OFFICE OF ENVIRONMENT
PRINCIPALITY OF LIECHTENSTEIN

Liechtenstein's Greenhouse Gas Inventory 1990 - 2021

National Inventory Document 2023

Submission of 13 April 2023
under the United Nations Framework Convention on Climate Change

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Glossary

AR4, AR5	Fourth Assessment Report, Fifth Assessment Report of the IPCC
ARR	Annual Inventory Review Report (UNFCCC)
AD	Activity Data
ART	Agroscope Reckenholz-Tänikon Research Station
AZV	Abwasserzweckverband der Gemeinden Liechtensteins (Liechtenstein's wastewater administration union)
BCEF, BEF	Biomass Conversion and Expansion Factor, Biomass Expansion Factor
CC	Combined Category for land-use/land-cover
CFC	Chlorofluorocarbon (organic compound: refrigerant, propellant)
CH_4	Methane
chp.	Chapter
CLRTAP	UNECE Convention on Long-Range Transboundary Air Pollution
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO_2, (CO_2eq)	Carbon dioxide (equivalent)
CORINAIR	CORe INventory of AIR emissions (under the European Topic Centre on Air Emissions and under the European Environment Agency)
CP	Commitment Period
CRF	Common Reporting Format
DOC	Degradable Organic Carbon
EF	Emission Factor
EMEP	European Monitoring and Evaluation Programme (under the Convention on Long-range Transboundary Air Pollution)
EMIS	Swiss Emission Information System (database run by FOEN)
EMPA	Swiss Federal Laboratories for Material Testing and Research
ERT	Expert Review Team
FAL	Swiss Federal Research Station for Agroecology and Agriculture (since 2006: ART)
FCCC	Framework Convention on Climate Change
FMRL	Forest Management Reference Level
FOCA	Swiss Federal Office of Civil Aviation
FOD	First Order Decay Model
FOEN	Swiss Federal Office of the Environment (former name SAEFL)

g	Gramme
GHFL	Genossenschaft für Heizöllagerung im Fürstentum Liechtenstein (Cooperative society for the Storage of Gas Oil in the Principality of Liechtenstein)
GHG	Greenhouse Gas
GJ	Giga Joule (10^9 Joule = 1’000 Mega Joule)
GRUDAF	Grundlagen für die Düngung im Acker – und Futterbau
GWh	Gigawatt hour (energy unit), one million kilowatt hours, 1 GWh = 3.6 TJ
GWP, (GWP_{100})	Global Warming Potential (100-year time-horizon)
ha	Hectare (100 m x 100 m)
HFC	Hydrofluorocarbons (e.g. HFC-32 difluoromethane)
HWP	Harvested Wood Products
IDP	Inventory Development Plan
IEF	Implied Emission Factor
IPCC	Intergovernmental Panel on Climate Change
IR	Initial Report (UNFCCC)
KC, KCA	Key Category, Key Category Analysis
KP	Kyoto Protocol
kg	Kilogramme (1’000 g)
kha	Kilo hectare (1’000 ha)
kt	Kilo tonne (1’000 tons)
kWh	Kilowatt hour (energy unit), 1 kWh = 3.6 MJ
LFO	Light fuel oil (Gas oil)
LGV	Liechtensteinische Gasversorgung (Liechtenstein’s gas utility)
LKW	Liechtensteinische Kraftwerke (Liechtenstein’s electric power company)
LPG	Liquefied Petroleum Gas (Propane/Butane)
LTO	Landing-Take-off-Cycle (Aviation)
LULUCF	Land-Use, Land-Use Change and Forestry
LWI	Landeswaldinventar (Liechtenstein's National Forest Inventory)
MJ	Mega Joule (10^6 Joule = 1’000'000 Joule)
MSW	Municipal Solid Waste
MCF	Methane Conversion Factor
MWh	Megawatt hour (energy unit), 1 MWh = 3.6 GJ
MWWTP	Municipal Waste Water Treatment Plant
NCV	Net Calorific Value

NFI	National Forest Inventory (see also LWI)
NF_3	Nitrogen trifluoride 2006 IPCC GWP: 17’200 (UNFCCC 2014, Annex III)
NFR	Nomenclature For Reporting (IPCC code of categories)
NIC	National Inventory Compiler
NID	National Inventory Document (formerly NIR)
NIR	National Inventory Report (now NID)
NIS	National Inventory System
NMVOC	Non-Methane Volatile Organic Compounds
N_2O	Nitrous oxide (laughing gas)
NO_x	Nitrogen oxides
OA	Office for Agriculture, former name of today’s Division of Agriculture within the Office of Environment, since 2012
OCI	Office of Construction and Infrastructure
ODS	Ozone-Depleting Substances (CFCs, halons etc.)
OE	Office of Environment
OEA	Office of Economic Affairs
OEP	Office of Environmental Protection, former name of today’s Office of Environment (OE) since 2012
OFIVA	Office of Food Inspection and Veterinary Affairs
OS	Office of Statistics
PFC	Perfluorinated carbon compounds (e.g. Tetrafluoromethane)
QA/QC	Quality assurance/quality control: QA includes a system of review procedures conducted by persons not directly involved in the inventory development process; QC is a system of routine technical activities to control the quality of the inventory
SAEFL	Swiss Agency for the Environment, Forests and Landscape (former name of Federal Office of the Environment FOEN)
SF_6	Sulphur hexafluoride, 2006 IPCC GWP: 22’800 (UNFCCC 2014, Annex III)
SFOE	Swiss Federal Office of Energy
SFSO	Swiss Federal Statistical Office
SO_2	Sulphur dioxide
TJ	Tera Joule (10^{12} Joule = 1’000'000 Mega Joule)
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile organic compounds

