**1.9**	**1.8**	**1.6**	**1.5**
5C Waste incineration and open burning of waste	2.2	1.7	1.7	1.4	1.3
5E Other	0.064	0.10	0.13	0.13	0.13
6 Other	**1.3**	**1.4**	**1.5**	**1.4**	**0.93**
6Ad Fire damages	1.3	1.4	1.5	1.4	0.93
Total	**392**	**284**	**205**	**144**	**133**

Indirect fossil CO$_2$ emissions by source category	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	kt CO$_2$									
1 Energy	**16**	**15**	**14**	**12**	**12**	**11**	**11**	**9.9**	**9.5**	**9.5**
1B Fugitive emissions from fuels	16	15	14	12	12	11	11	9.9	9.5	9.5
2 Industrial processes and product use	**98**	**95**	**91**	**93**	**93**	**86**	**91**	**88**	**84**	**83**
2A Mineral industry	0.10	0.10	0.092	0.095	0.094	0.094	0.094	0.089	0.089	0.087
2B Chemical industry	6.1	6.6	7.1	14	14	8.1	13	11	6.8	5.8
2C Metal industry	0.80	0.78	0.67	0.63	0.65	0.64	0.46	0.41	0.43	0.46
2D Non-energy products from fuels and solvent use	44	42	39	37	37	36	36	36	36	36
2G Other product manufacture and use	45	43	42	40	40	40	40	40	40	40
2H Other	2.0	2.0	1.9	1.0	1.0	1.1	0.94	0.88	0.92	0.88
5 Waste	**1.4**	**1.3**	**1.3**	**1.3**	**1.3**	**1.2**	**1.2**	**1.2**	**1.2**	**1.1**
5C Waste incineration and open burning of waste	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.0	1.0
5E Other	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
6 Other	**0.84**	**0.92**	**0.84**	**0.83**	**0.93**	**0.84**	**0.71**	**0.69**	**0.77**	**0.77**
6Ad Fire damages	0.84	0.92	0.84	0.83	0.93	0.84	0.71	0.69	0.77	0.77
Total	**116**	**112**	**107**	**107**	**107**	**100**	**103**	**100**	**95**	**94**

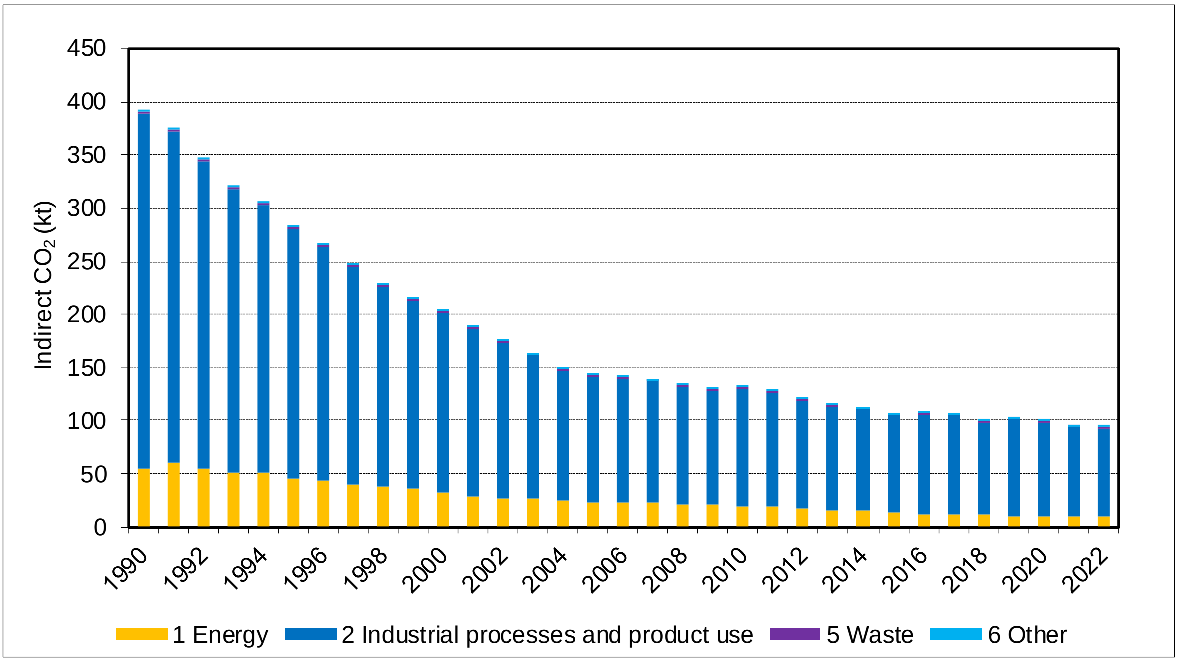

Figure 9-1 Switzerland's indirect fossil CO$_2$ emissions.

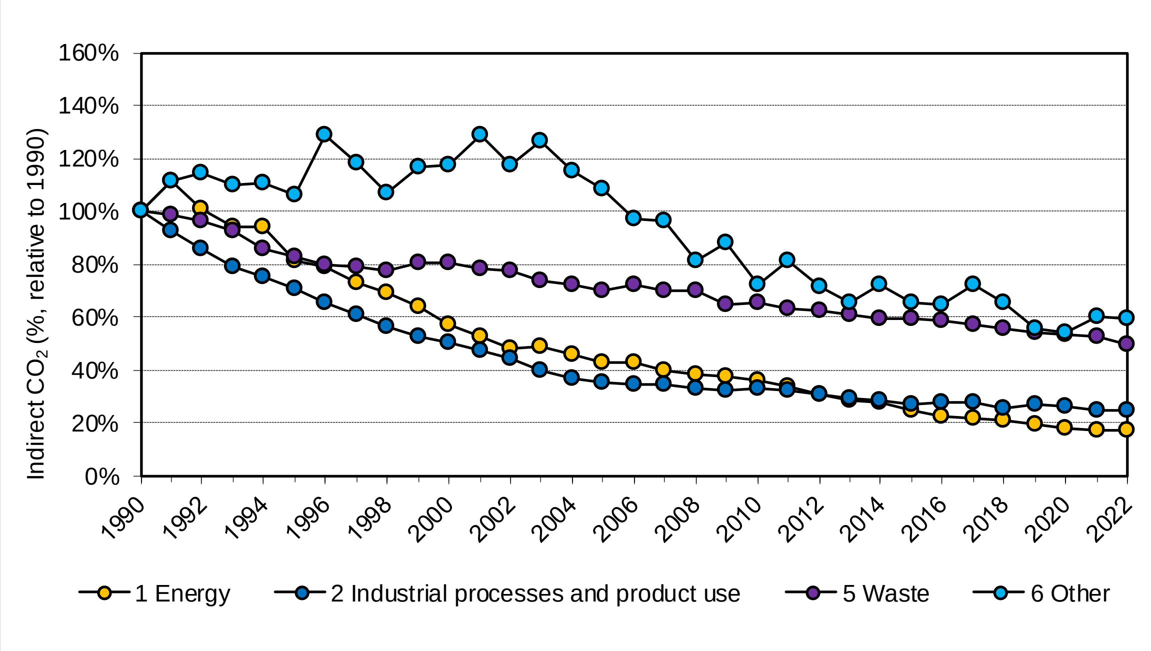

Figure 9-2 Relative trends of the indirect fossil CO_2 emissions by sector. The base year 1990 represents 100 %.

Table 9-2 Indirect N_2O emissions.

Indirect N_2O emissions by source category	1990	1995	2000	2005	2010
	kt N_2O				
1 Energy	**1.7**	**1.4**	**1.3**	**1.2**	**1.1**
1A Fuel combustion activities	1.7	1.4	1.3	1.2	1.1
1B Fugitive emissions from fuels	0.0025	0.0037	0.0037	0.0034	0.0014
2 Industrial processes and product use	**0.018**	**0.014**	**0.017**	**0.015**	**0.012**
2A Mineral industry	0.00021	0.00017	0.00015	0.00016	0.00018
2B Chemical industry	0.0014	0.0012	0.0012	0.0011	0.0012
2C Metal industry	0.0038	0.0023	0.0024	0.0025	0.0026
2G Other product manufacture and use	0.0069	0.0068	0.0080	0.0081	0.0035
2H Other	0.0054	0.0038	0.0051	0.0035	0.0044
5 Waste	**0.033**	**0.030**	**0.031**	**0.032**	**0.032**
5A Solid waste disposal	0.020	0.015	0.014	0.014	0.012
5B Biological treatement of solid waste	0.0060	0.0086	0.012	0.012	0.014
5C Waste incineration and open burning of waste	0.0040	0.0030	0.0026	0.0027	0.0027
5D Wastewater handling and discharge	0.0032	0.0034	0.0034	0.0036	0.0039
6 Other	**0.00029**	**0.00029**	**0.00030**	**0.00028**	**0.00021**
6Ad Fire damages	0.00029	0.00029	0.00030	0.00028	0.00021
Total	**1.8**	**1.4**	**1.4**	**1.3**	**1.1**

Indirect N_2O emissions by source category	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	kt N_2O									
1 Energy	**1.0**	**0.97**	**0.91**	**0.88**	**0.83**	**0.78**	**0.74**	**0.65**	**0.63**	**0.59**
1A Fuel combustion activities	1.0	0.96	0.91	0.88	0.83	0.78	0.74	0.65	0.63	0.59
1B Fugitive emissions from fuels	0.00094	0.00111	0.00063	0.00004	0.000030	0.000031	0.000020	0.000022	0.000017	0.000008
2 Industrial processes and product use	**0.010**	**0.012**	**0.0099**	**0.0092**	**0.010**	**0.0092**	**0.0088**	**0.0080**	**0.0081**	**0.0078**
2A Mineral industry	0.00016	0.00016	0.00015	0.00015	0.00015	0.00015	0.00015	0.00014	0.00014	0.00014
2B Chemical industry	0.00082	0.00094	0.00070	0.00094	0.0010	0.00045	0.00025	0.00022	0.00017	0.000008
2C Metal industry	0.0026	0.0027	0.0027	0.0026	0.0026	0.0027	0.0024	0.0023	0.0026	0.0025
2G Other product manufacture and use	0.0027	0.0025	0.0023	0.0024	0.0026	0.0029	0.0029	0.0028	0.0029	0.0028
2H Other	0.0041	0.0051	0.0040	0.0031	0.0036	0.0030	0.0031	0.0025	0.0022	0.0023
5 Waste	**0.032**	**0.031**	**0.031**	**0.032**	**0.031**	**0.031**	**0.032**	**0.032**	**0.032**	**0.031**
5A Solid waste disposal	0.011	0.010	0.0096	0.0092	0.0088	0.0083	0.0078	0.0075	0.0071	0.0067
5B Biological treatement of solid waste	0.015	0.014	0.014	0.016	0.016	0.016	0.018	0.018	0.019	0.018
5C Waste incineration and open burning of waste	0.0028	0.0028	0.0029	0.0026	0.0022	0.0018	0.0018	0.0018	0.0018	0.0017
5D Wastewater handling and discharge	0.0041	0.0041	0.0042	0.0042	0.0043	0.0043	0.0043	0.0044	0.0044	0.00441
6 Other	**0.00019**	**0.00021**	**0.00019**	**0.00019**	**0.00021**	**0.00019**	**0.00017**	**0.00017**	**0.00018**	**0.00018**
6Ad Fire damages	0.00019	0.00021	0.00019	0.00019	0.00021	0.00019	0.00017	0.00017	0.00018	0.00018
Total	**1.1**	**1.0**	**0.95**	**0.92**	**0.87**	**0.82**	**0.78**	**0.69**	**0.67**	**0.62**

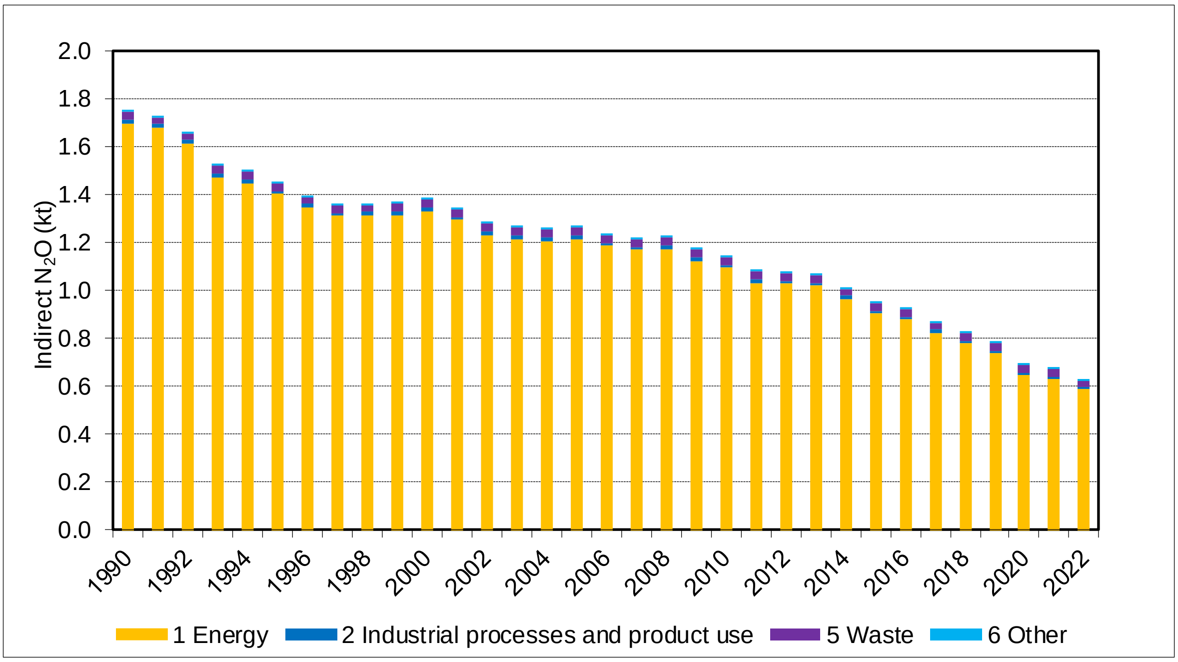

Figure 9-3 Switzerland's indirect N_2O emissions.

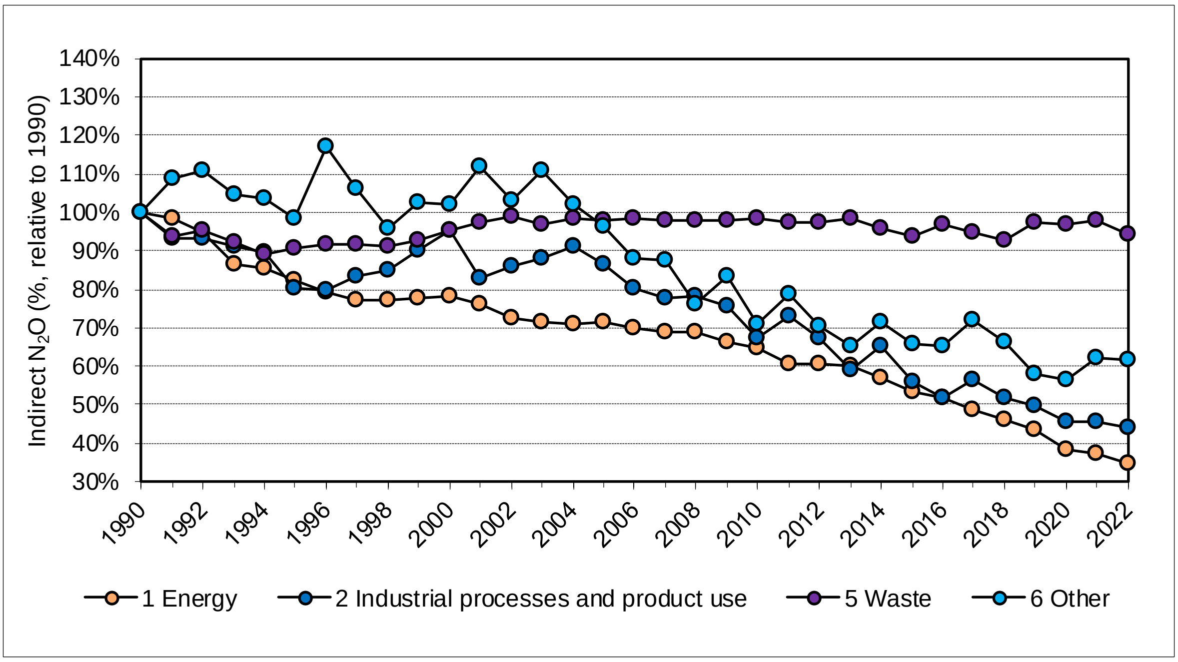

Figure 9-4 Relative trends of the indirect N_2O emissions by sector. The base year 1990 represents 100 %.

Table 9-3 Switzerland’s emissions of the precursor gases CH_4, CO and NMVOC in the source categories of sector 1 Energy, together with the respective indirect CO_2 emissions. The numbers in parentheses indicate the fractions of precursor gases that are relevant for indirect CO_2, i.e. the share of fossil emissions of precursor gases not already considered under the direct CO_2 emissions. To derive the indirect CO_2 emissions, the emissions of precursor gases need to be multiplied by the provided fractions as well as by the factors for the stoichiometric conversion of CH_4, CO and NMVOC to indirect CO_2 as given in the text (chp. 9.2.1). As an illustrative example, an emission of NMVOC indicated as “150 (40.0 %)” leads to indirect CO_2 emissions of 132 kt (150 kt * 40.0 % * 0.6 * 44/12 = 132 kt, with 0.6 corresponding to the carbon content of NMVOC, see formula in chp. 9.2.1).

Emissions of NMVOC, CO and CH_4 as well as indirect CO_2	**1990**	**1995**	**2000**	**2005**	**2010**
	kt				
1 Energy: CH_4	**15.3 (21.7%)**	**13.1 (27.7%)**	**11.0 (29.5%)**	**9.7 (29.3%)**	**8.8 (34.3%)**
1A Fuel combustion	11.9 (0.0%)	9.5 (0.0%)	7.7 (0.0%)	6.9 (0.0%)	5.8 (0.0%)
1B Fugitive emissions from fuels	3.3 (99.6%)	3.6 (99.4%)	3.3 (99.4%)	2.9 (99.4%)	3.0 (99.8%)
1 Energy: CO	**802 (0.0%)**	**521 (0.0%)**	**406 (0.0%)**	**310 (0.0%)**	**243 (0.0%)**
1A Fuel combustion	802 (0.0%)	521 (0.0%)	406 (0.0%)	310 (0.0%)	243 (0.0%)
1B Fugitive emissions from fuels	0.0 (0.0%)	0.1 (0.0%)	0.1 (0.0%)	0.1 (0.0%)	0.0 (0.0%)
1 Energy: NMVOC	**140 (14.9%)**	**89.4 (17.7%)**	**67.2 (15.3%)**	**46.2 (15.6%)**	**32.6 (15.9%)**
1A Fuel combustion	119 (0.0%)	73.5 (0.0%)	56.9 (0.0%)	39.0 (0.0%)	27.4 (0.0%)
1B Fugitive emissions from fuels	20.8 (99.9%)	15.9 (99.9%)	10.3 (99.8%)	7.2 (99.7%)	5.2 (99.8%)
1 Energy: Total indirect CO_2	**55**	**45**	**32**	**24**	**20**
1A Fuel combustion	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	55	45	32	24	20
1 Energy: Indirect CO_2 from CH_4	**9.1**	**10**	**8.9**	**7.9**	**8.3**
1A Fuel combustion	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	9.1	10	8.9	7.9	8.3
1 Energy: Indirect CO_2 from CO	**NO**	**NO**	**NO**	**NO**	**NO**
1A Fuel combustion	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	NO	NO	NO	NO	NO
1 Energy: Indirect CO_2 from NMVOC	**46**	**35**	**23**	**16**	**11**
1A Fuel combustion	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	46	35	23	16	11

Emissions of NMVOC, CO and CH_4 as well as indirect CO_2	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	kt									
1 Energy: CH_4	**7.1 (30.0%)**	**6.1 (33.9%)**	**6.0 (32.2%)**	**6.0 (30.3%)**	**6.0 (32.2%)**	**5.5 (31.3%)**	**5.3 (30.4%)**	**5.0 (32.0%)**	**5.3 (29.6%)**	**4.7 (32.5%)**
1A Fuel combustion	5.0 (0.0%)	4.0 (0.0%)	4.1 (0.0%)	4.2 (0.0%)	4.0 (0.0%)	3.8 (0.0%)	3.7 (0.0%)	3.4 (0.0%)	3.7 (0.0%)	3.2 (0.0%)
1B Fugitive emissions from fuels	2.1 (99.8%)	2.1 (99.7%)	1.9 (99.8%)	1.8 (100.0%)	1.9 (100.0%)	1.7 (100.0%)	1.6 (100.0%)	1.6 (100.0%)	1.6 (100.0%)	1.5 (100.0%)
1 Energy: CO	**206 (0.0%)**	**184 (0.0%)**	**175 (0.0%)**	**172 (0.0%)**	**167 (0.0%)**	**161 (0.0%)**	**157 (0.0%)**	**143 (0.0%)**	**145 (0.0%)**	**136 (0.0%)**
1A Fuel combustion	206 (0.0%)	184 (0.0%)	175 (0.0%)	172 (0.0%)	167 (0.0%)	161 (0.0%)	157 (0.0%)	143 (0.0%)	145 (0.0%)	136 (0.0%)
1B Fugitive emissions from fuels	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
1 Energy: NMVOC	**26.7 (17.1%)**	**24.0 (18.2%)**	**22.2 (17.2%)**	**21.2 (15.7%)**	**20.4 (15.3%)**	**19.5 (15.5%)**	**18.7 (15.1%)**	**16.8 (14.8%)**	**16.9 (14.1%)**	**15.9 (15.2%)**
1A Fuel combustion	22.1 (0.0%)	19.6 (0.0%)	18.4 (0.0%)	17.9 (0.0%)	17.3 (0.0%)	16.4 (0.0%)	15.9 (0.0%)	14.4 (0.0%)	14.6 (0.0%)	13.5 (0.0%)
1B Fugitive emissions from fuels	4.6 (99.8%)	4.4 (99.8%)	3.8 (99.8%)	3.3 (99.9%)	3.1 (99.8%)	3.0 (99.8%)	2.8 (99.8%)	2.5 (99.8%)	2.4 (99.8%)	2.4 (99.8%)
1 Energy: Total indirect CO_2	**16**	**15**	**14**	**12**	**12**	**11**	**11**	**9.9**	**9.5**	**9.5**
1A Fuel combustion	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	16	15	14	12	12	11	11	9.9	9.5	9.5
1 Energy: Indirect CO_2 from CH_4	**5.9**	**5.7**	**5.3**	**5.0**	**5.3**	**4.7**	**4.5**	**4.4**	**4.3**	**4.2**
1A Fuel combustion	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	5.9	5.7	5.3	5.0	5.3	4.7	4.5	4.4	4.3	4.2
1 Energy: Indirect CO_2 from CO	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
1A Fuel combustion	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1 Energy: Indirect CO_2 from NMVOC	**10**	**9.6**	**8.4**	**7.3**	**6.8**	**6.6**	**6.2**	**5.5**	**5.2**	**5.3**
1A Fuel combustion	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	10	9.6	8.4	7.3	6.8	6.6	6.2	5.5	5.2	5.3

Table 9-4 Switzerland’s emissions of the precursor gases CH_4, CO and NMVOC in the source categories of sector 2 Industrial processes and product use, together with the respective indirect CO_2 emissions. The numbers in parentheses indicate the fractions of precursor gases that are relevant for indirect CO_2, i.e. the share of fossil emissions of precursor gases not already considered under the direct CO_2 emissions. To derive the indirect CO_2 emissions, the emissions of precursor gases need to be multiplied by the provided fractions as well as by the factors for the stoichiometric conversion of CH_4, CO and NMVOC to indirect CO_2 as given in the text (chp. 9.2.1). As an illustrative example, an emission of NMVOC indicated as “150 (40.0 %)” leads to indirect CO_2 emissions of 132 kt (150 kt * 40.0 % * 0.6 * 44/12 = 132 kt, with 0.6 corresponding to the carbon content of NMVOC, see formula in chp. 9.2.1).

Emissions of NMVOC, CO and CH_4 as well as indirect CO_2	**1990**	**1995**	**2000**	**2005**	**2010**
			kt		
2 IPPU: CH_4	**0.1 (100.0%)**	**0.2 (100.0%)**	**0.2 (100.0%)**	**0.3 (100.0%)**	**0.3 (100.0%)**
2B Chemical industry	0.1 (100.0%)	0.2 (100.0%)	0.2 (100.0%)	0.3 (100.0%)	0.3 (100.0%)
2 IPPU: CO	**11.1 (50.2%)**	**7.1 (66.2%)**	**9.1 (66.9%)**	**8.1 (58.8%)**	**7.2 (78.4%)**
2A Mineral industry	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
2B Chemical industry	4.0 (100.0%)	3.7 (100.0%)	4.9 (100.0%)	4.2 (100.0%)	4.6 (100.0%)
2C Metal industry	5.3 (13.3%)	2.0 (26.7%)	2.6 (19.0%)	2.9 (9.8%)	1.1 (20.7%)
2D Non-energy products from fuels and solvent use	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
2G Other product manufacture and use	0.9 (0.7%)	0.9 (0.9%)	0.9 (1.3%)	0.7 (1.4%)	0.7 (1.8%)
2H Other	0.9 (94.6%)	0.4 (91.4%)	0.6 (96.8%)	0.3 (94.1%)	0.8 (97.8%)
2 IPPU: NMVOC	**150 (98.6%)**	**106 (98.0%)**	**74.6 (97.2%)**	**51.8 (95.9%)**	**48.0 (95.4%)**
2A Mineral industry	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
2B Chemical industry	0.6 (96.5%)	0.2 (90.7%)	0.0 (30.9%)	0.0 (21.4%)	0.0 (32.9%)
2C Metal industry	1.1 (92.0%)	0.8 (92.7%)	0.7 (89.9%)	0.5 (82.1%)	0.3 (75.6%)
2D Non-energy products from fuels and solvent use	88.2 (100.0%)	57.8 (100.0%)	42.0 (100.0%)	23.0 (100.0%)	22.3 (100.0%)
2G Other product manufacture and use	57.1 (99.9%)	44.4 (99.8%)	29.4 (99.7%)	25.9 (99.8%)	22.8 (99.7%)
2H Other	2.7 (26.7%)	2.6 (24.3%)	2.4 (18.9%)	2.4 (17.3%)	2.5 (19.7%)
2 IPPU: Total indirect CO_2	**334**	**236**	**170**	**117**	**110**
2A Mineral industry	0.15	0.12	0.11	0.11	0.12
2B Chemical industry	8.0	6.8	8.4	7.3	8.1
2C Metal industry	3.4	2.4	2.2	1.3	0.93
2D Non-energy products from fuels and solvent use	194	127	92	51	49
2G Other product manufacture and use	126	97	65	57	50
2H Other	2.8	2.0	1.9	1.3	2.3
2 IPPU: Indirect CO_2 from CH_4	**0.39**	**0.65**	**0.57**	**0.69**	**0.76**
2B Chemical industry	0.39	0.65	0.57	0.69	0.76
2 IPPU: Indirect CO_2 from CO	**8.8**	**7.4**	**9.5**	**7.5**	**8.9**
2A Mineral industry	0.044	0.037	0.034	0.038	0.039
2B Chemical industry	6.3	5.8	7.8	6.6	7.3
2C Metal industry	1.1	0.85	0.79	0.44	0.35
2D Non-energy products from fuels and solvent use	0.00075	0.00067	0.00062	0.00045	0.00061
2G Other product manufacture and use	0.010	0.012	0.018	0.016	0.020
2H Other	1.3	0.64	0.91	0.39	1.2
2 IPPU: Indirect CO_2 from NMVOC	**325**	**228**	**160**	**109**	**101**
2A Mineral industry	0.10	0.08	0.071	0.077	0.081
2B Chemical industry	1.3	0.35	0.017	0.013	0.027
2C Metal industry	2.3	1.6	1.4	0.82	0.58
2D Non-energy products from fuels and solvent use	194	127	92	51	49
2G Other product manufacture and use	125	97	65	57	50
2H Other	1.6	1.4	1.0	0.91	1.1

Emissions of NMVOC, CO and CH_4 as well as indirect CO_2	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	kt									
2 IPPU: CH_4	**0.2 (100.0%)**	**0.2 (100.0%)**	**0.2 (100.0%)**	**0.3 (100.0%)**	**0.3 (100.0%)**	**0.3 (100.0%)**	**0.3 (100.0%)**	**0.3 (100.0%)**	**0.2 (100.0%)**	**0.3 (100.0%)**
2B Chemical industry	0.2 (100.0%)	0.2 (100.0%)	0.2 (100.0%)	0.3 (100.0%)	0.3 (100.0%)	0.3 (100.0%)	0.3 (100.0%)	0.3 (100.0%)	0.2 (100.0%)	0.3 (100.0%)
2 IPPU: CO	**6.0 (74.1%)**	**6.2 (75.4%)**	**6.5 (76.9%)**	**10.1 (85.5%)**	**10.1 (85.1%)**	**6.5 (77.2%)**	**9.5 (85.7%)**	**8.4 (83.5%)**	**5.7 (73.7%)**	**4.9 (71.7%)**
2A Mineral industry	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
2B Chemical industry	3.5 (100.0%)	3.8 (100.0%)	4.1 (100.0%)	8.3 (100.0%)	8.2 (100.0%)	4.6 (100.0%)	7.8 (100.0%)	6.7 (100.0%)	3.9 (100.0%)	3.2 (100.0%)
2C Metal industry	1.1 (18.0%)	1.1 (16.5%)	1.1 (14.6%)	1.0 (14.3%)	1.0 (14.3%)	1.0 (13.8%)	0.9 (11.4%)	0.9 (9.9%)	1.0 (9.2%)	0.9 (10.4%)
2D Non-energy products from fuels and solvent use	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
2G Other product manufacture and use	0.7 (2.5%)	0.6 (2.2%)	0.6 (2.1%)	0.6 (1.5%)	0.6 (2.1%)	0.6 (2.3%)	0.6 (1.3%)	0.6 (1.3%)	0.6 (2.0%)	0.6 (2.5%)
2H Other	0.7 (97.7%)	0.7 (97.5%)	0.7 (97.5%)	0.2 (92.5%)	0.2 (93.1%)	0.3 (93.8%)	0.2 (92.7%)	0.2 (92.2%)	0.2 (91.7%)	0.2 (92.2%)
2 IPPU: NMVOC	**43.2 (95.0%)**	**41.7 (94.8%)**	**39.8 (94.6%)**	**37.9 (94.4%)**	**37.8 (94.4%)**	**37.4 (94.3%)**	**37.2 (94.3%)**	**36.9 (94.2%)**	**37.0 (94.2%)**	**37.0 (94.2%)**
2A Mineral industry	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
2B Chemical industry	0.0 (11.1%)	0.0 (22.6%)	0.0 (12.4%)	0.0 (5.6%)	0.0 (8.7%)	0.0 (10.0%)	0.0 (13.2%)	0.0 (15.3%)	0.0 (10.4%)	0.0 (11.7%)
2C Metal industry	0.3 (72.6%)	0.3 (70.8%)	0.3 (68.3%)	0.3 (67.8%)	0.3 (68.0%)	0.3 (67.3%)	0.2 (63.7%)	0.2 (61.1%)	0.2 (59.3%)	0.2 (62.1%)
2D Non-energy products from fuels and solvent use	20.0 (100.0%)	19.2 (100.0%)	17.9 (100.0%)	16.8 (100.0%)	16.9 (100.0%)	16.6 (100.0%)	16.5 (100.0%)	16.1 (100.0%)	16.2 (100.0%)	16.2 (100.0%)
2G Other product manufacture and use	20.4 (99.7%)	19.7 (99.7%)	19.1 (99.7%)	18.4 (99.7%)	18.3 (99.7%)	18.3 (99.7%)	18.2 (99.7%)	18.2 (99.7%)	18.3 (99.7%)	18.3 (99.7%)
2H Other	2.4 (17.5%)	2.4 (17.2%)	2.4 (17.2%)	2.3 (13.7%)	2.3 (13.9%)	2.3 (13.7%)	2.3 (12.3%)	2.2 (11.5%)	2.3 (12.5%)	2.3 (11.3%)
2 IPPU: Total indirect CO_2	**98**	**95**	**91**	**93**	**93**	**86**	**91**	**88**	**84**	**83**
2A Mineral industry	0.10	0.10	0.092	0.095	0.094	0.094	0.094	0.089	0.089	0.087
2B Chemical industry	6.1	6.6	7.1	14	14	8.1	13	11	6.8	5.8
2C Metal industry	0.80	0.78	0.67	0.63	0.65	0.64	0.46	0.41	0.43	0.46
2D Non-energy products from fuels and solvent use	44	42	39	37	37	36	36	36	36	36
2G Other product manufacture and use	45	43	42	40	40	40	40	40	40	40
2H Other	2.0	2.0	1.9	1.0	1.0	1.1	0.94	0.88	0.92	0.88
2 IPPU: Indirect CO_2 from CH_4	**0.58**	**0.63**	**0.61**	**0.77**	**0.78**	**0.83**	**0.76**	**0.71**	**0.67**	**0.75**
2B Chemical industry	0.58	0.63	0.61	0.77	0.78	0.83	0.76	0.71	0.67	0.75
2 IPPU: Indirect CO_2 from CO	**7.0**	**7.3**	**7.8**	**14**	**13**	**7.9**	**13**	**11**	**6.6**	**5.6**
2A Mineral industry	0.031	0.029	0.026	0.027	0.027	0.027	0.027	0.025	0.024	0.023
2B Chemical industry	5.5	6.0	6.5	13	13	7.2	12	11	6.1	5.0
2C Metal industry	0.30	0.29	0.24	0.23	0.23	0.23	0.16	0.14	0.14	0.15
2D Non-energy products from fuels and solvent use	0.00070	0.00070	0.00070	0.00071	0.00071	0.00071	0.00071	0.00071	0.00071	0.00071
2G Other product manufacture and use	0.027	0.021	0.019	0.014	0.020	0.021	0.012	0.012	0.018	0.022
2H Other	1.1	1.0	1.0	0.32	0.35	0.39	0.33	0.31	0.30	0.32
2 IPPU: Indirect CO_2 from NMVOC	**90**	**87**	**83**	**79**	**79**	**78**	**77**	**76**	**77**	**77**
2A Mineral industry	0.073	0.073	0.066	0.068	0.068	0.067	0.067	0.064	0.065	0.064
2B Chemical industry	0.0062	0.011	0.0056	0.0019	0.0024	0.0033	0.0046	0.0051	0.0036	0.0040
2C Metal industry	0.50	0.49	0.43	0.40	0.42	0.41	0.31	0.27	0.29	0.30
2D Non-energy products from fuels and solvent use	44	42	39	37	37	36	36	36	36	36
2G Other product manufacture and use	45	43	42	40	40	40	40	40	40	40
2H Other	0.94	0.92	0.91	0.69	0.69	0.69	0.61	0.57	0.63	0.56

Table 9-5 Switzerland’s emissions of the precursor gases CH_4, CO and NMVOC in the source categories of sector 5 Waste, together with the respective indirect CO_2 emissions. The numbers in parentheses indicate the fractions of precursor gases that are relevant for indirect CO_2, i.e. the share of fossil emissions of precursor gases not already considered under the direct CO_2 emissions. To derive the indirect CO_2 emissions, the emissions of precursor gases need to be multiplied by the provided fractions as well as by the factors for the stoichiometric conversion of CH_4, CO and NMVOC to indirect CO_2 as given in the text (chp. 9.2.1). As an illustrative example, an emission of NMVOC indicated as “150 (40.0 %)” leads to indirect CO_2 emissions of 132 kt (150 kt * 40.0 % * 0.6 * 44/12 = 132 kt, with 0.6 corresponding to the carbon content of NMVOC, see formula in chp. 9.2.1).

Emissions of NMVOC, CO and CH_4 as well as indirect CO_2	**1990**	**1995**	**2000**	**2005**	**2010**
	kt				
5 Waste: CH_4	**38.7 (0.2%)**	**30.7 (0.3%)**	**28.6 (0.3%)**	**28.7 (0.2%)**	**25.5 (0.2%)**
5A Solid waste disposal	30.8 (0.0%)	23.1 (0.0%)	21.0 (0.0%)	21.2 (0.0%)	17.6 (0.0%)
5B Biological treatment of solid waste	0.5 (0.0%)	0.6 (0.0%)	0.8 (0.0%)	0.8 (0.0%)	0.8 (0.0%)
5C Incineration and open burning of waste	0.4 (27.1%)	0.3 (26.5%)	0.3 (27.8%)	0.2 (27.1%)	0.2 (27.7%)
5D Waste water treatment and discharge	7.1 (0.0%)	6.7 (0.0%)	6.5 (0.0%)	6.5 (0.0%)	6.9 (0.0%)
5 Waste: CO	**2.8 (29.8%)**	**2.4 (27.8%)**	**2.2 (28.7%)**	**1.9 (28.6%)**	**1.7 (29.3%)**
5A Solid waste disposal	0.0 (0.0%)	0.1 (0.0%)	0.1 (0.0%)	0.1 (0.0%)	0.0 (0.0%)
5B Biological treatment of solid waste	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
5C Incineration and open burning of waste	2.8 (30.2%)	2.3 (28.9%)	2.1 (30.0%)	1.9 (29.5%)	1.7 (30.0%)
5D Waste water treatment and discharge	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
5E Other	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
5 Waste: NMVOC	**1.1 (25.5%)**	**1.0 (25.7%)**	**1.0 (25.3%)**	**1.0 (22.7%)**	**1.2 (18.8%)**
5A Solid waste disposal	0.4 (0.0%)	0.3 (0.0%)	0.3 (0.0%)	0.3 (0.0%)	0.2 (0.0%)
5B Biological treatment of solid waste	0.2 (0.0%)	0.2 (0.0%)	0.3 (0.0%)	0.3 (0.0%)	0.5 (0.0%)
5C Incineration and open burning of waste	0.6 (47.4%)	0.5 (47.3%)	0.4 (48.1%)	0.4 (47.0%)	0.4 (45.2%)
5D Waste water treatment and discharge	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
5E Other	0.0 (100.0%)	0.0 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)
5 Waste: Total indirect CO_2	**2.2**	**1.9**	**1.8**	**1.6**	**1.5**
5A Solid waste disposal	NO	NO	NO	NO	NO
5B Biological treatment of solid waste	NO	NO	NO	NO	NO
5C Incineration and open burning of waste	2.2	1.7	1.7	1.4	1.3
5D Waste water treatment and discharge	NO	NO	NO	NO	NO
5E Other	0.064	0.10	0.13	0.13	0.13
5 Waste: Indirect CO_2 from CH_4	**0.26**	**0.22**	**0.21**	**0.18**	**0.17**
5A Solid waste disposal	NO	NO	NO	NO	NO
5B Biological treatment of solid waste	NO	NO	NO	NO	NO
5C Incineration and open burning of waste	0.26	0.22	0.21	0.18	0.17
5D Waste water treatment and discharge	NO	NO	NO	NO	NO
5 Waste: Indirect CO_2 from CO	**1.3**	**1.1**	**1.0**	**0.86**	**0.80**
5A Solid waste disposal	NO	NO	NO	NO	NO
5B Biological treatment of solid waste	NO	NO	NO	NO	NO
5C Incineration and open burning of waste	1.3	1.1	1.0	0.86	0.80
5D Waste water treatment and discharge	NO	NO	NO	NO	NO
5E Other	0.0022	0.0024	0.0024	0.0024	0.0024
5 Waste: Indirect CO_2 from NMVOC	**0.64**	**0.57**	**0.58**	**0.52**	**0.49**
5A Solid waste disposal	NO	NO	NO	NO	NO
5B Biological treatment of solid waste	NO	NO	NO	NO	NO
5C Incineration and open burning of waste	0.58	0.47	0.45	0.39	0.36
5D Waste water treatment and discharge	NO	NO	NO	NO	NO
5E Other	0.06	0.10	0.13	0.13	0.13

Emissions of NMVOC, CO and CH_4 as well as indirect CO_2	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	kt									
5 Waste: CH_4	**23.6 (0.2%)**	**23.1 (0.2%)**	**22.6 (0.2%)**	**22.2 (0.2%)**	**21.7 (0.2%)**	**21.1 (0.2%)**	**20.6 (0.2%)**	**20.1 (0.2%)**	**19.6 (0.2%)**	**19.2 (0.2%)**
5A Solid waste disposal	15.3 (0.0%)	14.7 (0.0%)	14.1 (0.0%)	13.4 (0.0%)	12.8 (0.0%)	12.1 (0.0%)	11.4 (0.0%)	10.9 (0.0%)	10.3 (0.0%)	9.8 (0.0%)
5B Biological treatment of solid waste	0.9 (0.0%)	0.9 (0.0%)	0.9 (0.0%)	1.0 (0.0%)	1.0 (0.0%)	1.0 (0.0%)	1.1 (0.0%)	1.1 (0.0%)	1.1 (0.0%)	1.1 (0.0%)
5C Incineration and open burning of waste	0.2 (26.9%)	0.2 (26.6%)	0.2 (26.7%)	0.2 (26.6%)	0.2 (26.2%)	0.2 (26.1%)	0.2 (25.8%)	0.2 (25.7%)	0.2 (25.6%)	0.2 (24.8%)
5D Waste water treatment and discharge	7.1 (0.0%)	7.3 (0.0%)	7.4 (0.0%)	7.6 (0.0%)	7.7 (0.0%)	7.8 (0.0%)	7.9 (0.0%)	7.9 (0.0%)	8.0 (0.0%)	8.1 (0.0%)
5 Waste: CO	**1.7 (28.8%)**	**1.6 (28.7%)**	**1.6 (28.8%)**	**1.6 (28.8%)**	**1.5 (28.5%)**	**1.5 (28.4%)**	**1.5 (28.2%)**	**1.5 (28.1%)**	**1.4 (27.9%)**	**1.4 (27.1%)**
5A Solid waste disposal	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
5B Biological treatment of solid waste	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
5C Incineration and open burning of waste	1.6 (29.3%)	1.6 (29.2%)	1.6 (29.3%)	1.6 (29.3%)	1.5 (29.0%)	1.5 (28.9%)	1.4 (28.7%)	1.4 (28.6%)	1.4 (28.4%)	1.4 (27.6%)
5D Waste water treatment and discharge	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
5E Other	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)	0.0 (100.0%)
5 Waste: NMVOC	**1.3 (15.7%)**	**1.4 (15.2%)**	**1.4 (14.7%)**	**1.5 (13.6%)**	**1.5 (13.1%)**	**1.6 (12.5%)**	**1.7 (11.5%)**	**1.7 (11.0%)**	**1.8 (10.6%)**	**1.7 (10.3%)**
5A Solid waste disposal	0.2 (0.0%)	0.2 (0.0%)	0.2 (0.0%)	0.2 (0.0%)	0.2 (0.0%)	0.2 (0.0%)	0.2 (0.0%)	0.1 (0.0%)	0.1 (0.0%)	0.1 (0.0%)
5B Biological treatment of solid waste	0.7 (0.0%)	0.8 (0.0%)	0.8 (0.0%)	0.9 (0.0%)	1.0 (0.0%)	1.0 (0.0%)	1.1 (0.0%)	1.2 (0.0%)	1.3 (0.0%)	1.3 (0.0%)
5C Incineration and open burning of waste	0.3 (44.1%)	0.3 (43.9%)	0.3 (43.8%)	0.3 (43.4%)	0.3 (42.8%)	0.3 (42.4%)	0.3 (42.3%)	0.3 (42.2%)	0.3 (42.2%)	0.3 (41.8%)
5D Waste water treatment and discharge	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
5E Other	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)	0.1 (100.0%)
5 Waste: Total indirect CO_2	**1.4**	**1.3**	**1.3**	**1.3**	**1.3**	**1.2**	**1.2**	**1.2**	**1.2**	**1.1**
5A Solid waste disposal	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5B Biological treatment of solid waste	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5C Incineration and open burning of waste	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.0	0.97
5D Waste water treatment and discharge	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5E Other	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
5 Waste: Indirect CO_2 from CH_4	**0.16**	**0.15**	**0.15**	**0.15**	**0.14**	**0.14**	**0.14**	**0.13**	**0.13**	**0.12**
5A Solid waste disposal	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5B Biological treatment of solid waste	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5C Incineration and open burning of waste	0.16	0.15	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.12
5D Waste water treatment and discharge	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5 Waste: Indirect CO_2 from CO	**0.75**	**0.73**	**0.73**	**0.72**	**0.69**	**0.67**	**0.65**	**0.64**	**0.63**	**0.59**
5A Solid waste disposal	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5B Biological treatment of solid waste	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5C Incineration and open burning of waste	0.75	0.73	0.72	0.72	0.69	0.67	0.65	0.64	0.63	0.59
5D Waste water treatment and discharge	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5E Other	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024
5 Waste: Indirect CO_2 from NMVOC	**0.47**	**0.46**	**0.46**	**0.45**	**0.44**	**0.43**	**0.42**	**0.42**	**0.41**	**0.39**
5A Solid waste disposal	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5B Biological treatment of solid waste	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5C Incineration and open burning of waste	0.33	0.33	0.32	0.32	0.31	0.30	0.29	0.29	0.28	0.26
5D Waste water treatment and discharge	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5E Other	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13

Table 9-6 Switzerland’s emissions of the precursor gases CH_4, CO and NMVOC in the source categories of sector 6 Other, together with the respective indirect CO_2 emissions. The numbers in parentheses indicate the fractions of precursor gases that are relevant for indirect CO_2, i.e. the share of fossil emissions of precursor gases not already considered under the direct CO_2 emissions. To derive the indirect CO_2 emissions, the emissions of precursor gases need to be multiplied by the provided fractions as well as by the factors for the stoichiometric conversion of CH_4, CO and NMVOC to indirect CO_2 as given in the text (chp. 9.2.1). As an illustrative example, an emission of NMVOC indicated as “150 (40.0 %)” leads to indirect CO_2 emissions of 132 kt (150 kt * 40.0 % * 0.6 * 44/12 = 132 kt, with 0.6 corresponding to the carbon content of NMVOC, see formula in chp. 9.2.1).

Emissions of NMVOC, CO and CH_4 as well as indirect CO_2	1990	1995	2000	2005	2010
	kt				
6 Other: CH_4	0.0 (70.6%)	0.0 (76.3%)	0.0 (81.9%)	0.0 (82.3%)	0.0 (83.5%)
6 Other: CO	0.9 (68.9%)	0.9 (74.8%)	0.9 (80.6%)	0.9 (80.8%)	0.6 (81.2%)
6 Other: NMVOC	0.1 (68.2%)	0.1 (74.2%)	0.1 (80.2%)	0.1 (80.2%)	0.1 (80.3%)
6 Other: Total indirect CO_2	1.3	1.4	1.5	1.4	0.93
6 Other: Indirect CO_2 from CH_4	0.057	0.061	0.068	0.063	0.045
6 Other: Indirect CO_2 from CO	1.0	1.1	1.2	1.1	0.73
6 Other: Indirect CO_2 from NMVOC	0.22	0.23	0.26	0.23	0.15

Emissions of NMVOC, CO and CH_4 as well as indirect CO_2	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	kt									
6 Other: CH_4	0.0 (84.0%)	0.0 (83.7%)	0.0 (84.2%)	0.0 (84.2%)	0.0 (83.9%)	0.0 (84.3%)	0.0 (84.9%)	0.0 (85.1%)	0.0 (84.7%)	0.0 (84.8%)
6 Other: CO	0.5 (81.4%)	0.6 (81.3%)	0.5 (81.5%)	0.5 (81.5%)	0.6 (81.4%)	0.5 (81.5%)	0.4 (81.8%)	0.4 (81.9%)	0.5 (81.7%)	0.5 (81.8%)
6 Other: NMVOC	0.1 (80.4%)	0.1 (80.3%)	0.1 (80.4%)	0.1 (80.4%)	0.1 (80.4%)	0.1 (80.4%)	0.1 (80.5%)	0.1 (80.5%)	0.1 (80.5%)	0.1 (80.5%)
6 Other: Total indirect CO_2	0.84	0.92	0.84	0.83	0.93	0.84	0.71	0.69	0.77	0.77
6 Other: Indirect CO_2 from CH_4	0.041	0.045	0.042	0.041	0.046	0.042	0.037	0.036	0.040	0.039
6 Other: Indirect CO_2 from CO	0.66	0.73	0.66	0.65	0.73	0.66	0.56	0.54	0.61	0.60
6 Other: Indirect CO_2 from NMVOC	0.14	0.15	0.14	0.14	0.15	0.14	0.12	0.11	0.13	0.12

9.2. Indirect CO_2 and N_2O emissions from all source categories of the GHG inventory

Table 9-7 Key categories of indirect CO_2 emissions. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
2D	Non-energy products from fuels and solvent use	Ind. CO2 (NMVOC)	T1

As described in chp. 9.1, indirect CO_2 emissions cover all emissions that result from the atmospheric oxidation of CH_4, CO and NMVOC, while indirect N_2O emissions reflect emissions that are induced by the deposition of NO_x and NH_3. Accordingly, a large number of source categories – contributing to the emissions of precursor gases CH_4, CO, NMVOC, NO_x and NH_3 – are involved (see Table 9-1 and Table 9-2 for an overview as well as Table 9-3 to Table 9-6 for the full details). Only the contributions of one source category was identified as key category of indirect CO_2 emissions as shown in Table 9-7.

9.2.1. Methodological issues to derive indirect CO_2 emissions

Indirect CO_2 emissions resulting from the atmospheric oxidation of CH_4 and CO are calculated based on the stoichiometric conversion (molecular weight of CO_2 divided by the molecular weight of CH_4 or CO, respectively). Indirect CO_2 emissions from the atmospheric oxidation of NMVOC are also calculated based on the stoichiometric conversion (carbon content fraction multiplied by the molecular weight of CO_2 divided by the molecular weight of carbon). Thereby, a constant carbon content of NMVOC of 60 % is assumed, based on the IPCC Guidelines (IPCC 2006). Thus, indirect CO_2 emissions (Em) result from the following equations:

- $Em_{CO2,\ indirect\ from\ CH4} = Em_{CH4,\ fossil} * 44/16$
- $Em_{CO2,\ indirect\ from\ CO} = Em_{CO,\ fossil} * 44/28$
- $Em_{CO2,\ indirect\ from\ NMVOC} = Em_{NMVOC,\ fossil} * 0.6 * 44/12$

Activity data for the calculation of indirect CO_2 emissions

Activity data to calculate indirect CO_2 emissions consists of CH_4, CO and NMVOC emissions as reported in each individual sector and source category, carefully excluding CH_4, CO and NMVOC emissions of biogenic origin and emissions already included as direct CO_2 emissions (e.g. when using an oxidation factor of 100 %). For the different sectors and source categories, the situation is as follows:

1A Fuel combustion activities: Since according to the IPCC Guidelines (IPCC 2006) emission factors in source category 1A Fuel combustion activities are based on the assumption of complete oxidation (100 %), CO_2 resulting from the atmospheric oxidation of CH_4, CO and NMVOC emitted from this source category is already accounted for in the corresponding emission factors for direct CO_2 emissions. The respective emissions are thus implicitly reported as direct CO_2 emissions in 1A Fuel combustion activities and no indirect CO_2 emissions from 1A Fuel combustion activities are reported (see chp. 3.2.4.5.1).