EXECUTIVE SUMMARY

ES.1. Background information on GHG inventories and climate change

ES.1.1 Background information on climate change

Research shows that significant negative effects of global climate warming in the Alpine region have developed in the last decades and further negative impacts are expected in the future. The observations show significant increases in temperature, in the number of summer days and a decrease in the number of frost days in Liechtenstein. Associated with warming, the zero-degree limit has also risen, the vegetation period has been extended significantly, and the biological beginning of spring has advanced.

The following effects are expected as a consequence of a further temperature rise (OE 2020h, Government 2018):

- The temperature increase projected in the RCP8.5 scenario between today and 2060 is expected to be around 2-3°C, with more pronounced heating in summer than in winter periods.
- The changes in precipitation by 2060 are still uncertain, but decreasing precipitation are most likely to occur in summer.
- The snowline is expected to increase from today around 850 m a.s.l. to about 1250 to 1500 m a.s.l.
- Heat waves with increased mortality will occur more frequently, also tropical diseases will surface in Central Europe and existing diseases will spread to higher elevations.
- Indirect consequences for health are to be expected from storm, floods, landslides, and the reduction in the permafrost layer. The increasing weather instabilities may lead to floods in winter and droughts in summertime and composition of forest vegetation may change too.
- Global climate warming will therefore affect various economic sectors in Liechtenstein (e.g. Tourism, Agriculture, Forestry).

ES.1.2 Background information on greenhouse gas inventories

In 1995, the Principality of Liechtenstein ratified the United Nations Framework Convention on Climate Change (UNFCCC). Furthermore, Liechtenstein ratified the Kyoto Protocol (both commitment periods) in 2004 and the Paris Agreement in 2017.

On 23 April 2015, Liechtenstein submitted its “Intended Nationally Determined Contribution (INDC)” to the UNFCCC, which aims at a reduction of greenhouse gases by 40% compared to 1990 by 2030. With the adoption of the new Climate Strategy 2050 in December 2022, the Parliament of Liechtenstein approved the increase of the reduction target for 2030 to 55% below 1990 levels. The revision of article 4 paragraph 1 of the Emissions Trading Act reflecting the target increase will come into force on 1st of July

2023. In course of the year, Liechtenstein will accordingly communicate its updated Nationally Determined Contribution to the UNFCCC.

Submission of Greenhouse Gas Inventories

In 2005, the first Greenhouse Gas Inventory of Liechtenstein was submitted in the Common Reporting Format (CRF) without National Inventory Report. From 2006-2014 Liechtenstein annually submitted its Greenhouse Gas Inventory together with the National Inventory Report prepared under the UNFCCC and under the Kyoto Protocol (OEP 2006-2011, OEP 2006a, 2007a, 2007b, 2012b, OE 2013-2014).

During its October 2014 session, the Liechtenstein Parliament approved the second commitment period of the Kyoto Protocol accepting a **20% reduction until 2020**.

The submission of the Greenhouse Gas Inventory and National Inventory Report in 2015 was postponed and submitted in 2016. From 2016-2022 Liechtenstein annually submitted its Greenhouse Gas Inventory together with the National Inventory Report prepared under the UNFCCC and under the Kyoto Protocol (OE 2016a, OE 2016c, OE 2017-2022).

Liechtenstein's greenhouse gas inventory was subject to in-country reviews in the years 2007 and 2013. Furthermore, centralized reviews took place in 2008, 2009, 2010, 2011, 2012, 2014, 2016, 2018, 2020 and 2022. The review of the GHG inventories and National Inventory Reports 2015 and 2016 took place simultaneously in September 2016 due to the postponed submission in 2015. In response to the Potential Problems formulated in the course of the review of the 2022 annual submission of Liechtenstein, Liechtenstein corrected an error in the preparation of emission data in sector 1B and submitted updated CRF tables in November 2022 (OE 2022g).

The Office of Environment (OE) is in charge of compiling the emission data and bears the overall responsibility for Liechtenstein's national greenhouse gas inventory. All inventory data are assembled and prepared for input by an inventory group, which is responsible for ensuring the conformity of the inventory with UNFCCC guidelines. In addition to the OE, the Office of Economic Affairs (OEA), the Office of Statistics (OS) and the Office of Construction and Infrastructure (OCI) participate directly in the compilation of the inventory. Several other administrative and private institutions are involved in the inventory preparation.

The emissions are calculated based on the standard methods and procedures of the Revised 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC 2006) adopted by the UNFCCC. The activity data sources used to compile the national inventory and to estimate greenhouse gas emissions and removals are: The national energy statistics, separate statistics for the consumption of gasoline and diesel oil, agriculture, LULUCF and waste. The data is finally implemented in the CRF Reporter that generates the **reporting tables**.

The **National Inventory Document** follows in its structure the outline presented in "Guidance operationalizing the modalities, procedures and guidelines for the enhanced transparency framework referred to in Article 13 of the Paris Agreement" (UNFCCC 2021).

For the interpretation of Liechtenstein's emissions and removals it is important to recognise that Liechtenstein is a small central European state in the Alpine region with a population of 39’315 inhabitants (2021) and with an area of 160 km^2. Its neighbours are therefore important partners: Liechtenstein and Switzerland form a customs and monetary union governed by a customs treaty. On the basis of this union, Liechtenstein is linked to Swiss foreign trade strategies, with few exceptions, such as trade with the European Economic Community: Liechtenstein – contrary to Switzerland – is a member of the European Economic Area. The Customs Union Treaty with Switzerland impacts greatly on environmental and fiscal strategies. Many Swiss levies and regulations for special goods (for example, environmental standards) are also adapted and applied in Liechtenstein. For the determination of the GHG emissions, Liechtenstein appreciates having been authorised to adopt a number of Swiss methods and Swiss emission factors.

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

National total emissions

Liechtenstein’s greenhouse gas emissions in the year 2021 amount to 183.9 kt CO_2 equivalent (CO_2eq) excluding LULUCF sources or sinks (including LULUCF: 184.2 kt CO_2eq). This refers to 4.68 t CO_2eq per capita.

Total emissions in 2021 (excl. LULUCF) have declined by 19.9% compared to 1990. Compared to 2020, they increased by 1.68%. When including LULUCF categories, total emissions decreased by 0.79% between 2020-2021 and by 22.3% between 1990-2021.

Uncertainties

Uncertainty analyses with Approach 1 is carried out and presented in chp. 1.6.3. Approach 1 results show the following results:

- Uncertainty of national total CO_2eq emissions **excluding LULUCF:**
  The Approach 1 level uncertainty for the year 2021 is estimated to be 5.17%, trend uncertainty (1990-2021) is 4.80% (see Table 1-8). The level uncertainty for the year 1990 amounts 7.02% (see Table 1-9).
- Uncertainty of national total CO_2eq emissions **including LULUCF**:
  The Approach 1 level uncertainty for the year 2021 is estimated to be 6.10%, trend uncertainty (1990-2021) is 5.26% (see Table 1-10). The level uncertainty for the year 1990 amounts 6.93% (see Table 1-11).