1B Fugitive emissions from fuels: CO_2 resulting from the atmospheric oxidation of CH_4, CO and NMVOC emitted from source category 1B Fugitive emissions from fuels is reported as indirect CO_2 emissions unless it is already accounted for implicitly as direct CO_2 emissions in 1B (chp. 3.3). For 1B, Table 9-8 illustrates in which processes CH_4, CO and NMVOC emissions occur, and whether the related CO_2 emissions are reported as indirect CO_2 emissions or implicitly as direct CO_2 emissions. In summary, all CO_2 resulting from the atmospheric oxidation of CO emitted from 1B is implicitly included in 1B as direct CO_2 and is therefore not reported as indirect CO_2. CO_2 resulting from the atmospheric oxidation of CH_4 and NMVOC emitted from 1B is reported as indirect CO_2, except for source category 1B2c Venting and flaring, where an oxidation factor of 100 % is applied to calculate direct CO_2 emissions.

Table 9-8 Sources of indirect CO_2 emissions from source category 1B Fugitive emissions from fuels. Only relevant source categories are shown. Blue cells mark processes for which CO_2 emissions resulting from the atmospheric oxidation of CH_4, CO or NMOVC emissions are not accounted for as indirect CO_2 emissions because they are already considered under the direct CO_2 emissions.

1B Fugitive emissions from fuels		**CO_2 resulting from CH_4**	**CO_2 resulting from CO**	**CO_2 resulting from NMVOC**
1B2a Oil	Transport (1B2aiii)	Reported as indirect CO_2	NO	Reported as indirect CO2
	Refining/storage (1B2aiv)			
	Distribution of oil products (1B2av)	NO		
1B2b Natural gas	Production (1B2bii)	Reported as indirect CO2	NO	Reported as indirect CO2
	Transmission and storage (1B2biv)			
	Distribution (1B2bv)			
	Other leakage (1B2bvi)			
1B2c Venting and flaring	Flaring Oil (1B2cii1)	Included in direct CO_2 emissions (CO_2 emission factors assume full oxidation)	Included in direct CO_2 emissions (CO_2 emission factors assume full oxidation)	Included in direct CO_2 emissions (CO_2 emission factors assume full oxidation)
	H_2 Production refinery (1B2ci)	NO	NO	NO
	Flaring from gas production (1B2cii2)	Included in direct CO_2 emissions (CO_2 emission factors assume full oxidation)		Included in direct CO_2 emissions (CO_2 emission factors assume full oxidation)

2 Industrial processes and product use: CO_2 resulting from the atmospheric oxidation of CH_4, CO and NMVOC emitted from sector 2 IPPU is reported as indirect CO_2 emissions unless it is of biogenic origin or already accounted for implicitly as direct CO_2 emissions in sector 2 (chp. 4). For sector 2 IPPU, Table 9-9 illustrates in which processes CH_4, CO and NMVOC emissions occur, and whether the related CO_2 emissions are reported as indirect CO_2 emissions or implicitly as direct CO_2 emissions. In summary, only few of the CO_2 emissions resulting from the atmospheric oxidation of CH_4, CO and NMVOC emitted from sector 2 IPPU are already considered under the direct CO_2 emissions and thus not accounted for as indirect CO_2 emissions, namely:

- Emissions that are based on a carbon mass balance or material flows (including the carbon content) considering all carbon sources and sinks of the process. Examples are NMVOC from the cracker in source category 2B8b Ethylene or NMVOC and CO from steel production in electric arc furnaces in source category 2C1 Iron and steel production.
- Emissions from processes where full oxidation is assumed. An example is CO from source category 2C3 Aluminium production, where full oxidation of the anodes is

assumed. In contrast, NMVOC emissions from this process solely originate from the production of the electrodes at the plants. Therefore, these emissions are considered for the calculation of indirect CO$_2$ emissions.

- Emissions of biogenic origin. Examples are biogenic CO and NMVOC from tobacco consumption in source category 2G4 Other or from source category 2H2 Food and beverages industry.

The source categories 2D3a Solvent use and 2G4 Other include direct CO$_2$ emissions from post-combustion of NMVOC as well as indirect CO$_2$ emissions from oxidation of NMVOC in the atmosphere. Thereby, the CO$_2$ emissions resulting from NMVOC destroyed in post-combustion facilities are reported as direct CO$_2$ emissions (the respective NMVOC are therefore not part of the reported NMVOC emissions of the source categories 2D3a Solvent use and 2G4 Other).

Table 9-9 Sources of indirect CO$_2$ emissions from sector 2 Industrial processes and product use (IPPU). Only relevant source categories are shown. Blue cells mark processes for which CO$_2$ emissions resulting from the atmospheric oxidation of CH$_4$, CO or NMVOC emissions are not accounted for as indirect CO$_2$ emissions, either because they are already considered under the direct CO$_2$ emissions or because they are of biogenic origin.

2 Industrial processes and product use			**CO$_2$ resulting from CH$_4$**	**CO$_2$ resulting from CO**	**CO$_2$ resulting from NMVOC**
2A Mineral industry			NO	Reported as indirect CO$_2$	Reported as indirect CO$_2$
2B Chemical industry	2B5 Carbide production		Reported as indirect CO$_2$	Reported as indirect CO$_2$	NO
	2B8 Petrochemical and carbon black production		NO	NO	Included in direct CO$_2$ emissions (carbon mass balance)
	2B10 Other		Reported as indirect CO$_2$	Reported as indirect CO$_2$	Reported as indirect CO$_2$
2C Metal industry	2C1 Iron and steel production	Steel production in electric arc furnaces	NO	Included in direct CO$_2$ emissions (carbon mass balance)	Included in direct CO$_2$ emissions (carbon mass balance)
		Remaining emission sources	NO	Reported as indirect CO$_2$	Reported as indirect CO$_2$
	2C3 Aluminium production		NO	Included in direct CO$_2$ emissions (full oxidation of anodes assumed)	Reported as indirect CO$_2$
	2C7 Other		NO	Reported as indirect CO$_2$	Reported as indirect CO$_2$
2D Non-energy products from fuels and solvent use	2D3a Solvent use		NO	NO	Reported as indirect CO$_2$
	2D3b Road paving with asphalt		NO	NO	Reported as indirect CO$_2$
	2D3c Asphalt roofing		NO	Reported as indirect CO$_2$	Reported as indirect CO$_2$
2G Other product manufacture and use	2G4 Other	Tobacco consumption	NO	Not reported as indirect CO$_2$ emissions (biogenic origin)	Not reported as indirect CO$_2$ emissions (biogenic origin)
		Remaining emission sources	NO	Reported as indirect CO$_2$	Reported as indirect CO$_2$
2H Other	2H1 Pulp and paper		NO	NO	Reported as indirect CO$_2$
	2H2 Food and beverages industry		NO	Not reported as indirect CO$_2$ emissions (biogenic origin)	Not reported as indirect CO$_2$ emissions (biogenic origin)
	2H3 Other		NO	Reported as indirect CO$_2$	Reported as indirect CO$_2$

3 Agriculture and 4 LULUCF: CH$_4$, CO and NMVOC emissions from the sectors 3 Agriculture and 4 LULUCF are of biogenic origin. Accordingly, no indirect CO$_2$ emissions are reported for these sectors.

5 Waste: CH$_4$, CO and NMVOC emissions from sector 5 Waste contain fossil and biogenic shares. Only indirect CO$_2$ resulting from the atmospheric oxidation of fossil CH$_4$, CO and NMVOC is included in CRT Table6. Emissions of fossil CH$_4$, CO and NMVOC originate from the following processes:

- Hospital waste incineration (CO and NMVOC emissions): Completely fossil, see chp. 7.4 Incineration and open burning of waste (5C1), since 2002 no emissions from hospital waste incineration have occurred.
- Municipal solid waste incineration (illegal) (CH_4, CO and NMVOC emissions): Partly fossil, fossil share is assumed to be the same as for waste incinerated in municipal solid waste incineration plants, see chp. 7.4 Incineration and open burning of waste (5C1).
- Industrial waste incineration (consists of cable insulation materials) (CO and NMVOC emissions): Completely fossil, see chp. 7.4 Incineration and open burning of waste (5C1), since 1995 no emissions from incinerating cable insulation materials have occurred.
- Shredding (CO and NMVOC emissions): Completely fossil, see chp. 7.6 Other (5E Other).

Further emissions of CH_4, CO and NMVOC from sector 5 Waste – such as from solid waste disposal (5A), biological treatment of solid waste (5B) and wastewater treatment and discharge (5D) – are of biogenic origin and therefore not considered for the calculation of indirect CO_2 emissions as presented in CRT Table6.

6 Other: CH_4, CO and NMVOC emissions from sector 6 Other contain fossil and biogenic shares. Only CO_2 resulting from the atmospheric oxidation of fossil CH_4, CO and NMVOC is reported as indirect CO_2. Emissions of fossil CH_4, CO and NMVOC originate from the following processes:

- Fire damage buildings: The share of fossil CH_4, CO and NMVOC emissions is assumed to be equal to the share of fossil CO_2 emissions, which increased linearly from 20 % in 1950 to 80 % in 2000 and is assumed to have remained constant since then, see chp. 8.2 (6Ad).
- Fire damage motor vehicles: The share of fossil CH_4, CO and NMVOC emissions is assumed to be 100 %, see chp. 8.2 (6Ad).

9.2.2. Methodological issues to derive indirect N_2O emissions

Indirect N_2O emissions are estimated using a country-specific method according to a study of indirect N_2O emissions induced by nitrogen deposition in Switzerland (Bühlmann 2014, Bühlmann et al. 2015). In this study, ecosystem-specific emission factors for indirect N_2O resulting from nitrogen deposition were developed, based on a comprehensive literature survey. Thereby, the land cover types forests, grassland and wetlands were distinguished. In a next step, the ecosystem-specific emission factors were combined with a highly-resolved nitrogen deposition map of Switzerland as well with the geo-referenced data set of the Swiss Land Use Statistics (allowing for the localisation and estimation of spatial extent of the different ecosystems). This resulted in detailed and spatially resolved indirect N_2O emissions for Switzerland. To facilitate a simple application in the greenhouse gas inventory, the resulting total emissions were used to come up with a total emission factor expressed as indirect N_2O-N per N-deposition (deposited in form of NO_x or NH_3, see also chp. 5.3.2.4). The resulting total emission factor is in the order of 2.6 % and slightly varies with time as the shares of the different ecosystems are not constant over time. Based on this country-specific emission factor, higher indirect N_2O emissions result compared to the emissions that would result by applying the IPCC Guidelines (IPCC 2006, see also Bühlmann et al. 2015).

To calculate indirect N_2O emissions induced by the deposition of NO_x and NH_3 according to Bühlmann (2014) and Bühlmann et al. (2015), total N-deposition is needed. It is derived from

NO_x (which is always reported in NO_2 equivalents) and NH_3 emissions using the stoichiometric conversion according to the following equation:

Mass-N = Mass-$NO_{2,eq}$ * 14/46 + Mass-NH_3 * 14/17

Note: The emissions referred to as indirect N_2O emissions in CRT Table3.B and in CRT Table3.D are not addressed in this chapter, as they are not reported as indirect N_2O emissions in CRT Table6 and in CRT Table10 (these emissions are instead included in Sector 3 Agriculture along with direct N_2O emissions).

Activity data for the calculation of indirect N_2O emissions

The activity data to calculate indirect N_2O emissions from a specific sector corresponds to the NO_x and NH_3 emissions reported in the respective source categories. However, the following exceptions need to be considered:

- Indirect N_2O emissions from sector 3 Agriculture are reported in the respective sector together with direct N_2O emissions (chp. 5.3.2.5.4 Volatilisation of NH_3 and NO_x from manure management systems, chp. 5.5.2.3 Indirect N_2O emissions from atmospheric deposition of N volatilised from managed soils (3D2a) and chp. 5.5.2.4 Indirect N_2O emissions from leaching and run-off from managed soils (3D2b)).
- For sector 6, the only indirect N_2O emissions to be considered are those resulting from NO_x emissions in source category 6Ad Fire damages.

9.2.3. Uncertainties and time series consistency

Indirect CO_2 emissions are included in the uncertainty analysis, but indirect N_2O emissions are not included.

Uncertainties of indirect CO_2 emissions are based on respective uncertainties of CH_4, CO and NMVOC emissions. Uncertainties of CH_4 emissions are described in the respective chapters above. Uncertainties of CO and NMVOC emissions are documented in Switzerland’s Informative Inventory Report 2024 (FOEN 2024b). The uncertainties of the emission factors are partly based on values provided by the EMEP/EEA guidebook (EMEP/EEA 2019, part A, chp. 5, Table 2-2) and expert judgements. The estimated uncertainties distinguish between fossil and biogenic shares.

Combined uncertainties of indirect CO_2 emissions, for each category, are given in Annex A2.1.

Consistency: Time series for indirect CO_2 and N_2O emissions are all considered consistent.

9.2.4. Category-specific QA/QC and verification for indirect emissions

The general QA/QC measures are described in chp. 1.5.

The same QA/QC and verification procedures are conducted as for CH_4, CO, NMVOC, NO_x and NH_3 related source categories in chp. 3 (Energy), chp. 4 (Industrial processes and product use), chp. 7 (Waste) and chp. 8 (Other).

9.2.5. Category-specific recalculations for indirect emissions

The following recalculations were implemented in submission 2024:

- See CH_4 related recalculations reported in chp. 3 (Energy), chp. 4 (Industrial processes and product use), chp. 7 (Waste) and chp. 8 (Other).
- See CO related recalculations reported in chp. 4 (Industrial processes and product use), chp. 6 (Waste) and chp. 7 (Other) in Switzerland’s Informative Inventory Report 2024 (FOEN 2024b).
- See NMVOC related recalculations reported in chp. 3 (Energy), chp. 4 (Industrial processes and product use), chp. 6 (Waste) and chp. 7 (Other) in Switzerland’s Informative Inventory Report 2024 (FOEN 2024b).
- See NO_x and NH_3 related recalculations reported in chp. 3 (Energy), chp. 4 (Industrial processes and product use), chp. 6 (Waste) and chp. 7 (Other) in Switzerland’s Informative Inventory Report 2024 (FOEN 2024b).

General information, focussing on major recalculations which contribute significantly to the total differences in indirect emissions between the latest and the previous submissions, is presented in chp. 10.1.2.7.

9.2.6. Category-specific planned improvements for indirect emissions

No category-specific improvements are planned.

10. Recalculations and improvements

Responsibilities for chapter Recalculations and improvements	
Authors & annual updates (NID text, tables, figures)	Michael Bock (FOEN), Daniel Bretscher (Agroscope), Nele Rogiers (FOEN), Andreas Schellenberger (FOEN), Adrian Schilt (FOEN)
EMIS database operation	Adrian Schilt (FOEN)
Quality control NID (annual updates)	Michael Bock (FOEN), Adrian Schilt (FOEN)
Internal review	Anouk-Aimée Bass (FOEN), Daiana Leuenberger (FOEN), Sabine Schenker (FOEN), sector experts

10.1. Explanations and justifications for recalculations, incl. in response to the review process

The implementation of recommendations and encouragements from the UNFCCC review process are listed in chp. 10.1.1. Additionally, major recalculations are presented in chp. 10.1.2. In the relevant sectoral chapters, also minor recalculations are listed and a brief explanation for each is provided. A list with all recalculations and specifics of the recalculations is compiled by the EMIS experts and available to the reviewers on demand (partly in German).

10.1.1. Recommendations and encouragements from ERT and their implementation

The most recent in-depth review of the inventory was based on the submission of April 2022 (UNFCCC 2023). The recommendations and encouragements could already be addressed and implemented in the previous submission (FOEN 2023) (see Table 10-1 and Table 10-2).

Table 10-1 Implementation of recommendations from the in-depth review in 2022 (UNFCCC 2023) as documented in the previous submission (FOEN 2023).

ID	classification	Recommendation from ARR 2022 (UNFCCC 2023)	Answer including reference to chapter in NID
IPPU			
I.1	2.F.1 Refrigeration and air conditioning – HFCs	The ERT recommends that Switzerland provide in the NIR the reasons for the decreasing trends in the EFs and emissions for this category and the drivers behind the trends (in AD and EFs) in the most significant subcategories.	Text added in NID chp. 4.7.1 starting with: "From 2015 onwards there is a decline in emissions as a result of the regulations from the Chemical Risk Reduction Ordinance (Swiss Confederation 2005)...."
Agriculture			
A.2	3.B.1 Cattle – N2O (A.6, 2021) Transparency	Provide information in the NIR on the algorithms and background input data (e.g. crude protein intake, milk protein content and N retention, to the extent possible) used to evaluate the Nex rates for cattle (by subcategory).	Additional text as well as additional references to background literature for individual animal categories has been added to chp. 5.3.2.5.2.
A.3	3.D.a.4 Crop residues – N2O (A.7, 2021) Transparency	Clarify the model used to estimate N2O emissions from crop residues left on fields by including in the NIR information on the reference source for the model, the data sources and the calculation parameters used.	More specific references to the data tables in FAL/RAC (2001) and Richner et al. (2017) are provided in chp. 5.5.2.2.2. An additional paragraph on nitrogen in straw used as bedding material was added in chp. 5.5.2.2.2. Reference sources have been added to the headers of the tables on crop residues in Annex A5.3.
A.5	3.A.1 Cattle – CH4, N2O	The ERT recommends that Switzerland report in NIR table 5.5 and CRF table 3.As2 milk production for mature dairy cattle based on annual milk production, that is, a period covering 365 days, rather than on a lactation period of 305 days.	Milk production reported in the NID and CRF table 3.As2 is now calculated by dividing yearly milk production by 365 days instead of 305 days (which would be the standard lactation period). The respective paragraphs and tables in NID section 5.2.2.2.1 were updated
Waste			
W.4	5.D.1 Domestic wastewater – CH4 (W.5, 2021) Completeness	Estimate CH4 emissions from wastewater treatment systems not connected to the public sewer system, specifically from those systems that are very similar to centralized wastewater treatment plants, and include the emissions in the national total.	According to the mentioned desk study (Vuna 2023) emissions from decentralised wastewater treatment do occur and are estimated as explained in chapter 7.5 of the NID.
W.5	5.D.1 Domestic wastewater – CH4 (W.6, 2021) Transparency	Provide in the NIR a justification that simple systems serving as alternatives for wastewater treatment plants not connected to the public sewer system do not produce CH4 emissions, for example by providing air and soil temperature profiles for the regions where these systems are typically used.	According to the mentioned desk study (Vuna 2023) emissions from decentralised wastewater treatment do occur and are estimated as explained in chapter 7.5 of the NID.
W.6	5.D.1 Domestic wastewater – CH4 (W.7, 2021) Transparency	Explain in the NIR that the sewage sludge treated in centralized wastewater treatment plants or municipal waste incineration plants includes all sludge from wastewater treatment systems not connected to the public sewer system.	According to the mentioned desk study (Vuna 2023) all sludge from on-site sanitation systems is included in centralised treatment. Please see chapters 7.5.1 and 7.5.2.1.2 of the NID.
W.7	5.D.1 Domestic wastewater – CH4 (W.7, 2021) Transparency	Include in the NIR additional information on the fraction of wastewater in rural areas not connected to the public sewer system that is possibly spread to agricultural soils as a fraction of slurry	According to the mentioned desk study (Vuna 2023) activity data for emissions from decentralised wastewater treatment via manure tank storage and usage are estimated. Emissions are estimated accoring to the agricultur model as explained in chapter 7.5 of the NID.
W.8	5.C.1 Waste incineration – CH4	The ERT recommends that Switzerland include in the NIR the explanation provided during the review as to why CH4 emissions from the incineration of hospital waste, the incineration of industrial waste and cremation are not estimated, that is, that incineration of these sources is performed at high temperature with complete combustion processes and therefore CH4 EFs can be considered as zero, in accordance with the 2006 IPCC Guidelines (vol. 5, chap. 5, section 5.2.2.3, p.5.13).	A note on the applicability of an emission factor for CH4 was included in the section describing emission factors for the incineration of hospital waste, the incineration of industrial waste and cremation, respectively, in Chp. 7.4.2
W.9	5.C.1 Waste incineration – N2O	The ERT recommends that Switzerland correct the notation keys reported in CRF table 5.C for industrial waste for 1990–1994 (from "NO" to "NE" for the N2O IEFs and N2O emissions) and in NIR table 7-16 (from "NA" to "NE" for the N2O EFs). The ERT recommends that the Party either estimate and report these emissions for industrial waste or justify the use of "NE" based on the likely level of emissions, in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines. The ERT also encourages the Party to explain in the NIR why N2O emissions from cremation were not estimated.	A note on the omission of an emission factor for N2O was included in the section describing emission factors for the incineration of industrial waste in Chp. 7.4.2 Also a note is added, stating why N2O from cremation is not estimated.

Table 10-2 Implementation of encouragements from the in-depth review in 2022 (UNFCCC 2023) as documented in the previous submission (FOEN 2023).

ID	classification	Encouragement from ARR 2022 (UNFCCC 2023)	Answer including reference to chapter in NID
Energy			
E.1	1. General (energy sector) – CO2, CH4 and N2O	The ERT encourages Switzerland to consult with the secretariat on how to use CRF Reporter to report “NO” in CRF tables 1.A(a)s1, 1.A(a)s3–1.A(a)s4, 1.A(b) and 1.A(d) in all cases where cells have been left blank when the corresponding fuel is not used in the country (and thus there are no AD).	We consulted with the helpdesk (ANAIS-4120) and could fill some of the gaps. However, as there is no option in the CRF reporter to auto fill "NO" for empty cells, there are still empty cells. It has been decided to use the available ressources for QC efforts instead of filling empty cells manually.
IPPU			
I.2	2.F.1 Refrigeration and air conditioning – HFCs	The ERT encourages Switzerland to provide in its NIR a rationale for the main driver(s) of the high share (33 per cent) of emissions for category 2.F.1.e (mobile air conditioning) in the total emissions for category 2.F.1.	Text added in NID chapter 4.7.2.1. A comparison to neighbour countries shows higher stock and emissions from mobile air-condititiong in Switzerland. Model parameters were checked and a higher rate of air-conditioning of >95% in vehiclesis assumed plausible and is confirmed by companies dismantling vehicles.

10.1.2. Major recalculations and improvements implemented in the latest submission

In this chapter, the most important recalculations are presented. The figures show the differences between net emissions and removals in submission 2023 (previous) and submission 2024 (latest). Explanations are provided for categories that underwent recalculations larger than 2 % of the corresponding category emissions and resulted in absolute changes larger than 5 kt CO_2 eq (approximately 0.01 % of the national total emissions) for the sectors Energy, IPPU, Agriculture, Waste and Other, and larger than approximately |50| kt CO_2 eq for the LULUCF sector. Additional recalculations and corrections of minor errors, which had a smaller impact than the above thresholds, are listed in the relevant sectoral chapters only.

10.1.2.1. Energy

The total changes in emissions in the energy sector due to all recalculations are shown in Figure 10-1 for CO_2, Figure 10-2 for CH_4 and Figure 10-3 for N_2O.

The largest recalculations in the energy sector stem from the reassessment of fugitive emissions from 1B2b – Natural gas, resulting in lower losses of natural gas over the whole times series. As a consequence, more natural gas is available in source category 1A, in particular leading to higher emissions of CO_2 (but also CH_4 and N_2O) in the source categories 1A2, 1A4ai and 1A4bi. In contrast, in sector 1B, the reassessment of fugitive emissions from 1B2b – Natural gas is reflected in a major decrease of CH_4 emissions of up to 335 kt CO_2 eq.

Further, the introduction of the new model for stationary engines and gas turbines led to major reallocations within the source categories in 1A Fuel combustion activities, however, with no overall effect on total CO_2 emissions (and only small effects on CH_4 and N_2O emissions).

With regard to N_2O, the introduction of a new country-specific emission factor for source category 1A1a Special waste incineration plants led to higher N_2O emissions from 2004 onwards, with a maximum change of about +18 kt CO_2 eq.

Overall, emissions in sector 1 Energy change as follows as a consequence of the newly implemented recalculations:

- CO_2: +17 kt CO_2 (1990) and +18 kt CO_2 (2021), the overall change mainly corresponds to the change in source category 1A4.
- CH_4: -280 kt CO_2 eq (1990) and -157 kt CO_2 eq (2021). The decrease occurs in source category 1B2b, while a small increase of a few kilotons CO_2 eq occurs in source category 1A.
- N_2O: +1 kt CO_2 eq (1990) and +18 kt CO_2 eq (2021).

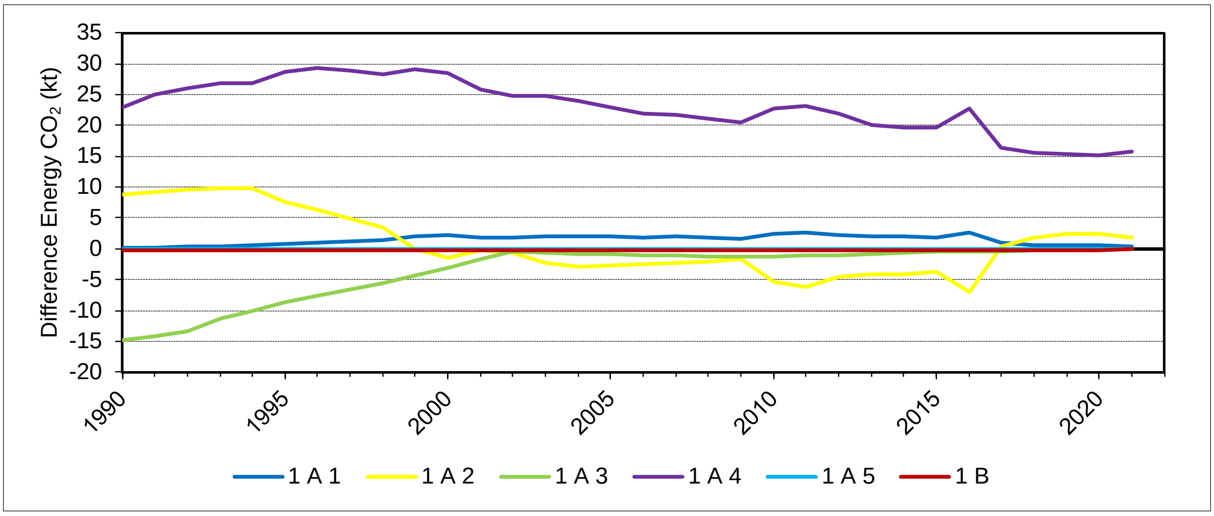

Figure 10-1 Differences in CO_2 emissions (in kt CO_2) between the latest and the previous submissions for various source categories in the energy sector. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

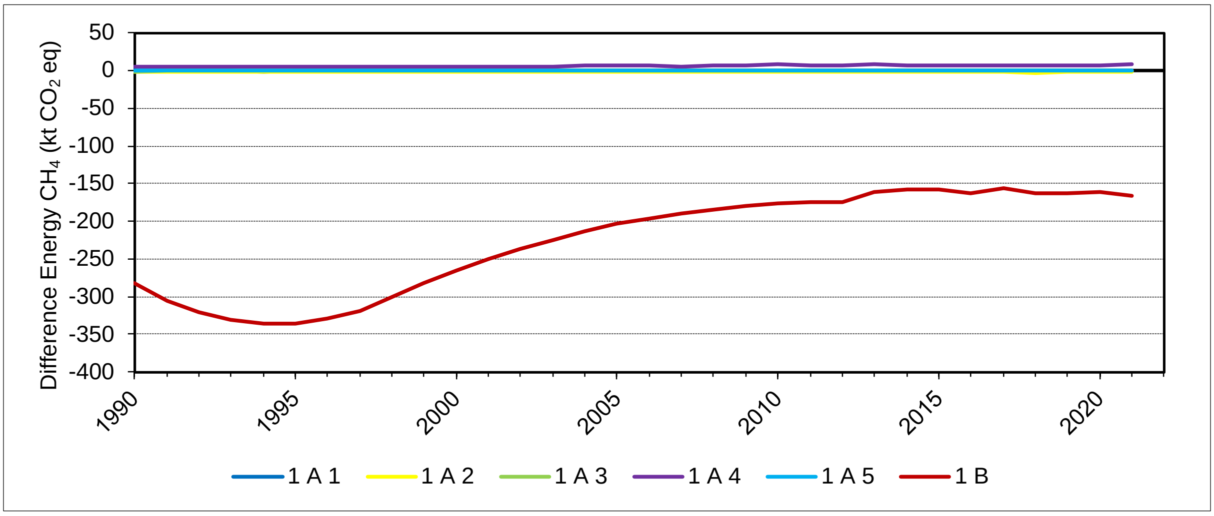

Figure 10-2 Differences in CH_4 emissions (in kt CO_2 eq) between the latest and the previous submissions for various source categories in the energy sector. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

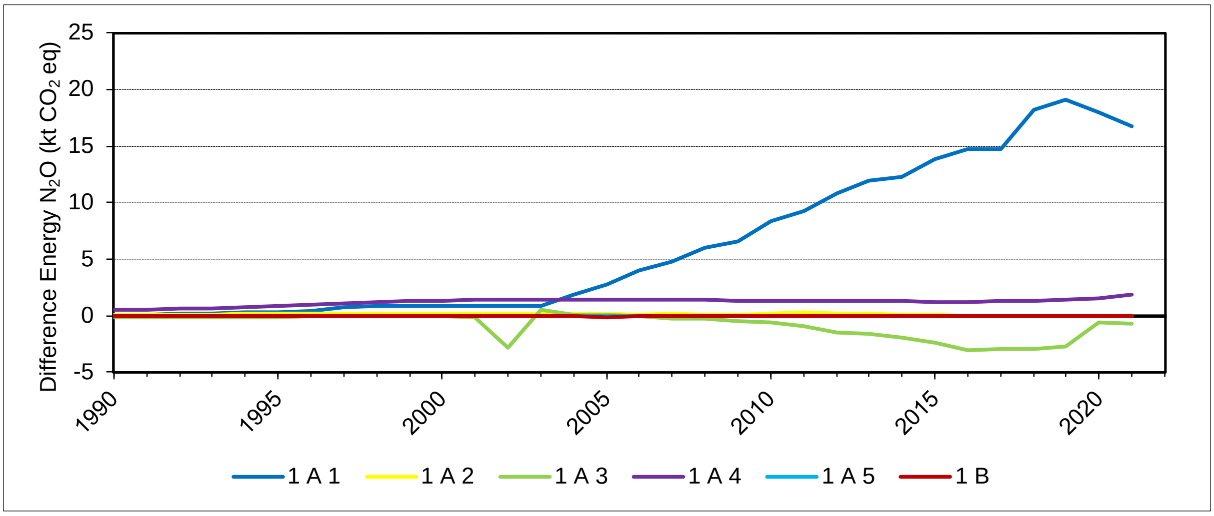

Figure 10-3 Differences in N_2O emissions (in kt CO_2 eq) between the latest and the previous submissions for various source categories in the energy sector. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

10.1.2.2. Industrial processes and other product use

The total changes in emissions in the IPPU sector due to all recalculations are shown in Figure 10-4 for CO_2, CH_4, and N_2O, and in Figure 10-5 for HFCs, PFCs, SF_6, and NF_3.

Large recalculations in sector 4 IPPU are due to:

- 2A1: The geogenic CO_2 emission factor for 2A1 Cement production was revised for all years from 1990–2021 based on plant-specific measurements of the CaO and MgO content of clinker. Emission estimates in the latest submission are -30.5 kt CO_2 eq in 1990 and -20.8 kt CO_2 eq in 2021 lower compared to the previous submission. See details in chapter 4.2.2.1.
- 2F1: Changes in portions of different refrigerants used for stationary refrigeration, changes in the time period required for the complete elimination of HFC/PFC blends. Correction in the disposal amount, remaining charge at the end of life. Emission estimates in the latest submission compared to the previous submission changed from 2000-2021 by -0.4 kt CO_2 eq to +34.6 CO_2 eq with the highest value in 2021. See chapter 4.7.2.
- 2G4: Other (confidential): -9 kt CO_2 eq in 2021.

All other recalculations had an impact that was smaller than 5 kt CO_2 eq (see Figure 10-4 and Figure 10-5).

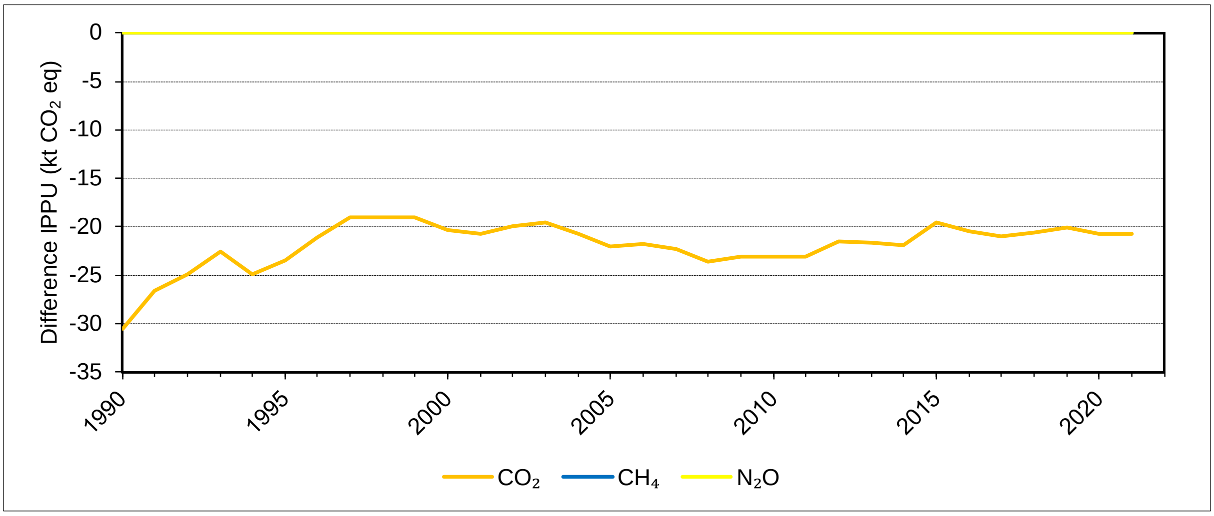

Figure 10-4 Differences in CO_2, CH_4, and N_2O emissions (in kt CO_2 eq) between the latest and the previous submissions for sector IPPU. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

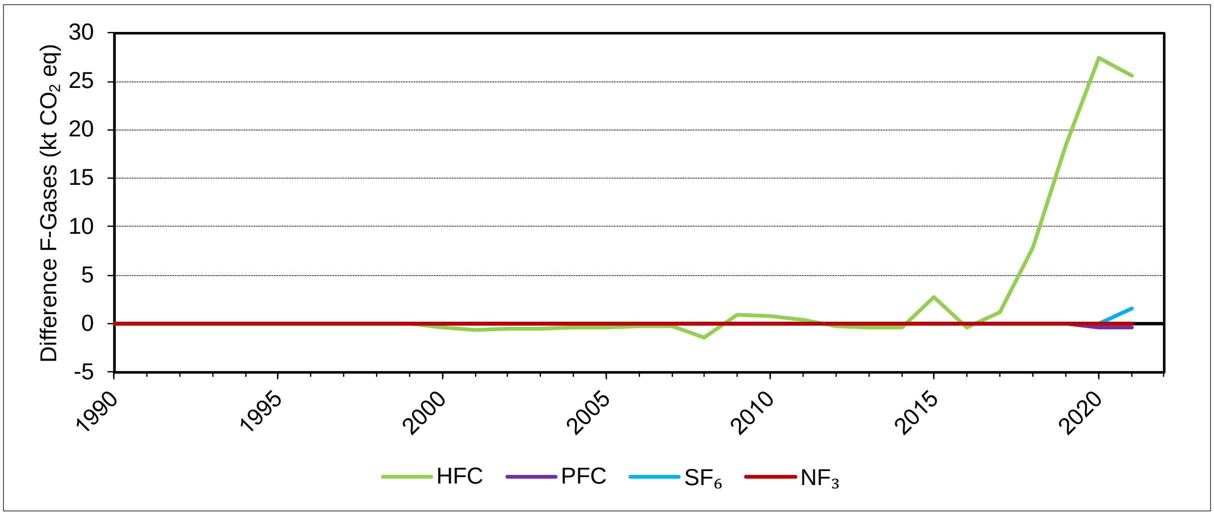

Figure 10-5 Differences in HFC, PFC, SF_6 and NF_3 emissions (in kt CO_2 eq) between the latest and the previous submissions for the sector IPPU. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

10.1.2.3. Agriculture

The total changes in emissions in the Agriculture sector due to all recalculations are shown in Figure 10-6 for CO_2, CH_4, and N_2O, and for the most important recalculations aggregated for all greenhouse gases in Figure 10-7.

Large recalculations concern N_2O emissions from 3D, see details in chapter 5.5.5, here an overview is given:

- N_2O emissions from other organic fertilizers applied to soils were recalculated for 1990-2021. Nitrogen from wastewater from decentralized human wastewater treatment from remote farms was added to the amount of other organic fertilizers (AD). The impact on overall emissions is +15.1 kt CO_2 equivalents for 1990 and subsequently declining to +4.0 kt CO_2 equivalents in 2021.

- N_2O emissions from crop residues were recalculated for the years 2019-2021. AD was revised due to updated values for arable crop yields from the Swiss Farmers Union (SFU/SBV) and updated values for grassland yields. The impact on overall emissions is negligible (<±1.0 kt CO_2 equivalents) for all years except for 2021 where emissions declined by -9.4 kt CO_2 equivalents.
- N_2O emissions from mineralization/immobilization associated with loss/gain of soil organic matter were recalculated for 1990-2021. AD was revised due to new values for the amount of nitrogen mineralized in the LULUCF sector. The impact on overall emissions ranges from -20.5 to +3.6 kt CO_2 equivalents.
- N_2O emissions from cultivated organic soils were recalculated for 1990-2021. New updated area estimates (AD) from the LULUCF sector were adopted. The impact on overall emissions fluctuated slightly around +9.0 kt CO_2 equivalents.
- N_2O emissions from cultivated organic soils were recalculated for 1990-2021. New disaggregated emission factors for grassland and cropland were adopted from the IPCC Wetland Supplement. The impact on overall emissions was +25.0 kt CO_2 equivalents for 1990 and declined to +21.5 kt CO_2 equivalents in 2021.

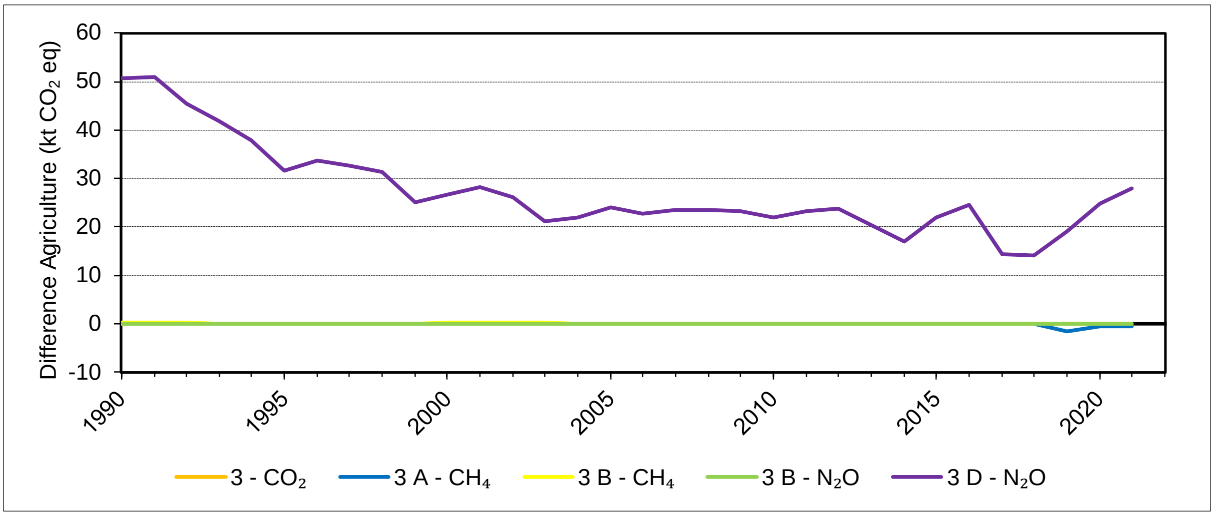

Figure 10-6 Differences in CO_2, CH_4, and N_2O emissions (in kt CO_2 eq) between the latest and the previous submissions for sector Agriculture. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

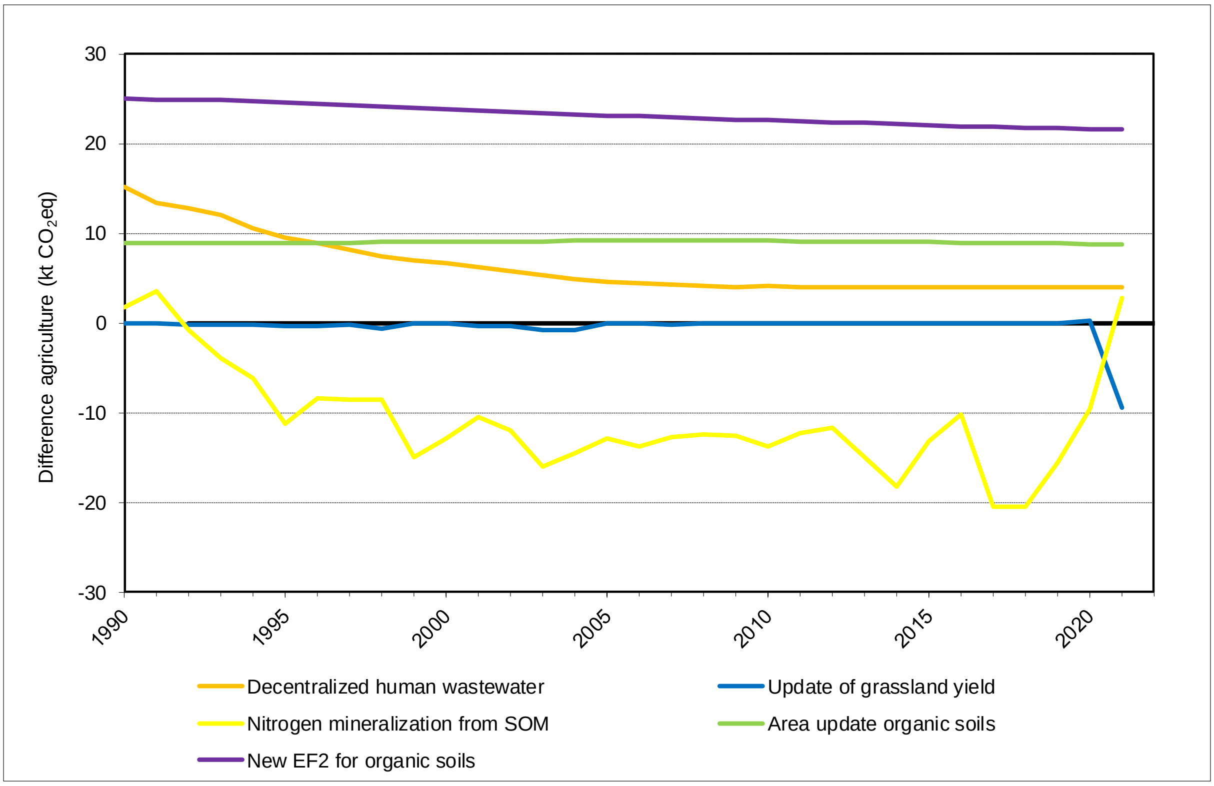

Figure 10-7 Differences in overall GHG emissions (in kt CO_2 eq) between the latest and the previous submissions for sector Agriculture due to the most important recalculations. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission. Note that due to the successive implementation of the different recalculations the amounts are not always exact but must be understood as approximations.

10.1.2.4. Land Use, Land-Use change and Forestry

Overall changes in GHG emissions by sources and removals by sinks in the LULUCF sector due to all recalculations realised for the latest submission are shown in Figure 10-8. The trend in net emissions and removals remains largely the same (Figure 10-24). Deviations in this figure are primarily seen towards the end of the time series.

The seesaw pattern of the deviation of CO_2 eq net emissions and removals between the latest and the previous submissions (range from -1’195.5 kt CO_2 eq in 1990 to 1’411.8 kt CO_2 eq in 2006; Figure 10-8) is controlled by recalculations in categories 4A and 4C (Figure 10-9). They affect the entire inventory period, whereby the trend is increasing (i.e. towards net emissions) due to the steadily climbing course of 4C. In some years, the changes in the individual land use categories largely offset each other (Figure 10-8).

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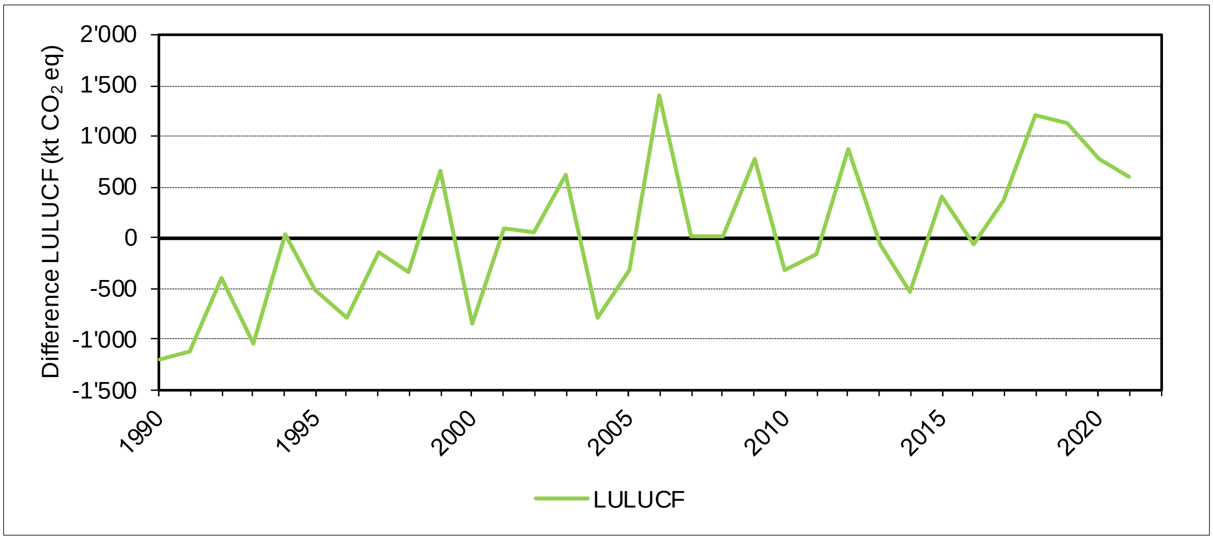


Figure 10-8 Differences in net emissions and removals (in kt CO_2 eq) between the latest and the previous submissions for the LULUCF sector. Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

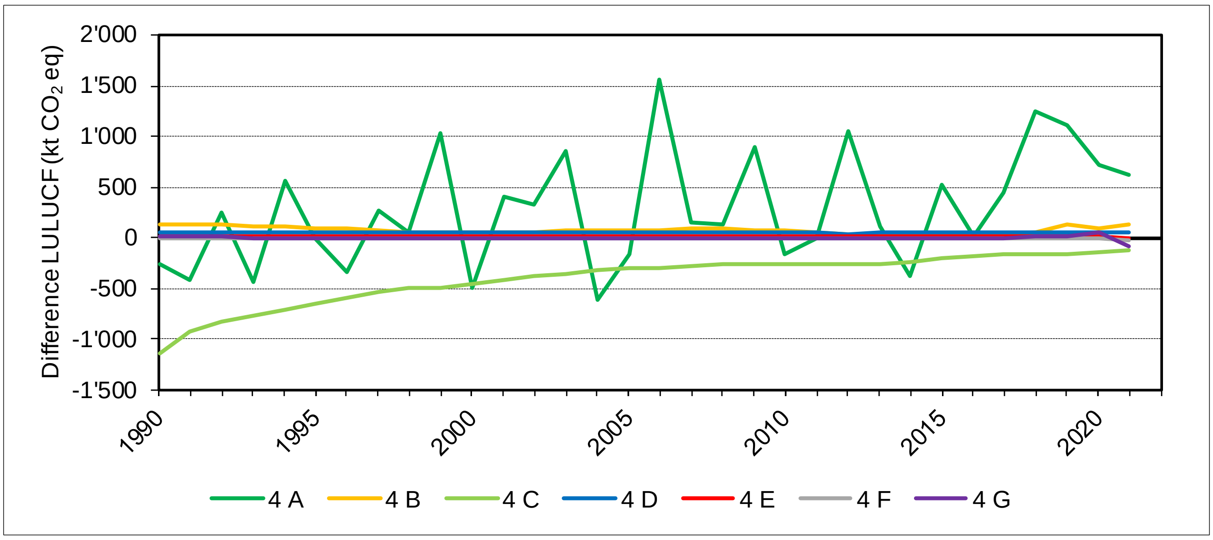


Figure 10-9 Differences in net emissions and removals (in kt CO_2 eq) between the latest and the previous submissions for main land-use categories 4A–4G in the LULUCF sector. Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission. Categories 4D, 4E, 4F and 4G all fall close to the zero line and are therefore hardly distinguishable.

The updated estimate of Switzerland's organic soil surface is entirely responsible for changes in CO_2 emissions from organic soils, for all categories (see chp. 6.3.1.5 with Figure 6-6, and Figure 10-10).

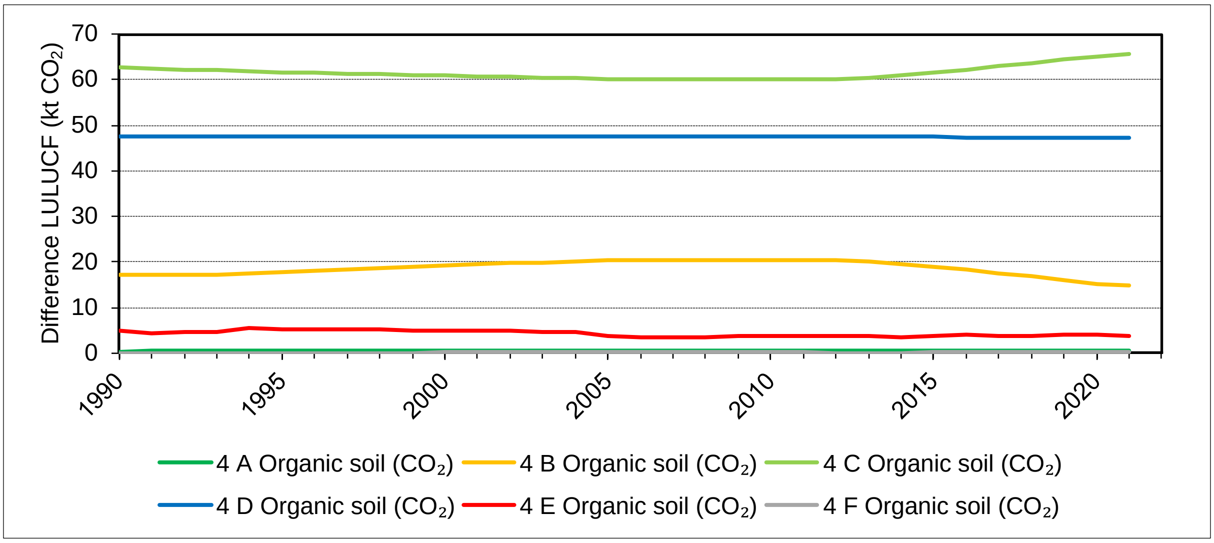


Figure 10-10 Differences in emissions (in kt CO_2) between the latest and the previous submissions for organic soils of the main LULUCF land-use categories. Positive values refer to higher emissions compared to the previous submission.

In category 4A Forest land two recalculations dominated the changes in CO_2 net emissions and removals (chp. 6.4.5).