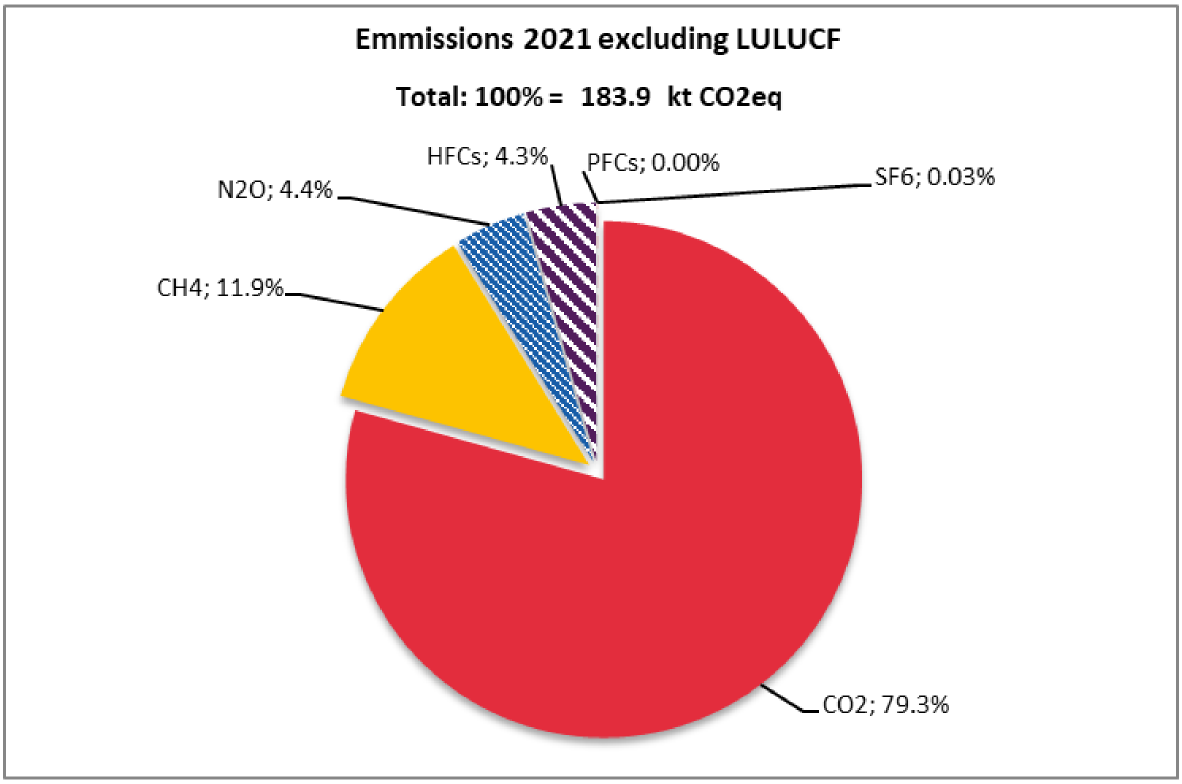
Recalculations

Some emissions have been recalculated due to updates in respective sectors. Additionally, the current greenhouse gas inventory of Liechtenstein 1990-2021 (NID and CRF reporting tables) uses the 100-year time-horizon global warming potentials (GWP_{100}) from the Fifth Assessment Report (AR5) of the IPCC (Myhre et al. 2013). In the previous submissions GWP values from the Fourth Assessment Report (AR4) were used. This leads to changes in CH_4, N_2O, and F-gas emissions.

The results are discussed in Chapter 10. For the base year 1990, the recalculations carried out in submission 2023 lead to an increase of 0.51% in the national total emissions (excluding LULUCF categories). The national total emissions of the year 2020 increased by 0.48% due to the recalculations (excluding LULUCF categories).

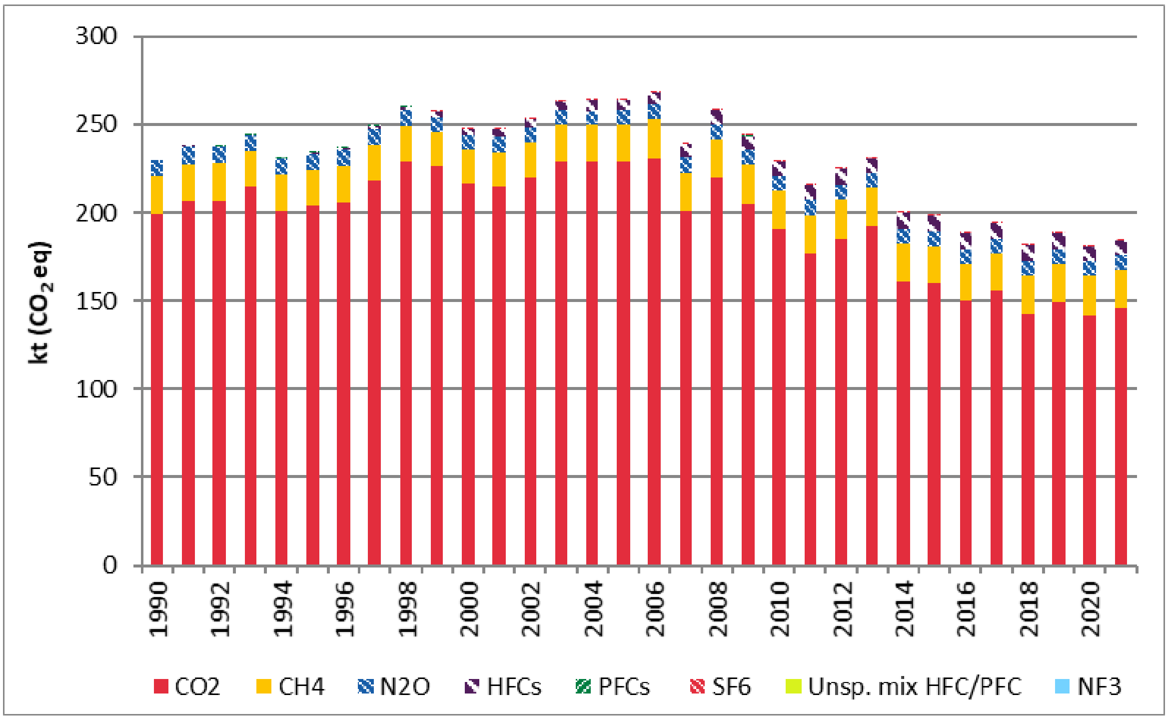
ES.3. Overview of source and sink category emission estimates and trends

ES Figure 1 shows the emissions in 2020 by GHG. The main GHG is CO_2 with a share of 79.3%. CH_4 and N_2O contribute with 11.9% and 4.4%, F-gases with about 4.4%, respectively.



ES Figure 1 Liechtenstein's GHG emissions by gas (excluding LULUCF).