- 4A1: The accounting of the first 5 years of the NFI5 affected carbon gains and carbon losses in living biomass primarily in the years 2018 to 2021 (Figure 10-11). Deviations before 2018 are within two standard errors of the corresponding values in FOEN (2023), i.e. it can be assumed that the differences between the previous and the latest estimates are not statistically significant, particularly when considering the uncertainty related to allometric relationships, basic wood density, and carbon fraction. The variability of differences in carbon losses from living biomass in the period 1990–2017 (Figure 10-11) is the result of the method adjustment to an annualisation of fellings only. Overall, the changes since 2018 reflect the increasing stress due to drought and pest infestations on growth and mortality in Swiss forests that was observed in recent years (Allgaier Leuch and Fischer 2023; FOEN 2023g). Even though the differences in carbon gains and losses, respectively, are large, the relative deviations in net emissions and net removals from living biomass between the latest and the previous submissions remain moderate over the inventory period (Figure 10-12).
- 4A1: Deviations in dead wood, litter, and mineral soil between the latest and the previous submissions as shown in Figure 10-11 were further the result of the application of an improved version of the soil carbon model Yasso. Similar to living biomass, net carbon stock changes in dead wood and litter changed primarily in the years 2018–2021, when dead wood and litter production increased due to the higher mortality. Deviations before 2018 were mainly due to the improved and more realistic calibration in Yasso20, resulting in a higher sensitivity of decomposition. This affected primarily the more easily decomposable litter, but can also be observed in the other two pools dead wood and mineral soil (Figure 10-13 and Figure 10-14).

The resulting differences of all recalculations in net emissions and removals between the latest and the previous submissions for category 4A are shown in Figure 10-9. The annual fluctuation is pronounced and ranges from -612.0 kt CO_2 eq in 2004 to 1'568.4 kt CO_2 eq in 2006.

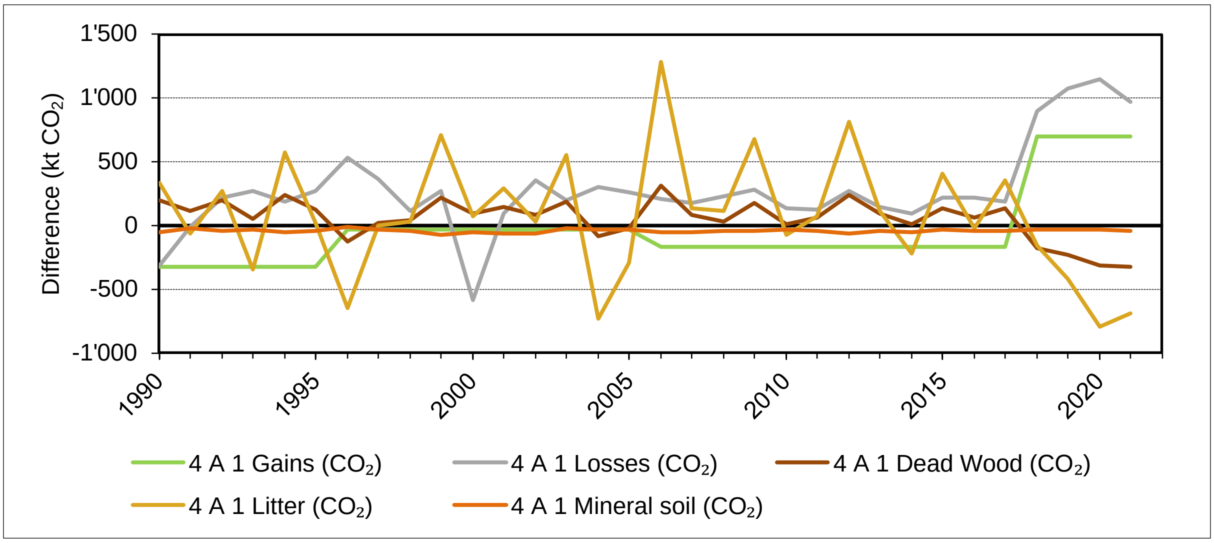


Figure 10-11 Differences in net emissions and removals (in kt CO_2) between the latest and the previous submissions for category 4A1 Gains in living biomass, category 4A1 Losses in living biomass, category 4A1 Net carbon stock change in dead wood, category 4A1 Net carbon stock change in litter, and category 4A1 Net carbon stock change in mineral soil. Positive values refer to higher emissions/lower removals and negative values to lower emissions/higher removals in the latest submission compared to the previous submission.

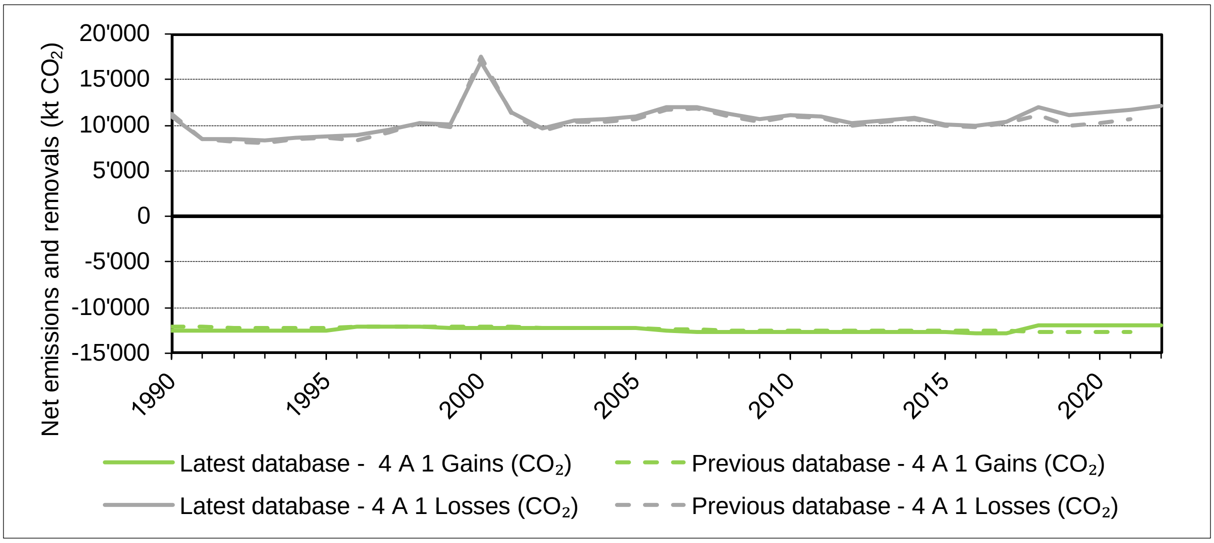


Figure 10-12 Comparison of net emissions (positive values) and net removals (negative values) from category 4A1 Gains in living biomass and category 4A1 Losses in living biomass as reported in the previous and the latest submissions.

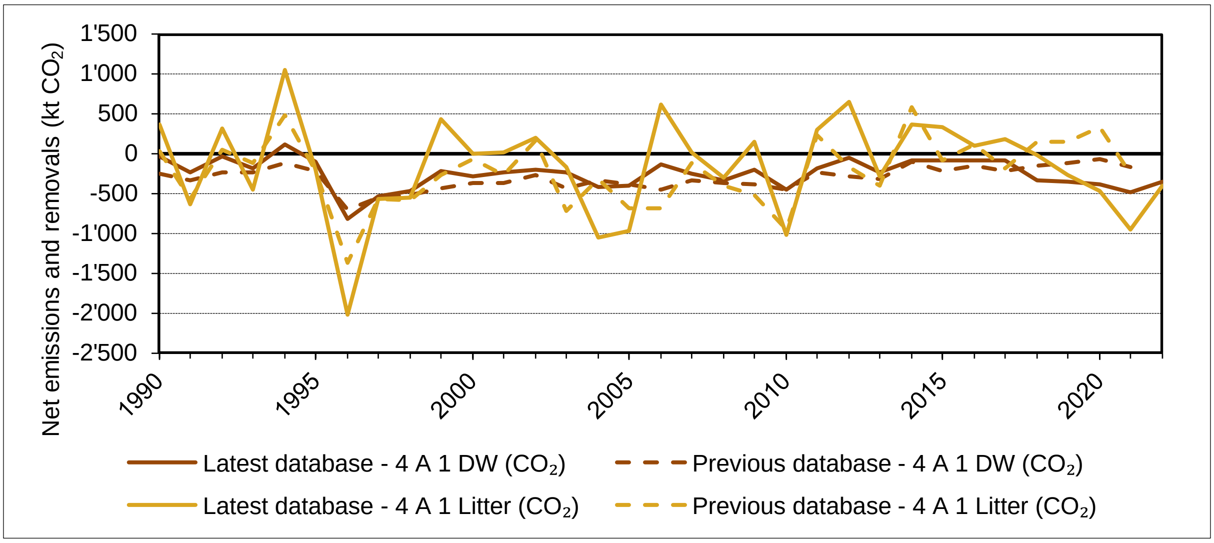


Figure 10-13 Comparison of net emissions (positive values) and net removals (negative values) from category 4A1 Dead wood (DW) and category 4A1 Litter as reported in the previous and the latest submissions.

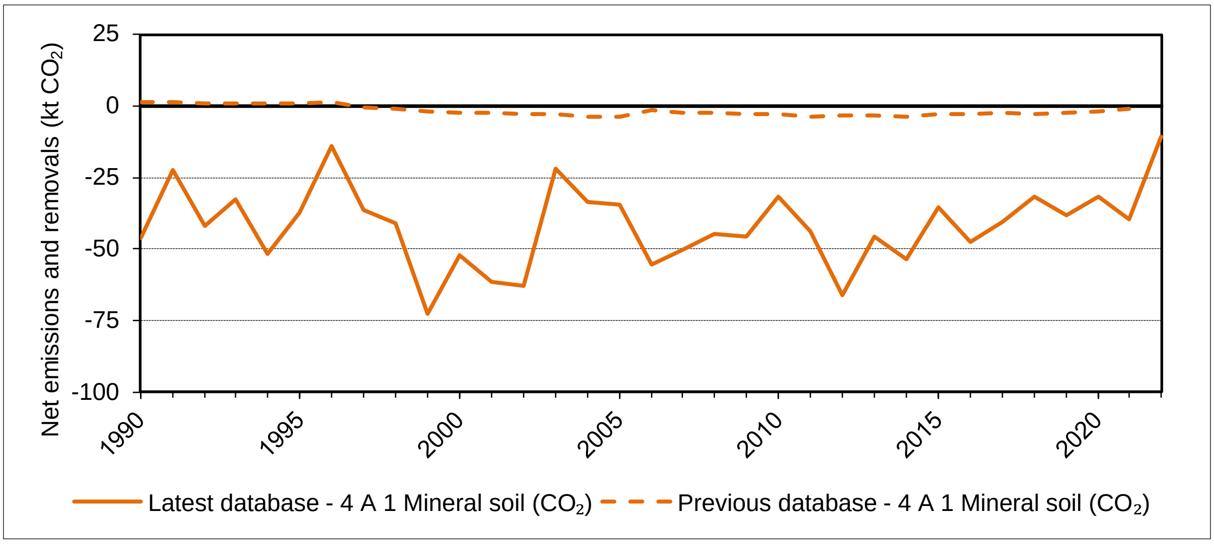


Figure 10-14 Comparison of net emissions (positive values) and net removals (negative values) from category 4A1 Mineral soil as reported in the previous and the latest submissions.

In category 4B Cropland one recalculation dominated the changes in CO_2 net emissions and removals (chp. 6.5.5).

- 4B1: New soil information (initial soil carbon stocks and clay content classes) was used for soil carbon modelling. This recalculation is almost entirely responsible for the difference in CO_2 net emissions and removals between the latest and the previous submissions for category 4B1 Net carbon stock change in mineral soil and determines – together with the above-mentioned recalculation of emissions from organic soil (Figure 10-10) – the deviations in category 4B. Net emissions are 48.6 (2014) to 161.6 (2020) kt CO_2 higher for the entire inventory period (Figure 10-15) and Cropland mineral soil represents a CO_2 source in more years than before (Figure 10-16).
  In comparison to the previous submission (with a trend of 0.006 t C ha^{-1} yr^{-1}), the mean carbon stock change for Cropland mineral soil over the inventory period changed the trend to -0.068 t C ha^{-1} yr^{-1}. The main explanation is that initial SOC stocks are 19 to 23 % higher (depending on the elevation zone) compared to the SOC stocks used in previous submissions. If initial SOC stocks are higher but carbon inputs to the soil for the

inventory years remain similar, the SOC stocks decrease over time, because the model moves towards a new steady state. Overall, the direction of the new trend is consistent with results from Swiss long-term experiments (Keel et al. 2019) and in general agreement with De Rosa et al. (2024). However, uncertainties are high and carbon stock changes are not statistically significant for any of the inventory years.

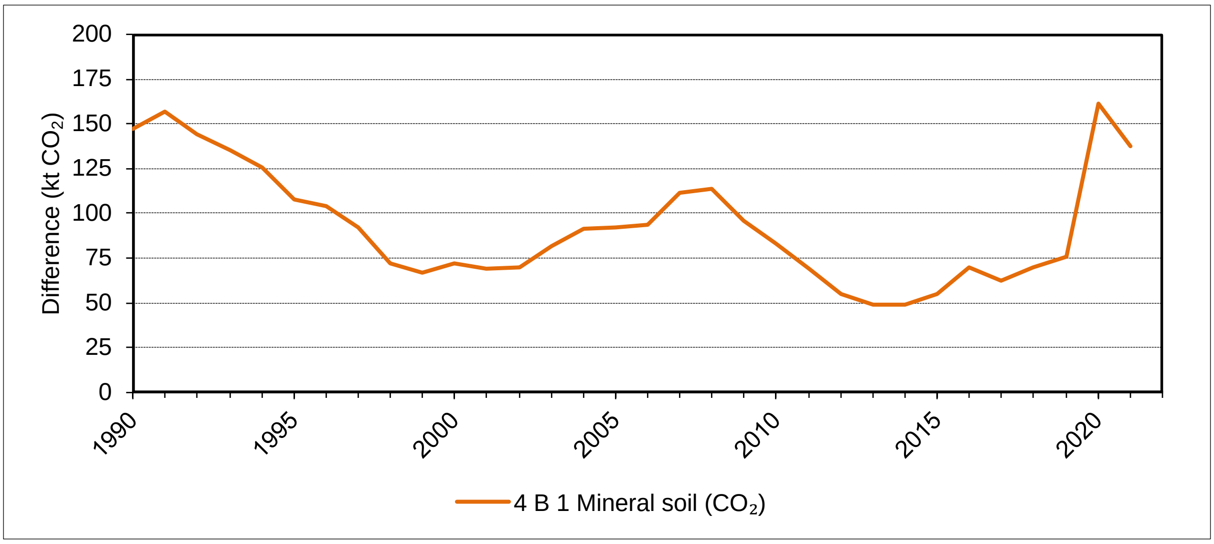


Figure 10-15 Differences in net emissions and removals (in kt CO_2) between the latest and the previous submissions for category 4B1 Net carbon stock change in mineral soil. Positive values refer to higher emissions/lower removals in the latest submission compared to the previous submission.

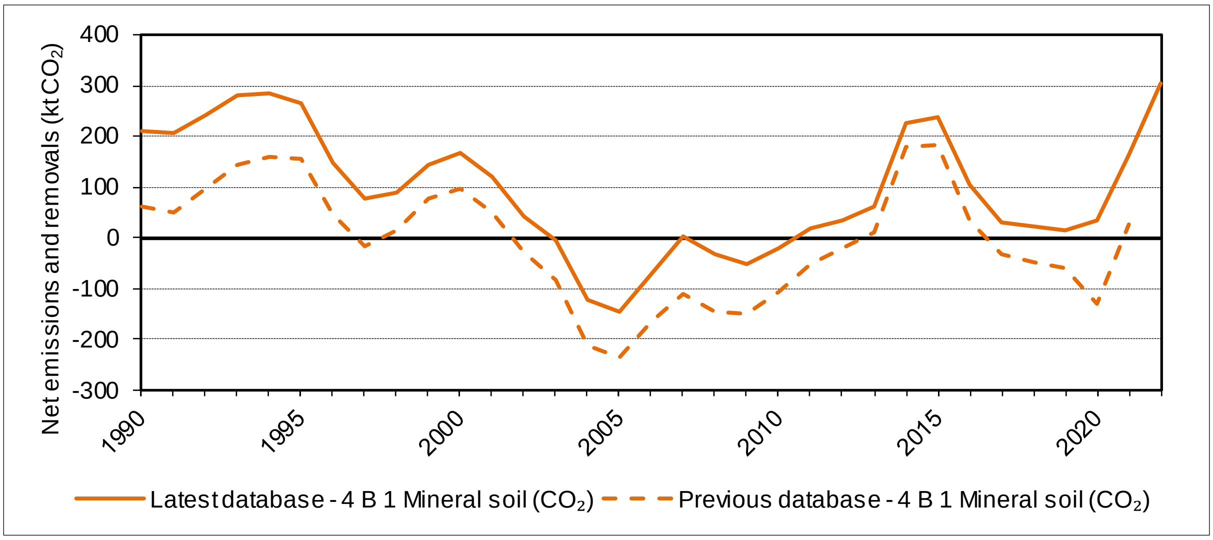


Figure 10-16 Comparison of net emissions (positive values) and net removals (negative values) from category 4B1 Mineral soil as reported in the previous and the latest submissions.

In category 4C Grassland the same recalculation as in category 4B Cropland dominated the changes in CO_2 net emissions and removals, but with an opposite effect for permanent grassland mineral soil (chp. 6.6.5).

- 4C1: Similar to 4B Cropland, new soil information (initial soil carbon stocks and clay content classes) was used for soil carbon modelling. This recalculation is almost entirely responsible for the difference in CO_2 net emissions and removals between the latest and the previous submissions for category 4C1 Net carbon stock change in mineral soil and determines – together with the above-mentioned recalculation of emissions from organic soil (Figure 10-10) – the deviations in category 4C. Net removals are 256.9 (2020) to 1’246.7 kt CO_2 (1990) higher for the entire inventory period (Figure 10-17) and permanent grassland soil now represents a consistent CO_2 sink (Figure 10-18).

In comparison to the previous submission (with a trend of -0.054 t C ha^{-1} yr^{-1}), the mean carbon stock change for permanent grassland soil over the inventory period changed the trend to 0.092 t C ha^{-1} yr^{-1}. The main explanation is that initial SOC stocks are 11 to 23 % lower for the two dominant elevation zones Z2 and Z3 compared to the SOC stocks used in previous submissions. If initial SOC stocks are lower but carbon inputs to the soil for the inventory years remain unchanged, the SOC stocks increase over time, because the model moves towards a new steady state. Overall, the direction of the new trend is consistent with results from Swiss long-term experiments (Keel et al. 2019). However, uncertainties are high and carbon stock changes are only statistically significant for the first three inventory years.

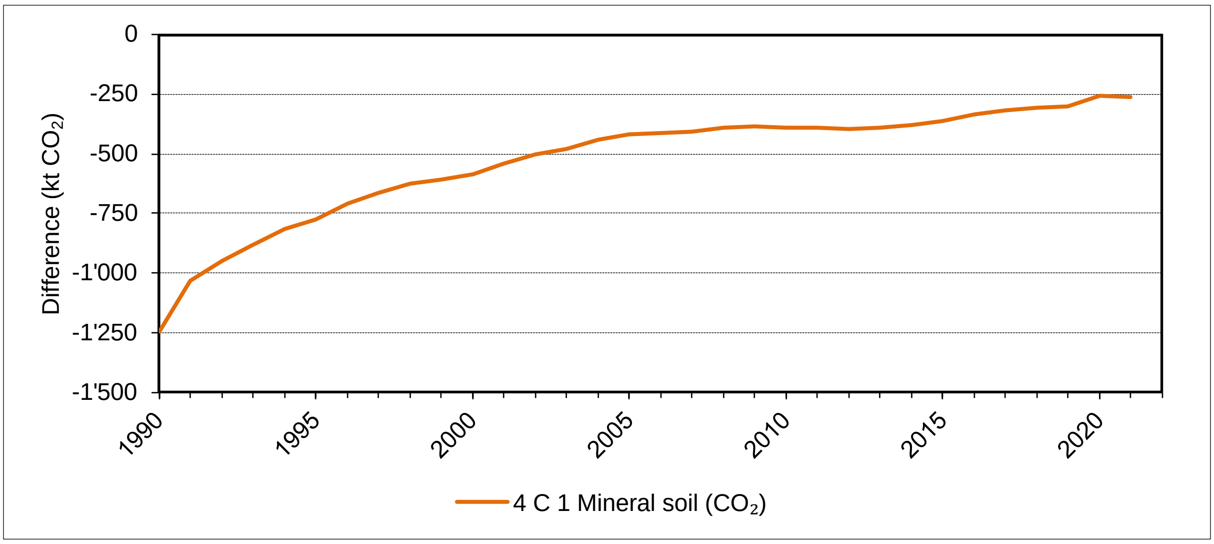


Figure 10-17 Differences in net emissions and removals (in kt CO_2) between the latest and the previous submissions for the category 4C1 Net carbon stock change in mineral soil. Negative values refer to lower emissions/higher removals in the latest submission compared to the previous submission.

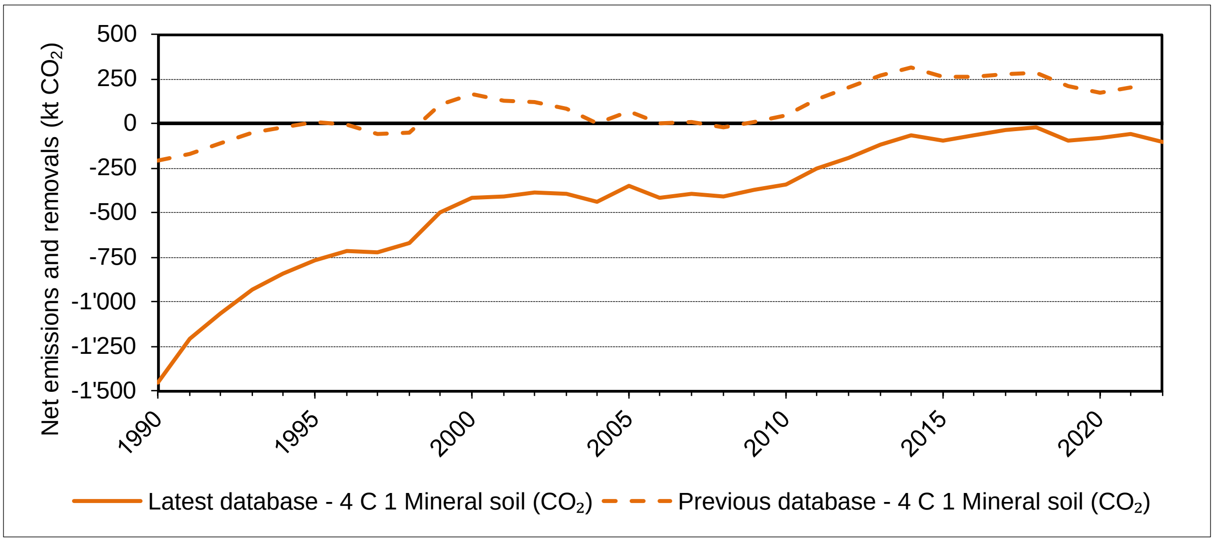


Figure 10-18 Comparison of net emissions (positive values) and net removals (negative values) from category 4C1 Mineral soil as reported in the previous and the latest submissions.

10.1.2.5. Waste

The total changes in emissions in the Waste sector due to all recalculations are shown in Figure 10-19 for CO_2, CH_4, and N_2O.

Large recalculations are due to two improvements in 5D Wastewater treatment and discharge: (1) the implementation of new emission estimates for CH_4 and N_2O from receiving waters (see chp. 7.5.2 and chp. 7.5.5); (2) CH_4 emissions from wastewater storage on remote farms is reduced because of a lower conversion factor for TOC in the agriculture model based on literature (see chp. 7.5.2.1.2) Furthermore, N_2O emissions from wastewater storage on remote farms are reduced as only storage is now considered in sector 5D but spreading is allocated to sector 3D1biii Other organic fertilizers applied to soils (see also chapter 10.1.2.3). Accordingly, for sector 5 Waste and the latest submission, this results in lower CH_4 and N_2O emissions by 10.9 and 16.8 kt CO_2 eq in 1990, respectively, while for 2021 CH_4 is higher by 5.7 kt CO_2 eq but N_2O is lower by 6.1 kt CO_2 eq (see chp. 7.5.5 for details).

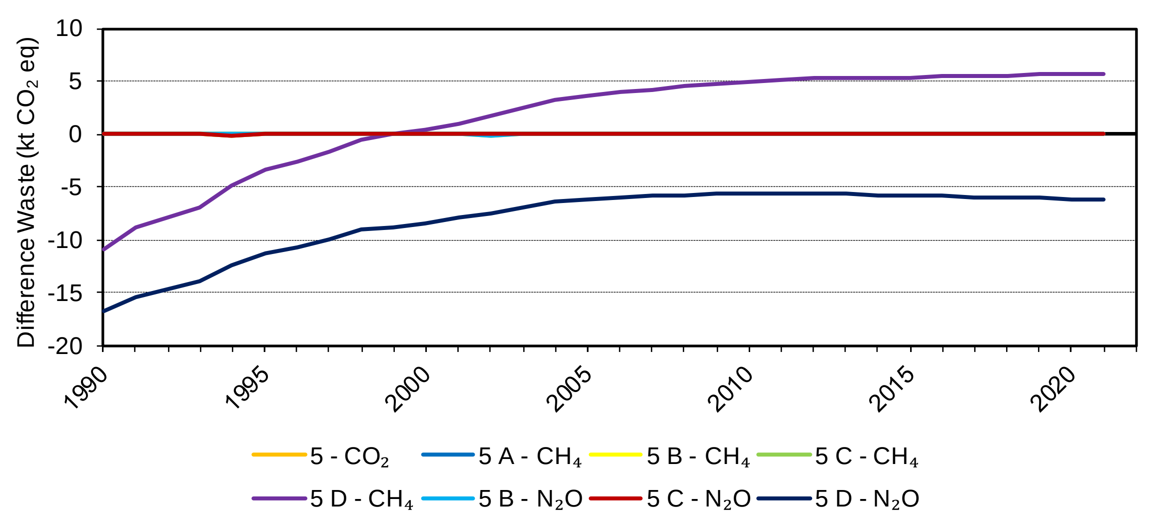


Figure 10-19 Differences in CO_2, CH_4, N_2O emissions (in kt CO_2 eq) between the latest and the previous submissions for sector Waste. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

10.1.2.6. Other

The recalculations implemented for source category 6 Other are shown in Figure 10-17. Activity data are now based on the number of fires per year instead of the total costs of fires. This reassessment causes emissions changes from +10 % in 1990 to -45 % in 2021, for CO_2, CH_4, N_2O. The emission factor for CO_2 fossil emitted during accidental car fires has been reassessed using car fire experiments. This causes an increase in emissions for the time period 1990–2021 by 53 %.

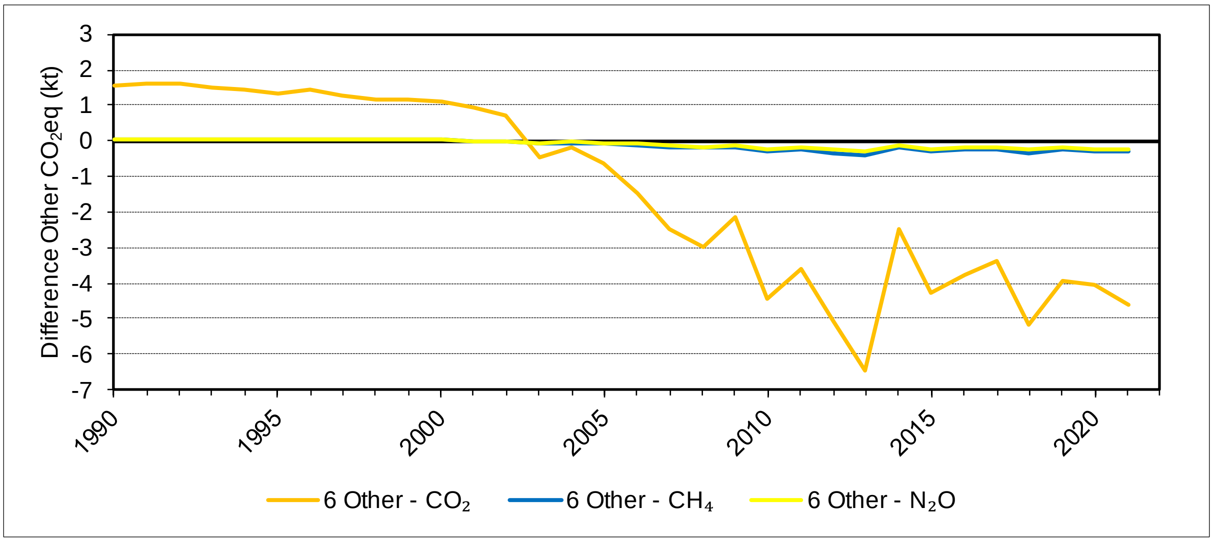


Figure 10-20 Differences in CO_2, CH_4, N_2O emissions (in kt CO_2 eq) between the latest and the previous submissions for source category Other. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

10.1.2.7. Indirect CO_2 Emissions

The total changes in indirect CO_2 emissions due to all recalculations are shown in Figure 10-21.

The recalculations are largely caused by the newly introduced country-specific methodology to estimated fugitive emissions from 1B2b – Natural gas. As total gas losses from this source category are now estimated to be lower, NMVOC emissions result lower as well. This reassessment causes emissions changes for total indirect CO_2 of -5 % (-19 kt CO_2) in 1990 and -16 % (-18 kt CO_2) in 2021 (see chp. 3.3.4).

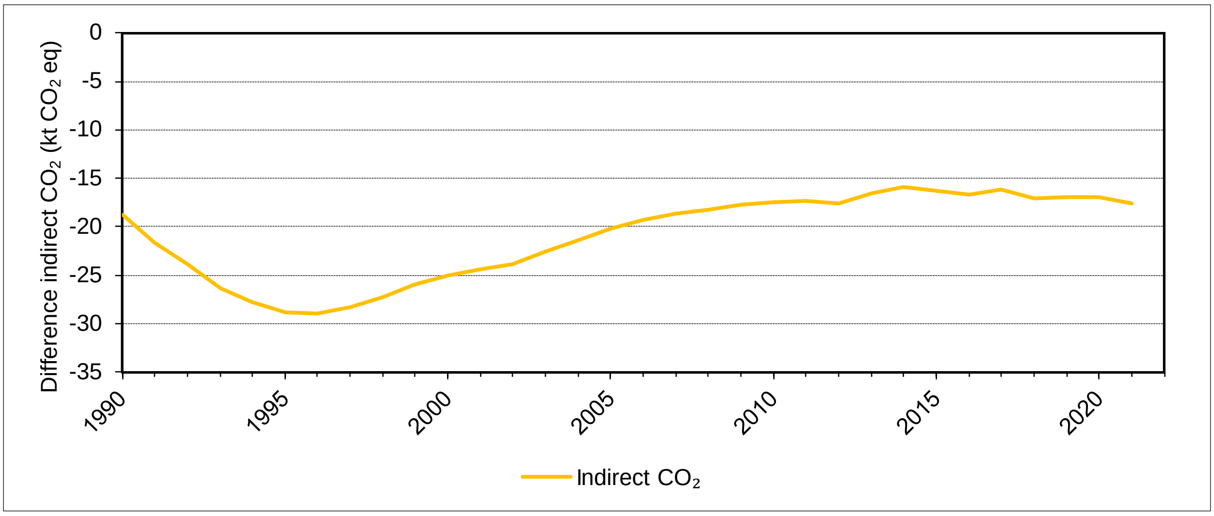


Figure 10-21 Differences in indirect CO_2 emissions (in kt CO_2 eq) between the latest and the previous submissions. Positive values refer to higher emissions and negative values to lower emissions in the latest submission compared to the previous submission.

10.2. Implications for emission and removal levels

Table 10-3 and Table 10-4 show the aggregated effect of all recalculations on the emission estimates for the base year 1990 and for the year 2021, respectively.

Table 10-3 Implications of recalculations for emission levels in 1990. Emissions are shown for the previous submission (FOEN 2023) and the latest submission. The difference refers to absolute values (Latest - Previous).

Emissions for 1990	**CO_2**			**CH_4**			**N_2O**			**F-Gases**			**Sum of all gases**		
	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference
	CO_2 equivalent (kt)														
1 Energy	40'924	40'908	16.5	427.2	707.1	-279.9	284.2	283.7	0.6				41'636	41'899	-262.8
2 IPPU	3'122	3'153	-30.5	4.0	4.0	0.0	540.5	540.5	0.0	246.0	246.0	0.0	3'913	3'943	-30.5
3 Agriculture	48.9	48.9	0.0	4'707	4'706	0.1	2'097	2'046	50.8				6'852	6'801	50.9
5 Waste	40.2	40.2	0.0	1'084	1'094	-10.9	1'126.8	1'143.6	-16.8				2'251	2'278	-27.7
6 Other	12.8	11.2	1.5	0.8	0.8	0.1	0.6	0.5	0.1				14.2	12.5	1.7
CO_2 indirect	392.3	411.1	-18.8										392.3	411.1	-18.8
Total excluding LULUCF	**44'541**	**44'572**	**-31.2**	**6'222**	**6'513**	**-290.5**	**4'049**	**4'014**	**34.6**	**246**	**246**	**0.0**	**55'058**	**55'345**	**-287.2**
	99.9%	***100.0%***	***-0.1%***	***95.5%***	***100.0%***	***-4.5%***	***100.9%***	***100.0%***	***0.9%***	***100.0%***	***100.0%***	***0.0%***	***99.5%***	***100.0%***	***-0.5%***
4 LULUCF	-3'047	-1'848	-1'200.0	34.4	31.7	2.6	53.9	52.0	1.9				-2'959.2	-1'764	-1'195.5
Total including LULUCF	**41'493**	**42'725**	**-1'231.2**	**6'257**	**6'544**	**-287.9**	**4'103**	**4'066**	**36.5**	**246.0**	**246.0**	**0.0**	**52'099**	**53'581**	**-1'482.6**
	97.1%	***100.0%***	***-2.9%***	***95.6%***	***100.0%***	***-4.4%***	***100.9%***	***100.0%***	***0.9%***	***100.0%***	***100.0%***	***0.0%***	***97.2%***	***100.0%***	***-2.8%***

Emissions for 1990	**HFC**			**PFC**			**SF_6**			**NF_3**		
	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference
	CO_2 equivalent (kt)											
2 IPPU	0.0	0.0	0.0	104.8	104.8	0.0	141.2	141.2	0.0	0.0	0.0	0.0

Table 10-4 Implications of recalculations for emission levels in 2021. Emissions are shown for the previous submission (FOEN 2023) and the latest submission. The difference refers to the absolute values (Latest - Previous).

Emissions for 2021	**CO_2**			**CH_4**			**N_2O**			**F-Gases**			**Sum of all gases**		
	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference
	CO_2 equivalent (kt)														
1 Energy	33'635	33'617	17.9	147.1	304.1	-157.1	244.5	226.5	17.9				34'027	34'148	-121.3
2 IPPU	2'081	2'102	-20.7	6.8	6.8	0.0	425.2	425.2	0.0	1'426.0	1'399.2	26.8	3'939	3'933	6.0
3 Agriculture	46.0	46.0	0.0	4'248	4'249	-0.6	1'631	1'603	28.0				5'925	5'898	27.4
5 Waste	8.7	8.7	0.0	549	544	5.7	583.7	589.8	-6.1				1'142	1'142	-0.4
6 Other	8.4	13.0	-4.6	0.5	0.8	-0.3	0.3	0.5	-0.2				9.2	14.3	-5.2
CO_2 indirect	95.3	112.9	-17.6										95.3	112.9	-17.6
Total excluding LULUCF	**35'875**	**35'900**	**-25.1**	**4'952**	**5'104**	**-152.3**	**2'885**	**2'845**	**39.6**	**1'426**	**1'399**	**26.8**	**45'138**	**45'249**	**-111.0**
	99.9%	***100.0%***	***-0.1%***	***97.0%***	***100.0%***	***-3.0%***	***101.4%***	***100.0%***	***1.4%***	***101.9%***	***100.0%***	***1.9%***	***99.8%***	***100.0%***	***-0.2%***
4 LULUCF	-1'336	-1'937	601.2	13.6	13.5	0.1	48.5	48.4	0.1				-1'273.7	-1'875	601.4
Total including LULUCF	**34'539**	**33'963**	**576.1**	**4'965**	**5'118**	**-152.2**	**2'933**	**2'894**	**39.6**	**1'426.0**	**1'399.2**	**26.8**	**43'864**	**43'374**	**490.4**
	101.7%	***100.0%***	***1.7%***	***97.0%***	***100.0%***	***-3.0%***	***101.4%***	***100.0%***	***1.4%***	***101.9%***	***100.0%***	***1.9%***	***101.1%***	***100.0%***	***1.1%***

Emissions for 2021	**HFC**			**PFC**			**SF_6**			**NF_3**		
	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference	Latest	Previous	Difference
	CO_2 equivalent (kt)											
2 IPPU	1'267.1	1'241.5	25.6	28.0	28.4	-0.4	130.6	129.0	1.5	0.4	0.4	0.0

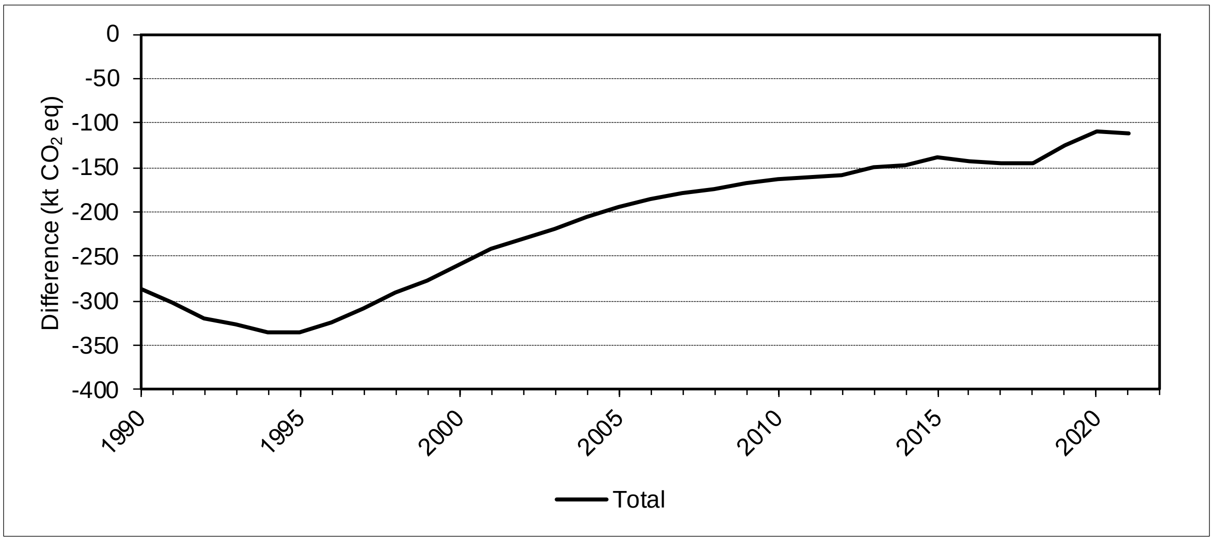


Figure 10-22 Implications of recalculations for the national total emissions (including indirect CO_2, without LULUCF). Positive values refer to higher emissions and negative values to lower emissions in the latest compared to the previous submission. For the implications of recalculations for LULUCF see Figure 10-8.

Figure 10-22 shows the aggregated effect of all the recalculations on national total emissions without LULUCF. The effect of the recalculations ranges from -268 kt CO_2 eq in 1990 to -93 kt CO_2 eq in 2021 (with the largest effect of -307 kt CO_2 eq in 1995), corresponding to -0.5 % of annual total emissions in 1990 and -0.2 % in 2021.

The aggregated effect of all recalculations on total net emissions and net removals from LULUCF are shown in Figure 10-8.

To further visualize the aggregated effect of all the recalculations, the following figures compare total emissions as reported in the previous and the latest submissions in absolute terms (instead of showing differences as in the figures above): Total emissions (without LULUCF) in Figure 10-23, and total net emissions and net removals from LULUCF in Figure 10-24.

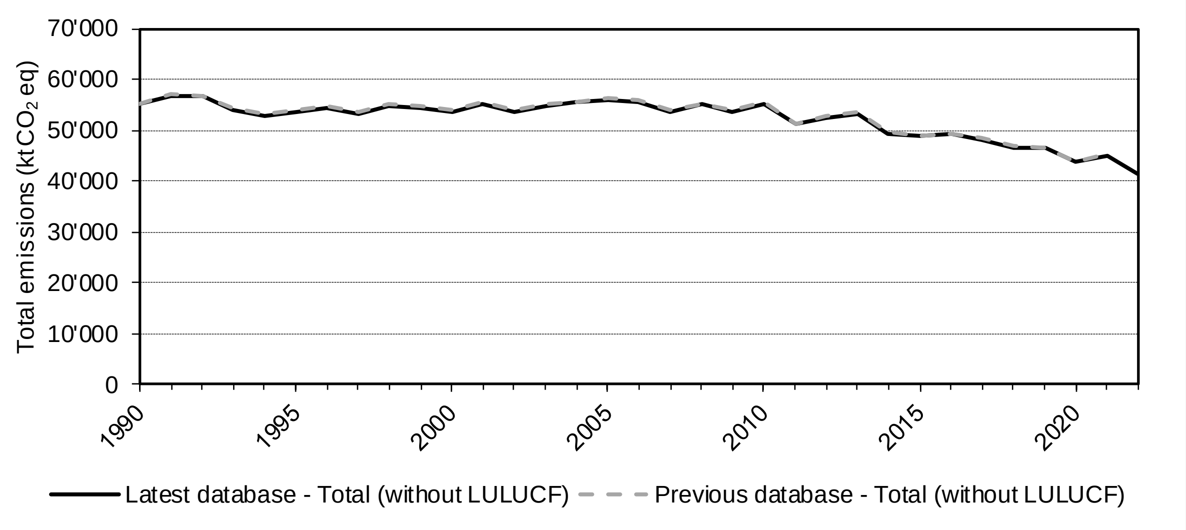


Figure 10-23 Comparison of total emissions (including indirect CO_2, without LULUCF) as reported in the previous and the latest submissions.

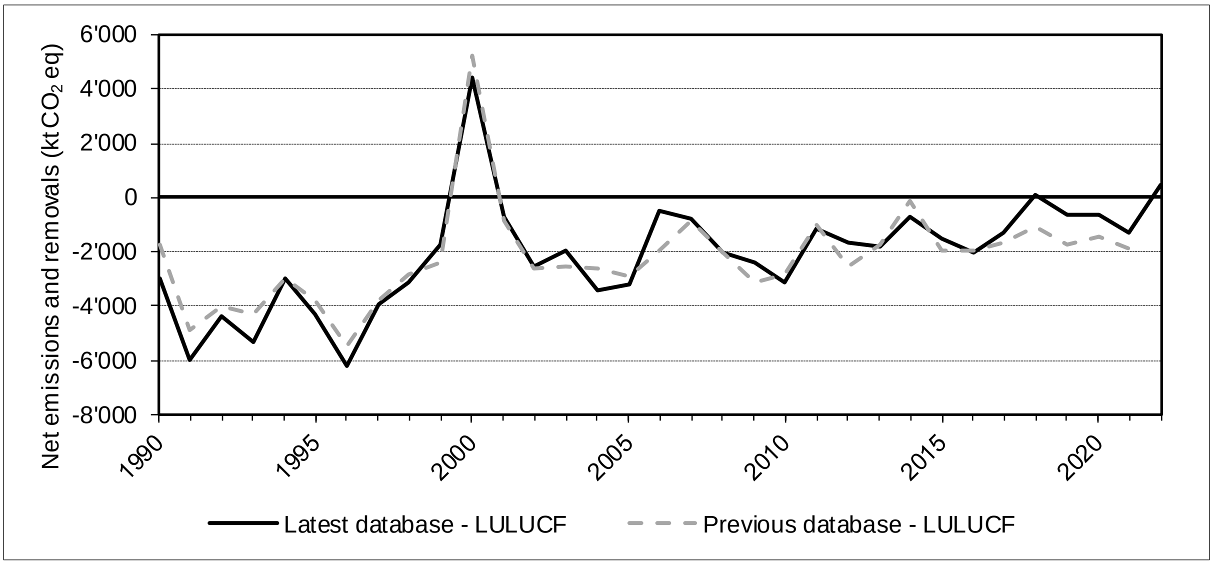


Figure 10-24 Comparison of net emissions (positive values) and net removals (negative values) from LULUCF as reported in the previous and the latest submissions.

10.3. Implications for emission and removal trends, including time series consistency

As recalculations are applied to the entire time series (as appropriate), time series consistency is maintained. The emission trend for the total emissions (including indirect CO_2, excluding LULUCF) from 1990–2021 has changed (see Table 10-5) slightly.

Table 10-5 Estimated emission trends 1990–2021, calculated based on national total emissions including indirect CO_2 as shown in the previous and the latest submission (for additional details see Table 10-3 and Table 10-4).

Trend	**1990**		**2021**		**Change 1990/2021**	
	Latest	Previous	Latest	Previous	Latest	Previous
	CO_2 equivalent (kt)				%	
Total excluding LULUCF	55'058	55'345	45'138	45'249	-18.0%	-18.2%
Total including LULUCF	52'099	53'581	43'864	43'374	-15.8%	-19.1%

10.4. Areas of improvement, including in response to the review process

All categories mentioned hereafter have been identified as key categories, or contain categories identified as key categories, according to the key category analysis (see overview of key categories in Table 1-6).

- 2F1: Improvements of HFC emission calculations from refrigeration and air conditioning equipment.
- 2F1: Changes are expected and will be analysed in this area due to the revision of the Chemical Risk Reduction Ordinance and CO_2 compensation programmes (share of products with HFC, recycling of HFC, early replacement of HFC).
- 3D: After the suitability of the DayCent model for reporting N_2O emissions has been proven (LACHSIM project), it is now to be integrated into the reporting of the Agriculture sector. Three years (2024–2026) are planned for the compilation of the necessary input

data (in particular type and intensity of management) and the creation of a consistent time series back to 1990.

- 3D: Development of a country-specific emission factor for direct N_2O emissions from urine and dung deposited by grazing animals.
- 3D: Adjust the calculation of emissions from nitrogen in crop residues returned to soils in order to improve consistency between the Agriculture and LULUCF sectors.
- 4: Starting with the Land Use Statistics AREA5 the interval between two surveys will be successively shortened to six years.
- 4: The suitability of satellite data for land area representation in Switzerland is being evaluated.
- 4: The stratification by soil type will be adjusted once again after completion of the ongoing update of the distribution of organic soils.
- 4: Provided that the test phase is successful, the LULUCF approach will be switched to a geo-referenced reporting in one of the upcoming submissions.
- 4A: First data on carbon dynamics in brush forests will be derived from NFIs 4 and 5. Their implementation in LULUCF reporting is planned for the 2026 submission.
- 4A: Planned progress on Yasso focuses on improving the accuracy of estimates on dead wood and litter production, and opportunities arising from national and international projects, particularly in the context of the EU-Horizon project Pathfinder.
- 4B, 4C, 4D, 4E: The biomass model for trees outside the forest will be finalised in the course of 2024.
- 4B, 4C, 4D, 4E: The progress of digital soil modelling at the Competence Center for Soils (CCSoils) will be used to improve estimates of carbon stock in mineral non-Forest soils. The switch to grid-based SOC modelling with RothC for Cropland and Grassland will be pursued further.
- 4G: The availability of plant-specific activity data for wood panels and sawnwood for the years before 2021 will be further explored.
- Uncertainty and key category analyses: for the latest submission, four categories according to the CRF nomenclature are still used within sector 4 LULUCF: 4(II), 4(III), 4(IV) and 4(V). For submission 2025, it is planned to use categories according to the CRT nomenclature only.

Annexes

Annex 1 Key categories

Table A – 1 Overview of Switzerland's key category analysis, including LULUCF categories and indirect CO_2 emissions. Columns A (category code) and B (category name) contain the complete disaggregation level of categories used for the key category analysis. Note that for the KCA, four categories are still used according to the CRF nomenclature within sector 4 LULUCF: 4(II), 4(III), 4(IV) and 4(V). L: level assessment (2022); T: trend assessment (1990–2022); 1: KCA approach 1; 2: KCA approach 2. For none of the categories, SF_6 and NF_3 are key (therefore, the respective columns for SF_6 and NF_3 are disabled in the columns C and D). Results of the level assessment for the base year are not reported in this table. Columns A to D are labelled according to Table 4-4 in the 2006 IPCC Guidelines, vol.1, chp. 4 (IPCC 2006).

SUMMARIES TO IDENTIFY KEY CATEGORIES							
A	B	C & D					
Code	IPCC category	CO2	CH4	N2O	HFCs	PFCs	Ind. CO2 (NMVOC)
1A1	Energy industries; Biomass						
1A1	Energy industries; Gaseous fuels	L1, T1					
1A1	Energy industries; Liquid fuels	L1, T1					
1A1	Energy industries; Solid fuels						
1A1	Energy industries; Other fuels	L1, L2, T1, T2					
1A2	Manufacturing industries and construction; Biomass						
1A2	Manufacturing industries and construction; Gaseous fuels	L1, L2, T1					
1A2	Manufacturing industries and construction; Liquid fuels	L1, T1					
1A2	Manufacturing industries and construction; Solid fuels	L1, T1					
1A2	Manufacturing industries and construction; Other fuels	L1, L2, T1					
1A3a	Domestic aviation; Kerosene fossil	T1					
1A3b	Road transportation; Biomass						
1A3b	Road transportation; Gaseous fuels						
1A3b	Road transportation; Diesel oil	L1, L2, T1		T1			
1A3b	Road transportation; Gasoline	L1, T1	T1	T1			
1A3b	Road transportation; Liquefied petroleum gas						
1A3c	Railways; Biomass						
1A3c	Railways; Liquid fuels						
1A3d	Water-borne navigation; Biomass						
1A3d	Water-borne navigation; Liquid fuels						
1A3e	Other transportation; Gaseous fuels						
1A4a	Commercial; Biomass						
1A4a	Commercial; Gaseous fuels	L1, L2, T1					
1A4a	Commercial; Liquid fuels	L1, T1					
1A4b	Residential; Biomass						
1A4b	Residential; Gaseous fuels	L1, L2, T1					
1A4b	Residential; Liquid fuels	L1, T1					
1A4b	Residential; Solid fuels						
1A4c	Agriculture and forestry; Biomass						
1A4c	Agriculture and forestry; Gaseous fuels						
1A4c	Agriculture and forestry; Liquid fuels	L1, T1					
1A5	Non-specified; Biomass						
1A5	Non-specified; Liquid fuels						
1B	Fugitive emissions from fuels; All fuels						
1B2a	Oil; All fuels						
1B2b	Natural gas; All fuels						
1B2c	Venting and flaring; All fuels						
2A	Mineral industry						
2A1	Cement production	L1, L2, T1					
2A2	Lime production						
2A3	Glass production						
2A4	Other process uses of carbonates						
2B	Chemical industry						
2B2	Nitric acid production						
2B5	Carbide production						
2B8	Petrochemical and carbon black production						
2B10	Chemical industry other			T1, T2			
2C	Metal industry						
2C1	Iron and steel production						
2C3	Aluminium production	T1				T1	
2C4	Magnesium production						
2C7	Rare earths						
2D	Non-energy products from fuels and solvent use						T1
2D1	Lubricant use						
2D2	Paraffin wax use						
2D3	Other						
2E1	Integrated circuit or semiconductor						
2E3	Photovoltaics						
2E5	Electronics industry other						
2F1	Refrigeration and air conditioning				L1, L2, T1		
2F2	Foam blowing agents						
2F4	Aerosols						
2F5	Solvents						
2G	Other product manufacture and use						
2G3	N2O from product uses						
2G4	Other product manufacture and use other						
2H	Other						
2H3	Other						

Table A – 1 (continued)

SUMMARIES TO IDENTIFY KEY CATEGORIES							
A	B	C & D					
Code	IPCC category	CO2	CH4	N2O	HFCs	PFCs	Ind. CO2 (NMVOC)
3A	Enteric fermentation		L1, L2, T1				
3B1-4	Manure management all livestock direct		L1, L2	L2			
3B5	Manure management indirect			L1, L2			
3Da	Direct emissions from managed soils			L1, L2			
3Db	Indirect emissions from managed soils			L1, L2, T1			
3G	Liming						
3H	Urea application						
4A1	Forest land remaining forest land	L1, L2, T1, T2					
4A2	Land converted to forest land	L1, L2, T1					
4B1	Cropland remaining cropland	L1, L2, T1, T2					
4B2	Land converted to cropland	L2					
4C1	Grassland remaining grassland	L1, L2, T1, T2					
4C2	Land converted to grassland	L1, L2, T1					
4D1	Wetland remaining wetland	L2					
4D2	Land converted to wetland						
4E1	Settlements remaining settlements						
4E2	Land converted to settlements	L1, L2					
4F2	Land converted to other land	L1, L2					
4G	HWP Harvested Wood Products	T1, T2					
4II	Drainage and rewetting						
4III	Direct N2O from disturbance			L2			
4IV	Indirect N2O						
4V	Biomass burning						
5A	Solid waste disposal		L1, L2, T1				
5B	Biological treatment of solid waste						
5C	Incineration and open burning of waste			L2			
5D	Wastewater treatment and discharge		L1, L2	L1, L2, T1, T2			
5E	Waste other						
6A	Other						
Total number of key categories		27	5	10	1	1	1

Annex 2 Uncertainty assessment

A2.1 Input uncertainty values

Table A – 2 Input uncertainties for the year 2022, including LULUCF categories and indirect CO_2 emissions. Input uncertainties are assigned to activity data (column E) and emissions factors (column F) or, if unknown, to emissions only (column G). The uncertainties are given considering a 95 % confidence interval (from 2.5 % to 97.5 %) and expressed as the distance from edge to mean, in percentage of the mean. Columns are labelled according to Table 3-2 in the 2006 IPCC Guidelines, vol.1, chp. 3 (IPCC 2006). Note that for the uncertainty analyses still four categories are used according to the CRF nomenclature within sector 4 LULUCF: 4(II), 4(III), 4(IV) and 4(V). Abbreviations used within sector 4 LULUCF: CS-CH-LB Carbon gains: gains in carbon stock change in living biomass. CS-CH-LB Carbon losses: losses in carbon stock change in living biomass. Net CS-CH-S Carbon min soils: net carbon stock change in mineral soil. Net CS-CH-S Carbon org soils: net carbon stock change in organic soils. Net CS-CH-DOM Carbon: net carbon stock change in dead organic matter.

A	B	E					F					G				
Code	Gas	Activity data uncertainty year 2022					Emission factor uncertainty year 2022					Emission uncertainty year 2022				
		Distribu-tion type	2*std. dev. %	(-)%	(+)%	Corr.	Distribu-tion type	2*std. dev. %	(-)%	(+)%	Corr.	Distribu-tion type	2*std. dev. %	(-)%	(+)%	Corr.
1A1; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	28.3	28.3	28.3	yes					
1A1; Biomass	N2O	normal	10.0	10.0	10.0	no	normal	79.4	79.4	79.4	yes					
1A1; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	0.4	0.4	0.4	no					
1A1; Gaseous fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A1; Gaseous fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A1; Liquid fuels	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	yes					
1A1; Liquid fuels	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					
1A1; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	normal	80.0	80.0	80.0	yes					
1A1; Solid fuels	CO2	normal	5.0	5.0	5.0	no	normal	5.1	5.1	5.1	yes					
1A1; Solid fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A1; Solid fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A1; Other fuels	CO2	normal	5.0	5.0	5.0	no	normal	16.9	16.9	16.9	yes					
1A1; Other fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	no					
1A2; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	28.3	28.3	28.3	yes					
1A2; Biomass	N2O	normal	10.0	10.0	10.0	no	normal	79.4	79.4	79.4	yes					
1A2; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	0.4	0.4	0.4	no					
1A2; Gaseous fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A2; Gaseous fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A2; Liquid fuels	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	yes					
1A2; Liquid fuels	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					
1A2; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	normal	80.0	80.0	80.0	yes					
1A2; Solid fuels	CO2	normal	5.0	5.0	5.0	no	normal	5.1	5.1	5.1	yes					
1A2; Solid fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A2; Solid fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A2; Other fuels	CO2	normal	5.0	5.0	5.0	no	normal	9.2	9.2	9.2	yes					
1A2; Other fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A2; Other fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	no					
1A3a; Kerosene fossil	CO2	normal	1.0	1.0	1.0	no	normal	0.2	0.2	0.2	no					
1A3a; Kerosene fossil	CH4	normal	1.0	1.0	1.0	no	normal	60.0	60.0	60.0	yes					
1A3a; Kerosene fossil	N2O	normal	1.0	1.0	1.0	no	gamma	150.0	150.0	150.0	yes					
1A3b; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	59.2	59.2	59.2	yes					
1A3b; Biomass	N2O	normal	10.0	10.0	10.0	no	gamma	149.7	149.7	149.7	yes					
1A3b; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	0.4	0.4	0.4	no					
1A3b; Gaseous fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A3b; Gaseous fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A3b; Diesel oil	CO2	normal	0.9	0.9	0.9	no	normal	0.1	0.1	0.1	no					
1A3b; Diesel oil	CH4	normal	0.9	0.9	0.9	no	normal	20.0	20.0	20.0	yes					
1A3b; Diesel oil	N2O	normal	0.9	0.9	0.9	no	normal	22.0	22.0	22.0	yes					
1A3b; Gasoline	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	no					
1A3b; Gasoline	CH4	normal	0.7	0.7	0.7	no	normal	37.0	37.0	37.0	yes					
1A3b; Gasoline	N2O	normal	0.7	0.7	0.7	no	normal	50.0	50.0	50.0	yes					
1A3b; Liquefied petroleum gas	CO2	normal	0.7	0.7	0.7	no	normal	10.0	10.0	10.0	yes					
1A3b; Liquefied petroleum gas	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					
1A3b; Liquefied petroleum gas	N2O	normal	0.7	0.7	0.7	no	normal	80.0	80.0	80.0	yes					
1A3c; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	59.2	59.2	59.2	yes					
1A3c; Biomass	N2O	normal	10.0	10.0	10.0	no	gamma	149.7	149.7	149.7	yes					
1A3c; Liquid fuels	CO2	normal	0.9	0.9	0.9	no	normal	0.1	0.1	0.1	no					
1A3c; Liquid fuels	CH4	normal	0.9	0.9	0.9	no	normal	30.0	30.0	30.0	yes					
1A3c; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	normal	80.0	80.0	80.0	yes					
1A3d; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	59.2	59.2	59.2	yes					
1A3d; Biomass	N2O	normal	10.0	10.0	10.0	no	gamma	149.7	149.7	149.7	yes					
1A3d; Liquid fuels	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	no					
1A3d; Liquid fuels	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					
1A3d; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	gamma	150.0	150.0	150.0	yes					
1A3e; Biomass	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A3e; Biomass	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A3e; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	0.4	0.4	0.4	no					
1A3e; Gaseous fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A3e; Gaseous fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A4a; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	28.3	28.3	28.3	yes					
1A4a; Biomass	N2O	normal	10.0	10.0	10.0	no	normal	79.4	79.4	79.4	yes					
1A4a; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	0.4	0.4	0.4	no					
1A4a; Gaseous fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A4a; Gaseous fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A4a; Liquid fuels	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	yes					
1A4a; Liquid fuels	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					

Table A – 2 (continued)

A	B	E					F					G				
Code	Gas	Activity data uncertainty year 2022					Emission factor uncertainty year 2022					Emission uncertainty year 2022				
		Distribution type	2*std. dev. %	(-)%	(+)%	Corr.	Distribution type	2*std. dev. %	(-)%	(+)%	Corr.	Distribution type	2*std. dev. %	(-)%	(+)%	Corr.
1A4a; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	normal	80.0	80.0	80.0	yes					
1A4b; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	28.3	28.3	28.3	yes					
1A4b; Biomass	N2O	normal	10.0	10.0	10.0	no	normal	79.4	79.4	79.4	yes					
1A4b; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	0.4	0.4	0.4	no					
1A4b; Gaseous fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A4b; Gaseous fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A4b; Liquid fuels	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	yes					
1A4b; Liquid fuels	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					
1A4b; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	normal	80.0	80.0	80.0	yes					
1A4b; Solid fuels	CO2	normal	5.0	5.0	5.0	no	normal	5.1	5.1	5.1	yes					
1A4b; Solid fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A4b; Solid fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A4c; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	28.3	28.3	28.3	yes					
1A4c; Biomass	N2O	normal	10.0	10.0	10.0	no	normal	79.4	79.4	79.4	yes					
1A4c; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	0.4	0.4	0.4	no					
1A4c; Gaseous fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1A4c; Gaseous fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
1A4c; Liquid fuels	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	yes					
1A4c; Liquid fuels	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					
1A4c; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	normal	80.0	80.0	80.0	yes					
1A5; Biomass	CH4	normal	10.0	10.0	10.0	no	normal	59.2	59.2	59.2	yes					
1A5; Biomass	N2O	normal	10.0	10.0	10.0	no	gamma	149.7	149.7	149.7	yes					
1A5; Liquid fuels	CO2	normal	0.7	0.7	0.7	no	normal	0.1	0.1	0.1	no					
1A5; Liquid fuels	CH4	normal	0.7	0.7	0.7	no	normal	30.0	30.0	30.0	yes					
1A5; Liquid fuels	N2O	normal	0.7	0.7	0.7	no	gamma	150.0	150.0	150.0	yes					
1B; All fuels	Indirect CO2 from CH4											normal	29.6	29.6	29.6	no
1B; All fuels	Indirect CO2 from NMVOC											normal	33.8	33.8	33.8	no
1B2a; All fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1B2b; All fuels	CO2	normal	5.0	5.0	5.0	no	normal	8.7	8.7	8.7	yes					
1B2b; All fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1B2c; All fuels	CO2	normal	5.0	5.0	5.0	no	normal	8.7	8.7	8.7	yes					
1B2c; All fuels	CH4	normal	5.0	5.0	5.0	no	normal	29.6	29.6	29.6	yes					
1B2c; All fuels	N2O	normal	5.0	5.0	5.0	no	normal	79.8	79.8	79.8	yes					
2A	Indirect CO2 from CO											gamma	176.6	176.6	176.6	no
2A	Indirect CO2 from NMVOC											gamma	188.6	188.6	188.6	no
2A1	CO2	normal	2.0	2.0	2.0	no	normal	4.0	4.0	4.0	yes					
2A2	CO2	normal	2.0	2.0	2.0	no	normal	2.0	2.0	2.0	no					
2A3	CO2	normal	2.0	2.0	2.0	no	normal	3.0	3.0	3.0	no					
2A4	CO2	normal	2.0	2.0	2.0	no	normal	3.0	3.0	3.0	no					
2B	Indirect CO2 from CH4											normal	10.2	10.2	10.2	no
2B	Indirect CO2 from CO											normal	40.0	40.0	40.0	no
2B	Indirect CO2 from NMVOC											normal	40.0	40.0	40.0	no
2B2	N2O	normal	2.0	2.0	2.0	no	normal	7.2	7.2	7.2	no					
2B5	CO2	normal	2.0	2.0	2.0	no	normal	10.0	10.0	10.0	yes					
2B5	CH4	normal	2.0	2.0	2.0	no	normal	10.0	10.0	10.0	yes					
2B8	CO2	normal	2.0	2.0	2.0	no	normal	10.0	10.0	10.0	no					
2B10	CO2	normal	2.0	2.0	2.0	no	normal	20.0	20.0	20.0	no					
2B10	CH4	normal	2.0	2.0	2.0	no	normal	60.0	60.0	60.0	yes					
2B10	N2O	normal	2.0	2.0	2.0	no	normal	60.0	60.0	60.0	no					
2C	Indirect CO2 from CO											gamma	192.0	192.0	192.0	no
2C	Indirect CO2 from NMVOC											gamma	99.3	99.3	99.3	no
2C1	CO2	normal	2.0	2.0	2.0	no	normal	50.0	50.0	50.0	no					
2C3	CO2	normal	5.0	5.0	5.0	no	normal	20.0	20.0	20.0	yes					
2C3	PFCs											normal	9.0	9.0	9.0	no
2C4	SF6											normal	27.7	27.7	27.7	no
2C7	CO2	normal	2.0	2.0	2.0	no	normal	20.0	20.0	20.0	yes					
2D	Indirect CO2 from CO											gamma	201.7	201.7	201.7	no
2D	Indirect CO2 from NMVOC											normal	35.9	35.9	35.9	no
2D1	CO2	normal	20.0	20.0	20.0	yes	normal	50.0	50.0	50.0	yes					
2D2	CO2	normal	10.0	10.0	10.0	yes	gamma	100.0	100.0	100.0	yes					
2D3	CO2	normal	10.0	10.0	10.0	no	normal	20.0	20.0	20.0	no					
2E1	HFCs											normal	25.1	25.1	25.1	no
2E1	PFCs											normal	38.2	38.2	38.2	no
2E1	SF6											normal	47.6	47.6	47.6	no
2E3	NF3											gamma	110.9	110.9	110.9	no
2E5	PFCs											normal	43.9	43.9	43.9	no
2F1	HFCs											normal	14.2	14.2	14.2	no
2F1	PFCs											normal	55.3	55.3	55.3	no
2F2	HFCs											gamma	141.4	141.4	141.4	no
2F4	HFCs											normal	40.8	40.8	40.8	no
2F5	HFCs											normal	52.9	52.9	52.9	no
2G	HFCs											normal	20.0	20.0	20.0	no
2G	PFCs											normal	8.9	8.9	8.9	no
2G	SF6											gamma	51.1	51.1	51.1	yes
2G	Indirect CO2 from CO											gamma	303.8	303.8	303.8	no
2G	Indirect CO2 from NMVOC											gamma	75.1	75.1	75.1	no
2G3	N2O	normal	1.0	1.0	1.0	no	normal	80.0	80.0	80.0	yes					
2G4	CO2	normal	10.0	10.0	10.0	no	normal	20.0	20.0	20.0	no					
2G4	N2O	normal	1.0	1.0	1.0	no	normal	40.0	40.0	40.0	yes					
2H	Indirect CO2 from CO											gamma	200.3	200.3	200.3	no
2H	Indirect CO2 from NMVOC											gamma	176.0	176.0	176.0	no
2H3	CO2	normal	5.0	5.0	5.0	no	gamma	100.0	100.0	100.0	yes					

Table A – 2 (continued)

A	B	E					F					G				
Code	Gas	Activity data uncertainty year 2022					Emission factor uncertainty year 2022					Emission uncertainty year 2022				
		Distribu-tion type	2*std. dev. %	(-)%	(+)%	Corr.	Distribu-tion type	2*std. dev. %	(-)%	(+)%	Corr.	Distribu-tion type	2*std. dev. %	(-)%	(+)%	Corr.
3A	CH4	normal	6.5	6.5	6.5	no	gamma	19.2	19.2	19.2	no					
3B1-4	CH4	normal	6.5	6.5	6.5	no	normal	54.6	54.6	54.6	no					
3B1-4	N2O	normal	24.0	24.0	24.0	no	gamma	70.9	70.9	70.9	no					
3B5	N2O	gamma	55.0	55.0	55.0	no	gamma	80.0	80.0	80.0	yes					
3Da	N2O	normal	13.3	13.3	13.3	no	gamma	75.8	75.8	75.8	no					
3Db	N2O	gamma	30.5	30.5	30.5	no	gamma	62.5	62.5	62.5	no					
3G	CO2	normal	40.0	40.0	40.0	no	normal	5.0	5.0	5.0	yes					
3H	CO2	normal	5.0	5.0	5.0	no	normal	5.0	5.0	5.0	yes					
4A1	CO2	normal	1.1	1.1	1.1	yes	normal	34.9	34.9	34.9	yes					
4A2	CO2	normal	1.5	1.5	1.5	yes	normal	34.9	34.9	34.9	yes					
4B1; CS-CH-LB Carbon gains	CO2	normal	4.9	4.9	4.9	yes	normal	13.0	13.0	13.0	yes					
4B1; CS-CH-LB Carbon losses	CO2	normal	4.9	4.9	4.9	yes	normal	13.0	13.0	13.0	yes					
4B1; Net CS-CH-S Carbon min soils	CO2	normal	4.9	4.9	4.9	yes	normal	135.9	135.9	135.9	no					
4B1; Net CS-CH-S Carbon org soils	CO2	normal	37.3	37.3	37.3	yes	normal	23.0	23.0	23.0	yes					
4B1; Net CS-CH-DOM Carbon	CO2	normal	4.9	4.9	4.9	yes	normal	0.5	0.5	0.5	yes					
4B2; CS-CH-LB Carbon gains	CO2	normal	5.1	5.1	5.1	yes	normal	13.0	13.0	13.0	yes					
4B2; CS-CH-LB Carbon losses	CO2	normal	5.1	5.1	5.1	yes	normal	13.0	13.0	13.0	yes					
4B2; Net CS-CH-S Carbon min soils	CO2	normal	5.1	5.1	5.1	yes	normal	450.1	450.1	450.1	no					
4B2; Net CS-CH-S Carbon org soils	CO2	normal	37.3	37.3	37.3	yes	normal	23.0	23.0	23.0	yes					
4B2; Net CS-CH-DOM Carbon	CO2	normal	5.1	5.1	5.1	yes	normal	0.5	0.5	0.5	yes					
4C1; CS-CH-LB Carbon gains	CO2	normal	5.2	5.2	5.2	yes	normal	13.0	13.0	13.0	yes					
4C1; CS-CH-LB Carbon losses	CO2	normal	5.2	5.2	5.2	yes	normal	13.0	13.0	13.0	yes					
4C1; Net CS-CH-S Carbon min soils	CO2	normal	5.2	5.2	5.2	yes	normal	1'108.0	1'108.0	1'108.0	no					
4C1; Net CS-CH-S Carbon org soils	CO2	normal	68.6	68.6	68.6	yes	normal	23.0	23.0	23.0	yes					
4C1; Net CS-CH-DOM Carbon	CO2	normal	5.2	5.2	5.2	yes	normal	0.5	0.5	0.5	yes					
4C2; CS-CH-LB Carbon gains	CO2	normal	5.3	5.3	5.3	yes	normal	13.0	13.0	13.0	yes					
4C2; CS-CH-LB Carbon losses	CO2	normal	5.3	5.3	5.3	yes	normal	13.0	13.0	13.0	yes					
4C2; Net CS-CH-S Carbon min soils	CO2	normal	5.3	5.3	5.3	yes	normal	107.8	107.8	107.8	no					
4C2; Net CS-CH-S Carbon org soils	CO2	normal	68.6	68.6	68.6	yes	normal	23.0	23.0	23.0	yes					
4C2; Net CS-CH-DOM Carbon	CO2	normal	5.3	5.3	5.3	yes	normal	0.5	0.5	0.5	yes					
4D1	CO2	normal	90.8	90.8	90.8	yes	normal	72.2	72.2	72.2	yes					
4D2; CS-CH-LB Carbon gains	CO2	normal	3.7	3.7	3.7	yes	normal	13.0	13.0	13.0	yes					
4D2; CS-CH-LB Carbon losses	CO2	normal	3.7	3.7	3.7	yes	normal	13.0	13.0	13.0	yes					
4D2; Net CS-CH-S Carbon min soils	CO2	normal	3.7	3.7	3.7	yes	normal	50.0	50.0	50.0	yes					
4D2; Net CS-CH-S Carbon org soils	CO2	normal	90.8	90.8	90.8	yes	normal	72.2	72.2	72.2	yes					
4D2; Net CS-CH-DOM Carbon	CO2	normal	3.7	3.7	3.7	yes	normal	0.5	0.5	0.5	yes					
4E1	CO2	normal	4.4	4.4	4.4	yes	normal	50.0	50.0	50.0	yes					
4E2	CO2	normal	4.6	4.6	4.6	yes	normal	50.0	50.0	50.0	yes					
4F2	CO2	normal	3.1	3.1	3.1	yes	normal	50.0	50.0	50.0	yes					
4G	CO2	normal	11.2	11.2	11.2	yes	normal	54.8	54.8	54.8	yes					
4II	CH4	normal	10.0	10.0	10.0	yes	normal	70.0	70.0	70.0	yes					
4II	N2O	normal	50.8	50.8	50.8	yes	normal	66.9	66.9	66.9	yes					
4III	N2O	normal	83.5	83.5	83.5	yes	gamma	90.0	90.0	90.0	yes					
4IV	N2O	normal	85.8	85.8	85.8	yes	gamma	100.0	100.0	100.0	yes					
4V	CH4	normal	30.0	30.0	30.0	yes	normal	70.0	70.0	70.0	yes					
4V	N2O	normal	30.0	30.0	30.0	yes	normal	70.0	70.0	70.0	yes					
5A	CO2											normal	10.0	10.0	10.0	yes
5A	CH4											normal	30.0	30.0	30.0	yes
5B	CH4	normal	30.0	30.0	30.0	no	normal	30.0	30.0	30.0	yes					
5B	N2O	normal	30.0	30.0	30.0	no	normal	30.0	30.0	30.0	yes					
5C	CO2	normal	30.0	30.0	30.0	no	normal	26.5	26.5	26.5	yes					
5C	CH4	normal	50.0	50.0	50.0	no	normal	33.2	33.2	33.2	yes					
5C	N2O	normal	30.0	30.0	30.0	no	gamma	147.0	147.0	147.0	yes					
5C	Indirect CO2 from CH4											gamma	60.6	60.6	60.6	no
5C	Indirect CO2 from CO											gamma	71.9	71.9	71.9	no
5C	Indirect CO2 from NMVOC											gamma	71.8	71.8	71.8	no
5D	CH4											gamma	100.0	100.0	100.0	no
5D	N2O											gamma	50.0	50.0	50.0	no
5E	Indirect CO2 from CO											normal	28.4	28.4	28.4	no
5E	Indirect CO2 from NMVOC											normal	31.0	31.0	31.0	no
6A	Indirect CO2 from CH4											gamma	88.3	88.3	88.3	no
6A	Indirect CO2 from CO											gamma	76.8	76.8	76.8	no
6A	Indirect CO2 from NMVOC											gamma	58.8	58.8	58.8	no
6Ada	CO2	normal	60.0	60.0	60.0	no	gamma	120.0	120.0	120.0	yes					
6Ada	CH4	normal	50.0	50.0	50.0	no	gamma	100.0	100.0	100.0	yes					
6Ada	N2O	normal	50.0	50.0	50.0	no	gamma	150.0	150.0	150.0	yes					
6Adb	CO2	normal	50.0	50.0	50.0	no	gamma	120.0	120.0	120.0	yes					
6Adb	CH4	normal	50.0	50.0	50.0	no	gamma	100.0	100.0	100.0	yes					

Table A – 3 Input uncertainties for the year 1990, including LULUCF categories and indirect CO_2 emissions. Only uncertainty inputs not equal to their corresponding reporting year value are reported. Input uncertainties are assigned to activity data (column E) and emissions factors (column F) or, if unknown, to emissions only (column G). The uncertainties are given considering a 95 % confidence interval (from 2.5 % to 97.5 %) and expressed as the distance from edge to mean, in percentage of the mean. Columns are labelled according to Table 3-2 in the 2006 IPCC Guidelines, vol.1, chp. 3 (IPCC 2006). Abbreviations used within sector 4 LULUCF: Net CS-CH-S Carbon min soils: net carbon stock change in mineral soils.

A	B	E					F					G				
Code	Gas	Activity data uncertainty year 1990					Emission factor uncertainty year 1990					Emission uncertainty year 1990				
		Distribu-tion type	2*std. dev. %	(-)%	(+)%	Corr.	Distribu-tion type	2*std. dev. %	(-)%	(+)%	Corr.	Distribu-tion type	2*std. dev. %	(-)%	(+)%	Corr.
1A1; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	1.5	1.5	1.5	no					
1A2; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	1.5	1.5	1.5	no					
1A3e; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	1.5	1.5	1.5	no					
1A4a; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	1.5	1.5	1.5	no					
1A4b; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	1.5	1.5	1.5	no					
1A4c; Gaseous fuels	CO2	normal	5.0	5.0	5.0	no	normal	1.5	1.5	1.5	no					
1B; All fuels	Indirect CO2 from CH4											normal	28.8	28.8	28.8	no
1B; All fuels	Indirect CO2 from NMVOC											normal	37.0	37.0	37.0	no
2A	Indirect CO2 from CO											gamma	220.7	220.7	220.7	no
2A	Indirect CO2 from NMVOC											gamma	184.1	184.1	184.1	no
2A2	CO2	normal	2.0	2.0	2.0	no	normal	6.0	6.0	6.0	no					
2A3	CO2	normal	2.0	2.0	2.0	no	normal	30.0	30.0	30.0	no					
2A4	CO2	normal	2.0	2.0	2.0	no	normal	30.0	30.0	30.0	no					
2B	Indirect CO2 from CH4											normal	10.1	10.1	10.1	no
2B	Indirect CO2 from CO											normal	38.1	38.1	38.1	no
2B	Indirect CO2 from NMVOC											normal	40.0	40.0	40.0	no
2B2	N2O	normal	2.0	2.0	2.0	no	normal	60.0	60.0	60.0	no					
2B10	CO2	normal	2.0	2.0	2.0	no	normal	60.0	60.0	60.0	no					
2C	Indirect CO2 from CO											gamma	195.9	195.9	195.9	no
2C	Indirect CO2 from NMVOC											gamma	94.8	94.8	94.8	no
2D	Indirect CO2 from CO											gamma	201.8	201.8	201.8	no
2D	Indirect CO2 from NMVOC											normal	40.4	40.4	40.4	no
2D3	CO2	normal	10.0	10.0	10.0	no	normal	50.0	50.0	50.0	no					
2G	Indirect CO2 from CO											gamma	303.7	303.7	303.7	no
2G	Indirect CO2 from NMVOC											gamma	83.5	83.5	83.5	no
2G4	CO2	normal	10.0	10.0	10.0	no	normal	50.0	50.0	50.0	no					
2H	Indirect CO2 from CO											gamma	200.3	200.3	200.3	no
2H	Indirect CO2 from NMVOC											gamma	165.6	165.6	165.6	no
3A	CH4	normal	6.4	6.4	6.4	no	gamma	20.1	20.1	20.1	no					
3B1-4	CH4	normal	6.4	6.4	6.4	no	normal	54.1	54.1	54.1	no					
3B1-4	N2O	normal	21.0	21.0	21.0	no	gamma	70.8	70.8	70.8	no					
3B5	N2O	gamma	53.1	53.1	53.1	no	gamma	80.0	80.0	80.0	yes					
3Da	N2O	normal	13.5	13.5	13.5	no	gamma	80.1	80.1	80.1	no					
3Db	N2O	gamma	29.8	29.8	29.8	no	gamma	62.5	62.5	62.5	no					
4B1; Net CS-CH-S Carbon min soils	CO2	normal	4.9	4.9	4.9	yes	normal	237.8	237.8	237.8	no					
4B2; Net CS-CH-S Carbon min soils	CO2	normal	5.1	5.1	5.1	yes	normal	156.1	156.1	156.1	no					
4C1; Net CS-CH-S Carbon min soils	CO2	normal	5.2	5.2	5.2	yes	normal	86.0	86.0	86.0	no					
4C2; Net CS-CH-S Carbon min soils	CO2	normal	5.3	5.3	5.3	yes	normal	103.3	103.3	103.3	no					
5C	Indirect CO2 from CH4											gamma	60.6	60.6	60.6	no
5C	Indirect CO2 from CO											gamma	68.4	68.4	68.4	no
5C	Indirect CO2 from NMVOC											gamma	69.6	69.6	69.6	no
5D	N2O											gamma	90.0	90.0	90.0	no
5E	Indirect CO2 from CO											normal	28.4	28.4	28.4	no
5E	Indirect CO2 from NMVOC											normal	31.0	31.0	31.0	no
6A	Indirect CO2 from CH4											gamma	102.2	102.2	102.2	no
6A	Indirect CO2 from CO											gamma	76.9	76.9	76.9	no
6A	Indirect CO2 from NMVOC											gamma	58.8	58.8	58.8	no

A2.2 Detailed results of approach 1 uncertainty analysis

Table A – 4 Uncertainty analysis of greenhouse gas emissions and removals, approach 1, for 2022 and for the trend 1990–2022, including LULUCF categories and indirect CO_2 emissions. The uncertainties are given considering a 95 % confidence interval (from 2.5 % to 97.5 %), and expressed as the distance from edge to mean, in percentage of the mean. AD: activity data; EF: emission factor; EM: emission. d.EM stands for direct emission and indicates that input uncertainties are given for the emission but neither for activity data nor for emission factor. Columns are labelled according to Table 3-2 in the 2006 IPCC Guidelines, vol.1, chp. 3 (IPCC 2006). “Agg.”: indicates that values for AD and EF cannot be computed because the row results from an aggregation. Note that for the uncertainty analyses still four categories are used according to the CRF nomenclature within sector 4 LULUCF: 4(II), 4(III), 4(IV) and 4(V).

A	B	C	D	G		H		I	J	K		L		M	
IPCC category; fuel/source	Gas	Emissions 1990	Emissions 2022	Emission combined uncertainty 2022		Category contribution to inventory variance 2022		Sensitivity if corr. (type A)	Sensitivity if not corr. (type B)	Contribution to inventory trend uncertainty from AD		Contribution to inventory trend uncertainty from EF		Contribution to inventory trend uncertainty from EM	
				(-)%	(+)%	(-)%	(+)%			(-)%	(+)%	(-)%	(+)%	(-)%	(+)%
1A1; Biomass	CH4	0.10	0.18	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A1; Biomass	N2O	20.12	12.85	80	80	0.001	0.001	0.000	0.000	0.003	0.003	0.005	0.005	0.000	0.000
1A1; Gaseous fuels	CO2	243.40	370.85	5	5	0.002	0.002	0.003	0.007	0.050	0.050	0.004	0.004	0.003	0.003
1A1; Gaseous fuels	CH4	0.14	0.60	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A1; Gaseous fuels	N2O	0.14	0.72	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
1A1; Liquid fuels	CO2	685.90	386.83	1	1	0.000	0.000	0.003	0.007	0.007	0.007	0.000	0.000	0.000	0.000
1A1; Liquid fuels	CH4	0.58	0.22	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A1; Liquid fuels	N2O	1.01	0.26	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
1A1; Solid fuels	CO2	49.13	NO	NO	NO	NO	NO	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A1; Solid fuels	CH4	0.15	NO	NO	NO	NO	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A1; Solid fuels	N2O	0.21	NO	NO	NO	NO	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A1; Other fuels	CO2	1'491.55	2'387.58	18	18	1.001	1.001	0.023	0.046	0.324	0.324	0.384	0.384	0.252	0.252
1A1; Other fuels	N2O	21.63	26.32	80	80	0.003	0.003	0.000	0.001	0.004	0.004	0.057	0.057	0.003	0.003
1A2; Biomass	CH4	2.91	1.10	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
1A2; Biomass	N2O	4.69	19.38	80	80	0.001	0.001	0.000	0.000	0.005	0.005	0.024	0.024	0.001	0.001
1A2; Gaseous fuels	CO2	1'100.12	1'853.60	5	5	0.049	0.049	0.019	0.036	0.252	0.252	0.019	0.019	0.064	0.064
1A2; Gaseous fuels	CH4	0.61	0.94	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A2; Gaseous fuels	N2O	0.62	0.90	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
1A2; Liquid fuels	CO2	3'974.06	1'530.78	1	1	0.001	0.001	0.032	0.029	0.029	0.029	0.003	0.003	0.001	0.001
1A2; Liquid fuels	CH4	5.14	1.08	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.000
1A2; Liquid fuels	N2O	11.87	8.99	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
1A2; Solid fuels	CO2	1'274.70	360.40	7	7	0.004	0.004	0.013	0.007	0.049	0.049	0.065	0.065	0.007	0.007
1A2; Solid fuels	CH4	0.35	0.19	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A2; Solid fuels	N2O	5.46	1.51	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.004	0.000	0.000
1A2; Other fuels	CO2	192.37	434.64	10	10	0.012	0.012	0.005	0.008	0.059	0.059	0.049	0.049	0.006	0.006
1A2; Other fuels	CH4	0.87	0.69	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A2; Other fuels	N2O	1.97	5.15	80	80	0.000	0.000	0.000	0.000	0.001	0.001	0.011	0.011	0.000	0.000
1A3a; Kerosene fossil	CO2	252.55	68.70	1	1	0.000	0.000	0.003	0.001	0.002	0.002	0.000	0.000	0.000	0.000
1A3a; Kerosene fossil	CH4	0.19	0.10	60	60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A3a; Kerosene fossil	N2O	1.83	0.50	91	196	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.004	0.000	0.000
1A3b; Biomass	CH4	NO	0.59	60	60	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
1A3b; Biomass	N2O	NO	4.23	91	196	0.000	0.000	0.000	0.000	0.001	0.001	0.007	0.016	0.000	0.000
1A3b; Gaseous fuels	CO2	NO	29.12	5	5	0.000	0.000	0.001	0.001	0.004	0.004	0.000	0.000	0.000	0.000
1A3b; Gaseous fuels	CH4	NO	0.23	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A3b; Gaseous fuels	N2O	NO	0.43	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
1A3b; Diesel oil	CO2	2'631.94	7'026.84	1	1	0.022	0.022	0.094	0.135	0.168	0.168	0.013	0.013	0.028	0.028
1A3b; Diesel oil	CH4	2.56	7.02	20	20	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.000
1A3b; Diesel oil	N2O	5.41	92.05	22	22	0.002	0.002	0.002	0.002	0.002	0.002	0.037	0.037	0.001	0.001
1A3b; Gasoline	CO2	11'328.41	6'161.62	1	1	0.010	0.010	0.057	0.118	0.115	0.115	0.022	0.022	0.014	0.014
1A3b; Gasoline	CH4	128.74	14.41	37	37	0.000	0.000	0.002	0.000	0.000	0.000	0.064	0.064	0.004	0.004
1A3b; Gasoline	N2O	143.06	12.43	50	50	0.000	0.000	0.002	0.000	0.000	0.000	0.099	0.099	0.010	0.010
1A3b; Liquefied petroleum gas	CO2	NO	1.42	10	10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A3b; Liquefied petroleum gas	CH4	NO	0.00	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A3b; Liquefied petroleum gas	N2O	NO	0.01	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A3c; Biomass	CH4	NO	0.00	60	60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A3c; Biomass	N2O	NO	0.01	91	196	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A3c; Liquid fuels	CO2	28.69	27.74	1	1	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.000
1A3c; Liquid fuels	CH4	0.03	0.01	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A3c; Liquid fuels	N2O	0.38	0.36	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A3d; Biomass	CH4	NO	0.01	60	60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A3d; Biomass	N2O	NO	0.04	91	196	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A3d; Liquid fuels	CO2	114.27	109.49	1	1	0.000	0.000	0.000	0.002	0.002	0.002	0.000	0.000	0.000	0.000
1A3d; Liquid fuels	CH4	1.88	0.35	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
1A3d; Liquid fuels	N2O	1.03	1.05	91	196	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
1A3e; Gaseous fuels	CO2	31.42	22.40	5	5	0.000	0.000	0.000	0.000	0.003	0.003	0.000	0.000	0.000	0.000
1A3e; Gaseous fuels	CH4	0.08	0.06	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A3e; Gaseous fuels	N2O	0.10	0.07	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A4a; Biomass	CH4	9.55	5.11	30	30	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.000
1A4a; Biomass	N2O	3.27	11.79	80	80	0.001	0.001	0.000	0.000	0.003	0.003	0.014	0.014	0.000	0.000
1A4a; Gaseous fuels	CO2	928.49	1'028.69	5	5	0.015	0.015	0.005	0.020	0.140	0.140	0.010	0.010	0.020	0.020
1A4a; Gaseous fuels	CH4	2.32	2.58	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A4a; Gaseous fuels	N2O	0.49	0.64	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A4a; Liquid fuels	CO2	3'918.47	1'907.19	1	1	0.001	0.001	0.024	0.037	0.036	0.036	0.002	0.002	0.001	0.001
1A4a; Liquid fuels	CH4	16.89	7.62	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003	0.000	0.000
1A4a; Liquid fuels	N2O	8.72	4.43	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.004	0.000	0.000
1A4b; Biomass	CH4	103.98	22.96	30	30	0.000	0.000	0.001	0.000	0.006	0.006	0.033	0.033	0.001	0.001

Table A – 4 (continued)

A	B	C	D	G		H		I	J	K		L		M	
IPCC category; fuel/source	Gas	Emissions 1990	Emissions 2022	Emission combined uncertainty 2022		Category contribution to inventory variance 2022		Sensitivi-ty if corr. (type A)	Sensitivi-ty if not corr. (type B)	Contribution to inventory trend uncertainty from AD		Contribution to inventory trend uncertainty from EF		Contribution to inventory trend uncertainty from EM	
				(-)%	(+)%	(-)%	(+)%			(-)%	(+)%	(-)%	(+)%	(-)%	(+)%
1A4b; Biomass	N2O	23.00	18.52	80	80	0.001	0.001	0.000	0.000	0.005	0.005	0.000	0.000	0.000	0.000
1A4b; Gaseous fuels	CO2	1'465.04	2'547.65	5	5	0.092	0.092	0.026	0.049	0.346	0.346	0.026	0.026	0.120	0.120
1A4b; Gaseous fuels	CH4	3.66	6.37	30	30	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.002	0.000	0.000
1A4b; Gaseous fuels	N2O	0.70	1.22	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
1A4b; Liquid fuels	CO2	10'099.09	3'788.07	1	1	0.004	0.004	0.084	0.073	0.071	0.071	0.007	0.007	0.005	0.005
1A4b; Liquid fuels	CH4	39.01	14.51	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.010	0.000	0.000
1A4b; Liquid fuels	N2O	21.81	8.21	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.014	0.000	0.000
1A4b; Solid fuels	CO2	58.40	4.64	7	7	0.000	0.000	0.001	0.000	0.001	0.001	0.004	0.004	0.000	0.000
1A4b; Solid fuels	CH4	5.29	0.42	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.000
1A4b; Solid fuels	N2O	0.25	0.02	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A4c; Biomass	CH4	1.22	0.57	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A4c; Biomass	N2O	0.46	1.69	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.000
1A4c; Gaseous fuels	CO2	70.22	97.66	5	5	0.000	0.000	0.001	0.002	0.013	0.013	0.001	0.001	0.000	0.000
1A4c; Gaseous fuels	CH4	0.04	0.05	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A4c; Gaseous fuels	N2O	0.03	0.05	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A4c; Liquid fuels	CO2	742.46	440.14	1	1	0.000	0.000	0.003	0.008	0.008	0.008	0.000	0.000	0.000	0.000
1A4c; Liquid fuels	CH4	7.52	1.23	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003	0.000	0.000
1A4c; Liquid fuels	N2O	4.29	3.99	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
1A5; Biomass	CH4	NO	0.00	60	60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A5; Biomass	N2O	NO	0.01	91	196	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A5; Liquid fuels	CO2	217.65	122.43	1	1	0.000	0.000	0.001	0.002	0.002	0.002	0.000	0.000	0.000	0.000
1A5; Liquid fuels	CH4	0.13	0.04	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1A5; Liquid fuels	N2O	1.64	0.95	91	196	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
1B; All fuels	Indirect CO2 from CH4	9.12	4.22	30	30	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
1B; All fuels	Indirect CO2 from NMVOC	45.75	5.30	34	34	0.000	0.000	0.001	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
1B2a; All fuels	CH4	3.94	0.61	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
1B2b; All fuels	CO2	0.09	0.03	10	10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1B2b; All fuels	CH4	88.96	42.35	30	30	0.001	0.001	0.001	0.001	0.006	0.006	0.017	0.017	0.000	0.000
1B2c; All fuels	CO2	25.96	21.64	10	10	0.000	0.000	0.000	0.000	0.003	0.003	0.000	0.000	0.000	0.000
1B2c; All fuels	CH4	0.38	0.00	30	30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1B2c; All fuels	N2O	0.02	0.00	80	80	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2A	Indirect CO2 from CO	0.04	0.02	95	238	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2A	Indirect CO2 from NMVOC	0.10	0.06	97	257	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2A1	CO2	2'550.28	1'667.09	4	4	0.031	0.031	0.008	0.032	0.091	0.091	0.030	0.030	0.009	0.009
2A2	CO2	53.35	54.62	3	3	0.000	0.000	0.000	0.001	0.003	0.003	0.003	0.003	0.000	0.000
2A3	CO2	15.25	4.52	4	4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2A4	CO2	160.16	67.84	4	4	0.000	0.000	0.001	0.001	0.004	0.004	0.006	0.006	0.000	0.000
2B	Indirect CO2 from CH4	0.39	0.75	10	10	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2B	Indirect CO2 from CO	6.33	5.05	40	40	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2B	Indirect CO2 from NMVOC	1.29	0.00	40	40	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2B2	N2O	58.24	NO	NO	NO	NO	NO	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2B5	CO2	15.36	15.02	10	10	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.000
2B5	CH4	3.88	7.66	10	10	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000
2B8	CO2	94.08	104.19	10	10	0.001	0.001	0.001	0.002	0.006	0.006	0.028	0.028	0.001	0.001
2B10	CO2	17.34	19.24	20	20	0.000	0.000	0.000	0.000	0.001	0.001	0.010	0.010	0.000	0.000
2B10	CH4	0.10	NO	NO	NO	NO	NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2B10	N2O	384.50	1.12	60	60	0.000	0.000	0.006	0.000	0.000	0.000	0.002	0.002	0.000	0.000
2C	Indirect CO2 from CO	1.10	0.15	97	262	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2C	Indirect CO2 from NMVOC	2.25	0.30	73	121	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2C1	CO2	11.91	8.29	50	50	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.011	0.000	0.000
2C3	CO2	139.26	NO	NO	NO	NO	NO	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2C3	PFCs	104.71	NO	NO	NO	NO	NO	0.002	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2C7	CO2	NO	1.25	20	20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2D	Indirect CO2 from CO	0.00	0.00	98	278	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2D	Indirect CO2 from NMVOC	194.04	35.54	36	36	0.001	0.001	0.002	0.001	d.EM	d.EM	d.EM	d.EM	0.001	0.001
2D1	CO2	48.24	26.11	54	54	0.001	0.001	0.000	0.001	0.005	0.005	0.012	0.012	0.000	0.000
2D2	CO2	6.32	2.54	74	122	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.006	0.000	0.000
2D3	CO2	3.65	25.33	22	22	0.000	0.000	0.000	0.000	0.007	0.007	0.014	0.014	0.000	0.000
2E1	HFCs	NO	0.27	25	25	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2E1	PFCs	NO	6.08	38	38	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2E1	SF6	NO	3.78	48	48	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2E3	NF3	NO	0.31	78	138	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2E5	PFCs	NO	0.00	44	44	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2F1	HFCs	0.02	1'185.09	14	14	0.160	0.160	0.023	0.023	d.EM	d.EM	d.EM	d.EM	0.209	0.209
2F1	PFCs	0.05	2.21	55	55	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2F2	HFCs	NO	31.80	89	183	0.004	0.019	0.001	0.001	d.EM	d.EM	d.EM	d.EM	0.006	0.025
2F4	HFCs	NO	12.61	41	41	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2F5	HFCs	NO	0.02	53	53	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2G	HFCs	NO	43.08	20	20	0.000	0.000	0.001	0.001	d.EM	d.EM	d.EM	d.EM	0.001	0.001
2G	PFCs	NO	17.39	9	9	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2G	SF6	141.21	51.97	44	57	0.003	0.005	0.001	0.001	d.EM	d.EM	d.EM	d.EM	0.003	0.005
2G	Indirect CO2 from CO	0.01	0.02	100	446	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2G	Indirect CO2 from NMVOC	125.50	40.10	60	88	0.003	0.007	0.001	0.001	d.EM	d.EM	d.EM	d.EM	0.004	0.009
2G3	N2O	92.49	28.28	80	80	0.003	0.003	0.001	0.001	0.001	0.001	0.071	0.071	0.005	0.005
2G4	CO2	6.07	31.80	22	22	0.000	0.000	0.001	0.001	0.009	0.009	0.017	0.017	0.000	0.000
2G4	N2O	5.31	8.17	40	40	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003	0.000	0.000
2H	Indirect CO2 from CO	1.27	0.32	98	276	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2H	Indirect CO2 from NMVOC	1.56	0.56	95	237	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
2H3	CO2	1.04	0.26	74	122	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000

Table A – 4 (continued)

A	B	C	D	G		H		I	J	K		L		M	
IPCC category; fuel/source	Gas	Emissions 1990	Emissions 2022	Emission combined uncertainty 2022		Category contribution to inventory variance 2022		Sensitivi-ty if corr. (type A)	Sensitivi-ty if not corr. (type B)	Contribution to inventory trend uncertainty from AD		Contribution to inventory trend uncertainty from EF		Contribution to inventory trend uncertainty from EM	
				(-)%	(+)%	(-)%	(+)%			(-)%	(+)%	(-)%	(+)%	(-)%	(+)%
3A	CH4	3'930.28	3'617.33	19	21	2.786	3.304	0.009	0.069	0.634	0.634	1.797	1.976	3.632	4.307
3B1-4	CH4	776.24	615.24	55	55	0.647	0.647	0.000	0.012	0.108	0.108	0.912	0.912	0.843	0.843
3B1-4	N2O	168.15	107.76	63	86	0.026	0.048	0.001	0.002	0.070	0.070	0.169	0.241	0.034	0.063
3B5	N2O	208.60	233.17	79	113	0.191	0.392	0.001	0.004	0.299	0.392	0.079	0.117	0.095	0.168
3Da	N2O	1'118.54	869.02	62	90	1.656	3.448	0.001	0.017	0.314	0.314	1.435	2.097	2.159	4.495
3Db	N2O	601.31	400.95	59	79	0.321	0.562	0.002	0.008	0.306	0.356	0.570	0.778	0.419	0.732
3G	CO2	22.25	32.82	40	40	0.001	0.001	0.000	0.001	0.036	0.036	0.001	0.001	0.001	0.001
3H	CO2	26.66	11.32	7	7	0.000	0.000	0.000	0.000	0.002	0.002	0.001	0.001	0.000	0.000
4A1	CO2	-1'272.92	-635.00	35	35	0.278	0.278	0.008	0.012	0.008	0.008	0.263	0.263	0.069	0.069
4A2	CO2	-639.92	-632.45	35	35	0.276	0.276	0.002	0.012	0.003	0.003	0.078	0.078	0.006	0.006
4B1	CO2	561.42	743.03	59	59	1.102	1.102	Agg.	Agg.	Agg.	Agg.	Agg.	Agg.	1.267	1.267
4B2	CO2	-2.21	-6.76	692	692	0.012	0.012	Agg.	Agg.	Agg.	Agg.	Agg.	Agg.	0.016	0.016
4C1	CO2	-1'169.79	129.49	901	901	7.688	7.688	Agg.	Agg.	Agg.	Agg.	Agg.	Agg.	9.789	9.789
4C2	CO2	147.92	349.08	30	30	0.063	0.063	Agg.	Agg.	Agg.	Agg.	Agg.	Agg.	0.060	0.060
4D1	CO2	114.47	111.95	116	116	0.095	0.095	0.000	0.002	0.034	0.034	0.027	0.027	0.002	0.002
4D2	CO2	21.61	51.04	21	21	0.001	0.001	Agg.	Agg.	Agg.	Agg.	Agg.	Agg.	0.000	0.000
4E1	CO2	-40.90	-60.75	50	50	0.005	0.005	0.001	0.001	0.002	0.002	0.027	0.027	0.001	0.001
4E2	CO2	267.62	225.14	50	50	0.072	0.072	0.000	0.004	0.001	0.001	0.009	0.009	0.000	0.000
4F2	CO2	83.77	125.29	50	50	0.022	0.022	0.001	0.002	0.003	0.003	0.055	0.055	0.003	0.003
4G	CO2	-1'118.55	-35.50	56	56	0.002	0.002	0.017	0.001	0.187	0.187	0.913	0.913	0.868	0.868
4II	CH4	11.20	11.20	71	71	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003	0.000	0.000
4II	N2O	4.30	4.27	84	84	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.000	0.000
4III	N2O	31.61	36.53	108	137	0.009	0.014	0.000	0.001	0.018	0.018	0.015	0.023	0.001	0.001
4IV	N2O	7.17	7.17	113	149	0.000	0.001	0.000	0.000	0.002	0.002	0.002	0.003	0.000	0.000
4V	CH4	23.17	6.49	76	76	0.000	0.000	0.000	0.000	0.007	0.007	0.016	0.016	0.000	0.000
4V	N2O	10.80	2.87	76	76	0.000	0.000	0.000	0.000	0.003	0.003	0.008	0.008	0.000	0.000
5A	CH4	862.11	274.52	30	30	0.038	0.038	0.008	0.005	d.EM	d.EM	d.EM	d.EM	0.059	0.059
5B	CH4	13.32	30.52	42	42	0.001	0.001	0.000	0.001	0.025	0.025	0.011	0.011	0.001	0.001
5B	N2O	4.64	7.74	42	42	0.000	0.000	0.000	0.000	0.006	0.006	0.002	0.002	0.000	0.000
5C	CO2	40.23	8.14	40	40	0.000	0.000	0.000	0.000	0.007	0.007	0.012	0.012	0.000	0.000
5C	CH4	9.96	5.06	60	60	0.000	0.000	0.000	0.000	0.007	0.007	0.002	0.002	0.000	0.000
5C	N2O	64.53	48.66	95	194	0.012	0.050	0.000	0.001	0.040	0.040	0.006	0.013	0.002	0.002
5C	Indirect CO2 from CH4	0.26	0.12	51	69	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
5C	Indirect CO2 from CO	1.32	0.59	58	84	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
5C	Indirect CO2 from NMVOC	0.58	0.26	58	84	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
5D	CH4	198.22	226.95	74	122	0.158	0.433	0.001	0.004	d.EM	d.EM	d.EM	d.EM	0.206	0.565
5D	N2O	1'057.67	508.73	44	56	0.278	0.456	0.007	0.010	d.EM	d.EM	d.EM	d.EM	0.362	0.595
5E	Indirect CO2 from CO	0.00	0.00	28	28	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
5E	Indirect CO2 from NMVOC	0.06	0.13	31	31	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
6A	CO2	12.76	8.34	82	131	0.000	0.001	Agg.	Agg.	Agg.	Agg.	Agg.	Agg.	0.000	0.000
6A	CH4	0.83	0.47	71	105	0.000	0.000	Agg.	Agg.	Agg.	Agg.	Agg.	Agg.	0.000	0.000
6A	N2O	0.60	0.28	104	202	0.000	0.000	Agg.	Agg.	Agg.	Agg.	Agg.	Agg.	0.000	0.000
6A	Indirect CO2 from CH4	0.06	0.04	68	106	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
6A	Indirect CO2 from CO	1.00	0.60	61	90	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
6A	Indirect CO2 from NMVOC	0.22	0.12	50	67	0.000	0.000	0.000	0.000	d.EM	d.EM	d.EM	d.EM	0.000	0.000
Total						17.2	20.5							20.7	24.7
Total		52'098.6	42'063.5	Emissions 2022 uncertainty (%):		4.1	4.5			Trend uncertainty (%):				4.5	5.0

A2.3 Detailed results of approach 2 uncertainty analysis

Table A – 5 Uncertainty analysis of greenhouse gas emissions and removals, approach 2, for 2022 and for the trend 1990–2022, including LULUCF categories and indirect CO_2 emissions. d.EM stands for direct emission and indicates that input uncertainties are given for the emission but neither for the activity data nor for the emission factor. Monte Carlo simulations were run 400’000 times. The reported uncertainties correspond to the borders of the narrowest 95 % confidence interval. Contributions to inventory trend (mean, uncertainties, columns I and J) are values normalised by the total inventory base year emission. Columns A to J are labelled according to Table 3-3 in the 2006 IPCC Guidelines, vol.1, chp. 3 (IPCC 2006). “Agg.”: indicates that values for AD and EF cannot be computed because the row results from an aggregation. Note that for the uncertainty analyses still four categories are used according to the CRF nomenclature within sector 4 LULUCF: 4(II), 4(III), 4(IV) and 4(V).