ES Figure 2 illustrates that the emission shares of the various greenhouse gases are similar for the full time period. CO_2 accounts for the largest share of emissions, while CH_4, N_2O and F-Gases are only minor contributors. Emissions have increased after 1990, reaching a maximum in 2006. From then onwards, a decreasing trend starts to develop, still showing fluctuations driven by the varying temperatures of winter seasons and fuel prices. In 2021, emissions have slightly increased compared to the previous year 2020 (excluding LULUCF categories).



ES Figure 2 Trend of Liechtenstein's GHG emissions by gases. CO_2, CH_4 and N_2O correspond to the respective total emissions excluding LULUCF.

The emission shares (excl. LULUCF emissions) of the greenhouse gases developed as follows:

- The share of CO_2 emissions decreased from 86.6% in 1990 to 79.3% in 2021 (excl. LULUCF).
- The share of CH_4 increased from 9.4% in 1990 to 11.9% in 2021 (excl. LULUCF).
- The share of N_2O slightly increased from 4.0% in 1990 to 4.4% in 2021 (excl. LULUCF).

  The share of the sum of all F-gases (within total emissions excl. LULUCF) increased from 0.00004% (1990) to 4.4% (2021).

ES Table 2 represents the GHG emissions and removals by categories. Sector 1 Energy is the largest source of national emissions, contributing to 80.7% of the emissions (excluding LULUCF) in 2021. Emissions caused within the energy sector decreased by 26.3% over the period 1990-2021. The emissions from sector 2 Industrial processes and product use increased by a factor of about 14 due to a more frequent use of F-gases. Compared to total emissions, F-gas emissions still are of a minor importance. In sector 3 Agriculture, emissions in 2021 are 1.9% below the level of 1990. Emissions and removals in the sector 4 LULUCF form a net source in 2021, but show a decrease of 96.2% compared to 1990. The emissions from sector 5 Waste have decreased by 3.9% since 1990. They encompass only a small amount of emissions because municipal solid waste disposal has ceased since 1974 and is exported to a Swiss incineration plant.

ES Table 1 Summary of Liechtenstein's GHG emissions in CO_2eq (kt) by gas. The last column shows the percentage change in emissions in 2021 as compared to the base year 1990. HFC emissions have increased by about a factor of 83'200 in 2021 compared to 1990.
Note that the current inventory (submission 2023) uses for the first time the global warming potentials (GWP_{100}) from the Fifth Assessment Report (AR5) of the IPCC (Myhre et al. 2013).

Greenhouse Gas Emissions	1990	1995	2000	2005	2010
	CO_2 equivalent (kt)				
CO_2 emissions incl. net CO_2 from LULUCF	206.2	209.2	241.7	238.0	211.4
CO_2 emissions excl. net CO_2 from LULUCF	199.0	204.2	216.9	229.0	190.8
CH_4 emissions incl. CH_4 from LULUCF	21.5	20.1	18.7	20.8	21.4
CH_4 emissions excl. CH_4 from LULUCF	21.5	20.1	18.7	20.8	21.4
N_2O emissions incl. N_2O from LULUCF	9.4	9.3	8.8	8.5	8.6
N_2O emissions excl. N_2O from LULUCF	9.1	9.1	8.4	8.1	8.3
HFCs	0.0	1.1	3.5	6.3	8.3
PFCs	NO	0.0	0.0	0.1	0.1
SF_6	NO	NO	0.1	0.3	0.0
Unspecified mix of HFCs and PFCs	NO	NO	NO	NO	NO
NF_3	NO	NO	NO	NO	NO
Total (including LULUCF)	237.2	239.7	272.7	273.9	249.8
Total (excluding LULUCF)	229.6	234.4	247.6	264.5	228.8

Greenhouse Gas Emissions	2012	2013	2014	2015	2016
	CO_2 equivalent (kt)				
CO_2 emissions incl. net CO_2 from LULUCF	209.9	209.7	178.3	171.6	159.8
CO_2 emissions excl. net CO_2 from LULUCF	185.3	192.5	161.3	159.8	149.8
CH_4 emissions incl. CH_4 from LULUCF	22.3	21.3	21.5	21.3	21.4
CH_4 emissions excl. CH_4 from LULUCF	22.3	21.3	21.5	21.3	21.4
N_2O emissions incl. N_2O from LULUCF	8.8	8.6	8.5	8.5	8.4
N_2O emissions excl. N_2O from LULUCF	8.5	8.2	8.1	8.2	8.0
HFCs	9.1	9.0	9.3	9.4	9.0
PFCs	0.0	0.0	0.0	0.0	0.0
SF_6	0.0	0.2	0.1	0.0	0.0
Unspecified mix of HFCs and PFCs	NO	NO	NO	NO	NO
NF_3	NO	NO	NO	NO	NO
Total (including LULUCF)	**250.1**	**248.8**	**217.7**	**210.8**	**198.7**
Total (excluding LULUCF)	**225.2**	**231.3**	**200.3**	**198.6**	**188.3**