A	B	C	D	E		F		G		H	I	J	
IPCC category; fuel/source	Gas	Emissions 1990	Emissions 2022	Activity data uncertainty 2022		Emission factor uncertainty 2022		Emission combined uncertainty 2022		Emission contri-bution to variance 2022	Contri-bution to trend	Contribution to uncertainty of trend	
		kt CO2 eq.	kt CO2 eq.	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	Fraction	%	(-)%	(+)%
1A1; Biomass	CH4	0.10	0.18	10	10	28	28	30	30	0.000	0.000	0.000	0.000
1A1; Biomass	N2O	20.12	12.85	10	10	79	80	80	80	0.000	-0.014	0.013	0.012
1A1; Gaseous fuels	CO2	243.40	370.85	5	5	0	0	5	5	0.000	0.245	0.045	0.044
1A1; Gaseous fuels	CH4	0.14	0.60	5	5	30	29	30	30	0.000	0.001	0.000	0.000
1A1; Gaseous fuels	N2O	0.14	0.72	5	5	81	79	80	80	0.000	0.001	0.001	0.001
1A1; Liquid fuels	CO2	685.90	386.83	1	1	0	0	1	1	0.000	-0.574	0.029	0.028
1A1; Liquid fuels	CH4	0.58	0.22	1	1	30	30	30	30	0.000	-0.001	0.000	0.000
1A1; Liquid fuels	N2O	1.01	0.26	1	1	81	79	79	81	0.000	-0.001	0.001	0.001
1A1; Solid fuels	CO2	49.13	NO	NO	NO	NO	NO	NO	NO	0.000	-0.094	0.008	0.008
1A1; Solid fuels	CH4	0.15	NO	NO	NO	NO	NO	NO	NO	0.000	0.000	0.000	0.000
1A1; Solid fuels	N2O	0.21	NO	NO	NO	NO	NO	NO	NO	0.000	0.000	0.000	0.000
1A1; Other fuels	CO2	1'491.55	2'387.58	5	5	17	17	18	18	0.053	1.721	0.391	0.408
1A1; Other fuels	N2O	21.63	26.32	5	5	81	79	80	80	0.000	0.009	0.052	0.053
1A2; Biomass	CH4	2.91	1.10	10	10	28	28	30	30	0.000	-0.003	0.001	0.001
1A2; Biomass	N2O	4.69	19.38	10	10	79	80	81	80	0.000	0.028	0.023	0.023
1A2; Gaseous fuels	CO2	1'100.12	1'853.60	5	5	0	0	5	5	0.003	1.447	0.220	0.221
1A2; Gaseous fuels	CH4	0.61	0.94	5	5	30	30	30	30	0.000	0.001	0.000	0.000
1A2; Gaseous fuels	N2O	0.62	0.90	5	5	79	80	80	80	0.000	0.001	0.000	0.000
1A2; Liquid fuels	CO2	3'974.06	1'530.78	1	1	0	0	1	1	0.000	-4.692	0.220	0.224
1A2; Liquid fuels	CH4	5.14	1.08	1	1	30	30	30	30	0.000	-0.008	0.002	0.002
1A2; Liquid fuels	N2O	11.87	8.99	1	1	80	80	80	80	0.000	-0.006	0.004	0.005
1A2; Solid fuels	CO2	1'274.70	360.40	5	5	5	5	7	7	0.000	-1.756	0.173	0.171
1A2; Solid fuels	CH4	0.35	0.19	5	5	30	30	30	30	0.000	0.000	0.000	0.000
1A2; Solid fuels	N2O	5.46	1.51	5	5	80	79	80	80	0.000	-0.008	0.006	0.006
1A2; Other fuels	CO2	192.37	434.64	5	5	9	9	10	11	0.001	0.465	0.065	0.067
1A2; Other fuels	CH4	0.87	0.69	5	5	30	30	30	30	0.000	0.000	0.000	0.000
1A2; Other fuels	N2O	1.97	5.15	5	5	79	80	79	81	0.000	0.006	0.008	0.009
1A3a; Kerosene fossil	CO2	252.55	68.70	1	1	0	0	1	1	0.000	-0.353	0.017	0.017
1A3a; Kerosene fossil	CH4	0.19	0.10	1	1	60	60	60	60	0.000	0.000	0.000	0.000
1A3a; Kerosene fossil	N2O	1.83	0.50	1	1	99	150	99	150	0.000	-0.003	0.004	0.003
1A3b; Biomass	CH4	NO	0.59	10	10	59	60	59	61	0.000	0.001	0.001	0.001
1A3b; Biomass	N2O	NO	4.23	10	10	99	150	99	150	0.000	0.008	0.008	0.012
1A3b; Gaseous fuels	CO2	NO	29.12	5	5	0	0	5	5	0.000	0.056	0.004	0.004
1A3b; Gaseous fuels	CH4	NO	0.23	5	5	30	29	30	30	0.000	0.000	0.000	0.000
1A3b; Gaseous fuels	N2O	NO	0.43	5	5	80	79	79	80	0.000	0.001	0.001	0.001
1A3b; Diesel oil	CO2	2'631.94	7'026.84	1	1	0	0	1	1	0.001	8.440	0.413	0.405
1A3b; Diesel oil	CH4	2.56	7.02	1	1	20	20	20	20	0.000	0.009	0.002	0.002
1A3b; Diesel oil	N2O	5.41	92.05	1	1	22	22	22	22	0.000	0.166	0.036	0.038
1A3b; Gasoline	CO2	11'328.41	6'161.62	1	1	0	0	1	1	0.001	-9.923	0.483	0.482
1A3b; Gasoline	CH4	128.74	14.41	1	1	38	37	37	37	0.000	-0.220	0.082	0.081
1A3b; Gasoline	N2O	143.06	12.43	1	1	50	50	50	50	0.000	-0.251	0.127	0.124
1A3b; Liquefied petroleum gas	CO2	NO	1.42	1	1	10	10	10	10	0.000	0.003	0.000	0.000
1A3b; Liquefied petroleum gas	CH4	NO	0.00	1	1	30	30	30	30	0.000	0.000	0.000	0.000
1A3b; Liquefied petroleum gas	N2O	NO	0.01	1	1	79	81	80	80	0.000	0.000	0.000	0.000
1A3c; Biomass	CH4	NO	0.00	10	10	59	59	59	61	0.000	0.000	0.000	0.000
1A3c; Biomass	N2O	NO	0.01	10	10	99	149	99	151	0.000	0.000	0.000	0.000
1A3c; Liquid fuels	CO2	28.69	27.74	1	1	0	0	1	1	0.000	-0.002	0.001	0.001
1A3c; Liquid fuels	CH4	0.03	0.01	1	1	29	30	30	30	0.000	0.000	0.000	0.000
1A3c; Liquid fuels	N2O	0.38	0.36	1	1	79	81	80	80	0.000	0.000	0.000	0.000
1A3d; Biomass	CH4	NO	0.01	10	10	58	60	60	60	0.000	0.000	0.000	0.000
1A3d; Biomass	N2O	NO	0.04	10	10	99	150	99	151	0.000	0.000	0.000	0.000
1A3d; Liquid fuels	CO2	114.27	109.49	1	1	0	0	1	1	0.000	-0.009	0.002	0.002
1A3d; Liquid fuels	CH4	1.88	0.35	1	1	30	30	30	30	0.000	-0.003	0.001	0.001
1A3d; Liquid fuels	N2O	1.03	1.05	1	1	99	150	99	150	0.000	0.000	0.000	0.000
1A3e; Gaseous fuels	CO2	31.42	22.40	5	5	0	0	5	5	0.000	-0.017	0.004	0.004
1A3e; Gaseous fuels	CH4	0.08	0.06	5	5	29	30	30	30	0.000	0.000	0.000	0.000
1A3e; Gaseous fuels	N2O	0.10	0.07	5	5	80	79	81	79	0.000	0.000	0.000	0.000
1A4a; Biomass	CH4	9.55	5.11	10	10	28	28	30	30	0.000	-0.009	0.003	0.003
1A4a; Biomass	N2O	3.27	11.79	10	10	80	79	81	80	0.000	0.016	0.013	0.013
1A4a; Gaseous fuels	CO2	928.49	1'028.69	5	5	0	0	5	5	0.001	0.192	0.136	0.136
1A4a; Gaseous fuels	CH4	2.32	2.58	5	5	30	29	30	30	0.000	0.000	0.000	0.000
1A4a; Gaseous fuels	N2O	0.49	0.64	5	5	79	80	80	79	0.000	0.000	0.000	0.000
1A4a; Liquid fuels	CO2	3'918.47	1'907.19	1	1	0	0	1	1	0.000	-3.863	0.185	0.186
1A4a; Liquid fuels	CH4	16.89	7.62	1	1	30	30	30	30	0.000	-0.018	0.005	0.005
1A4a; Liquid fuels	N2O	8.72	4.43	1	1	79	81	80	80	0.000	-0.008	0.007	0.007
1A4b; Biomass	CH4	103.98	22.96	10	10	28	28	30	30	0.000	-0.156	0.050	0.048

Table A – 5 (continued)

A	B	C	D	E		F		G		H	I	J	
IPCC category; fuel/source	Gas	Emissions 1990	Emissions 2022	Activity data uncertainty 2022		Emission factor uncertainty 2022		Emission combined uncertainty 2022		Emission contri-bution to variance 2022	Contri-bution to trend	Contribution to uncertainty of trend	
		kt CO2 eq.	kt CO2 eq.	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	Fraction	%	(-)%	(+)%
1A4b; Biomass	N2O	23.00	18.52	10	10	79	80	81	79	0.000	-0.009	0.009	0.008
1A4b; Gaseous fuels	CO2	1'465.04	2'547.65	5	5	0	0	5	5	0.005	2.079	0.304	0.301
1A4b; Gaseous fuels	CH4	3.66	6.37	5	5	30	29	30	30	0.000	0.005	0.002	0.002
1A4b; Gaseous fuels	N2O	0.70	1.22	5	5	81	79	81	79	0.000	0.001	0.001	0.001
1A4b; Liquid fuels	CO2	10'099.09	3'788.07	1	1	0	0	1	1	0.000	-12.120	0.574	0.568
1A4b; Liquid fuels	CH4	39.01	14.51	1	1	30	30	30	30	0.000	-0.047	0.014	0.014
1A4b; Liquid fuels	N2O	21.81	8.21	1	1	80	80	80	81	0.000	-0.026	0.021	0.021
1A4b; Solid fuels	CO2	58.40	4.64	5	5	5	5	7	7	0.000	-0.103	0.009	0.009
1A4b; Solid fuels	CH4	5.29	0.42	5	5	29	30	30	30	0.000	-0.009	0.003	0.003
1A4b; Solid fuels	N2O	0.25	0.02	5	5	80	80	81	79	0.000	0.000	0.000	0.000
1A4c; Biomass	CH4	1.22	0.57	10	10	29	28	30	30	0.000	-0.001	0.000	0.000
1A4c; Biomass	N2O	0.46	1.69	10	10	80	79	79	81	0.000	0.002	0.002	0.002
1A4c; Gaseous fuels	CO2	70.22	97.66	5	5	0	0	5	5	0.000	0.053	0.012	0.012
1A4c; Gaseous fuels	CH4	0.04	0.05	5	5	29	30	30	30	0.000	0.000	0.000	0.000
1A4c; Gaseous fuels	N2O	0.03	0.05	5	5	79	80	80	80	0.000	0.000	0.000	0.000
1A4c; Liquid fuels	CO2	742.46	440.14	1	1	0	0	1	1	0.000	-0.581	0.029	0.029
1A4c; Liquid fuels	CH4	7.52	1.23	1	1	30	30	30	30	0.000	-0.012	0.004	0.004
1A4c; Liquid fuels	N2O	4.29	3.99	1	1	80	80	80	80	0.000	-0.001	0.000	0.000
1A5; Biomass	CH4	NO	0.00	10	10	58	60	60	61	0.000	0.000	0.000	0.000
1A5; Biomass	N2O	NO	0.01	10	10	99	150	99	150	0.000	0.000	0.000	0.000
1A5; Liquid fuels	CO2	217.65	122.43	1	1	0	0	1	1	0.000	-0.183	0.009	0.009
1A5; Liquid fuels	CH4	0.13	0.04	1	1	30	30	30	30	0.000	0.000	0.000	0.000
1A5; Liquid fuels	N2O	1.64	0.95	1	1	99	150	99	150	0.000	-0.001	0.002	0.001
1B; All fuels	Indirect CO2 from CH4	9.12	4.22	d.EM	d.EM	d.EM	d.EM	30	29	0.000	-0.009	0.006	0.006
1B; All fuels	Indirect CO2 from NMVOC	45.75	5.30	d.EM	d.EM	d.EM	d.EM	34	34	0.000	-0.078	0.033	0.033
1B2a; All fuels	CH4	3.94	0.61	5	5	29	30	30	30	0.000	-0.006	0.002	0.002
1B2b; All fuels	CO2	0.09	0.03	5	5	9	9	10	10	0.000	0.000	0.000	0.000
1B2b; All fuels	CH4	88.96	42.35	5	5	29	30	30	30	0.000	-0.090	0.029	0.028
1B2c; All fuels	CO2	25.96	21.64	5	5	9	9	10	10	0.000	-0.008	0.003	0.003
1B2c; All fuels	CH4	0.38	0.00	5	5	30	30	30	30	0.000	-0.001	0.000	0.000
1B2c; All fuels	N2O	0.02	0.00	5	5	80	80	79	81	0.000	0.000	0.000	0.000
2A	Indirect CO2 from CO	0.04	0.02	d.EM	d.EM	d.EM	d.EM	100	179	0.000	0.000	0.000	0.000
2A	Indirect CO2 from NMVOC	0.10	0.06	d.EM	d.EM	d.EM	d.EM	100	191	0.000	0.000	0.000	0.000
2A1	CO2	2'550.28	1'667.09	2	2	4	4	4	4	0.002	-1.696	0.157	0.150
2A2	CO2	53.35	54.62	2	2	2	2	3	3	0.000	0.002	0.007	0.007
2A3	CO2	15.25	4.52	2	2	3	3	4	4	0.000	-0.021	0.009	0.009
2A4	CO2	160.16	67.84	2	2	3	3	4	4	0.000	-0.177	0.092	0.094
2B	Indirect CO2 from CH4	0.39	0.75	d.EM	d.EM	d.EM	d.EM	10	10	0.000	0.001	0.000	0.000
2B	Indirect CO2 from CO	6.33	5.05	d.EM	d.EM	d.EM	d.EM	39	40	0.000	-0.002	0.006	0.006
2B	Indirect CO2 from NMVOC	1.29	0.00	d.EM	d.EM	d.EM	d.EM	40	40	0.000	-0.002	0.001	0.001
2B2	N2O	58.24	NO	NO	NO	NO	NO	NO	NO	0.000	-0.112	0.068	0.067
2B5	CO2	15.36	15.02	2	2	10	10	10	10	0.000	-0.001	0.001	0.001
2B5	CH4	3.88	7.66	2	2	10	10	10	10	0.000	0.007	0.001	0.001
2B8	CO2	94.08	104.19	2	2	10	10	10	10	0.000	0.019	0.027	0.028
2B10	CO2	17.34	19.24	2	2	20	20	20	20	0.000	0.004	0.021	0.021
2B10	CH4	0.10	NO	NO	NO	NO	NO	NO	NO	0.000	0.000	0.000	0.000
2B10	N2O	384.50	1.12	2	2	60	60	60	60	0.000	-0.736	0.438	0.446
2C	Indirect CO2 from CO	1.10	0.15	d.EM	d.EM	d.EM	d.EM	100	195	0.000	-0.002	0.005	0.003
2C	Indirect CO2 from NMVOC	2.25	0.30	d.EM	d.EM	d.EM	d.EM	82	101	0.000	-0.004	0.004	0.004
2C1	CO2	11.91	8.29	2	2	50	50	50	50	0.000	-0.007	0.014	0.014
2C3	CO2	139.26	NO	NO	NO	NO	NO	NO	NO	0.000	-0.267	0.057	0.056
2C3	PFCs	104.71	NO	NO	NO	NO	NO	NO	NO	0.000	-0.201	0.021	0.020
2C7	CO2	NO	1.25	2	2	20	20	20	20	0.000	0.002	0.000	0.000
2D	Indirect CO2 from CO	0.00	0.00	d.EM	d.EM	d.EM	d.EM	100	207	0.000	0.000	0.000	0.000
2D	Indirect CO2 from NMVOC	194.04	35.54	d.EM	d.EM	d.EM	d.EM	36	36	0.000	-0.304	0.152	0.152
2D1	CO2	48.24	26.11	20	20	51	49	53	55	0.000	-0.043	0.023	0.023
2D2	CO2	6.32	2.54	10	10	83	101	84	101	0.000	-0.007	0.007	0.006
2D3	CO2	3.65	25.33	10	10	20	20	22	22	0.000	0.042	0.012	0.012
2E1	HFCs	NO	0.27	d.EM	d.EM	d.EM	d.EM	25	25	0.000	0.001	0.000	0.000
2E1	PFCs	NO	6.08	d.EM	d.EM	d.EM	d.EM	38	38	0.000	0.012	0.004	0.005
2E1	SF6	NO	3.78	d.EM	d.EM	d.EM	d.EM	48	48	0.000	0.007	0.003	0.003
2E3	NF3	NO	0.31	d.EM	d.EM	d.EM	d.EM	88	111	0.000	0.001	0.001	0.001
2E5	PFCs	NO	0.00	d.EM	d.EM	d.EM	d.EM	44	44	0.000	0.000	0.000	0.000
2F1	HFCs	0.02	1'185.09	d.EM	d.EM	d.EM	d.EM	14	14	0.009	2.276	0.339	0.341
2F1	PFCs	0.05	2.21	d.EM	d.EM	d.EM	d.EM	55	56	0.000	0.004	0.002	0.002
2F2	HFCs	NO	31.80	d.EM	d.EM	d.EM	d.EM	98	141	0.001	0.061	0.060	0.086
2F4	HFCs	NO	12.61	d.EM	d.EM	d.EM	d.EM	41	41	0.000	0.024	0.010	0.010
2F5	HFCs	NO	0.02	d.EM	d.EM	d.EM	d.EM	53	52	0.000	0.000	0.000	0.000
2G	HFCs	NO	43.08	d.EM	d.EM	d.EM	d.EM	20	20	0.000	0.083	0.017	0.017
2G	PFCs	NO	17.39	d.EM	d.EM	d.EM	d.EM	9	9	0.000	0.033	0.003	0.003
2G	SF6	141.21	51.97	d.EM	d.EM	d.EM	d.EM	48	52	0.000	-0.171	0.088	0.083
2G	Indirect CO2 from CO	0.01	0.02	d.EM	d.EM	d.EM	d.EM	100	310	0.000	0.000	0.000	0.000
2G	Indirect CO2 from NMVOC	125.50	40.10	d.EM	d.EM	d.EM	d.EM	67	76	0.000	-0.164	0.216	0.189
2G3	N2O	92.49	28.28	1	1	80	80	79	80	0.000	-0.123	0.099	0.098
2G4	CO2	6.07	31.80	10	10	20	20	22	22	0.000	0.049	0.015	0.015
2G4	N2O	5.31	8.17	1	1	40	40	40	40	0.000	0.006	0.002	0.002
2H	Indirect CO2 from CO	1.27	0.32	d.EM	d.EM	d.EM	d.EM	100	204	0.000	-0.002	0.006	0.004
2H	Indirect CO2 from NMVOC	1.56	0.56	d.EM	d.EM	d.EM	d.EM	100	178	0.000	-0.002	0.006	0.005
2H3	CO2	1.04	0.26	5	5	84	100	84	100	0.000	-0.001	0.001	0.001

Table A – 5 (continued)

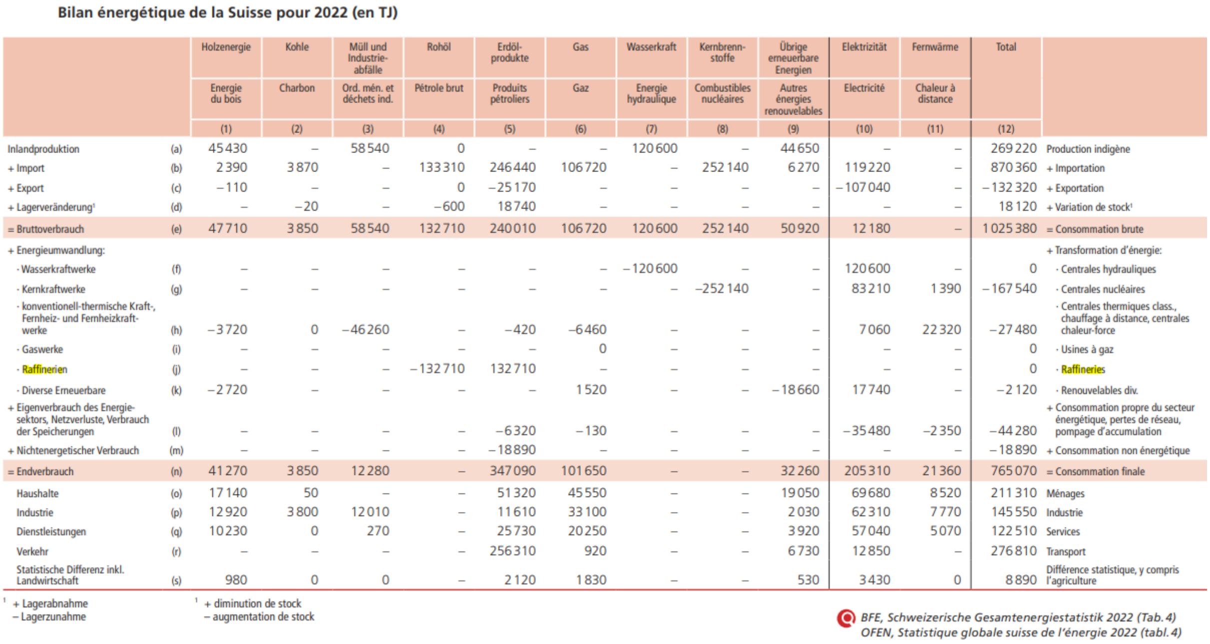
A	B	C	D	E		F		G		H	I	J	
IPCC category; fuel/source	Gas	Emissions 1990	Emissions 2022	Activity data uncertainty 2022		Emission factor uncertainty 2022		Emission combined uncertainty 2022		Emission contri-bution to variance 2022	Contri-bution to trend	Contribution to uncertainty of trend	
		kt CO2 eq.	kt CO2 eq.	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	Fraction	%	(-)%	(+)%
3A	CH4	3'930.28	3'617.33	6	7	19	20	20	20	0.162	-0.594	2.109	2.130
3B1-4	CH4	776.24	615.24	6	6	54	55	55	55	0.034	-0.307	1.044	1.033
3B1-4	N2O	168.15	107.76	24	24	64	72	66	77	0.002	-0.116	0.296	0.280
3B5	N2O	208.60	233.17	51	56	71	81	80	100	0.016	0.047	0.360	0.379
3Da	N2O	1'118.54	869.02	13	13	68	77	68	79	0.135	-0.469	2.244	2.121
3Db	N2O	601.31	400.95	30	31	57	63	62	72	0.024	-0.384	1.008	0.946
3G	CO2	22.25	32.82	40	41	5	5	40	41	0.000	0.020	0.031	0.030
3H	CO2	26.66	11.32	5	5	5	5	7	7	0.000	-0.029	0.003	0.003
4A1	CO2	-1'272.92	-635.00	1	1	35	35	35	35	0.015	1.226	0.439	0.443
4A2	CO2	-639.92	-632.45	1	2	35	35	35	35	0.015	0.014	0.005	0.005
4B1	CO2	561.42	743.03	Agg.	Agg.	Agg.	Agg.	60	59	0.058	0.350	1.249	1.260
4B2	CO2	-2.21	-6.76	Agg.	Agg.	Agg.	Agg.	696	693	0.001	-0.009	0.104	0.105
4C1	CO2	-1'169.79	129.49	Agg.	Agg.	Agg.	Agg.	912	916	0.408	2.507	3.299	3.336
4C2	CO2	147.92	349.08	Agg.	Agg.	Agg.	Agg.	30	30	0.003	0.386	0.202	0.200
4D1	CO2	114.47	111.95	91	91	72	72	104	127	0.005	-0.005	0.006	0.005
4D2	CO2	21.61	51.04	Agg.	Agg.	Agg.	Agg.	21	21	0.000	0.057	0.010	0.011
4E1	CO2	-40.90	-60.75	4	4	50	50	51	50	0.000	-0.038	0.019	0.019
4E2	CO2	267.62	225.14	5	5	50	50	50	50	0.004	-0.082	0.041	0.041
4F2	CO2	83.77	125.29	3	3	50	50	50	50	0.001	0.080	0.040	0.040
4G	CO2	-1'118.55	-35.50	11	11	55	54	57	55	0.000	2.084	1.165	1.220
4II	CH4	11.20	11.20	10	10	70	70	71	71	0.000	0.000	0.000	0.000
4II	N2O	4.30	4.27	50	51	67	67	80	87	0.000	0.000	0.000	0.000
4III	N2O	31.61	36.53	83	84	78	90	100	137	0.001	0.009	0.009	0.013
4IV	N2O	7.17	7.17	85	87	85	99	103	147	0.000	0.000	0.000	0.000
4V	CH4	23.17	6.49	30	30	70	70	75	79	0.000	-0.032	0.025	0.024
4V	N2O	10.80	2.87	30	30	69	71	74	79	0.000	-0.015	0.012	0.011
5A	CH4	862.11	274.52	d.EM	d.EM	d.EM	d.EM	30	30	0.002	-1.128	0.337	0.336
5B	CH4	13.32	30.52	30	30	30	30	42	43	0.000	0.033	0.021	0.022
5B	N2O	4.64	7.74	30	30	30	30	41	43	0.000	0.006	0.005	0.006
5C	CO2	40.23	8.14	30	30	27	27	39	40	0.000	-0.062	0.029	0.028
5C	CH4	9.96	5.06	50	50	33	33	58	62	0.000	-0.009	0.012	0.011
5C	N2O	64.53	48.66	30	30	99	147	99	151	0.002	-0.030	0.084	0.053
5C	Indirect CO2 from CH4	0.26	0.12	d.EM	d.EM	d.EM	d.EM	56	62	0.000	0.000	0.000	0.000
5C	Indirect CO2 from CO	1.32	0.59	d.EM	d.EM	d.EM	d.EM	65	73	0.000	-0.001	0.002	0.002
5C	Indirect CO2 from NMVOC	0.58	0.26	d.EM	d.EM	d.EM	d.EM	65	73	0.000	-0.001	0.001	0.001
5D	CH4	198.22	226.95	d.EM	d.EM	d.EM	d.EM	84	100	0.015	0.056	0.581	0.606
5D	N2O	1'057.67	508.73	d.EM	d.EM	d.EM	d.EM	48	50	0.019	-1.043	1.897	1.678
5E	Indirect CO2 from CO	0.00	0.00	d.EM	d.EM	d.EM	d.EM	28	28	0.000	0.000	0.000	0.000
5E	Indirect CO2 from NMVOC	0.06	0.13	d.EM	d.EM	d.EM	d.EM	31	31	0.000	0.000	0.000	0.000
6A	CO2	12.76	8.34	Agg.	Agg.	Agg.	Agg.	86	113	0.000	-0.008	0.025	0.017
6A	CH4	0.83	0.47	Agg.	Agg.	Agg.	Agg.	75	93	0.000	-0.001	0.001	0.001
6A	N2O	0.60	0.28	Agg.	Agg.	Agg.	Agg.	100	163	0.000	-0.001	0.001	0.001
6A	Indirect CO2 from CH4	0.06	0.04	d.EM	d.EM	d.EM	d.EM	76	90	0.000	0.000	0.000	0.000
6A	Indirect CO2 from CO	1.00	0.60	d.EM	d.EM	d.EM	d.EM	68	78	0.000	-0.001	0.002	0.002
6A	Indirect CO2 from NMVOC	0.22	0.12	d.EM	d.EM	d.EM	d.EM	55	60	0.000	0.000	0.000	0.000
Total, Monte Carlo simulations		52'098.0	42'064.2					4.3	4.4	1.0	-19.2	4.9	4.8
Total, inventory		52'098.6	42'063.5								-19.3		

Annex 3 Detailed description of the reference approach (including inputs to the reference approach such as the national energy balance) and the results of the comparison of national estimates of emissions with those obtained using the reference approach

A3.1 National energy balance

The national energy balance is provided in Table A – 6. A detailed description of the reference approach and the results of the comparison is provided in chp. 3.2.1.

Table A – 6 Switzerland’s energy balance 2022 (SFOE 2023) in TJ. Liechtenstein’s consumption of liquid fuels is included in the numbers (see general remarks in annex A3.2 below on final Swiss energy consumption).



Bilan énergétique de la Suisse pour 2022 (en TJ)

		Holzenergie	Kohle	Müll und Industrie-abfälle	Rohöl	Erdöl-produkte	Gas	Wasserkraft	Kernbrenn-stoffe	Übrige erneuerbare Energien	Elektrizität	Fernwärme	Total	
		Energie du bois	Charbon	Ord. mén. et déchets ind.	Pétrole brut	Produits pétroliers	Gaz	Energie hydraulique	Combustibles nucléaires	Autres énergies renouvelables	Electricité	Chaleur à distance		
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	
Inlandproduktion	(a)	45 430	–	58 540	0	–	–	120 600	–	44 650	–	–	269 220	Production indigène
+ Import	(b)	2 390	3 870	–	133 310	246 440	106 720	–	252 140	6 270	119 220	–	870 360	+ Importation
+ Export	(c)	–110	–	–	0	–25 170	–	–	–	–	–107 040	–	–132 320	+ Exportation
+ Lagerveränderung[1]	(d)	–	–20	–	–600	18 740	–	–	–	–	–	–	18 120	+ Variation de stock[1]
= Bruttoverbrauch	(e)	47 710	3 850	58 540	132 710	240 010	106 720	120 600	252 140	50 920	12 180	–	1 025 380	= Consommation brute
+ Energieumwandlung:														+ Transformation d’énergie:
· Wasserkraftwerke	(f)	–	–	–	–	–	–	–120 600	–	–	120 600	–	0	· Centrales hydrauliques
· Kernkraftwerke	(g)	–	–	–	–	–	–	–	–252 140	–	83 210	1 390	–167 540	· Centrales nucléaires
· konventionell-thermische Kraft-, Fernheiz- und Fernheizkraftwerke	(h)	–3 720	0	–46 260	–	–420	–6 460	–	–	–	7 060	22 320	–27 480	· Centrales thermiques class., chauffage à distance, centrales chaleur-force
· Gaswerke	(i)	–	–	–	–	–	0	–	–	–	–	–	0	· Usines à gaz
· Raffinerien	(j)	–	–	–	–132 710	132 710	–	–	–	–	–	–	0	· Raffineries
· Diverse Erneuerbare	(k)	–2 720	–	–	–	–	1 520	–	–	–18 660	17 740	–	–2 120	· Renouvelables div.
+ Eigenverbrauch des Energiesektors, Netzverluste, Verbrauch der Speicherungen	(l)	–	–	–	–	–6 320	–130	–	–	–	–35 480	–2 350	–44 280	+ Consommation propre du secteur énergétique, pertes de réseau, pompage d’accumulation
+ Nichtenergetischer Verbrauch	(m)	–	–	–	–	–18 890	–	–	–	–	–	–	–18 890	+ Consommation non énergétique
= Endverbrauch	(n)	41 270	3 850	12 280	–	347 090	101 650	–	–	32 260	205 310	21 360	765 070	= Consommation finale
Haushalte	(o)	17 140	50	–	–	51 320	45 550	–	–	19 050	69 680	8 520	211 310	Ménages
Industrie	(p)	12 920	3 800	12 010	–	11 610	33 100	–	–	2 030	62 310	7 770	145 550	Industrie
Dienstleistungen	(q)	10 230	0	270	–	25 730	20 250	–	–	3 920	57 040	5 070	122 510	Services
Verkehr	(r)	–	–	–	–	256 310	920	–	–	6 730	12 850	–	276 810	Transport
Statistische Differenz inkl. Landwirtschaft	(s)	980	0	0	–	2 120	1 830	–	–	530	3 430	0	8 890	Différence statistique, y compris l'agriculture

[1] + Lagerabnahme
– Lagerzunahme

[1] + diminution de stock
– augmentation de stock

BFE, Schweizerische Gesamtenergiestatistik 2022 (Tab. 4)
OFEN, Statistique globale suisse de l’énergie 2022 (tabl. 4)

A3.2 Differences between International Energy Agency (IEA) data and the reference approach

Reviewers have repeatedly asked for explanations of the apparent differences between the energy data held by the International Energy Agency (IEA) and the data reported in the Reference Approach. In order to clarify the pertaining issues, the reasons for the major differences are given below. Data for the year 2010 are used to illustrate the description, however, a more recent comparison with data for 2016 produced similar results.

General remarks

The net calorific values used by IEA differ from those used in the greenhouse gas inventory. In order to avoid differences caused by the conversion with different NCV, the comparison between IEA and the Reference Approach is made in kt.

Stock changes as reported by IEA are only including primary stocks (IEA 2005), while the reporting in the Reference Approach includes secondary and tertiary stocks. This results in a particularly large difference for gas oil, as retailers and end-consumers hold considerable amounts of heating fuel on stock. The IEA subsumes secondary and tertiary stock changes under statistical differences.

All data regarding liquid fuel consumption reported by the IEA includes fuel consumption in Liechtenstein (geographical coverage in IEA 2012). For reporting purposes under the UNFCCC, consumption of Liechtenstein is subtracted.

Data sources used for the comparison shown in Table A – 7 below are:

- Switzerland's greenhouse gas inventory 1990–2011, submission of 15. April 2013, CRF Table1.A(b), (FOEN 2013).
- Energy statistics of OECD countries (2012 Edition), (IEA 2012).

Liquid fuels

The total amount of liquid fuel consumption as reported in the greenhouse gas inventory is 11'052 kt. There is a difference of 13 kt (0.1 %) between CRF and IEA. This difference is primarily caused by the different methodology used for aviation bunkers (see below).

Crude oil

Crude oil in the reference approach contains additives, while IEA lists them separately (data in italics in Table A – 7. The difference between CRF and IEA is smaller than 0.1 % if the sum of additives, refinery feedstocks and crude oil is considered.

Gasoline

The comparison is made for motor gasoline only. Aviation gasoline is included under aviation fuels. Gasoline reported by IEA includes gasoline used in Liechtenstein (LIE), which is subtracted for reporting under the UNFCCC. The difference between CRF and IEA is approximately 0.1 %, if the consumption of LIE is taken into account.

Aviation fuels

The different aviation fuels are aggregated in the greenhouse gas inventory. For comparison of IEA and reference approach, all aviation fuels are summed up. The difference between IEA and reference approach if considering the apparent final consumption is 12 kt (approximately 1 % of imports). This difference is largely due to a different methodology used to estimate international bunker. Aviation bunkers have to be reported monthly to the IEA. As the tier 3 approach used for the greenhouse gas inventory is not available on a monthly basis, the international bunker fuel estimate of IEA consists of the total consumption at the two international airports in Zurich and Geneva, while all remaining fuel use is considered domestic. The reporting in the national greenhouse gas inventory is based on a much more detailed approach, where information on single flights is taken into account. Due to the different approach, the numbers are somewhat different. However, the order of magnitude is the same, and the information in the inventory is based on a higher-tier method and presumably more accurate.

Diesel oil and gas oil

The IEA numbers include diesel oil and gas oil used in Liechtenstein. Furthermore, stock changes are reported differently in the CRF and by the IEA. Secondary and tertiary stock changes are subsumed under statistical differences by the IEA, while they are included in the stock change reported in the reference approach. If the statistical differences are taken into account, the difference in the apparent consumption is less than 0.1 %.

Residual fuel oil

Data agree between IEA and greenhouse gas inventory. It seems as if there is a rounding error in the imported amounts, leading to an apparent difference of 1 kt. According to the foreign trade statistics, 33'693 t of residual fuel oil had been imported in 2010.

Bitumen

Bitumen is a main feedstock in the greenhouse gas inventory. Data between IEA and the reference approach compare well. Again, small differences are likely due to the use of rounded values, leading to apparent differences of the order of 1–2 kt.

Petroleum coke

There are considerable differences (26 kt) in the reported numbers for petroleum coke import. The reason for this apparent difference is that for IEA, all petroleum coke is reported together. In the greenhouse gas inventory submitted in 2013, however, only the petroleum coke used as a fuel was reported under petroleum coke, while calcined petroleum coke was reported together with “other oil” as feedstocks. This is largely a consequence of the treatment of fuels and feedstocks in the Swiss overall energy statistics (SFOE 2012).

Lubricants

There are small differences between IEA and the reference approach, as the data reported to the IEA comprises a slightly different set of customs tariff headings for lubricants to the one used for the Swiss overall energy statistics. The substances not reported under lubricants in the reference approach are reported under other oil.

Liquefied petroleum gas

The reporting of liquefied petroleum gas in the greenhouse gas inventory includes white spirit and lamp oil. As for petroleum coke, IEA numbers include fuels that are used as feedstocks, while in the reference approach, only liquefied petroleum gas, white spirit and lamp oil used as fuels are reported under liquefied petroleum gas. The difference in apparent consumption between IEA and the reference approach is 3 kt (0.03 % of total liquid fuel consumption).

Other oil products

In the greenhouse gas inventory, all other oil products are reported together, while IEA has a finer degree of disaggregation. As already mentioned above, the share of petroleum coke that is used as a feedstock is reported under other oil in the greenhouse gas inventory. Therefore, the difference between IEA and the reference approach corresponds largely to the difference in apparent consumption of petroleum coke.

Solid fuels

Solid fuels, mainly other bituminous coal and lignite, play only a minor role in Switzerland (246 kt) and are reported in good agreement.

Gaseous fuels

In the greenhouse gas inventory, the amount of gas reported under 1B2b Fugitive emissions is subtracted from the total gas import as reported by IEA, as this gas is not used for energy purposes. Taking this into account the difference is of the order of 2 TJ.

Table A – 7 Comparison of the IEA energy statistic with the Reference Approach for the year 2010. Numbers in italics are fuels that are reported in a finer disaggregation in the IEA energy statistic than in the Reference Approach. Numbers in bold aggregate the data to the level of disaggregation used in the Reference Approach.

CRF vs. IEA (2010)	**Import**		**Export**		**Bunker**		**Stock change**		**Stat. Diff.**	**LIE**	**Consumption**	
Gg	**IEA**	**CRF**	**IEA**	**CRF**	**IEA**	**CRF**	**IEA**	**CRF**	**IEA**	**CRF**	**IEA**	**CRF**
Liquid Fuels											**11'039**	**11'052**
Sum											**4'546**	**4'547**
Crude oil	4'488	4'546						1.0			4'488	4'547
Refinery feedstokcs	3.0						1.0		2.0		6.0	
Additives/blending components	51						-1.0		2.0		52	
Motor gasoline	1'850	1'838					-9.0	-6.0	4.0	15	**1'830**	**1'832**
Sum											**0.0**	**12**
Aviation gasoline	7.0						-2.0		-1.0		4.0	
Kerosene type jet fuel	1'354	1'362			-1'367	-1'352		2.0	6.0		-7.0	12
Other kerosene	3.0										3.0	
Gas/diesel oil	3'510	3'485	-21	-39	-10	-11	38	1'072	1'020	27	**4'510**	**4'507**
Fuel oil	33	34	-323	-316			-17	-17	7.0		**-300**	**-299**
White spirit & SBP	7.0								-1.0		**6.0**	
Bitumen	317	318	-2.0	-2.0							**315**	**316**
Lubricants	86	72	-38	-16					7.0		**55**	**56**
Petroleum coke	73	47									**73**	**47**
Sum											**10**	**34**
Naptha	1.0						5.0		-1.0		5.0	
Paraffin waxes	1.0										1.0	
Non-specified oil products / other oil	4.0	63		-23				-6.0			4.0	34
Solid fuels											**246**	**246**
Anthracite	7.0										7.0	
Other bituminous coal	123	152					*36*	*32*			159	184
Lignite	66	62					*-4.0*				62	62
Coke oven coke	18										18	
Gaseous Fuels											**126'014**	**126'016**
Natural gas (TJ, NCV)	126'014	125'627									126'014	125'627
Fugitive emissions (TJ, NCV)		389										389

Additional information regarding reporting of waste-derived fuels

During the in-country review in 2016, the ERT identified that the apparent consumption of non-biomass fraction of waste in the CRF Table1.A(b) was systematically smaller than the consumption reported to IEA. The difference stems from the assumptions made with regard to the fossil and renewable fractions. The SFOE, which is responsible for reporting to the IEA, allocates total wastes to 50 % fossil and 50 % renewable. For the greenhouse gas inventory, a more sophisticated method based on a detailed analysis of waste composition and measurements in the flue gas of waste incineration plants is used to estimate fossil and renewable fractions (see chp. 3.2.5.2.1).

Annex 4 QA/QC plan

Since 2007, the National Inventory System (NIS) quality management system (QMS) has been certified to comply with ISO 9001. The QMS has been audited annually and recertified according to the ISO 9001 requirements ever since. The latest audit according to ISO 9001:2015 was on 6th July 2023 and the current certificate is valid until 2025 (Swiss Safety Center 2022).

Here, information on the quality assurance / quality control (QA/QC) plan for the Swiss Greenhouse gas inventory as required by UNFCCC (2019, paragraphs 34 and 35) and the IPCC Guidelines (IPCC 2006, IPCC 2019) are provided.

In the quality management system (QMS) for the Swiss greenhouse gas inventory, the QA/QC plan is represented in an internal quality manual as formerly required by the ISO 9001:2008 standard. It has been updated ever since, also under ISO 9001:2015 (FOEN 2024a). Therein, all information and documents relevant to quality assurance (QA) and quality control (QC) are compiled (in German). The quality manual is reviewed annually and modified by the QA/QC officer where necessary. The process owner is reviewing the changes accordingly. The quality manual is made available via a SharePoint for all persons involved in the inventory preparation. It will be made available for the Expert Review Team in line with the procedures agreed under the UNFCCC for the technical review of GHG inventories (UNFCCC 2019) upon request.

The quality manual (FOEN 2024a) provides information regarding:

- The scope and the quality policy and data quality objectives;
- the management structure, institutional arrangements and responsibilities;
- a risk analysis, requirements, process flow charts, and results;
- scheduled time frame for the inventory preparation until submission and associated QA/QC activities including verification activities;
- archiving, internal and external audits, internal and external reviews;
- documents and a description of feedback loops allowing improvement;
- links to supporting documents and official inventory submission data.

As such the QMS is fit for purpose, in the sense that the following inventory principles are achieved:

- Timeliness
- Completeness
- Consistency (internal consistency as well as time series consistency)
- Comparability
- Accuracy
- Transparency
- Improvement

Annex 5 Other detailed methodological descriptions for individual source or sink categories

A5.1 Sector Energy

A5.1.1 Civil aviation

This paragraph contains further information on the emission modelling. More complete information is provided in FOCA (2006, 2006a, 2007–2023) and on request for reviewers by FOCA.

Emission factors (1A3a)

Table A – 8 Aircraft cruise factors, used for cruise emission calculation (extract of list of 881 aircraft) GKL_ICAO = ICAO seat categories. Mass emissions are given in kilograms or grams per nautical mile (NM).

Aircraft Cruise _Factors						
Aircraft_ICAO	GKL_ICAO	Cruise_D_Source	kg_fuel_NM	kg_NOx_NM	g_VOC_NM	g_CO_NM
AA1	0	P002FOCA	0.21	0.0098	1.79	61.7
AA5	0	P002FOCA	0.21	0.0098	1.79	61.7
AC11	0	P002FOCA	0.21	0.0098	1.79	61.7
AC14	0	P002FOCA	0.21	0.0098	1.79	61.7
AC50	0	P001FOCA	0.77	0.021	4.14	364.17
AC68	0	P001FOCA	0.77	0.0075	4.14	364.17
AC6T	1	FOCAINV95-03.2T	1.58	0.021	0.87	2.9
AC90	1	FOCAINV95-03.2T	1.58	0.021	0.87	2.9
AC95	1	FOCAINV95-03.2T	1.58	0.021	0.87	2.9
AEST	0	P001FOCA	0.77	0.021	4.14	364.17
AJET	0	FOCAEDBJ014	2.92	0.0146	8.53	63
ALO2	0	FOCAHeli	1.91	0.024	0.42	2.1
ALO3	0	FOCAHeli	1.91	0.024	0.42	2.1
AN12	0	AN26*2	5.36	0.0062	143	348
AN2	0	FOCA/91/DC3	0.82	0.0002	13.7	1000
AN22	6	FOCAINV95-03.2T*2	3.16	0.042	1.74	5.8
AN24	2	AN26	2.68	0.0031	71.7	174
AN26	1	500	2.68	0.0031	71.7	174
AN72	2	FOCAINV95-03.2J	6.4	0.1	0.83	10
AR7	0	P002FOCA	0.21	0.0098	1.79	61.7
AR7A	0	P002FOCA	0.21	0.0098	1.79	61.7
AS02	0	P002FOCA	0.21	0.0098	1.79	61.7
AS16	0	P002FOCA	0.21	0.0098	1.79	61.7
AS20	0	P002FOCA	0.21	0.0098	1.79	61.7
AS24	0	P002FOCA	0.21	0.0098	1.79	61.7
AS25	0	P002FOCA	0.21	0.0098	1.79	61.7
AS26	0	P002FOCA	0.21	0.0098	1.79	61.7
AS2T	0	FOCAEDBT758	0.95	0.005	1.8	12
AS30	0	FOCAHeli*2	3.82	0.048	0.82	4.2
AS32	1	FOCAHeli*2	3.82	0.048	0.82	4.2
AS33	0	FOCAHeli*2	3.82	0.048	0.82	4.2
AS35	0	FOCAHeli	1.91	0.024	0.42	2.1
AS50	0	FOCAHeli*2	3.82	0.048	0.82	4.2
AS55	0	FOCAHeli*2	3.82	0.048	0.82	4.2
AS65	0	FOCAHeli*2	3.82	0.048	0.82	4.2
ASK1	0	P002FOCA	0.21	0.0098	1.79	61.7
ASTA	0	FOCAINV95-03.B	3.016	0.046	0.3	2.8
ASTR	0	FOCAINV95-03.B	3.016	0.046	0.3	2.8
ASTRA	0	FOCAINV95-03.B	3.016	0.046	0.3	2.8
AT42	1	FOCAINV95-03.2T	1.58	0.021	0.87	2.9
AT43	1	500	1.6	0.013	0	15

Activity data (1A3a)

LTO-cycle times (minutes). ICAO standard cycle times were originally designed for emissions certification, not for emissions modelling. Today, they do generally not match real world aircraft LTO operations. Swiss FOCA has therefore adjusted some of the ICAO standard cycle times for different aircraft categories. For jets, the mean time for taxi-in and taxi-out at Swiss airports has been determined 20 minutes instead of the standard 26 minutes (Aerocert 2012, FOCA 2007b, ZRH 2017).

Table A – 9 For jets, business jets, turboprops, piston engines and helicopters, the times in mode are shown and are based on ICAO, US EPA and Swiss FOCA data. “Type” is a classification variable. J = Jet, T = Turboprop, P = Piston, H = Helicopter, HP = Helicopter with Piston Engine, B = Business jet, SJ = Supersonic Jet, E = Electric Aircraft. The number in “Type” stands for the number of engines. For Jet Aircraft, the cycle times and associated thrust settings still lead to an overestimation of LTO emissions (FOCA 2007b).

LTO Cycle				
Type	Time_Take_Off	Time_Climbout	Time_Approach	Time_Taxi
1J	0.7	2.2	4	20
1T	0.5	2.5	4.5	13
1P	0.3	2.5	3	12
1H	0	3	5.5	5
2B	0.4	0.5	1.6	13
3B	0.4	0.5	1.6	13
2T	0.5	2.5	4.5	13
4T	0.5	2.5	4.5	13
2J	0.7	2.2	4	20
3J	0.7	2.2	4	20
4J	0.7	2.2	4	20
2P	0.3	2.5	3	12
3P	0.3	2.5	3	12
4P	0.3	2.5	3	12
2H	0	3	5.5	5
4SJ	1.2	2	2.3	20
3H	0	3	5.5	5
4H	0	3	5.5	5
4B	0.4	0.5	1.6	13
1HP	0	4	5.5	5
2HP	0	4	5.5	5
3HP	0	4	5.5	5
4HP	0	4	5.5	5
1B	0.4	0.5	1.6	13
1E	0.7	10	5	13
4E	0.3	10	5	13
6J	0.7	2.2	4	20

Table A – 10 Aircraft-Engine Combinations and associated codes for SWISS FOCA emissions database. (Extract from list of more than 40’000 individual aircraft)

Aircraft Engine Combinations							
Engine Name	Aircraft Name	Aircraft Registr.	No. Eng.	Code	Type	Aircr. ICAO	Source
V2527-A5	AIRBUS A320-232	ECHXA	2	J220	2J	A320	1IA003
CF34-3B1	BOMBARDIER CRJ200ER (CL-600-2B19)	ECHXM	2	J090	2J	CRJ2	1GE034
CFM56-3C1	BOEING 737-4K5	ECHXT	2	J022	2J	B734	1CM007
TPE331-11U-611G	FAIRCHILD (SWEARIN-GEN) SA227AC METR	ECHXY	2	T310	2T	SW4	FOI
CFM56-5B4/P	AIRBUS A320-214	ECHYC	2	J067	2J	A320	3CM026
CFM56-5B4/P	AIRBUS A320-214	ECHYD	2	J067	2J	A320	3CM026
CF34-3B1	BOMBARDIER CRJ200ER (CL-600-2B19)	ECHYG	2	J090	2J	CRJ2	1GE034
CFEC-FE738-1-1B	DASSAULT FALCON 2000	ECHYI	2	B130	2B	F2TH	FOI-Ho-neywell
GA TPE331-11U-612G		ECHZH	2	T310	2T	FA3	FOI
CF34-3B1	BOMBARDIER CRJ200ER (CL-600-2B19)	ECHZR	2	J090	2J	CRJ2	1GE034
CFM56-7B27B1	BOEING 737-86Q (WINGLETS)	ECHZS	2	J075	2J	B738	3CM034
CFM56-5B4/P	AIRBUS A320-214	ECHZU	2	J067	2J	A320	3CM026
CF34-3B1	BOMBARDIER CRJ200ER (CL-600-2B19)	ECIAA	2	J090	2J	CRJ2	1GE034
FJ44-1A	CESSNA 525 CITATIONJET	ECIAB	2	B001	2B	C525	FOCA
CFM56-5B4/P	AIRBUS A320-214	ECIAG	2	J067	2J	A320	3CM026
V2527-A5	AIRBUS A320-232	ECIAZ	2	J220	2J	A320	1IA003
BRBR700-710A2-20	BOMBARDIER BD-700-1A10 GLOBAL EX-PRE	ECIBD	2	J854	2J	GLEX	4BR009
PT6A-60A	BEECH-CRAFT KING AIR 350 (RAYTHEON B	ECIBK	2	T738	2T	B350	FOI
CF34-3B1	BOMBARDIER CRJ200ER (CL-600-2B19)	ECIBM	2	J090	2J	CRJ2	1GE034
CFM56-7B27B1	BOEING 737-81Q (WINGLETS)	ECICD	2	J075	2J	B738	3CM034
CFM56-5B4/P	AIRBUS A320-214	ECICK	2	J067	2J	A320	3CM026

Emissions (1A3a)

The output of the FOCA emission modelling consists of tables with the following structure:

Table A – 11 Extract of the output file of FOCA emission and fuel consumption modelling (example for 2004). Emissions and fuel consumption in tonnes.

Airport	Distance	Type Traffic	Move-ments	Type	Aircraft ICAO	Engine Name	Fuel (LTO) tons	Emissions (LTO) in tons					
	Km		No.					CO_2	H_2O	SO_2	NO_x	VOC	CO
LSGG	181501.69	Taxi	165	2B	C550	JT15D-4	5673.492	17871.5	6978.395	5.673	26.04	139	359.2
LSGG	164165.197	Taxi	77	2J	B752	RB211-535E4	47470.5	149532.1	58388.72	47.47	554.91	0	361.47
LSGG	133166.837	Taxi	118	2B	F2TH	CFE738-1-1B	6164.2728	19417.46	7582.056	6.164	87.539	40.59	185.53
LSGG	117228.943	Taxi	99	3B	F900	TFE731-60-1C	5668.542	17855.91	6972.307	5.669	46.937	28.13	163.44
LSGG	114258.902	Taxi	134	2B	LJ45	TFE731-20R	4725.108	14884.09	5811.883	4.725	31.31	53.62	169.01
LSGG	112510.267	Taxi	100	2B	F2TH	CFE738-1-1B	5223.96	16455.47	6425.471	5.224	74.186	34.4	157.23
LSGG	107945.477	Taxi	96	2B	C560	JT15D-5D	3795.3216	11955.26	4668.246	3.795	16.959	271.6	287.98
LSGG	181501.69	Taxi	165	2B	C550	JT15D-4	307732.68	969357.9	378511.2	307.7	4513	29.43	274.71
LSGG	164165.197	Taxi	77	2J	B752	RB211-535E4	673698.47	2122150	828649.1	673.7	7986.4	647.8	1038.2
LSGG	133166.837	Taxi	118	2B	F2TH	CFE738-1-1B	225781.85	711212.8	277711.7	225.8	3311.2	21.59	201.55
LSGG	117228.943	Taxi	99	3B	F900	TFE731-60-1C	298139.18	939138.4	366711.2	298.1	4372.3	28.52	266.14
LSGG	114258.902	Taxi	134	2B	LJ45	TFE731-20R	193723.81	610230	238280.3	193.7	2841	18.53	172.93
LSGG	106761.289	Taxi	100	2B	F2TH	CFE738-1-1B	181011.75	570187	222644.4	181	2654.6	17.31	161.58
LSGG	103217.159	Taxi	96	2B	C560	JT15D-5D	175002.74	551258.6	215253.4	175	2566.5	16.74	156.22

A5.1.2 Road transportation

Base emission factors (1A3b)

The derivation of the emission factors for road transport is described in detail in INFRAS (2019a), Matzer et al. (2019) and Notter et al. (2022). The emission factors are contained in the “Handbook Emission Factors for Road Transport (HBEFA)” (version 4.2), which is available publicly as a database application (INFRAS 2022). Some important features of the emission factor methodologies are summarised in the following paragraphs.

HBEFA differentiates emission factors by emission category, vehicle types and traffic situations.

The following **emission categories** are accounted for:

a) Hot emissions – the emissions caused by vehicles on the road with hot engines;

b) Cold start (excess) emissions – the excess emissions caused by vehicles after cold start when the engine is still cold (note that these emissions can be negative in some cases, when the cold engine produces less emissions than in the hot state)

c) Evaporation emissions – evaporation of hydrocarbons (i.e. methane, NMVOC) from the fuel tank of gasoline vehicles. Three sub-processes are distinguished:

- Soak emissions: evaporation after stopping when the engine is still hot;
- Diurnal emissions: evaporation caused by the daily temperature variation;
- Running losses: evaporation during driving.

The hot emissions are generally the most relevant emission category; results show that for CO_2 the hot exhaust emissions contribute about 98 % of the total in the year 2019. Only 2 % stem from cold start excess emissions. For CH_4, however, the picture is different. Hot exhaust emissions contribute about two thirds to the total, cold start emissions about one third. For N_2O, the cold start emission factors are based on the EMEP guidebook (EMEP/EEA 2019). According to these emission factors, the share of cold start emissions amounts to roughly 7 % of total emissions in the year 2019.

Regarding **vehicle types**, HBEFA distinguishes six vehicle categories at the highest aggregation level (i.e. passenger cars, light commercial vehicles, urban buses, coaches, heavy goods vehicles and motorcycles). Each vehicle category is further differentiated by technology (in turn related to fuel type), emission standard, and (optionally) size class. The following table illustrates the segmentation of passenger cars. Similar “segmentations” hold for the other vehicle categories, too.

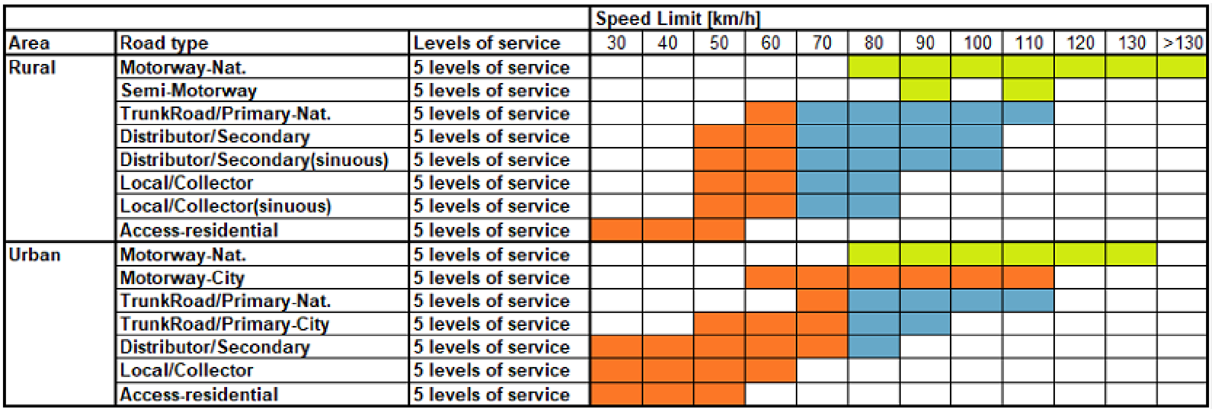
Table A – 12 Vehicle segmentation of passenger cars for different fuel types (according to HBEFA 4.2, INFRAS 2022).

Technology	Vehicle sub-segment
Gasoline	<ECE
	AGV82 (CH)
	ECE-15'00
	ECE-15'01/02
	ECE-15'03
	PreEuro 3WCat <1987
	PreEuro 3WCat 1987-90
	Euro-1
	Euro-2
	Euro-3
	Euro-4
	Euro-5
	Euro-6ab
	Euro-6c
	Euro-6d-temp
	Euro-6d
Diesel	conv
	1986-1988
	Euro-1
	Euro-2
	Euro-3
	Euro-4
	Euro-5
	Euro-5 EA189 before software update
	Euro-5 EA189 after software update
	Euro-6ab
	Euro-6c
	Euro-6d-temp
	Euro-6d

Technology	Vehicle sub-segments
Bifuel CNG/Gasoline	Euro-2
	Euro-3
	Euro-4
	Euro-5
	Euro-6
Bifuel LPG/Gasoline	Euro-2
	Euro-3
	Euro-4
	Euro-5
	Euro-6
Flex-fuel E85	Euro-3
	Euro-4
	Euro-5
	Euro-6
PHEV	Euro-4
	Euro-5
	Euro-6d
	Euro-6ab
Electricity	BEV
FuelCell	FuelCell

Traffic situations are relevant for hot emissions. They are defined by a scheme (see table below) taking into account 4 parameters: area type (urban/rural areas), 10 road types, speed limits and 5 levels of service (i.e. traffic density classes). This leads to the definition of 365 different traffic situations in total. Each traffic situation implies a typical driving behaviour. The traffic situations have been defined based on driving behaviour studies in Germany and in Switzerland (see Ericsson et al. 2019, INFRAS 2015b).

Table A – 13 Traffic situation-scheme in HBEFA 4.2 (INFRAS 2022). Every traffic situation is characterised by a typical driving pattern (i.e. a speed-time curve). Legend: Orange colour = urban, blue colour = rural, green colour = motorway.



			Speed Limit [km/h]											
Area	Road type	Levels of service	30	40	50	60	70	80	90	100	110	120	130	>130
Rural	Motorway-Nat.	5 levels of service						🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Semi-Motorway	5 levels of service							🟩		🟩			
	TrunkRoad/Primary-Nat.	5 levels of service				🟧	🟦	🟦	🟦	🟦	🟦			
	Distributor/Secondary	5 levels of service			🟧	🟧	🟦	🟦	🟦	🟦				
	Distributor/Secondary(sinuous)	5 levels of service			🟧	🟧	🟦	🟦	🟦	🟦				
	Local/Collector	5 levels of service			🟧	🟧	🟦	🟦						
	Local/Collector(sinuous)	5 levels of service			🟧	🟧	🟦	🟦						
	Access-residential	5 levels of service	🟧	🟧	🟧									
Urban	Motorway-Nat.	5 levels of service						🟩	🟩	🟩	🟩	🟩	🟩	
	Motorway-City	5 levels of service				🟧	🟧	🟧	🟧	🟧	🟧			
	TrunkRoad/Primary-Nat.	5 levels of service					🟧	🟦	🟦	🟦	🟦			
	TrunkRoad/Primary-City	5 levels of service			🟧	🟧	🟧	🟦	🟦					
	Distributor/Secondary	5 levels of service	🟧	🟧	🟧	🟧	🟧	🟦						
	Local/Collector	5 levels of service	🟧	🟧	🟧	🟧								
	Access-residential	5 levels of service	🟧	🟧	🟧									

Traffic situations are defined independently of vehicle categories (LDV, HDV, 2-wheelers). But for the same traffic situation, each vehicle category is assigned its own “driving pattern” which is expressed as a speed curve (i.e. speed time series).

(Hot) emission factors for these driving patterns are developed by first creating engine maps (i.e. emissions by torque and engine speed) based on measurements performed both on laboratory test benches and on the road using Portable Emission Measurement Systems (PEMS); the PHEM model (Passenger car and Heavy duty Emission model) is then used to simulate emissions for the HBEFA driving patterns by using the emission maps as input. This process is described in detail in Matzer et al. (2019). Hot emission factors are differentiated for 7 gradient classes (flat, +/-2 %, +/-4 %, +/-6 %) within each traffic situation. The driving pattern is adapted automatically in PHEM if it cannot be realised at a given gradient (e.g. a fully loaded truck might not be able to accelerate as quickly on an upward slope as on a flat or downhill road).

For **cold start and evaporation emission factors**, not the driving pattern is determining but ambient conditions. These include climatic parameters (diurnal temperature and humidity profiles for all seasons) but also diurnal profiles of traffic volumes, trip length and parking time distributions. The methodology for the development of cold start emission factors is described in INFRAS (2004, 2019a). The methodology for the evaporation emission factors is adopted from EMEP/EEA guidebook (EMEP/EEA 2016); its implementation in HBEFA is described in INFRAS (2019a).

Cold start excess emissions for N_2O are estimated on the basis of the Tier 3 emission factors for cold-start and hot-start urban conditions published in Tables 3-56 ff. in the EMEP/EEA guidebook (EMEP/EEA 2019). Based on these emission factors, two N_2O emission calculations are carried out for Switzerland – one hypothetical calculation assuming all starts are hot starts, and a second calculation using the actual cold start share in Switzerland. The difference between the two emission values are the cold start excess emissions. These are divided by the number of cold starts in order to obtain the cold start excess emission factors in g/start.

Activity data (1A3b)

Activity data for the emission model include (see also chp. 3.2.9.2.2.):

a) mileage (vehicle kilometres) for hot emissions and evaporation running losses.

b) the number of starts for cold start excess emissions.

c) the number of stops for evaporation soak emissions.

d) the number of vehicles multiplied by the number of days in the reporting period for evaporation diurnal emissions.

Mileage must be differentiated by vehicle types, traffic situations, and gradients in order to be able to link it to the hot emission factors differentiated by the same parameters. To do so, three steps must be carried out:

1. Vehicle turnover: The vehicle fleet is built up for each year accounting for stock changes. This vehicle turnover is modelled

a) for historical periods (ex-post) on the basis of vehicle stock and age distributions, and

b) for future periods on the basis of new registrations and by applying survival probabilities.

Trends in traffic volume per vehicle category and segment, including structural changes (size distributions, shares of diesel vehicles) are then combined to model the continuous substitution of older technologies by new ones, constantly altering the fleet composition or mileage by emission concepts (Euro classes) in all vehicle categories, see also the following Figure A-1 (INFRAS 2017).

2. The total mileage is an input dataset by the Federal Statistical Office (FSO 2023f, 2023g).

3. Assignment of the traffic situations to the mileage for all vehicle categories: This step requires the use of a traffic model: Each road network link carries the information on modelled traffic volume and can be characterized with the parameters defining traffic situations (described above) and gradients, which allows the assignment sought.

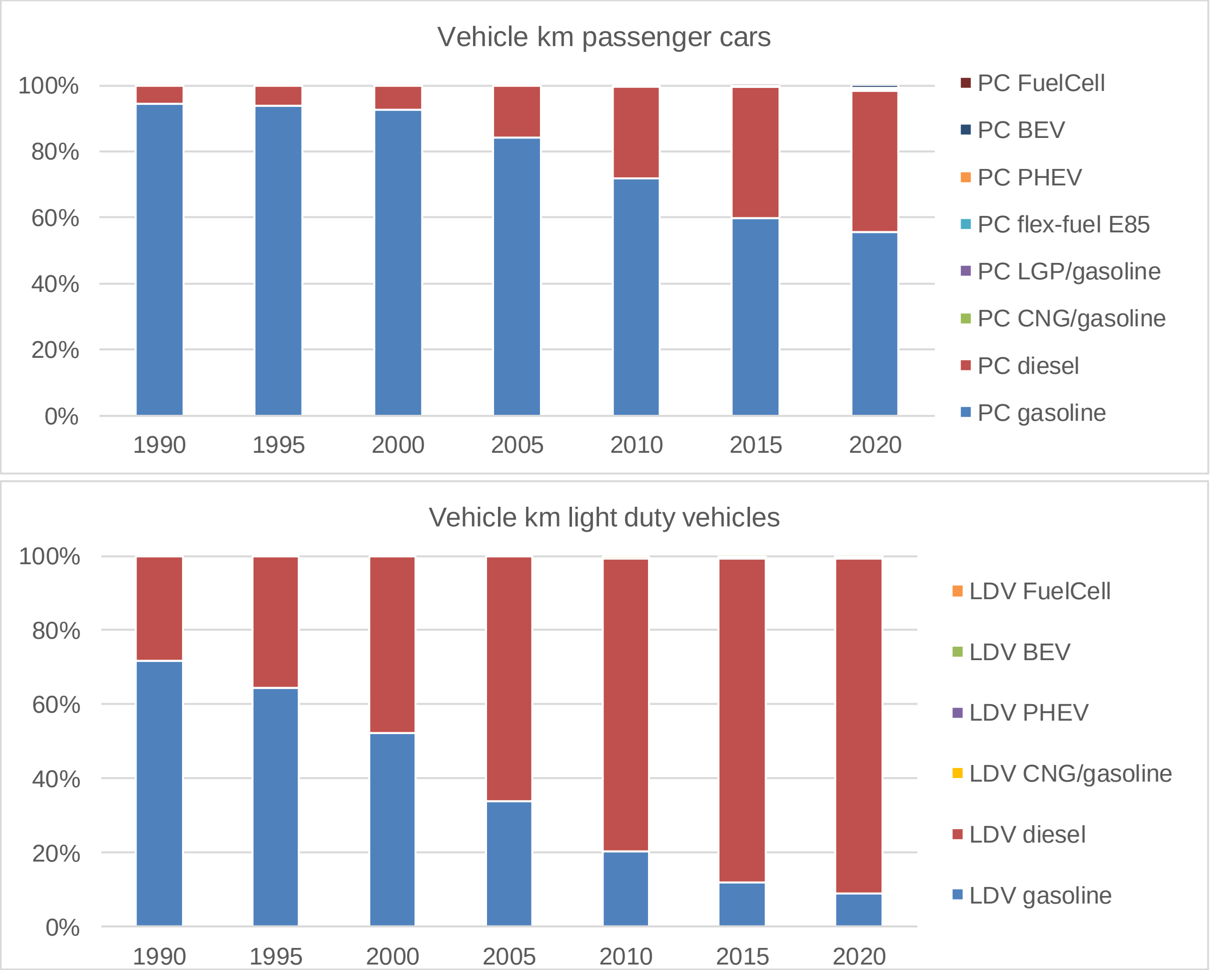


Figure A – 1 Vehicle kilometres per fleet composition for passenger cars (PC, above) and light duty vehicles (LDV, below). Data source: INFRAS (2022).

Aggregated emission factors (1A3b)

From the base emission factors differentiated by vehicle type, traffic situations and gradients, aggregated emissions can be derived by using the activity data described above – i.e. taking into account the fleet composition, which varies from year to year, and the distribution of

vehicle kilometres across traffic situations (temporally dynamic as well, derived from traffic models – see section on activity data below).
Mean emission factors by vehicle and emission category for Switzerland are shown in the next table.

Table A – 14 Mean emission factors of passenger cars (PC), light duty vehicles (LDV), heavy duty vehicles (HDV), coaches and urban buses (Bus) and Motorcycles (MC) in grams per kilometre (from HBEFA 4.2). Cold start excess emissions are given in g/start.

Pollutant	Year	PC	LDV	HDV	Bus	MC	PC	LDV
		Emission factors in gram per vehicle kilometre					**Cold starts in** gram per start	
CH_4	1990	0.031	0.054	0.036	0.045	0.183	0.675	0.725
CH_4	1995	0.017	0.038	0.029	0.041	0.125	0.423	0.496
CH_4	2000	0.013	0.026	0.019	0.032	0.152	0.282	0.288
CH_4	2005	0.010	0.015	0.012	0.019	0.141	0.186	0.149
CH_4	2010	0.006	0.007	0.004	0.045	0.130	0.120	0.070
CH_4	2015	0.004	0.004	0.004	0.020	0.095	0.073	0.035
CH_4	2020	0.006	0.005	0.001	0.011	0.080	0.051	0.022
CO	1990	6.9	24.2	3.8	5.1	12.2	41.2	60.8
CO	1995	3.0	17.9	3.3	4.9	12.5	29.4	46.9
CO	2000	1.6	12.1	2.4	4.1	12.2	22.0	31.3
CO	2005	1.1	6.5	1.9	2.9	10.9	15.7	17.5
CO	2010	0.8	2.9	2.0	1.8	8.8	10.4	8.7
CO	2015	0.5	1.0	2.0	1.6	5.5	6.6	4.7
CO	2020	0.4	0.6	0.8	0.8	3.3	5.2	3.3
CO_2 (fossil)	1990	233	299	828	1097	110	108	140
CO_2 (fossil)	1995	238	297	856	1117	122	102	134
CO_2 (fossil)	2000	242	293	855	1126	109	99	126
CO_2 (fossil)	2005	232	284	895	1123	117	101	115
CO_2 (fossil)	2010	220	272	872	1072	110	104	105
CO_2 (fossil)	2015	198	264	837	1008	113	91	99
CO_2 (fossil)	2020	178	233	771	898	112	80	93
VOC	1990	0.86	1.57	1.49	1.88	3.01	7.16	6.84
VOC	1995	0.37	0.97	1.20	1.71	2.32	5.75	5.59
VOC	2000	0.17	0.48	0.78	1.35	2.40	4.69	4.14
VOC	2005	0.09	0.19	0.47	0.78	1.56	3.32	2.50
VOC	2010	0.03	0.06	0.16	0.27	1.02	2.21	1.32
VOC	2015	0.01	0.02	0.12	0.11	0.63	1.34	0.67
VOC	2020	0.01	0.01	0.04	0.05	0.46	0.95	0.42
N_2O	1990	0.0096	0.0054	0.0086	0.0107	0.0016	0.0175	0.0018
N_2O	1995	0.0132	0.0073	0.0091	0.0107	0.0018	0.0372	0.0180
N_2O	2000	0.0116	0.0091	0.0094	0.0102	0.0018	0.0419	0.0316
N_2O	2005	0.0050	0.0075	0.0079	0.0080	0.0019	0.0028	0.0356
N_2O	2010	0.0031	0.0057	0.0295	0.0168	0.0019	0.0109	0.0369
N_2O	2015	0.0032	0.0057	0.0422	0.0302	0.0019	0.0086	0.0226
N2O	2020	0.0043	0.0079	0.0460	0.0372	0.0019	0.0073	0.0074
NMVOC	1990	0.82	1.52	1.46	1.84	2.83	6.48	6.11
NMVOC	1995	0.35	0.93	1.17	1.67	2.19	5.33	5.10
NMVOC	2000	0.16	0.45	0.76	1.31	2.24	4.40	3.86
NMVOC	2005	0.08	0.18	0.46	0.76	1.42	3.14	2.35
NMVOC	2010	0.03	0.05	0.16	0.23	0.89	2.09	1.25
NMVOC	2015	0.01	0.02	0.11	0.09	0.53	1.27	0.64
NMVOC	2020	0.00	0.01	0.03	0.04	0.38	0.90	0.40
NO_x	1990	0.98	2.38	12.45	17.21	0.15	0.56	0.03
NO_x	1995	0.58	1.90	11.75	16.62	0.20	1.20	0.53
NO_x	2000	0.46	1.48	10.35	15.23	0.19	1.20	0.57
NO_x	2005	0.44	1.36	8.73	12.57	0.21	0.75	0.24
NO_x	2010	0.42	1.53	5.45	8.73	0.24	0.36	0.02
NO_x	2015	0.44	1.53	3.65	5.95	0.19	0.28	-0.07
NOx	2020	0.31	0.98	1.42	3.03	0.12	0.22	0.04
SO_2	1990	0.0366	0.1093	0.7770	1.0289	0.0126	0.0165	0.0438
SO_2	1995	0.0281	0.0477	0.2076	0.2708	0.0140	0.0124	0.0207
SO_2	2000	0.0233	0.0430	0.1745	0.2299	0.0100	0.0098	0.0178
SO_2	2005	0.0007	0.0010	0.0034	0.0043	0.0004	0.0003	0.0004
SO_2	2010	0.0007	0.0011	0.0038	0.0048	0.0003	0.0003	0.0004
SO_2	2015	0.0007	0.0011	0.0039	0.0047	0.0003	0.0003	0.0004
SO_2	2020	0.0006	0.0010	0.0035	0.0041	0.0003	0.0003	0.0004

Modelling total emissions (1A3b)

In order to calculate total emissions, the activity data are multiplied with the respective emission factors resulting in total emissions.

These results correspond to territorial emissions; they do not yet contain the emissions from fuel tourism and statistical differences. Emissions from fuel tourism and statistical differences are calculated by assigning the fuel consumption to categories 1A3bi, 1A3bii, and 1A3biii (as described in chp. 3.2.9.2.2), and using mean emission factors averaged over all vehicle categories.

A5.1.3 Non-road vehicles and machinery: supplementary activity data

The following table shows some aggregated information on stock numbers and annual operation hours of non-road vehicles and machinery. Detailed information is available in the report FOEN (2015j) and most disaggregated information is available by query from the online non-road database INFRAS (2015a):
https://www.bafu.admin.ch/bafu/en/home/topics/air/state/non-road-datenbank.html

Table A – 15 Overview over stock and operating hours of non-road vehicles and machinery (FOEN 2015j): Upper table: Number of vehicles; middle table Specific operating hours per year; lower table: Total operating hours per year (in million hours)

Category	**1980**	**1990**	**2000**	**2010**	**2020**	**2030**
	number of vehicles					
Construction machinery	63'364	58'816	52'729	57'102	60'384	62'726
Industrial machinery	26'714	43'244	70'671	69'786	69'757	70'083
Agricultural machinery	292'773	324'567	337'869	318'876	309'825	305'235
Forestry machinery	11'815	13'844	13'055	11'857	10'831	10'170
Garden-care / hobby appliances	1'198'841	1'539'624	1'944'373	2'322'737	2'464'323	2'499'627
Navigation machinery	94'866	103'383	93'912	95'055	97'522	99'104
Railway machinery	529	1'300	1'255	697	640	640
Military machinery	13'092	13'373	14'272	13'083	12'853	12'856
Total	**1'701'994**	**2'098'151**	**2'528'136**	**2'889'193**	**3'026'135**	**3'060'441**

Category	**1980**	**1990**	**2000**	**2010**	**2020**	**2030**
	Specific operating hours per year					
Construction machinery	247	322	406	417	424	429
Industrial machinery	666	670	684	680	675	671
Agricultural machinery	136	119	112	103	99	95
Forestry machinery	203	199	203	193	188	182
Garden-care / hobby appliances	12	17	20	64	77	81
Navigation machinery	39	38	38	36	35	35
Railway machinery	877	613	617	783	719	719
Military machinery	64	64	63	73	74	74

Category	**1980**	**1990**	**2000**	**2010**	**2020**	**2030**
	million operating hours per year					
Construction machinery	16	19	21	24	26	27
Industrial machinery	18	29	48	48	47	47
Agricultural machinery	40	39	38	33	31	29
Forestry machinery	2.4	2.8	2.6	2.3	2.0	1.9
Garden-care / hobby appliances	15	26	39	150	191	201
Navigation machinery	3.7	3.9	3.5	3.4	3.4	3.4
Railway machinery	0.50	0.80	0.80	0.50	0.50	0.50
Military machinery	0.80	0.90	0.90	0.90	0.90	0.90
Total	**95**	**121**	**155**	**261**	**301**	**311**

A5.1.4 Sulphur dioxide (SO_2): Country-specific and fuel-specific default emission factors for 1A Fuel combustion

Methodology

For fossil standard fuels in source category 1A Fuel combustion, country-specific and fuel-specific default emission factors are used for SO_2.This means that the same emission factor values are applicable to several source categories. This is appropriate for SO_2 because in many cases, the amount of SO_2 emitted per amount of fuel burned directly depends on the sulphur content of the fuel. For a given fuel, the sulphur content for the whole country is considered homogenous. For other pollutants, the emission factors depend on the combustion process as well and are reported in their specific chapters.

The country-specific default emission factors for SO_2 are estimated as follow:

Where available, we use sulphur content measured annually in fuels in Switzerland, usually expressed as a mass of sulphur per mass of fuel. For liquid fuels, due to yearly fluctuating average values probably caused by a low number of samples per year, we use as annual sulphur content the average value from all samples available from the given year as well as the previous and subsequent year. In case no data are available for a given year, we use a linear interpolation between existing 3-year-average data points. An overview of the available measured data is presented in Table A – 17. These data are available for diesel oil, gasoline, gas oil and residual fuel oil.

In case no measurement is available, we assume that the legal emission limits are respected and use these legal limits as emission factors. An overview of applicable maximal emission limits as defined in the Federal Ordinance on Air Pollution Control OAPC (Swiss Confederation 1985) is given in Table A – 16. This approach is used in particular for bituminous coal and lignite.

The SO_2 emission factor expressed as mass per energy amount of a given fuel *i* is computed as:

$$EF_{SO_2,i} = \frac{M_{SO_2}}{M_S} * \frac{C_{S,i}}{NCV_i}$$

Where:

$EF_{SO2,\,i}$ is the emission factor for SO_2 for a given fuel *i* (g/GJ)

M_{SO2} is the molar mass of SO_2 (g/mol)

M_S is the molar mass of sulphur (g/mol)

$C_{S,\,i}$ is the measured sulphur content of the given fuel *i* if applicable, otherwise the maximum legal limit for sulphur content (g/t)

NCV_i is the net calorific value for the given fuel *i* (GJ/t)

The obtained country-specific and fuel-specific SO_2 emission factors are reported in Table A – 18.

Ongoing measurement surveys

“Schwerpunktaktion, SPA”: The data produced by the Federal Office for Customs and Border Security (FOCBS) through its measurement project “Schwerpunktaktion Brenn und Treibstoffe” (“SPA”) are used from 2004 onwards. This project aims at estimating the sulphur content for diesel oil, gasoline, gas oil Euro and Eco and residual fuel oil.

“Tankstellensurvey, TSS”: For diesel oil and gasoline, the measurement project “Tankstellensurvey” (“TSS”), piloted by the FOEN, started in 2009 and is conducted annually. Samples are taken from a representative set of fueling stations in Switzerland and analysed for sulphur content.

Details per fuel type

Gas oil, heating gas

2006 saw the introduction to the market of low-sulphur eco-grade gas oil with a maximum legal sulphur limit of 50 g/t. From 2009 onwards, FOCBS measurements (“SPA” campaign) include both standard Euro- and eco-grade gas oil. For eco-grade gas oil for the years before 2009, values are assumed equal to those from 2009. For each year, the sulphur content for the sum of gas oil is the measured sulphur content for each grade, weighted by the respective total annual fuel consumption. From 2014 onwards, the detailed annual fuel consumption for the two grades is available from the activity report of Carbura (latest report: Carbura 2022b). The fraction of used eco-grade is interpolated linearly between 2006 and 2013. Measurements from both the SPA (from 2004 onwards) and the TSS (from 2009 onwards) campaigns are used. Before 2004, we use data as published in SAEFL 2000.

The emission factor for heating gas (used as fuel in source category 1A2c Chemicals) is assumed equal to the one for gas oil.

Diesel oil, Biodiesel

Measurements from both the SPA (from 2004 onwards) and the TSS (from 2009 onwards) campaigns are used. Before 1994, data are assumed equal to the measured values for Gas oil (Euro grade). Between 1994 and 2004, data are used as published in SAEFL 2000.

The emission factor for biodiesel is assumed equal to the one for diesel oil.

Gasoline, Bioethanol

Measurements from both the SPA (from 2004 onwards) and the TSS (from 2009 onwards) campaigns are used. Due to the absence of data for 1990-2000 included, the sulphur content in gasoline is assumed to be 10 % less than the legal maximum limit of 200 g/t, producing a value of 180 g/t. Values are linearly interpolated between 2000 and 2004.

The emission factor for bioethanol is assumed equal to the one for gasoline.

Residual fuel oil, Gasolio

Measurements from the SPA campaign are used from 2004 onwards. For previous years, we use data as published in SAEFL 2000.

The emission factor for gasolio (used as fuel in source category 1A2c Chemicals) is assumed equal to the one for residual fuel oil.

Liquefied petroleum gas

No data is available for liquified petroleum gas. We assume that the sulphur content is near the legal limit of 190 g/t for natural gas and therefore use a value of 0.5 g/GJ.

Natural gas

For natural gas for 2003, 2006, 2009 and then annually from 2011 onwards, we use the measured sulphur content as published by the SGWA (latest report: SGWA 2023). We use the annual data without averaging over 3 years because fluctuations between years are likely caused by different field origins of the natural gas. We also use a linear interpolation in case of missing data. For all years before 2003, we assume that the sulphur content in natural gas is near the legal limit of 190 g/t and therefore use a value of 0.5 g/GJ.

Gaseous fuels of biogenic origin

For biogas, sewage gas and landfill gas, no data are available. We assume that the sulphur content is near the legal limit of 190 g/t and therefore use a value of 0.5 g/GJ.

Other bituminous coal

There are no measured data and we assume that the sulphur content is 20 % below the legal limit. The legal limit of sulphur content depends on the size of the heat capacity of the combustion system. The value of 1 % sulphur content (350 g SO_2/GJ) shown in Table A – 16 holds for heat capacity below 1 MW (see OAPC Annex 3, §513 (Swiss Confederation 1985)). For larger capacities, the value is 3 % (OAPC Annex 5, §2, Swiss Confederation 1985). For industrial combustion plants, the limit for the exhaust emissions actually sets the corresponding maximum sulphur content to 1.4 % (500 g SO_2/GJ).

Lignite

There are no measured data and we assume that the sulphur content is 10 % below the legal limit, which is the same as for bituminous coal.

Jet kerosene

There is no default, country-specific emission factor for SO_2 for jet kerosene. Category-specific emission factors are reported in their respective chapters.

Table A – 16 Maximum legal limits of sulphur content in various fuels.

Maximum legal limit of sulphur content										
Fuel	Diesel oil	Gasoline	Gas oil (Euro extra-light)	Gas oil (eco extra-light)	Natural gas	Res. fuel oil Class A	Res. fuel oil Class B	Coal, thermal input < 1MW	Coal, thermal input > 1MW
Ref. OAPC 2022	OAPC Annex 5 §6	OAPC Annex 5 §5	OAPC Annex 5 §11bis a	OAPC Annex 5 §11bis b	OAPC Annex 5 §42	OAPC Annex 3, §421, lit.2	OAPC Annex 5 §11bis c	OAPC Annex 3 §513	OAPC Annex 5 §2
Unit	g/t	g/t	g/t	g/t	g/t	g/t	g/t	g/t	g/t
1990	2'000	200	2'000	NO	190	15'000	28'000	10'000	30'000
1991	2'000	200	2'000	NO	190	10'000	28'000	10'000	30'000
1992	2'000	200	2'000	NO	190	10'000	28'000	10'000	30'000
1993	2'000	200	2'000	NO	190	10'000	28'000	10'000	30'000
1994	2'000	200	2'000	NO	190	10'000	28'000	10'000	30'000
2000	350	150	2'000	NO	190	10'000	28'000	10'000	30'000
2005	50	50	2'000	NO	190	10'000	28'000	10'000	30'000
2008	50	50	2'000	NO	190	10'000	28'000	10'000	30'000
2009	10	10	1'000	NO	190	10'000	28'000	10'000	30'000
2018	10	10	1'000	50	190	10'000	28'000	10'000	30'000
2022	10	10	1'000	50	190	10'000	28'000	10'000	30'000

Table A – 17 Measured sulphur content in various fuels.

	Measured sulphur content in fuels				
Fuel	Diesel oil	Gasoline	Gas oil (Euro)	Gas oil (Eco)	Res. fuel oil Class A
Unit	g/t	g/t	g/t	g/t	g/t
1990	NE	NE	1'600	NO	9'747
1991	NE	NE	1'300	NO	8'900
1992	NE	NE	1'200	NO	8'600
1993	NE	NE	1'000	NO	8'700
1994	434	NE	1'350	NO	7'710
1995	341	NE	1'170	NO	7'770
1996	372	NE	1'160	NO	7'770
1997	353	NE	1'250	NO	7'000
1998	402	NE	926	NO	8'300
1999	443	NE	650	NO	6'200
2000	272	NE	680	NO	6'600
2001	250	NE	830	NO	8'200
2002	235	NE	798	NO	8'200
2003	200	NE	NE	NO	7'900
2004	5.2	3.8	730	NO	7'600
2005	6.4	5.6	788	NO	7'800
2006	NE	NE	NE	NE	NE
2007	NE	NE	NE	NE	NE
2008	NE	NE	NE	NE	NE
2009	7.6	5.3	641	25	9'217
2010	6.7	4.3	631	34	8'825
2011	6.6	4.7	531	21	8'967
2012	6.5	4.8	672	26	9'100
2013	7.1	4.5	308	25	8'967
2014	6.8	4.4	502	27	7'800
2015	8.6	4.2	516	14	8'233
2016	7.0	4.2	246	10	8'450
2017	7.7	5.0	248	19	9'833
2018	7.5	5.2	486	5	9'133
2019	NE	NE	NE	NE	NE
2020	6.2	NE	319	18	5'533
2021	7.1	NE	337	19	5'600
2022	6.2	4.8	551	17	6'567

Table A – 18 Sulphur dioxide emission factors used for the inventory.

	SO_X (as SO_2) country-specific and fuel-specific default emission factors used for Switzerland's emission inventory									
Fuel	Diesel oil, biodiesel (average in 1A3b)	Gasoline, bioethanol (average in 1A3b)	Gas oil (boilers and engines in 1A1a, 1A2, 1A4)	Natural gas (boilers and engines in 1A1, 1A2, 1A4, 1A3e)	Natural gas (for 1A3b only)	Biogas, sewage gas, landfill gas, LPG	Res. fuel oil (boilers in 1A1a, 1A2)	Lignite (boilers in 1A2g)	Bituminous coal (boilers in 1A1a, 1A2g)	Bituminous coal (boilers in 1A4b)
Unit	g/GJ									
1990	69	8.5	72	0.50	NO	0.5	466	500	500	350
1991	61	8.5	64	0.50	NO	0.5	440	500	500	350
1992	54	8.5	55	0.50	NO	0.5	424	500	500	350
1993	41	8.5	55	0.50	NO	0.5	404	500	500	350
1994	28	8.5	55	0.50	NO	0.5	391	500	500	350
1995	18	8.5	58	0.50	NO	0.5	376	500	500	350
1996	17	8.5	56	0.50	NO	0.5	364	500	500	350
1997	18	8.5	52	0.50	NO	0.5	373	500	500	350
1998	19	8.5	44	0.50	NO	0.5	348	500	500	350
1999	17	8.5	35	0.50	NO	0.5	341	500	500	350
2000	15	6.8	34	0.50	NO	0.5	339	500	500	350
2001	12	5.1	36	0.50	0.50	0.5	372	500	500	350
2002	11	3.5	37	0.50	0.50	0.5	393	500	500	350
2003	6.8	1.8	36	0.49	0.49	0.5	383	500	500	350
2004	3.3	0.8	36	0.47	0.47	0.5	377	500	500	350
2005	0.28	0.23	35	0.45	0.45	0.5	381	500	500	350
2006	0.30	0.26	32	0.43	0.43	0.5	395	500	500	350
2007	0.30	0.25	30	0.43	0.43	0.5	413	500	500	350
2008	0.32	0.25	27	0.43	0.43	0.5	430	500	500	350
2009	0.32	0.23	25	0.43	0.43	0.5	435	500	500	350
2010	0.32	0.22	23	0.43	0.43	0.5	438	500	500	350
2011	0.31	0.21	23	0.42	0.42	0.5	435	500	500	350
2012	0.31	0.22	19	0.44	0.44	0.5	437	500	500	350
2013	0.32	0.21	18	0.44	0.44	0.5	431	500	500	350
2014	0.33	0.20	14	0.44	0.44	0.5	416	500	500	350
2015	0.33	0.20	14	0.43	0.43	0.5	396	500	500	350
2016	0.35	0.21	11	0.43	0.43	0.5	448	500	500	350
2017	0.34	0.22	8.8	0.38	0.38	0.5	453	500	500	350
2018	0.33	0.24	8.4	0.38	0.38	0.5	460	500	500	350
2019	0.32	0.24	7.8	0.13	0.13	0.5	356	500	500	350
2020	0.32	0.22	6.8	0.15	0.15	0.5	269	500	500	350
2021	0.31	0.22	4.9	0.039	0.039	0.5	290	500	500	350
2022	0.31	0.22	2.0	0.18	0.18	0.5	297	500	500	350

A5.2 Industrial processes and product use (illustrative example of mobile air conditioning)

The use of HFCs as substitutes of ODSs in 2F1 refrigeration and air conditioning is the main factor for the increase of HFC emissions from 1990 to 2015. Refrigerants contained in installed equipment lead to a considerable stock with annual losses of between 0.5 % to 20 % depending on the equipment type (see Table 4-48). Emissions are calculated for the production, operation, service and disposal of equipment. The following illustrative example shows the calculations for the example of mobile air conditioning (HFC-134a use as refrigerant). The example is calculated bottom-up, based on vehicle statistics and information on air conditioning equipment. There is no production of air conditioning equipment for cars in Switzerland, equipment is imported already charged.

Table A – 19 Applied model parameters and assumption for mobile air conditioning of cars.

Characteristic values			
Initial charge in kg HFC per unit AC	1994	0.81	kg
	2002	0.70	kg
	2014	0.55	kg
	Extrapolation of other years		
Lifetime		15	years
Production			
Import of precharged equipment		100	%
Operation			
Annual losses		8.5	%
Recharge of losses (7.2% of 8.5%)		85	%
Additional service losses over lifetime		10	%
Disposal			
Export rate		31-72	%
Share with total loss of refrigerant		40	%
Disposal loss of professional recovery		15	%

Since 1991 HFC-134a has been used to replace ODS in the mobile air conditioning sector leading to a considerable stock of about 1’613 t of HFC-134a in registered cars at present (peak value of stock 2’418 t of HFC-134a in 2014). A phase-out of HFC-134a and replacement with HFO-1234yf is under way, due to regulations in the European Union and their implementation in Switzerland. AC-refrigerants exceeding a GWP of 150 are not allowed for new car models since 2011. Since 2017, no new cars with AC-refrigerant exceeding a GWP of 150 are allowed. Due to safety concerns with alternative use of HFO-1234yf (GWP 4), there has been a delay in the replacement of HFC-134a.

Interviews were carried out 2014, 2017 and 2018 with garages in Switzerland to follow the development of HFC-134a replacement. The first interviews held in 2014 showed that only few of the imported brands switched to HFO-1234yf (GWP 4). In 2014, garages confirmed a minor portion below 5 % of equipment with HFO-1234yf. In 2017 feedback of garages on the sold vehicles of the former year varied widely depending on the models sold and origin of cars. In interviews carried out in 2018, garages confirmed complete phase-out of HFC-134a in new vehicles sold in 2017 (excluding sold vehicles from former years in stock and second-hand vehicles). Most of them switched to HFO-1234yf, few models apply CO_2 (R744). A complete replacement of HFC-134a was assumed for all new vehicles models sold since 2020.

Table A – 20 Bottom-up calculations to identify the number of air conditioning equipment and amount of HFC-134a

Year	**New registered vehicles**	**Vehicles in use**	**Disposed vehicles**	**New equipment: number of air conditioning units with HFC-134a in new registered cars**			**Equipment stock: Number of air conditioning units with**		**Equipment disposal**	**Initial equipment charge**
	Statistics	Statistics	Calculated	Portion of vehicles with AC [%]	HFC-134a as refrigerant [%]	AC units with HFC-134 [units]	Portion of vehicles with HFC-134a [%]	AC units with HFC-134 [units]	Units AC with HFC-134a [units]	Filled in amount [kg HFC/ unit]
1989	335'094	2'895'842		5	0	0	0	0	0	1
1990	327'456	2'985'399	237'899	6	0	0	0	0	0	1
1991	314'824	3'057'800	242'423	7	10	2'204	0	2'204	0	1
1992	296'009	3'091'230	262'579	9	30	7'992	0	10'196	0	1
1993	262'814	3'109'524	244'520	14	66	24'284	1	34'480	0	1
1994	270'009	3'165'043	214'490	19	90	46'172	3	80'652	0	1
1995	272'897	3'229'169	208'771	24	100	65'495	5	146'147	0	1
1996	269'529	3'268'073	230'625	38	100	102'421	8	248'568	0	1
1997	272'441	3'323'421	217'093	52	100	141'669	12	390'237	0	1
1998	297'336	3'383'275	237'482	68	100	202'188	18	592'426	0	1
1999	317'985	3'467'275	233'985	75	100	238'489	24	830'914	0	1
2000	315'398	3'545'247	237'426	77	100	242'856	30	1'073'771	0	1
2001	317'126	3'629'713	232'660	85	100	269'557	37	1'343'328	0	1
2002	295'109	3'704'822	220'000	87	100	256'745	43	1'600'073	0	1
2003	271'541	3'754'000	222'363	89	100	241'671	49	1'841'744	0	1
2004	269'211	3'811'351	211'860	91	100	244'982	55	2'086'726	0	1
2005	259'426	3'863'807	206'970	92	100	238'672	60	2'325'398	0	1
2006	269'421	3'899'917	233'311	96	100	258'644	66	2'581'839	2'204	1
2007	284'674	3'955'787	228'804	96	100	273'287	72	2'847'133	7'992	1
2008	288'525	4'030'965	213'347	96	100	276'984	77	3'099'833	24'284	1
2009	266'018	4'051'569	245'414	96	100	255'377	82	3'309'039	46'172	1
2010	294'239	4'119'370	226'438	96	100	282'469	86	3'526'013	65'495	1
2011	327'896	4'209'300	237'966	96	100	314'780	90	3'738'372	102'421	1
2012	328'139	4'254'725	282'714	96	100	315'013	92	3'911'717	141'669	1
2013	310'154	4'320'885	243'994	96	92	273'928	92	3'983'456	202'188	1
2014	304'083	4'384'490	240'478	96	85	248'132	91	3'993'099	238'489	1
2015	327'143	4'458'069	253'564	96	77	241'510	90	3'991'753	242'856	1
2016	319'331	4'524'029	253'371	96	69	211'525	87	3'933'720	269'557	1
2017	315'032	4'570'823	268'238	96	30	90'729	82	3'767'705	256'745	1
2018	300'887	4'602'688	269'022	97	10	29'186	77	3'555'219	241'671	1
2019	312'902	4'623'952	291'638	97	6	18'211	72	3'328'448	244'982	1
2020	238'664	4'658'335	204'281	97	0	0	66	3'089'776	238'672	1
2021	242'263	4'688'235	212'363	97	0	0	60	2'831'132	258'644	1
2022	243'474	4'719'346	284'674	97	0	0	54	2'557'845	273'287	1

Table A – 21 Results and structure of emission calculations of HFC-134a from mobile air conditioning of cars for 1990 to 2022.

HFC-134a	Activity			Emissions				Recharge	Disposal
	Input with vehicles	Stock	Retiring vehicles (incl. Export)	Production	Stock incl. Recharge	Disposal	Total	import in bulk	recovered for disposal
	[t]	[t]	[t]	[t]	[t]	[t]	[t]	[t]	[t]
1990	0	0	0	NO	0	0	0	0	0
1991	2	2	0	NO	0	0	0	0	0
1992	7	8	0	NO	1	0	1	0	0
1993	20	28	0	NO	3	0	3	1	0
1994	37	65	0	NO	6	0	6	2	0
1995	51	116	0	NO	11	0	11	5	0
1996	79	193	0	NO	18	0	18	9	0
1997	107	297	0	NO	27	0	27	15	0
1998	151	444	0	NO	41	0	41	23	0
1999	175	613	0	NO	56	0	56	35	0
2000	175	779	0	NO	71	0	71	48	0
2001	191	960	0	NO	88	0	88	61	0
2002	180	1'127	0	NO	103	0	103	75	0
2003	166	1'277	0	NO	117	0	117	88	0
2004	165	1'425	0	NO	131	0	131	100	0
2005	158	1'564	0	NO	143	0	143	111	0
2006	168	1'709	1	NO	157	0	157	122	1
2007	174	1'856	4	NO	170	1	171	133	2
2008	173	1'992	12	NO	183	3	186	145	6
2009	156	2'096	25	NO	192	8	200	155	13
2010	169	2'206	31	NO	202	9	211	163	16
2011	185	2'311	50	NO	212	14	226	172	26
2012	181	2'379	81	NO	218	18	236	180	41
2013	155	2'412	90	NO	221	24	245	185	46
2014	136	2'418	96	NO	222	26	248	188	49
2015	133	2'416	102	NO	222	26	248	188	52
2016	117	2'389	111	NO	219	28	247	188	57
2017	50	2'287	118	NO	210	30	240	186	60
2018	16	2'152	119	NO	197	31	228	166	61
2019	10	2'003	130	NO	184	33	217	155	66
2020	0	1'885	90	NO	173	23	196	147	46
2021	0	1'763	96	NO	162	25	186	137	49
2022	0	1'613	126	NO	148	32	180	125	64

A5.3 Agriculture

A5.3.1 Additional data for estimating CH_4 emission from 3A Enteric fermentation

Table A – 22 Data for estimating enteric fermentation emission factors for cattle (Table according to outline in IPCC 1997c, p 4.31–4.33).

Type	Age [a]	Weight [a] kg	Weight Gain [a] $kg*day^{-1}$	Feeding Situation / Further Specification [a]	Milk [b] $kg*day^{-1}$	Work $hrs*day^{-1}$	Pregnant [a] %	Digestibility of Feed % [d]	Y_m [d] %	Em. Factor $kg*head^{-1}*year^{-1}$ [e]
Mature Dairy Cattle	NA	679	0		13.2-19.8 [c]	0	305 days of lactation	72	6.90	115.5 - 141.0
Other Mature Cattle	NA	650	0		6.85	0		62	6.50	106.8
Fattening Calves	0-98 days	124	1.43	Rations of unskimmed milk and supplementary milk feed when life weight exceeds 100 kg. Rations are apportioned on two servings per day.	0	0	0	95	0.00	0.0
Pre-Weaned Calves	0-300 days	195	0.88	"Natura beef" production, milk from mother cow and additional feed.	0	0	0	65	4.00	15.8
Breeding Calves	0-105 days	85	0.67	Feeding plan for a dismission with 14 to 15 weeks. Milk, feed concentrate (100kg in total), hay (80 kg in total).	0	0	0	73	3.99	29.0
Breeding Cattle (4-12 months)	4-12 month	210	0.80	Premature race (Milk-race)	0	0	0	65	6.30	
Breeding Cattle (> 1 year)	12-28/30 month	450	0.80	Premature race (Milk-race)	0	0	0	65	6.30	59.3
Fattening Calves (0-4 months)	0-132 days	115	0.83	Diet based on milk or milk-powder and feed concentrate, hay and/or silage	0	0	0	73	5.54	41.9
Fattening Cattle (4-12 months)	4-12 month	361	1.37	Feeding recommendations for fattening steers, concentrate based	0	0	0	65	6.30	

[a] Data source: RAP 1999 and calculations according to Soliva 2006.

[b] Milk production in kg/day is calculated by dividing the average annual milk production per head by 365 days.

[c] data source: Swiss farmers union (MISTA 2023).

[d] data source: IPCC 2019 and Zeitz et al. 2012.

[e] For better comparability emission factors of young cattle were converted to $kg*head^{-1}*year^{-1}$ although the time span of most of the individual categories is less than 365 days.

A5.3.2 Additional data for estimating CH_4 and N_2O emission from 3B Manure management

Table A – 23 Data for estimating manure management CH_4 emission factors (Table according to outline in IPCC 1997c, Tables B-1 to B-7).