Greenhouse Gas Emissions	2017	2018	2019	2020	2021	1990-2021
	CO_2 equivalent (kt)					%
CO_2 emissions incl. net CO_2 from LULUCF	167.1	164.9	161.0	146.4	145.8	-29.3%
CO_2 emissions excl. net CO_2 from LULUCF	155.8	143.0	149.0	141.9	145.9	-26.7%
CH_4 emissions incl. CH_4 from LULUCF	20.9	21.2	21.9	22.1	21.8	1.2%
CH_4 emissions excl. CH_4 from LULUCF	20.9	21.2	21.9	22.1	21.8	1.2%
N_2O emissions incl. N_2O from LULUCF	8.4	8.5	8.6	8.5	8.5	-9.5%
N_2O emissions excl. N_2O from LULUCF	8.0	8.1	8.3	8.2	8.2	-10.6%
HFCs	9.3	9.4	9.1	8.6	8.0	see caption
PFCs	0.0	0.0	0.0	0.0	0.0	-
SF_6	0.0	0.1	0.0	0.1	0.1	-
Unspecified mix of HFCs and PFCs	NO	NO	NO	NO	NO	-
NF_3	NO	NO	NO	NO	NO	-
Total (including LULUCF)	**205.6**	**204.1**	**200.7**	**185.7**	**184.2**	**-22.3%**
Total (excluding LULUCF)	**193.9**	**181.7**	**188.3**	**180.9**	**183.9**	**-19.9%**

ES Table 2 Summary of Liechtenstein's GHG emissions by source and sink categories in CO_2 equivalent (kt). The last column indicates the percent change in emissions in 2021 as compared to the base year 1990.

Source and Sink Categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	CO_2 equivalent (kt)									
1 Energy	**201.3**	**208.9**	**209.7**	**217.8**	**203.8**	**207.0**	**208.9**	**221.4**	**232.3**	**229.7**
1A1 Energy industries	0.2	0.8	1.9	2.0	1.8	2.1	2.6	2.5	2.9	2.9
1A2 Manufacturing ind. & constr.	36.3	35.9	36.3	37.6	35.6	35.7	35.7	37.6	40.3	39.8
1A3 Transport	76.9	90.2	89.5	87.4	80.0	82.0	83.3	86.9	86.6	90.7
1A4 Other sectors	87.6	81.4	81.4	90.3	85.8	86.6	86.5	93.6	101.7	95.4
1A5 Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9
2 IPPU	**0.6**	**0.6**	**0.6**	**0.7**	**0.9**	**1.6**	**1.8**	**2.2**	**2.7**	**3.2**
3 Agriculture	**26.0**	**26.0**	**25.3**	**24.2**	**24.3**	**24.1**	**24.3**	**24.0**	**23.5**	**22.5**
5 Waste	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**
Total (excluding LULUCF)	***229.6***	***237.2***	***237.3***	***244.4***	***230.7***	***234.4***	***236.7***	***249.2***	***260.2***	***257.1***
4 LULUCF	**7.5**	**-8.1**	**2.7**	**-0.5**	**18.6**	**5.3**	**-2.9**	**8.4**	**0.7**	**-0.4**
Total (including LULUCF)	***237.2***	***229.1***	***240.1***	***243.8***	***249.3***	***239.7***	***233.8***	***257.6***	***260.9***	***256.7***

Source and Sink Categories	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	CO_2 equivalent (kt)									
1 Energy	**220.1**	**217.8**	**223.1**	**232.4**	**232.0**	**231.6**	**233.8**	**203.4**	**222.3**	**208.1**
1A1 Energy industries	2.8	2.9	2.5	2.8	3.0	3.1	2.9	2.6	2.9	3.0
1A2 Manufacturing ind. & constr.	36.4	36.4	37.9	41.2	39.8	39.1	40.5	33.9	36.3	27.5
1A3 Transport	91.5	88.1	84.1	83.8	82.3	81.9	79.3	83.4	87.9	81.9
1A4 Other sectors	88.4	89.4	97.6	103.5	105.8	106.3	109.9	82.3	93.9	94.5
1A5 Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	0.9	1.0	1.0	1.1	1.2	1.2	1.3	1.3	1.3	1.2
2 IPPU	**4.0**	**4.8**	**5.5**	**6.1**	**6.7**	**7.1**	**7.4**	**8.2**	**8.7**	**8.2**
3 Agriculture	**21.9**	**23.0**	**23.4**	**23.5**	**23.5**	**24.2**	**25.3**	**25.6**	**25.8**	**25.7**
5 Waste	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**
Total (excluding LULUCF)	***247.6***	***247.3***	***253.6***	***263.7***	***264.0***	***264.5***	***268.2***	***238.9***	***258.6***	***243.8***
4 LULUCF	**25.1**	**2.2**	**3.1**	**7.1**	**9.3**	**9.3**	**14.1**	**23.2**	**25.3**	**22.4**
Total (including LULUCF)	***272.7***	***249.5***	***256.7***	***270.8***	***273.2***	***273.9***	***282.3***	***262.1***	***283.9***	***266.2***

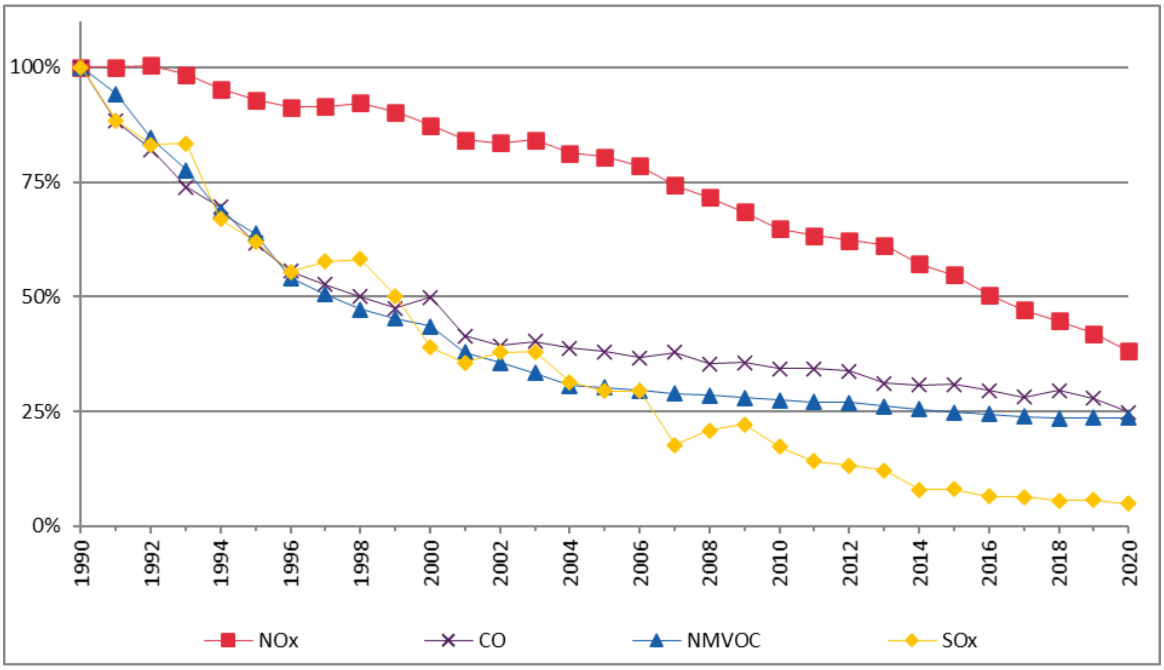
Source and Sink Categories	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	CO_2 equivalent (kt)									
1 Energy	**193.5**	**179.4**	**188.0**	**195.2**	**163.7**	**162.3**	**152.3**	**158.3**	**145.5**	**151.6**
1A1 Energy industries	3.3	3.1	2.8	3.0	2.5	2.0	2.2	2.1	2.2	3.4
1A2 Manufacturing ind. & constr.	26.1	23.6	25.7	26.4	27.3	27.6	25.9	27.7	24.6	24.1
1A3 Transport	77.7	76.9	79.9	79.6	73.8	61.8	60.4	60.8	58.8	57.3
1A4 Other sectors	85.2	74.7	78.3	84.9	58.9	69.5	62.5	66.4	58.6	65.4
1A5 Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	1.3	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
2 IPPU	**8.7**	**9.1**	**9.4**	**9.5**	**9.7**	**9.7**	**9.3**	**9.6**	**9.7**	**9.4**
3 Agriculture	**24.9**	**25.7**	**26.0**	**24.8**	**25.2**	**25.0**	**25.1**	**24.4**	**24.9**	**25.7**
5 Waste	**1.7**	**1.8**	**1.7**	**1.7**	**1.6**	**1.6**	**1.6**	**1.6**	**1.6**	**1.6**
Total (excluding LULUCF)	***228.8***	***215.9***	***225.2***	***231.3***	***200.3***	***198.6***	***188.3***	***193.9***	***181.7***	***188.3***
4 LULUCF	**21.0**	**24.7**	**25.0**	**17.5**	**17.4**	**12.2**	**10.4**	**11.7**	**22.3**	**12.4**
Total (including LULUCF)	***249.8***	***240.6***	***250.1***	***248.8***	***217.7***	***210.8***	***198.7***	***205.6***	***204.1***	***200.7***