Type	Weight kg [a]	Digestibility of Feed % [b]	Energy Intake $MJ*day^{-1}$	Feed Intake $kg*day^{-1}$	% Ash Dry Basis [b]	VS $kg*head^{-1}*day^{-1}$	B_0 m^3 CH_4*kgVS^{-1} [b]
Mature Dairy Cattle	679	72	255 - 312	15.34 [c]	8.8 - 9.1	3.51 - 4.30	0.24
Other Mature Cattle	650	62	251	13.70 [c]	8	4.75	0.18
Fattening Calves	124	95	47	2.02 [a]	8	0.12	0.18
Pre-Weaned Calves	195	65	60	2.99 [a]	8	0.67	0.18
Breeding Calves	85	73	44	2.19 [a]	8	0.37	0.18
Breeding Cattle (4-12 months)	210	65	90	4.88 [a]	8	1.57	0.18
Breeding Cattle (> 1 year)	450	65	144	7.78 [a]	8	2.51	0.18
Fattening Calves (0-4 months)	115	73	57	3.00 [a]	8	0.67	0.18
Fattening Cattle (4-12 months)	361	65	126	6.84 [a]	8	2.20	0.18
Sheep	NA	65	21 - 24	1.08-1.24 [c]	8	0.40	0.19
Swine	NA	75	24 - 27	NA	6	0.31	0.45
Buffalo	NA	65	129 - 163	7.00-8.82 [c]	8	2.76	0.10
Camels	NA	65 [d]	31 - 38	1.68-2.05 [c]	8	0.55	0.26
Deer	NA	65	51 - 60	2.74-3.26 [c]	8	1.04	0.19
Goats	NA	65	25 - 28	1.34-1.40 [c]	8	0.44	0.18
Horses	NA	70	107 - 109	7.73-7.89 [c]	4	1.69	0.30
Mules and Asses	NA	70	38 - 40	2.76-2.83 [c]	4	0.60	0.33
Poultry	NA	NA	1.0 - 1.4 [c]	NA	NA	0.01	0.37 [#]
Rabbits	NA	NA	1.2	NA	NA	0.10	0.32
Livestock NCAC	NA	NA	NA	NA	NA	0.62	0.25

[a] RAP 1999

[b] IPCC 2006 and IPCC 2019

[c] Richner and Sinaj 2017

[d] Llamas and alpacas: same value as for sheep

[e] metabolizable energy (ME)

[#] weighted average

A5.3.3 Additional data for estimating N_2O emissions from 3D Agricultural soils

Table A – 24 Additional data for estimating N_2O emission from crop residues (based on SBV (2023), Richner and Sinaj (2017) and FAL/RAC (2001)).

2022		**Total crop production t DM**	**Nitrogen incorporated with crop residues $F_{(CR)}$ t N**	**N_2O emissions from crop residues t N_2O**
1. Cereals	Wheat	385'625	1'616	25.39
	Barley	155'685	794	12.47
	Maize	106'519	1'003	15.75
	Oats	10'872	67	1.06
	Rye	8'912	38	0.59
	Other:			
	Triticale	36'426	179	2.81
	Spelt	24'812	227	3.57
	Mix of Fodder Cereals	932	5	0.07
	Mix of Bread Cereals	275	1	0.02
	Millet	146	4	0.06
2. Pulse	Dry Beans	1'677	67	1.05
	Peas (Eiweisserbsen)	7'822	230	3.62
	Soybeans	5'249	216	3.40
	Leguminous Vegetables	2'823	294	4.62
	Lupines	741	29	0.46
3. Tuber and Root	Potatoes	81'768	299	4.69
	Other:			
	Fodder Beet	6'000	43	0.68
	Sugar Beet	297'737	2'125	33.39
5. Other	Fruit	42'638	398	6.26
	Grass	4'429'176'564	20'548	322.90
	Green Corn	126'085	120	1.88
	Non-Leguminous Vegetables	56'184	664	10.44
	Rape	82'853	1'420	22.32
	Renewable Energy Crops	747	13	0.20
	Silage Corn	741'677	437	6.87
	Sunflowers	12'091	256	4.02
	Tobacco	864	23	0.35
	Berries	2'832	50	0.78
	Vine	25'140	440	6.91
	Oil Squash	18	0	0.00
	Oil Hemp	23	1	0.02
	Oil Flax	432	4	0.06
	Hops	31	0	0.00
	Medicinal Plants and Herbs	365	30	0.47
Total Non-leguminous		2'207'690	10'254	161.14
Total Leguminous		18'311	836	13.14
Total excluding grass		2'226'001	11'091	174.28
Total including grass		4'431'402'565	31'639	497.18

Table A – 25 Additional data for estimating N_2O emission from crop residues (fractions, based on Richner and Sinaj (2017) and FAL/RAC (2001)).

2022		**Residue/ Crop ratio** kg/kg	**Dry matter fraction of residue** kg/kg	**Nitrogen content of residues** kg/kg
1. Cereals	Wheat	1.15	0.85	0.0037
	Barley	1.00	0.85	0.0051
	Maize	1.10	0.85	0.0086
	Oats	1.27	0.85	0.0049
	Rye	1.17	0.85	0.0036
	Other :			
	Triticale	1.25	0.85	0.0039
	Spelt	1.56	0.85	0.0059
	Mix of Fodder Cereals	1.00	0.85	0.0051
	Mix of Bread Cereals	1.15	0.85	0.0037
	Millet	1.29	0.85	0.0196
2. Pulse	Dry Beans	1.13	0.85	0.0353
	Peas (Eiweisserbsen)	1.25	0.85	0.0235
	Soybeans	1.00	0.85	0.0412
	Other:			
	Leguminous Vegetables	3.87	0.16	0.0328
	Lupines	1.00	0.85	0.0412
3. Tuber and Root	Potatoes	0.47	0.13	0.0127
	Other :			
	Fodder Beet	0.37	0.15	0.0233
	Sugar Beet	0.53	0.15	0.0220
5. Other	Fruit	NA	0.17	0.0040
	Grass	0.24	NA	0.0204
	Green Corn	0.05	0.32	0.0190
	Non-Leguminous Vegetables	0.46	0.13	0.0230
	Rape	2.57	0.85	0.0071
	Renewable Energy Crops	2.57	0.85	0.0071
	Silage Corn	0.05	0.32	0.0118
	Sunflowers	2.00	0.60	0.0150
	Tobacco	1.18	NA	0.0221
	Berries	NA	0.20	0.0060
	Vine	NA	0.20	0.0060
	Oil Squash	0.46	0.13	0.0230
	Oil Hemp	4.62	0.85	0.0106
	Oil Flax	1.25	0.85	0.0071
	Hops	NA	1.00	NA
	Medicinal Plants and Herbs	2.50	NA	0.0330

A5.3.4 Estimation of the distribution of nitrogen and volatile solids to manure management systems for cattle animals

The fraction of animal manure handled using different manure management systems (MS) as well as the percentages of urine and dung deposited on pasture, range and paddock was separately assessed for each cattle category.

In a first step the share of manure deposited on pasture, range and paddock is calculated assuming that the amount of deposited manure is proportional to the time spent grazing. The estimated grazing time is based on expert judgement and values from the literature (1990, 1995) and on extensive farm surveys (2002, 2007, 2010, 2015 and 2019) (Kupper et al. 2022). The approach is consistent for nitrogen and volatile solids.

Subsequently, the remaining manure is distributed to the different manure management systems. Data for manure management system distribution for cattle are different for VS and nitrogen. This is because cattle stables often have simultaneously both liquid and solid manure storage systems. As volatile solids are excreted mainly in dung and nitrogen mainly in urine, the proportion of VS stored as solid manure is higher compared to the proportion of N.

Estimation of the distribution of nitrogen is conducted within the Swiss ammonium model AGRAMMON and follows a nitrogen mass balance approach. Further details are provided in Kupper et al. (2022).

The distribution of VS was estimated using data on stable systems, manure accumulation and manure properties from Richner and Sinaj (2017; chapter 4, table 4 and 6). For this purpose five different stable systems are distinguished. For tie stall and loose housing systems with slurry production only (“Vollgülle”) it is assumed that all manure goes to liquid systems. For loose housing systems with deep litter 100 % of the manure is allocated to “deep litter”. For tie stall and loose housing systems with simultaneous production of liquid slurry and solid manure (dung) the distribution to the respective storage systems is conducted as exemplified for mature dairy cattle in Table A – 26. The final shares of volatile solids in the different manure management systems is then calculated based on the frequency of the 5 different stable systems as assessed based on expert judgement and values from the literature (1990, 1995) and on extensive farm surveys (2002, 2007, 2010, 2015 and 2019) (Kupper et al. 2022) (Table A – 27).

Table A – 26 Production of slurry and dung and manure management system distribution for nitrogen and volatile solids for mature dairy cattle in stable systems with simultaneous production of slurry and dung (according to Richner and Sinaj 2017).

	slurry*	dung	Richner and Sinaj 2017, chapter 4
Production per year	11 m^3*$year^{-1}$	8.9 t*$year^{-1}$	table 4
Content of nitrogen	4.5 kg*m^{-3}	4.5 kg*t^{-1}	table 6
Total amount of nitrogen produced	49.5 kg*$year^{-1}$	40.1 kg*$year^{-1}$	
Distribution of nitrogen	**55.3%**	**44.7%**	
Content of volatile solids	40 kg*m^{-3}	150 kg*t^{-1}	table 6
Total amount of volatile solids produced	440 kg*$year^{-1}$	1335 kg*$year^{-1}$	
Distribution of volatile solids	**24.8%**	**75.2%**	

* all values are for undiluted slurry

Table A – 27 Distribution of nitrogen and volatile solids to different storage systems in different stable systems for mature dairy cattle.

	Distribution of nitrogen*		Distribution of volatile solids		Frequency of stable system 2019	Distribution of nitrogen*		Distribution of volatile solids	
	Liquid Slurry / Digesters	Solid manure / Deep litter	Liquid Slurry / Digesters	Solid manure / Deep litter		Liquid Slurry / Digesters	Solid manure / Deep litter	Liquid Slurry / Digesters	Solid manure / Deep litter
Tie stall with slurry ("Vollgülle")	100.0	0.0	100.0	0.0	12.8%	80.4%	19.6%	67.7%	32.3%
Tie stall with liquid slurry and solid manure	55.3	44.7	24.8	75.2	29.5%				
Loose housing system with slurry ("Vollgülle")	100.0	0.0	100.0	0.0	44.6%				
Loose housing system with liquid slurry and solid manure	55.3	44.7	24.8	75.2	12.0%				
Loose housing system with deep litter	0.0	100.0	0.0	100.0	1.1%				

* all values for nitrogen are only indicative here as the exact distribution is assessed in a more detailed mass balance approach within the AGRAMMON-model

In order to assess the quality of the final result the distribution of volatile solids was calculated alternatively by multiplying the distribution of nitrogen from the AGRAMMON-model with average VS/N ratios for slurry and solid manure. The resulting values differ only slightly from the estimated distribution of volatile solids.

A5.4 Land use, land-use change and forestry (LULUCF)

A5.4.1 Category 4(III) – Direct and indirect N_2O emissions

A5.4.1.1 Description

Table A – 28 Key categories in category 4(III) Direct and indirect N_2O emissions from disturbance. Combined KCA results, level for 2022 and trend for 1990–2022, including LULUCF categories (L1/2 = level, Approach 1 or 2; T1/2 = trend, Approach 1 or 2).

Code	IPCC category	Gas	Identification criteria
4III	Direct N2O from disturbance	N2O	L2

Category 4(III) Indirect N_2O emissions is not a key category.

This chapter presents the method for calculating direct and indirect N_2O emissions from nitrogen (N) mineralisation in mineral soil (category 4(III)). The source of nitrogen is N mineralisation associated with loss of soil organic matter resulting from change of land use or management of mineral soils. As the approaches applied are not Tier 3, no N_2O immobilisation is reported (see footnote 1 in CRT Table4(III)).

On productive forest land, the Yasso model simulates small annual changes in soil carbon stocks (chp. 6.4.2.3.7). These changes were deliberately not considered for the calculation of N_2O emissions in category 4(III) as they are not associated with a land-use change or any change in management. Accordingly, N_2O emissions for category 4A.1 in CRT Table4(III) are reported as NO.

Direct N_2O emissions on Cropland remaining cropland (no category registered in CRT Table4(III)) and on Grassland remaining grassland (category 4(III)C1) were included in the Agriculture sector (category 3D1e, see chp. 5.5.1). In Switzerland, grassland is considered to be under agricultural management.

Likewise, indirect N_2O emissions due to nitrogen leaching and run-off on Cropland remaining cropland and on Grassland remaining grassland were included in the Agriculture sector (category 3D2, see chp. 5.5.1).

A5.4.1.2 Methodological issues

For deltaCs = 0 or deltaCs >0 (carbon gain), there are no N_2O emissions provoked by the specific change of land use or management.

For deltaCs <0, direct and indirect N_2O emissions were calculated according to IPCC (2019, Volume 4, chp. 11, equation 11.1 and equation 11.10, respectively):

$$\text{Direct Emission}(N_2O) = -\text{deltaCs} * 1 / (C{:}N) * EF_1 * 44/28 \qquad (\text{kt } N_2O)$$

$$\text{Indirect Emission}(N_2O) = -\text{deltaCs} * Frac_{LEACH-(H)} / (C{:}N) * EF_5 * 44/28 \qquad (\text{kt } N_2O)$$

where:

- deltaCs: soil carbon stock change induced by change of land use or management (calculated according to the methodology described in chp. 6.1.3.2) (kt C)

- C:N: C to N ratio of the soil before the land-use change
- EF_1: default emission factor = 0.01 kg N_2O-N (kg N)$^{-1}$ (IPCC 2019, Volume 4, Table 11.1)
- EF_5: default emission factor = 0.011 kg N_2O-N (kg N)$^{-1}$ (IPCC 2019, Volume 4, Table 11.3)
- $Frac_{LEACH-(H)}$: fraction of mineralised N lost by leaching or run-off; see Table 5-27.

The value of the C:N ratio is related to the land-use category before the change. For Forest land, the default value of C:N = 15 was used (IPCC 2019, Volume 4, equation 11.8). For Cropland and Grassland the ratio is 9.8 according to Leifeld et al. (2007). This value was also used for mineral soil in unproductive wetland (CC42) and unsealed settlement areas (CC52, CC53, CC54).

A5.4.1.3 Uncertainties and time-series consistency for 4(III)

Uncertainties

Activity data

The uncertainty of the activity data corresponds to the uncertainty of the amount of mineralised N. It was calculated as the combined uncertainty of:

- Uncertainty of the carbon stock losses in mineral soil: Land converted to settlements (category 4E2) is the main source in category 4(III). Therefore, the uncertainty of the area converted to settlements (4.6 %; Table 6-5) and the uncertainty of the CO_2 emission factor (50.0 %) were combined to estimate the uncertainty of the carbon stock loss: 50.2 %.
- Uncertainty of the C:N ratio: The uncertainty of the C:N ratio for Forest land was used. With a value of 15 and a 95 %-range between 10 and 30 (IPCC 2019, Volume 4, equation 11.8) the mean uncertainty results in 66.7 %.

The resulting uncertainty of activity data is 83.5 % for direct N_2O emissions (Table 6-5), calculated as $(50.2^2+66.7^2)^{0.5}$.

The uncertainty of the activity data for indirect N_2O emissions is 85.8 %. It is the combined uncertainty of the amount of leached N, which was adopted from the amount of mineralised N (uncertainty 83.5 %, see above) and $Frac_{LEACH-(H)}$ (uncertainty 20 %, adopted from ART 2008a) (Table 6-5).

Emission factors

A relative uncertainty for the emission factors was taken from IPCC (2019, Volume 4, Table 11.1 and Table 11.3). Since the uncertainty envelopes are skewed and no negative values occur, a gamma distribution was chosen (see Annex A2.1):

- Uncertainty EF_1: gamma distribution, corresponding to a 95 % confidence interval of -90 %, +90 %
- Uncertainty EF_5: gamma distribution, corresponding to a 95 % confidence interval of -100 %, +100 %

Results

Detailed results of approach 1 and approach 2 uncertainty analyses are given in Annex A2.2 and Annex A2.3, respectively. Note that in this submission the four categories according to the CRF nomenclature 4(II), 4(III), 4(IV) and 4(V) are still used.

Time-series consistency

Time series for categories 4(III) N_2O emissions from nitrogen mineralisation are all considered consistent; they were calculated based on consistent methods and homogenous databases.

A5.4.1.4 Category-specific QA/QC and verification for 4(III)

The general QA/QC measures are described in chp. 1.5. No category-specific QA/QC activities were undertaken.

A5.4.1.5 Category-specific recalculations for 4(III)

- 4(III) Activity data: The areas of land-use categories for 2013–2021 were updated (see chp. 6.3.1.5).
- 4(III) Activity data: The dataset defining the geographical distribution of organic soils in Switzerland was updated (see chp. 6.3.1.5). This led to a recalculation of the stratification between mineral and organic soils and thus to changes in the amount of soil organic matter loss in mineral soils.
- 4(III) Activity data: The loss of soil organic matter was recalculated due to recalculations of carbon stocks in mineral soil. In the case of a land-use change, the recalculated carbon stocks in mineral soils of Cropland (CC21) and permanent grassland (CC31) (see chp. 6.5.5 and chp. 6.6.5, respectively) led to recalculations of soil carbon stock changes (deltaCs) following the stock-difference approach (see Table 6-3) and – in a next step – of resulting direct N_2O emissions.

A5.4.1.6 Category-specific planned improvements for 4(III)

No category-specific improvements are planned.

Annex 6 Additional information on verification activities

A6.1 Independent verification of the National Greenhouse Gas Inventory for F-gases

Introduction

Since 2000, the Swiss Federal Laboratories for Materials Science and Technology (Empa) performs continuous measurements of halogenated greenhouse gases at the high-Alpine site of Jungfraujoch (3’580 m a.s.l.). These measurements are used for estimating emissions of fluorinated greenhouse gases (HFCs, SF_6) from Switzerland and neighbouring countries. The information can be used for an independent assessment of Swiss inventory data of these greenhouse gases. The independent emission estimate is not used directly for deriving data for the inventory. Data is used, however, to identify either consistency in support of the inventory or discrepancies, which could lead to a reassessment for identifying sources for disagreement and options for improvements.

For the independent assessment of fluorinated greenhouse gas emissions from Switzerland the so-called tracer-ratio method is applied, where Swiss pollution events of HFCs and SF_6, arriving at Jungfraujoch, are scaled to concurrent pollution events of carbon monoxide (CO) and then multiplied by the Swiss CO emission inventory (see Figure A – 2 for a graphical illustration of the method). Similar approaches are also used for the independent verification of greenhouse gas emissions in the United Kingdom (UK MetOffice – using atmospheric observations from Mace Head (Ireland) combined with atmospheric transport models), in Australia (CSIRO – using the tracer-ratio method with measurements from Cape Grim, Tasmania) and in the US (NOAA – using a combination of airborne and ground-based samples).

Method description

For estimates of annual Swiss HFC and SF_6 emissions, only observations at the high-Alpine station Jungfraujoch are taken from air masses that are predominantly influenced by emissions from Switzerland. The number of events which can be used each year depends on the meteorological conditions and lies between 7-15 days per year (mostly in the summer). The process to select these periods is shown in Figure A – 2 and is shortly described here. First, the footprints from the COSMO-model are screened for periods when the Jungfraujoch site is under the influence of air masses which were within the Swiss boundary layer for the last 48 hours. Second, for these periods, mixing ratios of halogenated greenhouse gases are compared with those of CO. Periods which show a concurrent increase are selected for the independent assessment of Swiss emissions, as this is taken as an indication of thorough mixing of Swiss emissions during the transport to Jungfraujoch. Third, the emissions are calculated for each case/day using the formula given in Figure A – 2. The resulting emissions are only used for the annual emission estimate if they are within three standard deviations of the average (Grubbs test). This criterion is met by approximately 90 % of the selected data. Finally, annual emissions are estimated as the median of these individual cases. These annual estimates are merged to a 3-year annual average centred over a 3-year period (e.g. the estimate for the 2022 emissions is calculated by using data from 2021–2023). Since 2009, the uncertainty of the estimates for HFCs has been assessed by using the range of the 25 % to 75 % percentiles of the estimates from single pollution events. For estimates between 2001–2008 the average of the 2009–2011 uncertainties has been taken. For SF_6, with comparably low emissions and a higher degree of uncertainty, an overall uncertainty of 50 % is estimated, based on the long-term average of the 25 % to 75 % percentiles. An additional systematic error could occur if the Swiss emissions of CO are over/underestimated by the inventory. This would linearly impact the emissions of the fluorinated greenhouse gases. Uncertainties may vary from year to year due to the limited amount of data for performing the analysis. Therefore, even subsequent years of lower or higher uncertainty do not signify a change towards lower or higher uncertainty but are just a result of this.

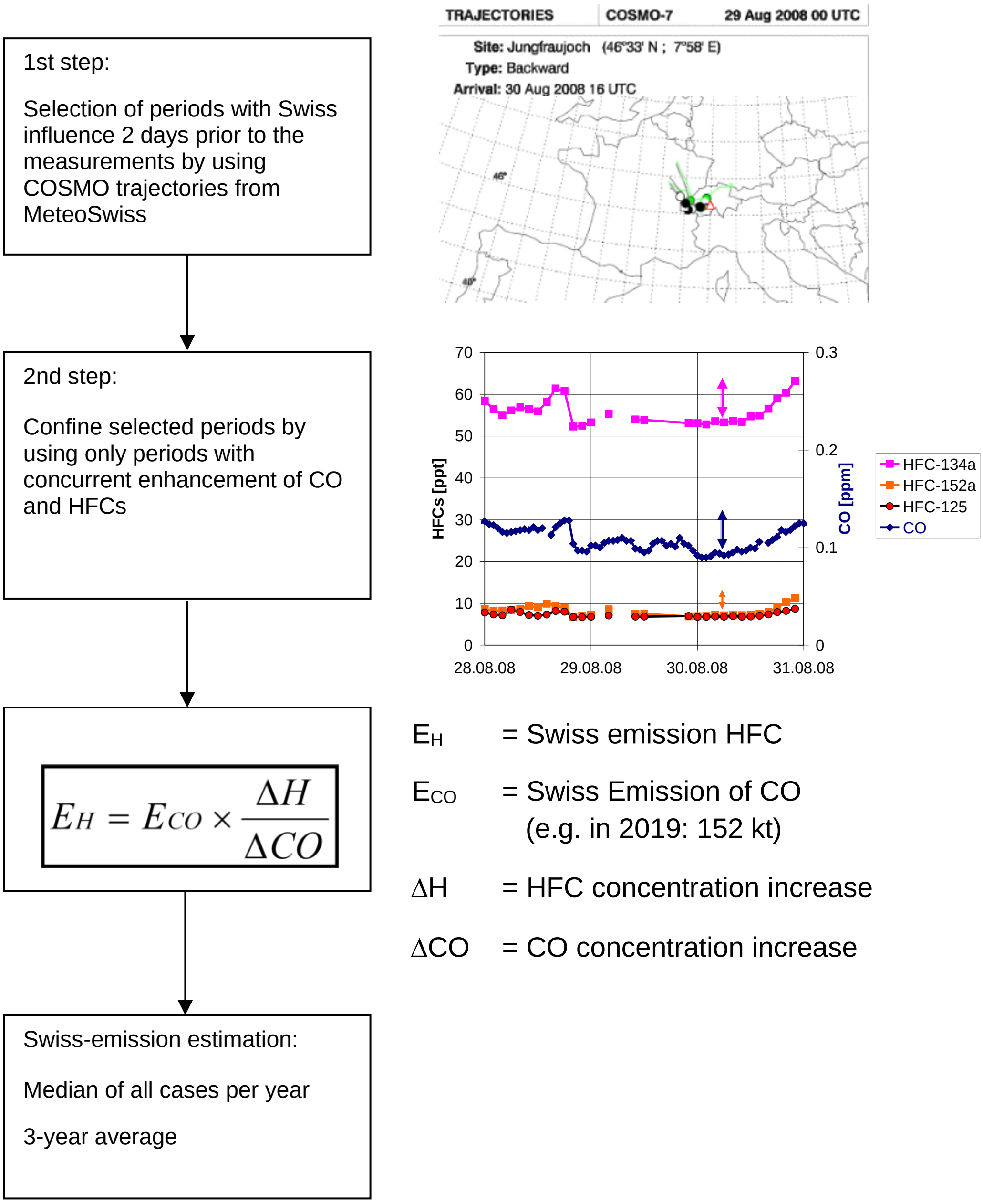


Figure A – 2 Description of the procedure to estimate annual emissions of halogenated greenhouse gases from Switzerland by using continuous measurements of HFCs at Jungfraujoch (Switzerland). Swiss emission of CO (E_{CO}) values are taken from FOEN (2021b), see chp. 3.2.4.1 concerning system boundaries.

Results and discussion

In the following, Swiss emissions of five HFCs (HFC-134a, HFC-125, HFC-152a, HFC-143a, HFC-32) and of SF_6 and the total of perfluorinated carbons PFCs are estimated based on data from Jungfraujoch and are compared to the emission estimate of the Swiss greenhouse gas inventory. Further emission estimates of other fluorinated greenhouse gases will be added in future National Inventory Documents (NID) upon availability.

HFC-134a

HFC-134a is the most important anthropogenic HFC. One of its main sources is the diffuse emission from its usage as cooling agent in mobile air conditioners (MACs). Further relevant applications are the usage in cooling mixtures in the industrial and commercial refrigeration as well as in stationary air conditioners and heat pumps and as propellant. The stock of HFC-134a in MACs and the related emissions have been steadily increasing until 2016 but are declining in most recent years due to the replacement of HFC-134a in this application by HFO-1234yf. Furthermore, in recent years, HFC-134a is also replaced in other cooling applications, which leads to a steady decline of its emissions.

After a common increase of estimated emissions from 2001 until 2007 both the estimate from Jungfraujoch and the inventory showed a stabilization of the emissions. This could be related to the decreasing HFCs used in propellants and to optimizations in the industrial and commercial refrigeration. In the inventory increasing tendencies are found again from 2008 until 2018, whereas the measurement-based estimate shows no clear trend and fluctuates around 300 tonnes/year. Overall, the agreement between the two methods was excellent from 2001 – 2006; while a discrepancy of ca. 25 % to 40 % is observed between 2012 and 2018 (Figure A – 3). Interestingly, also emission estimates for HFC-134a for the United Kingdom of Great Britain and Northern Ireland show a similar discrepancy in the comparison between measurement-based emission estimates (comparable to those performed here) and the UK inventory (Brown et al. 2019). Since 2019 both estimates show consistent declining numbers, which is more pronounced for the inventory-based emissions.

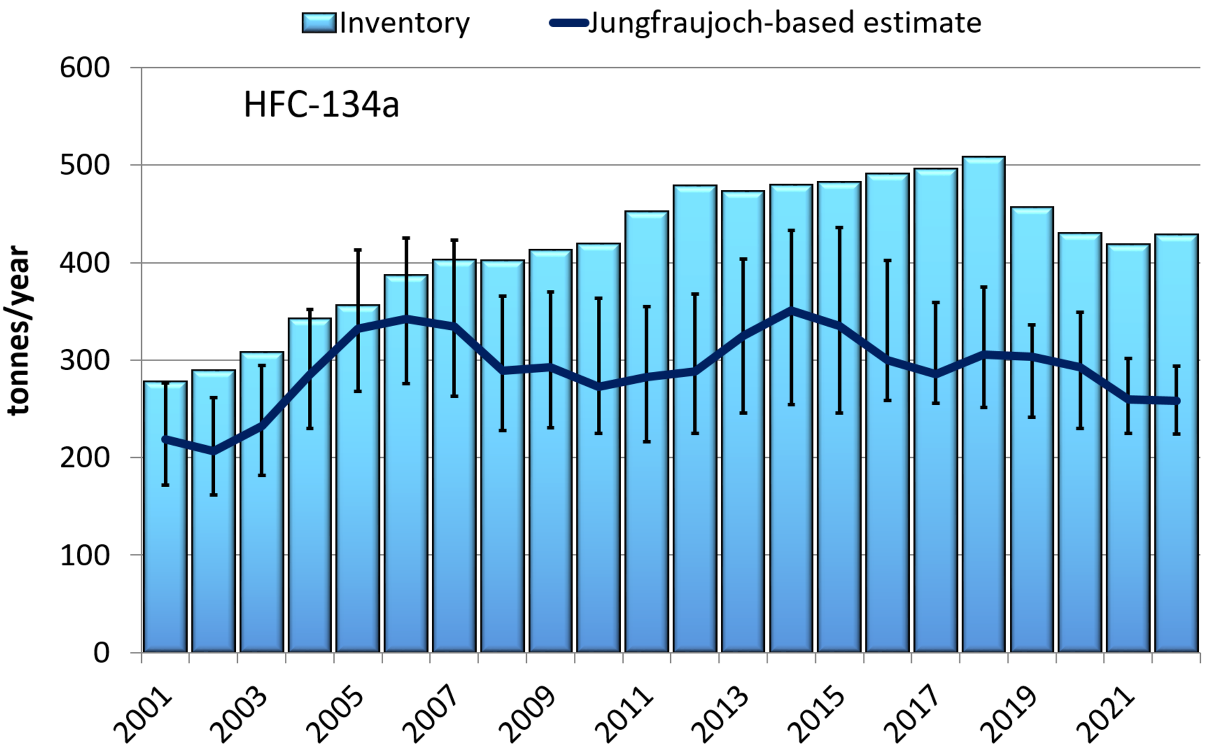


Figure A – 3 Comparison of HFC-134a emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

HFC-125

HFC-125 is mainly used in cooling mixtures in air conditioners and commercial refrigeration equipment. Estimated emissions from Jungfraujoch measurement data tend to be slightly but consistently lower than in the inventory (Figure A – 4). Emission estimates from Jungfraujoch show a decrease of emissions since 2016 and a stabilization thereafter. Due to efforts to eliminate high-GWP HFCs from refrigeration applications and the related elimination of HFC-125 containing blends, the emissions based on the inventory became stable in recent years and are expected to decrease in the near future. Potentially the timing between the two approaches is different due to differences in the real-world usage of HFC-125 and the model approach in the inventory.

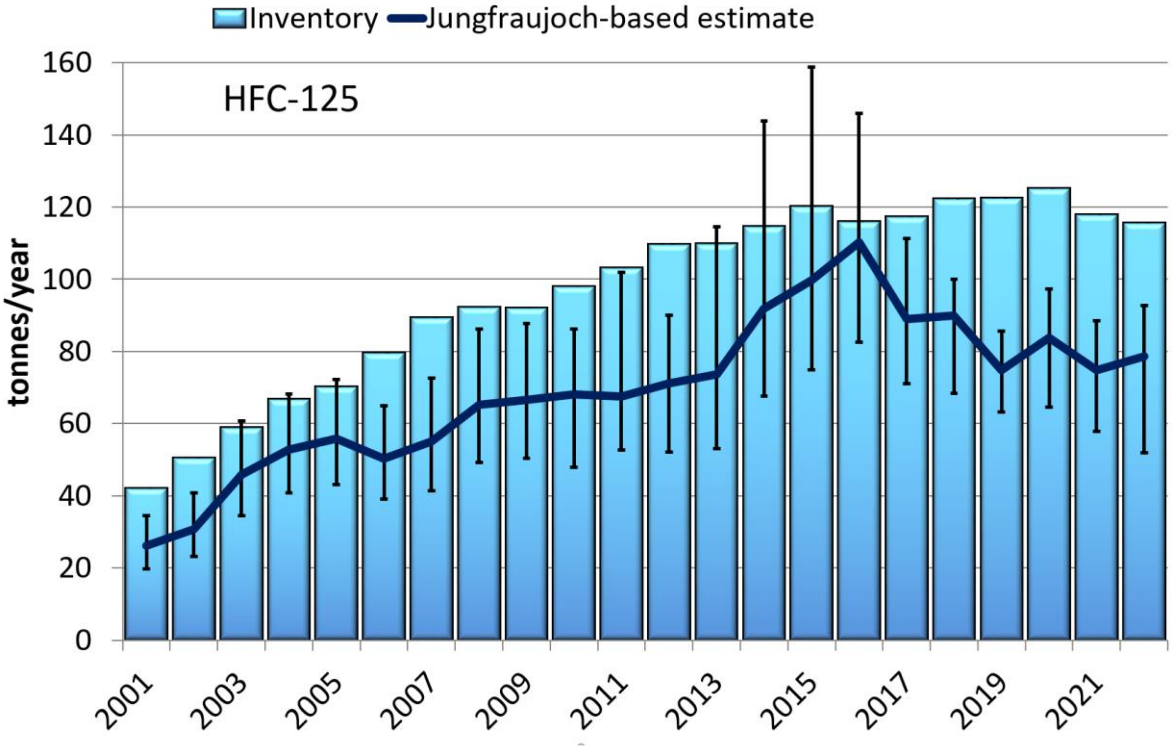


Figure A – 4 Comparison of HFC-125 emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

HFC-152a

HFC-152a is mainly used as a blowing agent in open-cell polyurethane (PU) foams, in closed cell PU sprays and closed-cell extruded polystyrene (XPS) foams. In open cell foams, 100 % of emissions are related to the blowing process. In closed cell foams, part of the blowing agent remains in the product and emissions occur over its lifetime, with a rate depending on the cell- and molecular-structure of the blowing agent. Unlike for other blowing agents, experts assume that within the first year of the lifetime of the foam 95 % to 100 % of HFC-152a is emitted. The emissions of the first year are commonly allocated to the country of production (according to UNFCCC good practice guidance). These assumptions and allocation are also applied for the model used in the Swiss inventory for estimating HFC-152a emissions under the source category 2F2 (Foam Blowing).

HFC-152a emissions from foams in the inventory are mainly related to the production and consumption of PU spray. Most of other foam products are imported, and consequently these emissions are allocated to the country of origin. The reported decrease in the inventory since 2003 reflects the replacement of HFC-152a in PU spray.

Up to the year 2002, estimated emissions from Jungfraujoch measurement data are lower than reported in the inventory and from then onwards they are higher. This can be explained by the UNFCCC practice to allocate HFC-152a emissions of the first year to the country of production of foams (which is except for PU spray mainly outside Switzerland). However, in reality a fraction of these first-year emissions occur during the usage of the products (e.g. for insulation) in Switzerland and are, therefore, reflected in the measurements but, by definition, not in the inventory. Nonetheless, it is important to apply the UNFCCC approach in the inventory as otherwise double counting may occur when allocating the total emissions to the country of origin and the country of product use. Emissions estimated from Jungfraujoch show a consistent decrease related to the partial phase-out of HFC-152a from the foam-blowing applications (Figure A – 5).

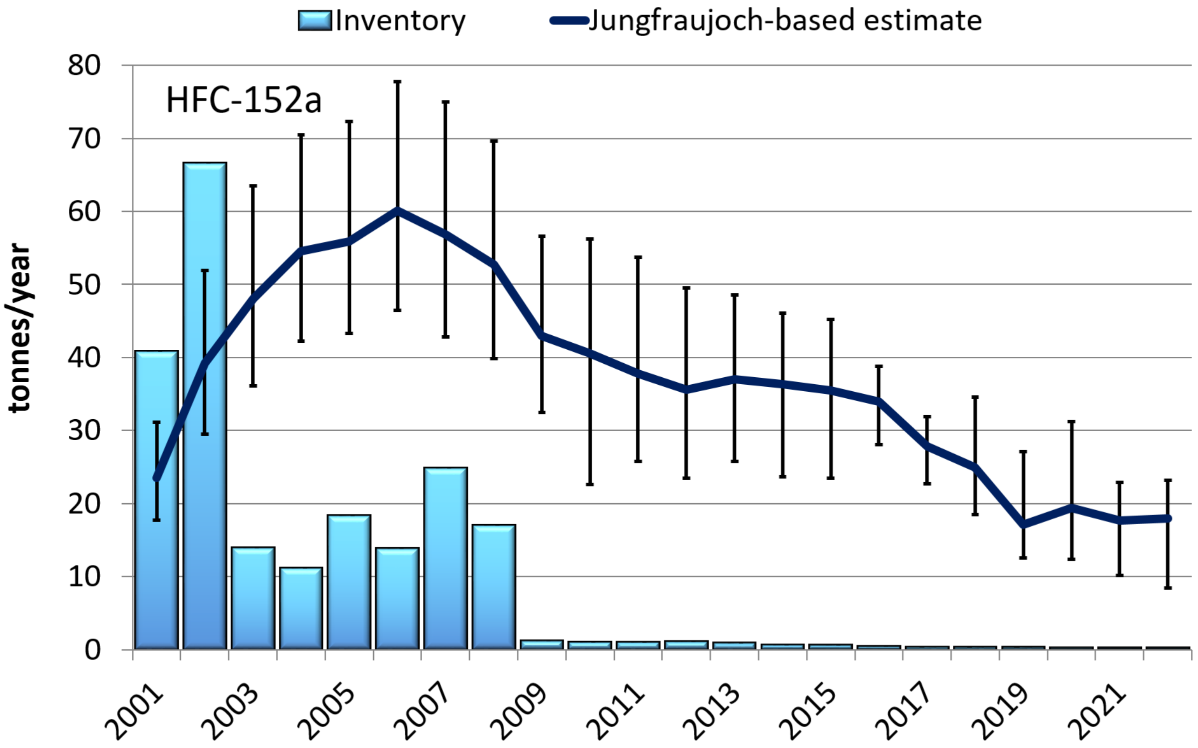


Figure A – 5 Comparison of HFC-152a emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

HFC-143a and HFC-32

HFC-143a (Figure A – 6) and HFC-32 (Figure A – 7) are mainly used in cooling agent mixtures in commercial refrigeration and stationary air conditioners (together with HFC-134a and/or HFC-125). Until 2013, HFC-143a emissions estimated from Jungfraujoch measurement data were slightly lower than those from the inventory. From 2014–2016, there was a very good agreement between the two methods and a slight decrease in emissions in most recent years, which is seen by both methods. Since 2017 a downward trend is seen by both methods, with a more pronounced tendency by the Jungfraujoch-based method. A further decline is expected in the future because of regulations of HFCs with a high GWP for refrigeration applications and the related elimination of HFC-143a containing blends.

For HFC-32, the measurement-based estimates of HFC-32 have been consistently lower (by about 40 %) than the data from the inventory between 2010 and 2018. In contrast to HFC-125 and HFC-143a, emissions of HFC-32 increased until 2018. This could be due to the fact that HFC-32 has a lower GWP than the other two compounds and is therefore preferably used in new air-conditioner applications. Since 2016, however, stable emissions are estimated by the measurement-based method estimates, whereas the inventory-based method sees a steady increase of emissions. Emissions of HFC-32 are in fact expected to increase, as its low GWP allows its use also in the future for cooling applications. The different behaviour of the two estimates could point to more leak-tight systems but could also be of transient nature, as real-world emissions are hold back and will only occur in the future.

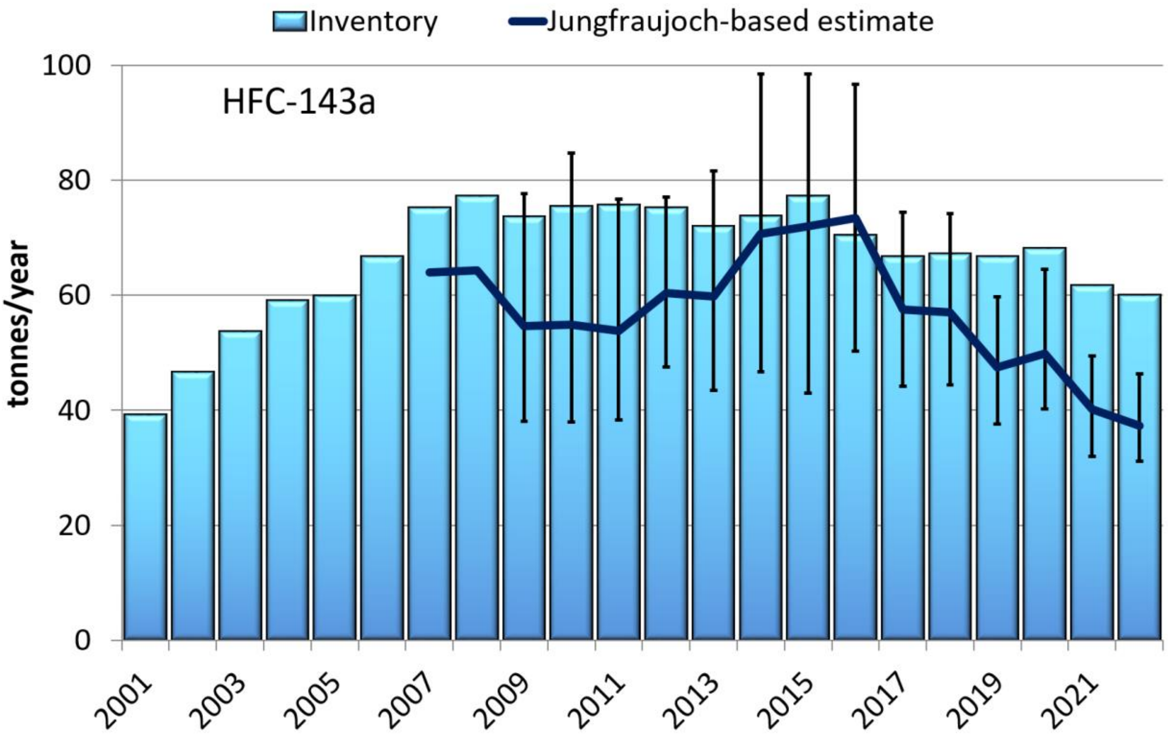


Figure A – 6 Comparison of HFC-143a emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

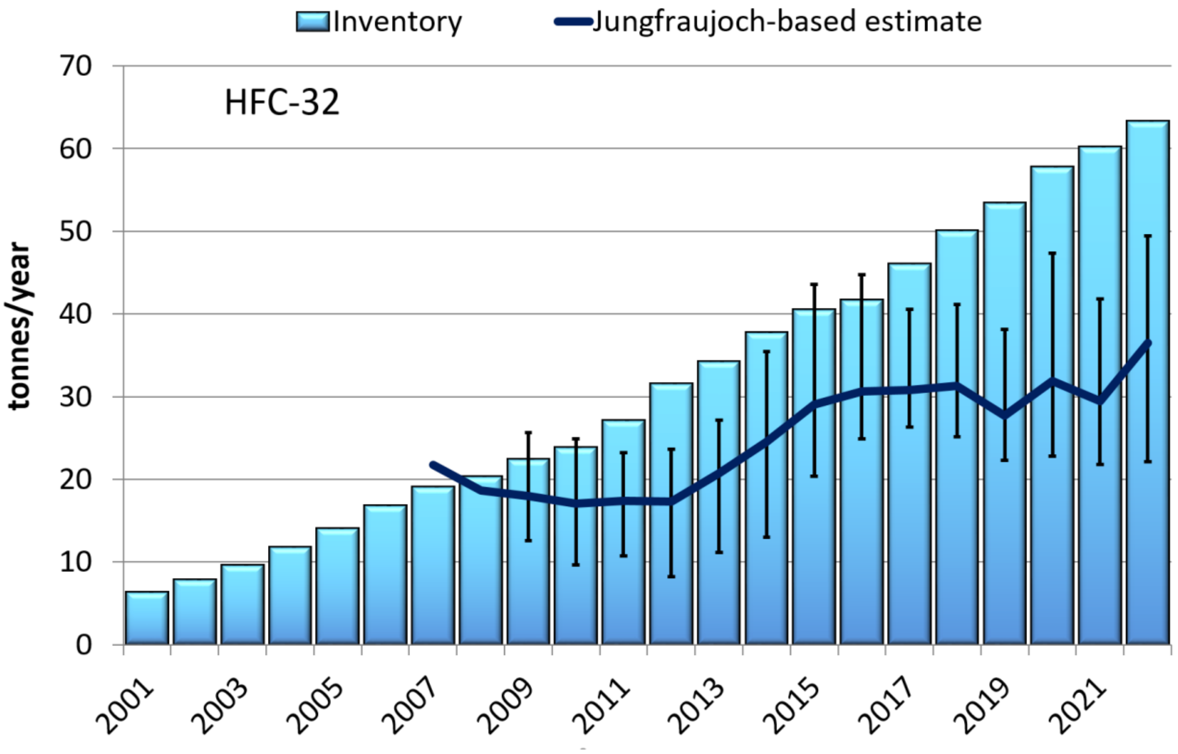


Figure A – 7 Comparison of HFC-32 emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

Sulfur hexafluoride (SF_6)

Until 2010, emissions of SF_6 in Switzerland were mainly due to its use as an insulator of electrical equipment, as for example in gas insulated switchgears and in gas circuit breakers. Since then, emissions from decommissioning of insulating windows are dominant. Additional minor emissions arise from magnesium smelters, industrial particle accelerators and various other applications. Generally, emission estimates for both methods show a remarkable similarity in the trend. Increasing SF_6 emissions were estimated between 2010 and 2015 and could be the result of the increased disposal of insulating windows (all SF_6 released) during this period. Since then, emissions from the inventory are constantly falling, whereas the Jungfraujoch-based estimate shows more or less stable emissions (Figure A – 8).

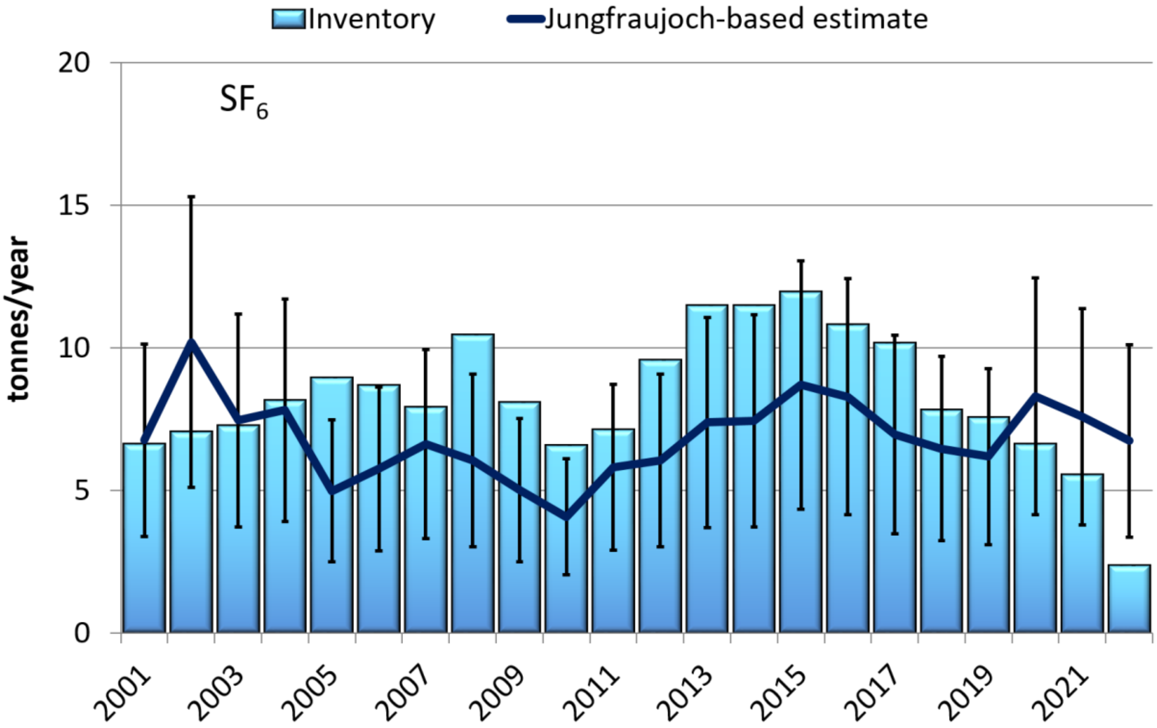


Figure A – 8 Comparison of SF_6 emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

Perfluorinated carbons (PFCs)

Perfluorinated carbons are mainly used and emitted in the electronics industry. Since 2014, all PFCs contained in the NID have been measured at Jungfraujoch, which enables an independent verification of the inventory. Emissions of single PFCs are very small. Therefore, only results for the whole group are reported. The inventory-based estimate shows a stabilization in the recent years, whereas the measurement-based estimate shows an increase. The amounts of both methods are, however, overlapping when uncertainties are taken into consideration (Figure A – 9).

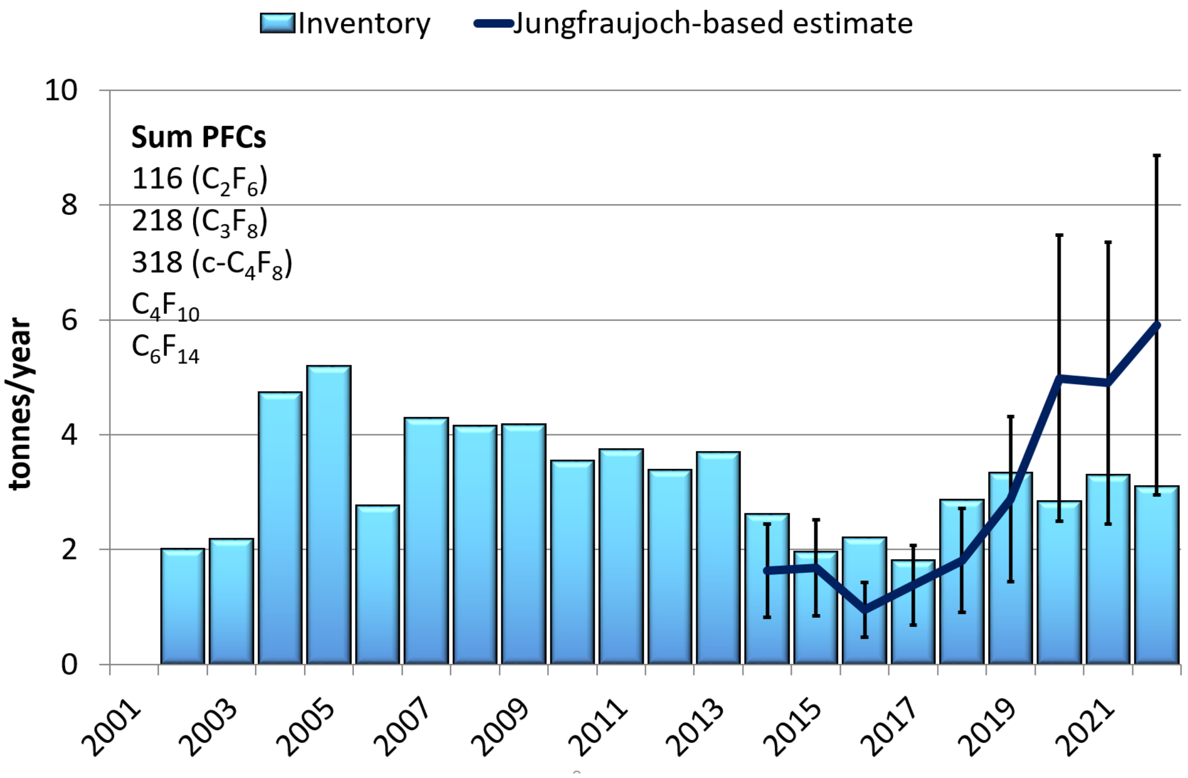


Figure A – 9 Comparison of PFC emissions from Switzerland: Inventory and estimates from measurements at Jungfraujoch.

A6.2 Independent verification of methane and nitrous oxide emissions by inverse modelling

Introduction

In 2013 the Swiss Federal Laboratories for Material Science and Technology (Empa), ETH Zurich and the University of Bern established a greenhouse gas (GHG) observing network in Switzerland as part of the CarboCount-CH SNF-Sinergia project (www.carbocount.ch). The network consisted of four sites that continuously measure the atmospheric concentration of carbon dioxide (CO_2) and methane (CH_4). The sites were chosen to cover most of the densely populated and agriculturally used Swiss Plateau (see Figure A – 10). Atmospheric transport simulations confirm that the measurements at these sites are sensitive to emissions from a large part of Switzerland (Oney et al. 2015). The aim of CarboCount-CH was to better understand and quantify the anthropogenic emissions and biosphere-atmosphere exchange of the abovementioned GHGs by inverse modelling. Currently (March 2024), 3 of the 4 sites (Beromünster, Lägern-Hochwacht, Gimmiz) are still operational, whereas the measurements at Früebüel were closed down in 2016. Additional GHG measurements were carried out in the summer of 2017 in north-eastern Switzerland (Gäbris, GBR, Appenzell) as part of a FOEN-funded validation study to analyse the sensitivity of inverse modelling results to additional measurements in an area poorly covered by the network. Further continuous GHG observations with sensitivity to emissions over Switzerland are available from the high altitude site Jungfraujoch (Empa) and Schauinsland (Germany, UBA, mountain top). High precision measurements of N_2O commenced in March 2017 at the tall tower site Beromünster and additional N_2O observations are available from Jungfraujoch and Schauinsland. Additional CH_4 and N_2O observations in the vicinity of Switzerland became available in recent years as part of the Integrated Carbon Observing Network (ICOS; https://www.icos-cp.eu). ICOS sites used here include the French sites Puy de Dome (PUY), Observatoire pérenne de l'environnement (OPE), the German sites Karlsruhe (KIT) and Hohenpeissenberg (HPB), and the Italian site Ispra (IPR).

Here, the results of inverse modelling to validate total Swiss CH_4 and N_2O emissions are reported. A previous analysis for CH_4 had been carried out for the measurement period March 2013 to February 2014, the first year with data available from all four CarboCount-CH sites, which showed good agreement between the NID reporting and the top-down inverse modelling (Henne et al. 2016). That study also raised further questions regarding the spatial and temporal distribution of the emissions and the sensitivity to boundary conditions (i.e., CH_4 baseline concentrations) required for the regional inversion. Additional sensitivity tests concerning the use of additional measurements in north-eastern Switzerland and the use of baseline concentrations from global scale models were reported in a previous NIR (FOEN 2018). Here, results for CH_4 are given for the period 2013 to 2023, whereas for N_2O inverse modelling results are given for 2017 to 2023.

Methods

The inversion approach applied here was described in detail in Henne et al. (2016). It is based on source sensitivities that were calculated for each of the mentioned measurement sites with the Lagrangian atmospheric transport model FLEXPART. Source sensitivities give the sensitivity of an atmospheric concentration observation to the emissions released at a distant source and as such can be given as concentration units divided by a mass flux (e.g. ppb kg^{-1} s). FLEXPART was driven with high resolution meteorological input data from the numerical weather prediction model COSMO (7 km by 7 km horizontal resolution) provided by the Swiss national weather service (MeteoSwiss) until 2020-10-29 (decommission of COSMO-7 forecasts and respective compute hardware). For FLEXPART simulations until the end of 2021, COSMO-7 analysis fields were calculated by Empa following the previous MeteoSwiss setup as closely as possible. In addition, FLEXPART simulations were conducted using operational MeteoSwiss COSMO-1 analysis fields for the period 2018–2023. Since the COSMO-1 domain is too small to represent the regional greenhouse gas signal sufficiently, FLEXPART-C1 simulations were extended using FLEXPART simulations based on larger-scale analysis fields taken from the European Centre for Medium-range Weather Forecast (ECMWF). For each site, 3-hourly source sensitivities were calculated by running the model in time-inverted mode, releasing in each 3-hour time interval 50'000 air parcels and following them 4 days and 8 days backward in time for FLEXPART-C7 and FLEXPART-C1/FLEXPART-ECMWF, respectively. More details to the model setup can be found in Katharopoulos et al. (2022) and Katharopoulos et al. (2023).

When convoluting source sensitivities with gridded surface emission fluxes, atmospheric concentrations at the location of the observations can be obtained. These simulated concentrations can be compared with the measurements, and through "inverse modelling" an optimized (*a posteriori*) emission distribution can be estimated that minimizes the differences between simulated and observed concentrations while also considering the uncertainties of the initial (*a priori*) emission distribution. In addition to the emission distribution, the applied inversion system also optimizes a baseline concentration for each site, which is required to subtract the non-regional contribution from the total observed concentration

In contrast to the previously reported approach (Henne et al. 2016), which contained a large number of sensitivity inversions to investigate the structural uncertainty of the inversion system, only a reduced set of sensitivity inversions was used here, varying some key aspects of the transport model and the inversion system (particle release height, absolute *a* *priori* emissions, and seasonality). Two sets of inversions were run based on the two different transport model versions: i) FLEXPART-C7 from 2013 to 2021 and ii) FLEXPART-C1 from 2018 to 2023.

As *a priori* emissions for Switzerland, the MAIOLICA CH_4 inventory was used (Hiller et al. 2014), which disaggregates the emissions reported by the Swiss National Inventory Report (NIR) onto a regular spatial grid. For emissions outside of Switzerland the European TNO/MACC-2 inventory was employed (Kuenen et al. 2014). The total anthropogenic emissions of the MAIOLICA inventory was 176 kt yr^{-1}, which corresponds to the Swiss CH_4 emissions in 2012 as reported by the NIR in 2014 (FOEN 2014). The MAIOLICA inventory also includes a small contribution from natural sources of 3 kt yr^{-1} (<2 %). For the application to more recent years the Swiss national total emissions were scaled to those included in the NIR in 2016 (FOEN 2016). For FLEXPART-C1 inversions the *a priori* emissions were updated based on a spatial disaggregation of the national inventory for the year 2015 (Heldstab et al. 2021) and using TNO Version 1.1 (Kuenen et al. 2014) and/or EDGAR Version 6.0 (Crippa et al., 2019), both taken for the base year 2015.

The same inversion technique as for CH_4 was also applied to N_2O for the period March 2017 to December 2023. In addition to the grid-resolved inversion used for CH_4, an additional sector-based inversion system was set-up for N_2O, allowing for the distinction between emissions from different source sectors, but at a reduced spatial resolution (Henne et al. 2019). *A priori* emissions for the N_2O inversion were developed with a spatial resolution of 500 m by 500 m and for 26 emission sectors based on EMIS/NID total national emission estimates and an evaluation of indirect emissions from (semi-)natural ecosystems (Bühlmann et al. 2015).

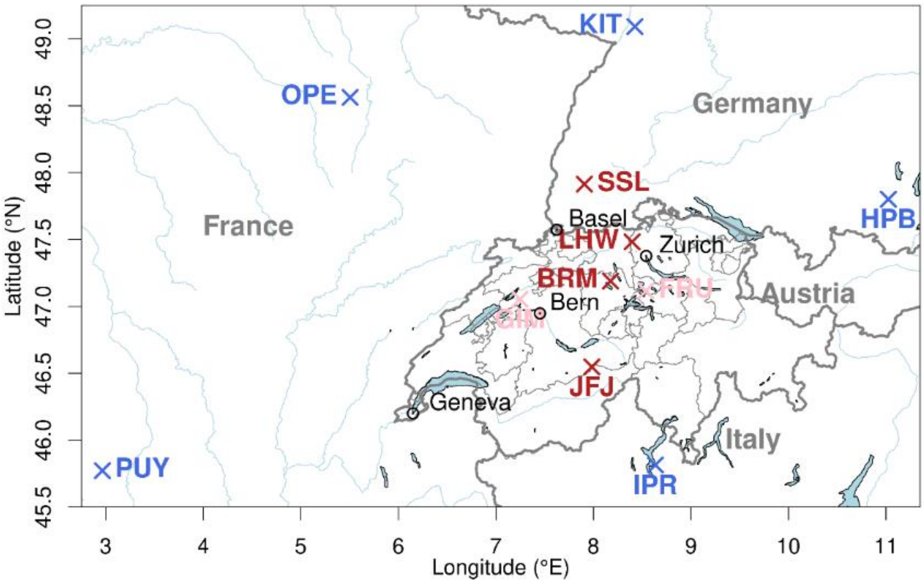


Figure A – 10 Map of Switzerland illustrating the location of observational sites used in FLEXPART-C7 inversions (red), additional ICOS sites used in FLEXPART-C1 inversions (blue), supplementary sites (pink), cantonal and national borders (grey) as well as major cities (black). The sites are: Beromünster (tall tower, BEO), Lägern Hochwacht (mountain top, tower, LHW), Gimmiz (flat, tower, GIM), Früehbüehl (mountain, near surface, FRU), Schauinsland (mountain top, SSL), Jungfraujoch (high Alpine, JFJ), Puy de Dome (mountain top, PUY), Observatoire pérenne de l'environnement (tall tower, OPE), Karlsruhe (tall tower, KIT), Hohenpeissenberg (mountain top, HPB), Ispra (tall tower, IPR).

Methane emissions

The inversion results are presented in the following in terms of national total emissions and spatial distribution. The inversion system was not set-up to optimize emissions by category separately, but to estimate the spatial distribution of total emissions. Nevertheless, through the spatial and temporal information the results can provide qualitative insights into the contribution from specific source categories that dominate in a given region or period. Further details and discussion on the inversion performance and results can be found in Henne et al. (2017).

Two sets of inversions were run based on FLEXPART-C7 and FLEXPART-C1. The former covered the period 2013 to 2021, whereas the latter the period 2017 to 2023. Since the results of the two inversion sets differ systematically, they are compared separately with the NID reporting. The overall mean inverse estimate of total Swiss CH_4 emissions by the FLEXPART-C7 inversions for the period 2013 to 2021 was 198±15 kt yr^{-1} (1-σ confidence interval around the mean). This number represents the average and standard deviation over the reference and all sensitivity inversions for all years. It is slightly (8 %) larger than NID values (incl. emissions from LULUCF) reported in the latest submission (2024) for the same period of 183 kt yr^{-1} (CRT Table10s3) but well within the 1-σ uncertainty range of ±15 kt yr^{-1} for the reporting year 2022. For the period 2017 to 2022 the inverse estimate using the FLEXPART-C1 simulations resulted in average emissions of 213±14 kt yr^{-1}, 19 % larger than the NID reporting. It is apparent that FLEXPART-C1 estimates are systematically larger than FLEXPART-C7 estimates (see Figure A – 11). Potential reasons are the differences in transport simulations, different sets of sensitivity inversions, different treatment/adjustment of baseline concentrations and the extended set of observations. Since inverse modelling estimates integrate all fluxes (sources and sinks) between the land surface and the atmosphere, they need to be compared to inventory emissions including those from LULUCF.

For the period 2013 to 2022, the NID suggests a CH_4 emission (incl. LULUCF) reduction of 13 kt (from 189 to 176 kt yr^{-1} between 2013 and 2022), whereas the inversion estimates showed large inter-annual variability with considerably lower emissions in some years (FLEXPART-C7: 2018, 2019) and increased emissions in recent years (FLEXPART-C1: 2019, 2021, 2023) (Figure A – 11). On one hand, this variability may reflect the uncertainty of the inverse modelling system itself, on the other hand, same variability may result from year-to-year variations in environmental drivers (e.g., temperature, precipitation). Due to this variability it is currently not possible to determine or validate the reported trend. Additional years of observations and further improvements in the inverse modelling are required for this purpose.

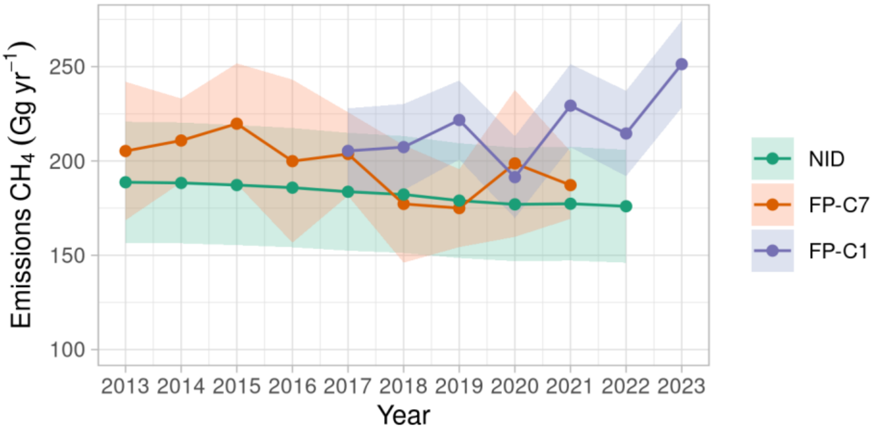


Figure A – 11 Time series of inversely estimated and NID reported Swiss CH_4 emissions. (NID reported and inversely estimated annual values and their uncertainties are given by lines, symbols and uncertainty ribbons. FP-C7 refers to the coarser FLEXPART-C7 simulations/inversions, whereas FP-C1 refers to the high-resolution FLEXPART-C1 simulations/inversions. All uncertainty indicators refer to 2-σ levels. Results for 2023 are based on preliminary atmospheric observations.

In Figure A – 12 the spatial distribution of the *a priori* emissions is shown, whereas the absolute differences between *a posteriori* minus *a priori* emissions for individual years are shown in Figure A – 13 (FLEXPART-C7) and Figure A – 14 (FLEXPART-C1). An irregular inversion grid was used that exhibits high spatial resolution close to the observations and gets coarser with distance to these. In the *a priori* emissions the dominating role of agricultural emissions in the rural areas of the Cantons Lucerne and Thurgau/Appenzell is clearly seen. In contrast, the densely populated areas of Zurich, Basel and Geneva do not show up as emission hot-spots, consistent with the small contribution of emissions from natural gas distribution and wastewater treatment reported in the NID.

The *a posteriori* results for the FLEXPART-C7 period (2013 to 2021) in terms of annual totals and spatial distribution were rather similar providing evidence for the robustness of the method. The *a posteriori* emissions were smaller than *a priori* emissions in the agricultural areas of Canton Lucerne, but were increased in the north-eastern part of Switzerland (Cantons Appenzell and Saint Gallen). Smaller differences were seen in other parts of the country. In contrast results from FLEXPART-C1 (2017–2023) were more variable in annual total emissions and exhibited less of the east-west pattern in the emission increments than seen in FLEXPART-C7.

Analysing the inversion results on a seasonal levels reveals different seasonal variability for the two inversion sets. For FLEXPART-C7 reduced winter time and increased spring emissions were detected for most years and as an average over all years (Figure A – 15). In contrast, FLEXPART-C1 inversions resulted in lower than average winter/spring and larger than average summer/fall emissions (Figure A – 16). This seasonal trend seems to be driven by several years with exceptionally larger summer/fall emissions (2019, 2021, 2023), but is also present, although less prominent, in other years (2017, 2018). The contradictory behaviour between the different inversions and the potential relation to environmental drivers like temperature and precipitation requires further analysis. For example the year 2021, with exceptionally large summer/fall emissions was characterised by a very wet summer (largest summer precipitation on record for several sites north of the Alps) followed by a warmer than average fall.

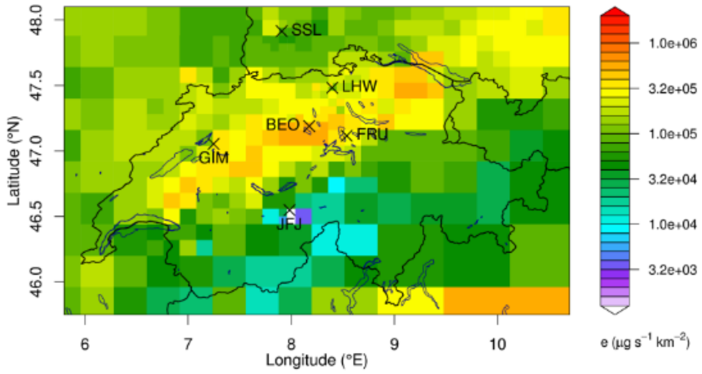


Figure A – 12 Spatial distribution of *a priori* CH_4 emissions. Within Switzerland the distribution follows that derived by Hiller et al. (2014), scaled to the bottom-up estimates of the NIR 2016 (FOEN 2016), outside Switzerland the bottom-up inventory of TNO/MACC (Kuenen et al. 2014) was used.

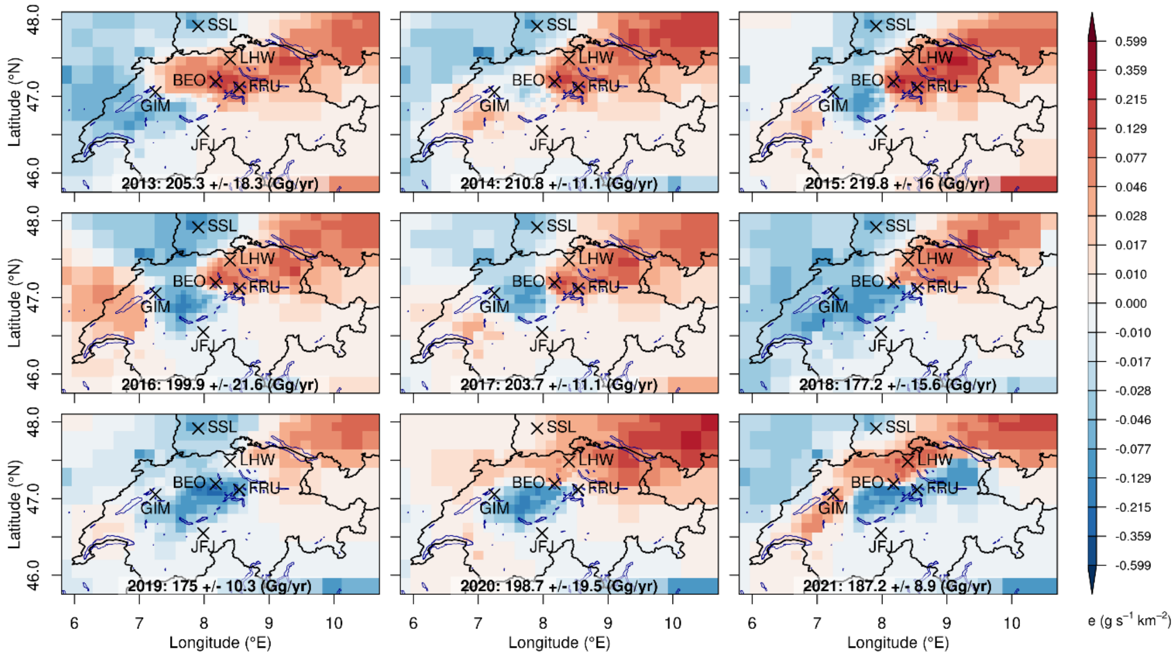


Figure A – 13 Absolute difference between *a posteriori* and *a priori* mean annual CH_4 emissions (each being the mean over 8 sensitivity runs) as obtained with FLEXPART-C7. The numbers given in the plots refer to the total *a posteriori* Swiss emissions and their uncertainty (1σ level) for the given year.

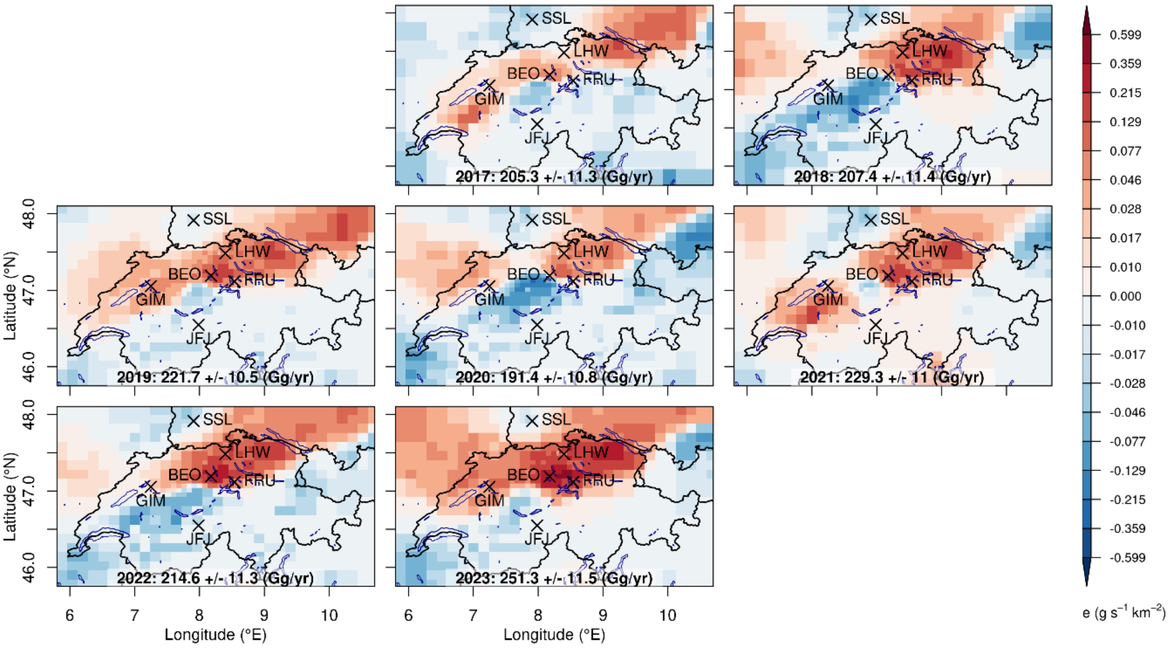


Figure A – 14 Absolute difference between *a posteriori* and *a priori* mean annual CH_4 emissions (base inversion only) as obtained with FLEXPART-C1. The numbers given in the plots refer to the total *a posteriori* Swiss emissions and their uncertainty (1σ level) for the given year. Results for 2023 are based on preliminary atmospheric observations.

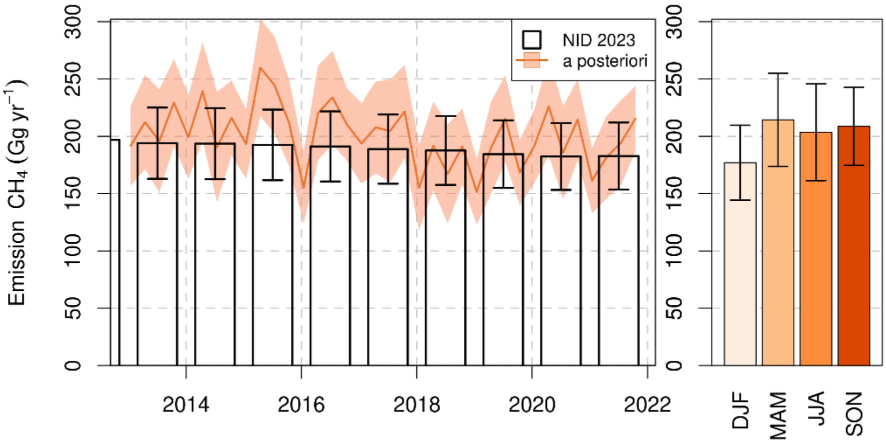


Figure A – 15 Seasonality of Swiss CH_4 emissions as obtained with FLEXPART-C7. Left panel: NID values and their uncertainties are given as black bars and error bars. *A posteriori* emissions are given as orange line and uncertainty ribbons. Average *a posteriori* emissions by season are given on the right panel (DJF: December, January, February; MAM: March, April, May; JJA: June, July, August; SON: September, October, November). All uncertainties refer to 2-σ confidence intervals.

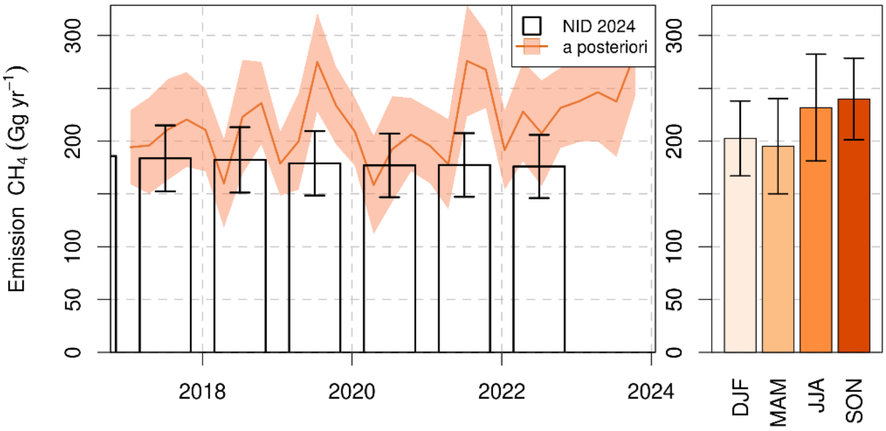


Figure A – 16 Seasonality of Swiss CH_4 emissions as obtained with FLEXPART-C1. Left panel: NID values and their uncertainties are given as black bars and error bars. *A posteriori* emissions are given as orange line and uncertainty ribbons. Average *a posteriori* emissions by season are given on the right panel (DJF: December, January, February; MAM: March, April, May; JJA: June, July, August; SON: September, October, November). All uncertainties refer to 2-σ confidence intervals. Results for 2023 are based on preliminary atmospheric observations.

Nitrous oxide emissions

With the N_2O observations established at the Beromünster tall tower site in 2017, it was possible to estimate Swiss N_2O emissions by inverse methods at the country scale for the period March 2017 to April 2018 (Henne et al. 2019). Inversely estimated Swiss N_2O emissions were slightly larger than reported N_2O emission. However, due to the large uncertainties connected to these numbers, the inverse estimates are not significantly different from the NID estimates. The relative uncertainty of the inverse modelling estimate was smaller than that of the NID estimate. The uncertainty range of the inverse method was calculated from the spread across 14 sensitivity inversions. These comprised the application of two different inversion approaches: one focussing on the spatial distribution (grid inversion), the other on the temporal evolution and emissions by sector (sector inversion). The largest contributors to the *a posteriori* spread were the definition and uncertainty of a baseline of the atmospheric concentrations required by the model approach and systematic differences between grid and sector inversions.

The inverse modelling methodology described in Henne et al. (2019) was extended to the period 2017 to 2023. A slightly different set of 14 sensitivity inversions (per year) was selected, using both inversion approaches and varying important factors of the inversion setup: baseline, a priori emissions, receptor height above model ground.

The best inverse estimate of Swiss annual N_2O emissions for the years 2018 to 2022 was 10.5±1.9 Gg yr^{-1} based on FLEXPART-C1 inversions. This compares to 11.1 (7.6 to 14.6) Gg yr^{-1} given for the same period in this NID (incl. emissions from LULUCF; 2-σ confidence range; compare Figure A – 17). With recent updates in the present NID, inverse estimates and NID estimates agree very closely. The small downward trend, as present in the NID for the most recent years and especially in 2022, can only partly be seen in the inverse estimate (FLEXPART-C7 inversions) but is less evident in FLEXPART-C1 inversions. The large emission estimate for 2023 is based on preliminary observational data and needs confirmation in the future.

The inversion model assigned the largest changes of N_2O emissions (*a priori* to *a posteriori* difference) to ‘industry’ (smaller than *a priori*) and ‘agriculture’ (larger than *a priori*), whereas emissions in all other categories remained similar to the *a priori*. In general, *a posteriori* emissions were larger (smaller) in eastern (western) Switzerland (compare Figure A – 18 for spatial distributions of emissions; Figure A – 19 for emissions by sector). Reductions in the uncertainty of these estimates were largest for the sectors ‘agriculture’ and ‘industry’, whereas they remained almost unchanged for the other categories. Further support for reduced industry emissions is provided by the grid inversions, which estimated that emissions in urban areas are potentially overestimated in the *a priori*.

All inversions suggested a pronounced seasonality in the emissions with a mean amplitude over all inversions of around ±40 % of the annual total (Figure A – 20). Largest emissions were estimated in summer, smallest in winter. However, there was considerable spread in the seasonal amplitude as well, with the tendency of inversions with smaller annual total emissions to predict smaller summertime emissions and correspondingly smaller seasonal amplitudes. Seasonality was dominated by emissions from soils. The strong seasonality obtained here for Switzerland compares well with other recent inverse estimates of N_2O emissions in Europe. Some of these studies also highlight a similarly pronounced seasonality (Ganesan et al. 2015, Brown et al. 2019).

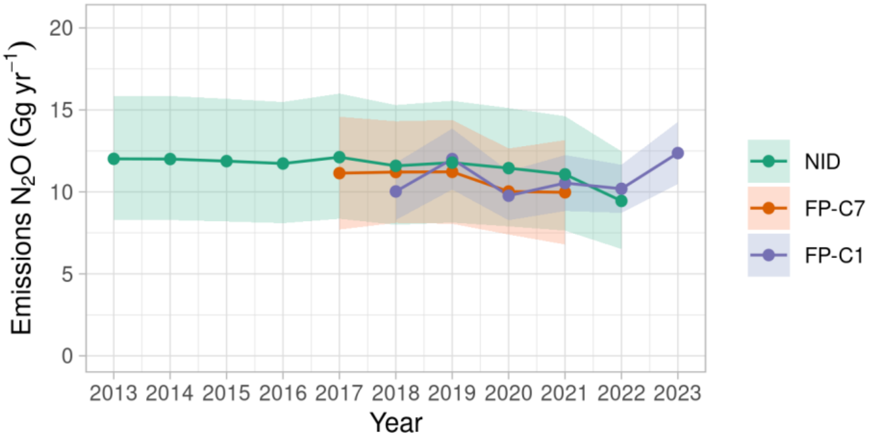


Figure A – 17 Time series of inversely estimated and NID reported Swiss N_2O emissions. (NID reported and inversely estimated annual values and their uncertainties are given by lines, symbols and uncertainty ribbons. FP-C7 refers to the coarser FLEXPART-C7 simulations/inversions, whereas FP-C1 refers to the high-resolution FLEXPART-C1 simulations/inversions. All uncertainty indicators refer to 2-σ levels. Results for 2023 are based on preliminary atmospheric observations.

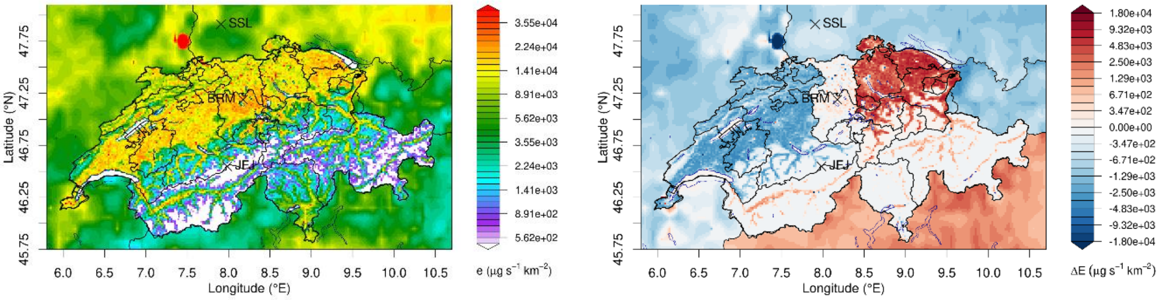


Figure A – 18 (Left) mean *a priori* and (right) *a posteriori* minus *a priori* N_2O emission distribution over all sensitivity inversions (sector inversion only) for the period 2018 March to 2023 November.

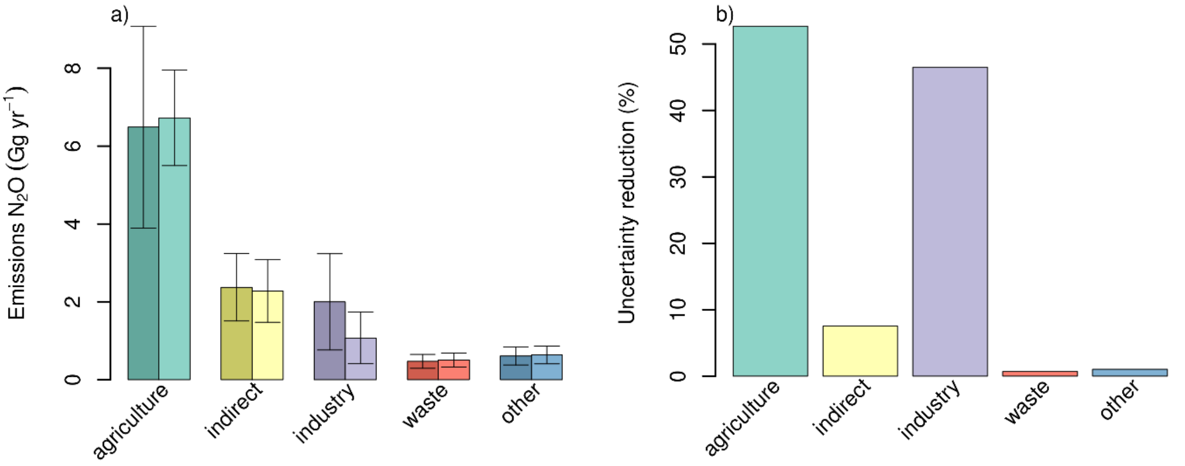


Figure A – 19 (Left) contributions to Swiss N_2O emissions: *a priori* darker colours, *a posteriori* lighter colours. (right) reduction of uncertainty estimate from *a priori* assumption to inverse *a posteriori* estimate. Results present the average for the period 2018 March to 2023 November. Uncertainty bars represent 2-σ confidence intervals.

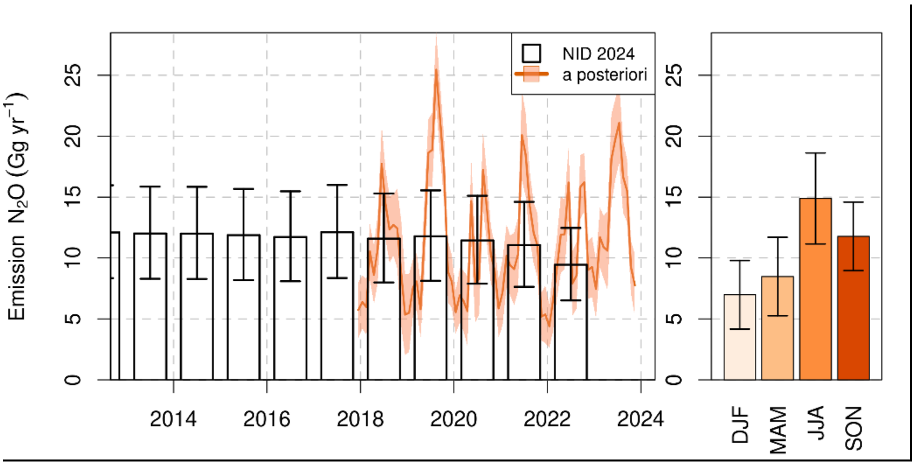


Figure A – 20 Seasonality of Swiss N_2O emissions based on FLEXPART-C1 inversions. Left panel: NID values and their uncertainties are given as black bars and error bars. Monthly a *posteriori* emissions are given as orange line and uncertainty ribbons. Average a posteriori emissions by season are given on the right panel (DJF: December, January, February; MAM: March, April, May; JJA: June, July, August; SON: September, October, November). All uncertainties refer to 2-σ confidence intervals.

Annex 7 Information on the CRF and CRT reporters

For the submission at hand the CRF reporter v6.0.10_AR5 provided by UNFCCC in late January 2023 has been used for quality control of reporting tables and tables presented in this NID. The CRF reporter still seems to generate errors in the numerical output of some reporting tables. A non-exhaustive list of issues and errors identified so far is provided in Table A – 29. In some instances where numbers are not identical in the NID and in the reporting tables (CRF, see submission 2024 under Switzerland's greenhouse gas inventories (admin.ch)), a remark was added in the NID.

At the time of finalisation of the NID (April 2024), the CRT reporter was not yet available. Therefore, possible issues with the CRT reporter are not discussed here and Table A – 29 will be updated or removed from the NID in the next submission.

These aspects should be taken into consideration when comparing information in the NID with the reporting tables.

Table A – 29 Identified issues or errors in the output of some reporting tables (CRF).

Reporting table CRF	Problem	Solution
Table1A(d)	The column “Reported under..." should include the NFR code in the Text.	Actually, there is no possibility to change it, because a drop-down-menu determines the text.
Table2(I)s1-s2	In all empty cells should be written „NO“, but the effort would be very big to generate in the navigation tree of the CRF web application for every cell a new node and then to adapt all the import files to these changes.	Because the effort would be quite big, and there is no real benefit, we passed on it.
Table2(II)	In all empty cells should be written „NO“, but the effort would be very big to generate in the navigation tree of the CRF web application for every cell a new nod and then to adapt all the import files to these changes.	Because the effort would be quite big, and there is no real benefit, we indicate in the documentation box: „2.B.9, 2.C, 2.E, 2.F.1-2.F6, 2.G: "NO" for all empty cells“.
Table2(II)B-Hs1	In Line 50 of the reporting table the emissions are indicated as kt CO_2 eq instead of t.	Problem in the CRF web application.
Table3.B(a)s2	NFR codes 3B4g and 3B4hi: cells I55 and L103 are still empty despite of correctly imported values.	Problem in the CRF web application.
Table3.B(b)	The IEF for "indirect emissions from atmospheric deposition" (cell R37): Wrong molecular weight. The IEF is displayed in kg N_2O per kg N handled	Problem in the CRF web application.

	instead of kg N_2O-N per kg N handled.	
Table3s1; Table3.As1; Table3.As2; Table3.B(a)s1; Table3.B(a)s2; Table3.B(b)	All cells for “Cattle, Option A” should be filled with “IE” but this Option A cannot be selected together with Option B.	Problem in the CRF web application. Solved with comment in documentation boxes of tables Table3.As1, Table3.B(a)s1, Table3.B(b)
Table4	N_2O from 4(IV) (indirect emissions) are included in the total sum in Table 4 without being displayed in any subcategory in Table 4. The sum is correct (with indirect emissions).	Inaccuracy in the CRF web application. The total in the table is not equal to the sum of the subcategories shown in the table.
Table4	There are several empty cells in the CH_4 and N_2O columns, where numbers and/or notation keys are not inserted.	Problem in the CRF web application.
Table4(V)	From 2015 or 2017 onwards, respectively, “Values” and “IEF” in lines 8 to 10 are missing.	Problem in the CRF web application.
Table5 Table5.C	The entry “5.C.1.1.b.iii Sewage Sludge:” in the last line of the documentation box is redundant.	Problem in the CRF web application.
Summary3s1 Summary3s2	Empty cells in “Method applied” and “Emission factor” for several sectors and gases: There should be indicated “NO” instead of empty cells.	Inaccuracy in the CRF web application. „NO“ is not imported and there is no possibility to change it, because „NO“ or „NA“ are not in the drop-down menu.
Summary3s1 Summary3s2	Some method and emission factor information are not imported into the web application.	Problem in the CRF web application.
Table8s4	PFC emissions from 2G2 are also displayed under 2G4.	Problem in the CRF web application.
Table9	For some entries “no gas” is documented for the first column “GHG” with no additional information in columns C, D, E.	Problem in the CRF web application.
Table9	For “allocation used by Party” 4.D an additional ‘ has to be added in front of 4.D in the web app. Else in the reporting tables is written 4.00 instead of 4.D	Problem in the CRF web application.
Table10s1	For CO_2 eq in sector 4 LULUCF, the total is not equal to the sum of the displayed CO_2 eq emissions in the categories 4A+4B+4C+4D+4E+4F (rows 40 to 47) but includes also	Inaccuracy in the CRF web application.

	indirect N_2O from 4(IV) in CO_2 eq. The sum is correct (with indirect emissions).	
Table10s2	Empty cell for CO_2 captured in the year 2005.	Problem in the CRF web application.
Table10s4	For N_2O in sector 4 LULUCF, the total is not equal to the sum of the displayed N_2O emissions in the categories 4A+4B+4C+4D+4E+4F (rows 39 to 46) but includes also indirect N_2O from 4(IV). The sum is correct (with indirect emissions).	Inaccuracy in the CRF web application.
Table10s5	The line “Unspecified mix of HFCs and PFCs - (kt CO2 equivalent)” (line 40) does not show the numerical values from the line “Unspecified mix of PFCs(4) - (kt CO2 equivalent)” (line 39). From 2011 onwards there are values other than “NA, NO”.	Problem in the CRF web application.
All	Documentation box entries are not consistent. Sometimes all entries are in a single cell, sometimes there are several lines with entries, some of them empty.	Inaccuracy in the CRF web application.

Annex 8 Common reporting tables

This NID describes expected reporting tables in CRT format produced by the CRT Reporter as it becomes available in summer 2024, making use of GWP values from the 5. Assessment Report of the IPCC (Myhre et al. 2013) for the years 1990–2022.

Annex 9 Additional information under Article 7 of the Kyoto Protocol

A9.1 Information on changes in the national system

No changes compared to Switzerland’s National Inventory Document (NID) 2023 (FOEN 2023).

A9.2 Information on changes in the national registry

No changes compared to Switzerland’s National Inventory Document (NID) 2023 (FOEN 2023).

In December 2023, a new version of the registry software was deployed to the PRODUCTION environment to adapt the national registry to national legislation. However, this new registry version does not impact the ITL connection or the Annex H CP2 conformance in any way.

A9.3 Information on minimization of activities under Article 3, paragraph 14, of the Kyoto Protocol

For the latest information see chp. 4.13 Economic and social consequences of response measures (minimising adverse effects) in Switzerland’s Eighth National Communication and Fifth Biennial Report submitted to the UNFCCC on 16 September 2022 (FOEN 2022j).

A9.4 Activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol

Not applicable. See Switzerland’s National Inventory Report (NIR) 2022 for the latest relevant information (FOEN 2022).

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References to EMIS database comments

Table A – 30 Assignments of NFR Codes to titles of EMIS (Swiss Emission Information System) database comments. These internal documents will be made available to reviewers on request.

NFR Code CRF [UNECE]	EMIS Title	NFR Code CRF [UNECE]	EMIS Title
1 A	Energiemodell***	2 D 3 a [2 D 3 g]	Feinchemikalien-Produktion**
1 A	Holzfeuerungen	2 D 3 a [2 D 3 g]	Gummi-Verarbeitung**
1 A	Non-Road	2 D 3 a [2 D 3 g]	Klebband-Produktion
1 A	Stationary engines and gas turbines	2 D 3 a [2 D 3 g]	Klebstoff-Produktion**
1 A 2	Sektorgliederung Industrie	2 D 3 a [2 D 3 g]	Lösungsmittel-Umschlag und -Lager
1 A 1 a	Kehrichtverbrennungsanlagen	2 D 3 a [2 D 3 g]	Pharmazeutische Produktion**
1 A 1 a	Sondermüllverbrennungsanlagen	2 D 3 a [2 D 3 g]	Polyester-Verarbeitung
1 A 1 a & 5 A	Kehrichtdeponien	2 D 3 a [2 D 3 g]	Polystyrol-Verarbeitung**
1 A 1 b	Heizkessel Raffinerien* (ab 2016)	2 D 3 a [2 D 3 g]	Polyurethan-Verarbeitung
1 A 1 c	Holzkohle Produktion	2 D 3 a [2 D 3 g]	PVC-Verarbeitung
1 A 2 a & 2 C 1	Eisengiessereien Kupolöfen	2 D 3 a [2 D 3 g]	Gerben von Ledermaterialien
1 A 2 a	Stahl-Produktion Wärmeöfen**	2 D 3 b	Strassenbelagsarbeiten**
1 A 2 b	Buntmetallgiessereien übriger Betrieb**	2 D 3 c	Dachpappe**
1 A 2 b & 2 C 3	Aluminium Produktion	2 D 3 d	Urea (AdBlue) Einsatz Strassenverkehr
1 A 2 c & 2 B 8 b [2 B 10 a]	Ethen-Produktion*	2 G 3 a	Lachgasanwendung Spitäler**
1 A 2 d & 2 A 4 d	Zellulose-Produktion Feuerung*	2 G 3 b	Lachgasanwendung Haushalt**
1 A 2 f	Kalkproduktion, Feuerung*	2 G 4 [2 D 3 a]	Pharma-Produkte im Haushalt
1 A 2 f	Mischgut Produktion	2 G 4 [2 D 3 a]	Reinigungs- und Lösemittel; Haushalte
1 A 2 f	Zementwerke Feuerung	2 G 4 [2 D 3 h]	Verpackungsdruckereien**
1 A 2 f & 2 A 3	Glas übrige Produktion*	2 G 4 [2 D 3 h]	Druckereien uebrige**
1 A 2 f & 2 A 3	Glaswolle Produktion Rohprodukt**	2 G 4 [2 D 3 i]	Entfernung von Farben und Lacken**
1 A 2 f & 2 A 3	Hohlglas Produktion*	2 G 4 [2 D 3 i]	Entwachsung von Fahrzeugen
1 A 2 f & 2 A 4 a	Feinkeramik Produktion*	2 G 4 [2 D 3 i]	Kosmetika-Produktion**
1 A 2 f & 2 A 4 a	Ziegeleien**	2 G 4 [2 D 3 i]	Lösungsmittel-Emissionen IG nicht zugeordnet
1 A 2 f & 2 A 4 d	Steinwolle Produktion*	2 G 4 [2 D 3 i]	Öl- und Fettgewinnung
1 A 2 g iv	Faserplatten Produktion* (ab 2020)	2 G 4 [2 D 3 i]	Papier- und Karton-Produktion**
1 A 2 g viii & 5 B 2	Vergärung IG (industriell-gewerblich)	2 G 4 [2 D 3 i]	Parfum- und Aromen-Produktion**
1 A 3 a & 1 A 5	Flugverkehr	2 G 4 [2 D 3 i]	Tabakwaren Produktion**
1 A 3 b i-viii	Strassenverkehr	2 G 4 [2 D 3 i]	Textilien-Produktion**
1 A 3 c	Schienenverkehr	2 G 4 [2 D 3 i]	Wissenschaftliche Laboratorien
1 A 3 e	Gastransport Kompressorstation	2 G 4 [2 G]	Korrosionsschutz im Freien
1 A 4 b i	Holzkohle-Verbrauch	2 G 4 [2 G]	Betonzusatzmittel-Anwendung
1 A 4 b i	Lagerfeuer	2 G 4 [2 G]	Coiffeursalons
1 A 4 c i	Gewächshäuser**	2 G 4 [2 G]	Fahrzeug-Unterbodenschutz**
1 A 4 c i	Grastrocknung**	2 G 4 [2 G]	Feuerwerke
1 A 4 c i & 5 B 2	Vergärung LW (landwirtschaftlich)	2 G 4 [2 G]	Flaechenenteisung Flughaefen
1 B 2 a iii	Raffinerie, Pipelinetransport	2 G 4 [2 G]	Flugzeug-Enteisung
1 B 2 a iv	Raffinerie, Leckverluste*	2 G 4 [2 G]	Frostschutzmittel Automobil
1 B 2 a iv	H2-Produktion*	2 G 4 [2 G]	Gas-Anwendung
1 B 2 a iv	Raffinerie, Clausanlage*	2 G 4 [2 G]	Gesundheitswesen, übrige**
1 B 2 a v	Benzinumschlag Tanklager	2 G 4 [2 G]	Glaswolle Imprägnierung**
1 B 2 a v	Benzinumschlag Tankstellen	2 G 4 [2 G]	Holzschutzmittel-Anwendung
1 B 2 b ii & 1 B 2 c ii 2	Gasproduktion & Gasproduktion, Flaring	2 G 4 [2 G]	Klebstoff-Anwendung**
1 B 2 b iv-vi	Netzverluste Erdgas	2 G 4 [2 G]	Kosmetik-Institute
1 B 2 c ii 1	Raffinerie, Abfackelung	2 G 4 [2 G]	Kühlschmiermittel-Verwendung
2 A 1	Zementwerke Rohmaterial	2 G 4 [2 G]	Medizinische Praxen**
2 A 1	Zementwerke übriger Betrieb	2 G 4 [2 G]	Pflanzenschutzmittel-Verwendung
2 A 2	Kalkproduktion, Rohmaterial*	2 G 4 [2 G]	Reinigung Gebäude IGD**
2 A 2	Kalkproduktion, übriger Betrieb*	2 G 4 [2 G]	Schmierstoff-Verwendung
2 A 4 d	Kehrichtverbrennungsanlagen Karbonat**	2 G 4 [2 G]	Spraydosen IndustrieGewerbe
2 A 4 d	Karbonatanwendung weitere	2 G 4 [2 G]	Tabakwaren Konsum
2 A 5 a	Gips-Produktion übriger Betrieb* (ab 2021)	2 G 4 [2 G]	Steinwolle-Imprägnierung*
2 A 5 a	Kieswerke	2 H 1	Faserplatten Produktion* (ab 2020)
2 B 1	Ammoniak-Produktion*	2 H 1	Zellulose Produktion übriger Betrieb*
2 B 10 [2 B 10 a]	Ammoniumnitrat-Produktion*	2 H 1	Spanplatten Produktion*
2 B 10 [2 B 10 a]	Chlorgas-Produktion*	2 H 2	Bierbrauereien
2 B 10 [2 B 10 a]	Essigsäure-Produktion* (ab 2013)	2 H 2	Branntwein Produktion
2 B 10 [2 B 10 a]	*Formaldehyd-Produktion*	2 H 2	Brot Produktion
2 B 10 [2 B 10 a]	PVC-Produktion	2 H 2	Fleischräuchereien
2 B 10 [2 B 10 a]	*Salzsäure-Produktion**	2 H 2	Kaffeeröstereien
2 B 10 [2 B 10 a]	Schwefelsäure-Produktion*	2 H 2	Müllereien
2 B 10	Kalksteingrube*	2 H 2	Wein Produktion
2 B 10	Niacin-Produktion*	2 H 2	Zucker Produktion
2 B 2	Salpetersäure Produktion*	2 H 3	Sprengen und Schiessen
2 B 5	Graphit und Siliziumkarbid Produktion*	2 I	Holzbearbeitung
2 C - 2 G	Synthetische Gase	2K, 1A1a, 2C1, 5A, 5C1, 5E & 6Ad	Emissions due to former PCB usage
2 C 1	Eisengiessereien Elektroschmelzöfen	2 L	NH3 aus Kühlanlagen
2 C 1	Eisengiessereien übriger Betrieb	3	Landwirtschaft
2 C 1 & 1 A 2 a	Stahl-Produktion Elektroschmelzöfen**	3 B	Tierhaltung
2 C 1	Stahl-Produktion übriger Betrieb**	3 C	Reisanbau
2 C 1	Stahl-Produktion Walzwerke**	3 D e	Landwirtschaftsflächen
2 C 7 a	Buntmetallgiessereien Elektroöfen**	4 V A 1 [11 B]	Waldbrände
2 C 7 c	Verzinkereien	5 B 1	Kompostierung
2 C 7 c	Batterie-Recycling*	5 B 2	Biogasaufbereitung (Methanverlust)
2 D 1	Schmiermittel-Anwendung	5 C 1 [5 C 1 a]	Abfallverbrennung illegal
2 D 1	Schmiermittel-Verbrauch B2T	5 C 1 [5 C 1 b i]	Kabelabbrand
2 D 2	Paraffinwachs-Anwendung	5 C 1 [5 C 1 b iii]	Spitalabfallverbrennung
2 D 3 a [2 D 3 d]	Farben-Anwendung Bau	5 C 1 [5 C 1 b iv]	Klärschlammverbrennung
2 D 3 a [2 D 3 d]	Farben-Anwendung andere	5 C 1 [5 C 1 b v]	Krematorien
2 D 3 a [2 D 3 d]	Farben-Anwendung Haushalte**	5 C 2 / 4 V A 1 (Forstwirtschaft)	Abfallverbrennung Land- und Forstwirtschaft und Private
2 D 3 a [2 D 3 d]	Farben-Anwendung Holz	5 D 1 [5 D]	Kläranlagen kommunal (Luftschadstoffe)
2 D 3 a [2 D 3 d]	Farben-Anwendung Autoreparatur**	5 D 2 [5 D]	Kläranlagen industriell (Luftschadstoffe)
2 D 3 a [2 D 3 e]	Elektronik-Reinigung**	5 D 1 / 5 D 2 [5 D]	Abwasserbehandlung GHG
2 D 3 a [2 D 3 e]	Metallreinigung**	5 E	Shredder Anlagen
2 D 3 a [2 D 3 e]	Reinigung Industrie übrige**	6 A d	Brand- und Feuerschäden Immobilien
2 D 3 a [2 D 3 f]	Chemische Reinigung**	6 A d	Brand- und Feuerschäden Motorfahrzeuge
2 D 3 a [2 D 3 g]	Druckfarben Produktion**	[11 C]	NMVOC Emissionen Wald
2 D 3 a [2 D 3 g]	Farben-Produktion**	1, 2, 5, 6 - indirect	Indirekte Emissionen

* confidential process
** confidential EMIS comment
*** work in progress
Italic: process not relevant for the years after 1990.
New model / comment for the current submission.