Source and Sink Categories	2020	2021	1990-2021
	CO_2eq (kt)		%
1 Energy	**144.4**	**148.4**	**-26.3%**
1A1 Energy industries	2.4	2.6	1410%
1A2 Manufacturing ind. & constr.	22.8	23.2	-36%
1A3 Transport	52.7	56.1	-27%
1A4 Other sectors	65.1	65.2	-26%
1A5 Other	NO	NO	-
1B Fugitive emissions from fuels	1.3	1.4	234%
2 IPPU	**8.9**	**8.3**	**1273%**
3 Agriculture	**25.9**	**25.5**	**-1.9%**
5 Waste	**1.6**	**1.7**	**-3.9%**
Total (excluding LULUCF)	***180.9***	***183.9***	***-19.9%***
4 LULUCF	**4.8**	**0.3**	**-96.2%**
Total (including LULUCF)	***185.7***	***184.2***	***-22.3%***

ES.4. Other information

Liechtenstein is member to the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) and submits data on air pollutants including indirect GHG. The submission in 2023 will take place at the end of April 2023, and **the overview and results provided below stem from the submission to CLRTAP in 2022** (OE 2022f). Therefore, results for 2021 are not yet available.

For the precursor substances NO_x, CO and NMVOC as well as for the gas SO_2, data are shown in ES Figure 3 (Acontec 2023). Emissions of road transportation are calculated by the territorial principle and, therefore, differ in methodology from emission estimation under the UNFCCC reporting (sales principle). For this reason, air pollutant emissions (ES Figure 3) may not consistently be compared to GHG emissions (ES Figure 2).



ES Figure 3 Trend of NO_x, CO, NMVOC and SO_x emissions as of CLRTAP submission 2022 (OE 2022f).

ES.5. Key Category Analysis

For 2021, among a total of 196 categories (excluding LULUCF categories), eleven have been identified as Approach 1 key categories by the CRF Reporter Software (see CRF Table7 of the reporting tables) with an aggregated contribution of 96.6% of the national total emissions. Within those eleven key categories, seven stem from the energy sector, contributing 79.9% to total CO_2 equivalent emissions in 2021. The other key categories are from the sectors Agriculture (three categories, contribution 12.4%) and Industrial Processes and Product Use IPPU (one category, contribution 4.3%).

The three major sources, all from the energy sector, sum up to a contribution of 65.2% of the national total emissions:

- 1A3b Road transportation, CO_2
- 1A4 Other sectors, gaseous fuels, CO_2
- 1A4 Other sectors, liquid fuels, CO_2

When including LULUCF categories in the analysis, 17 among the 223 categories are key. Five of the key categories are from the LULUCF sector. Furthermore, one additional category from the sector Agriculture is key when performing the KCA for the full inventory (including LULUCF categories).

ES.6. Improvements introduced

The current greenhouse gas inventory of Liechtenstein 1990-2021 (NID and CRF reporting tables) uses GWP values from the Fifth Assessment Report (AR5) of the IPCC (Myhre et al. 2013). In the previous submissions GWP values from the Fourth Assessment Report (AR4) were used.

Acknowledgement

Liechtenstein’s Office of Environment (OE) highly appreciates the generous support by the members of the GHG Inventory Core Group at the Swiss Federal Office for the Environment (FOEN). The free use of methods and tools developed by the FOEN has been essential during the permanent development of Liechtenstein’s GHG inventory and its NID.

The OE also gratefully acknowledges the support of the Agroscope Reckenholz Research Station. The use of the model developed by Agroscope greatly facilitated the calculation process of agricultural emissions and their uncertainties. Personal and close contacts between the GHG specialists of Switzerland and Liechtenstein developed during this work laid the basis for a very promising and fruitful cooperation both on a technical and political level.

The OE also thanks the data suppliers of Liechtenstein: Office of Economic Affairs (OEA), Office of Statistics (OS), Office of Construction and Infrastructure (OCI), Liechtenstein's Gas Utility (LGV) and Electric Power Company (LKW), Liechtenstein’s Wastewater Administration Union (AZV), Rotex Helicopter AG, Swiss Federal Office of Civil Aviation (FOCA), Swiss Federal Office for the Environment (FOEN), the sectoral experts and the NID authors. Their effort made it possible to finalise the inventory and the NID 2023.

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

1.1 Background information on Liechtenstein's greenhouse gas inventory and climate change

1.1.1 Principality of Liechtenstein

Liechtenstein is a small central European State between Switzerland and Austria in the Alpine region with a population of 39'315 inhabitants (2021) and with an area of 160 km^2.

Figure 1-1 The Principality of Liechtenstein. Vaduz is the capital.

With its neighbouring country Switzerland, Liechtenstein forms a customs and monetary union governed by a customs treaty (Government 1980). On the basis of this union, Liechtenstein is linked to Swiss foreign trade strategies, with few exceptions, such as trade with the European Economic Community: Liechtenstein – contrary to Switzerland – is a member of the European Economic Area. The Customs Union Treaty with Switzerland impacts greatly on environmental and fiscal strategies. Many Swiss levies and regulations for special goods, for example, environmental standards for motor vehicles and quality standards for fuels are also adapted and applied in Liechtenstein. For the determination of the GHG emissions, Liechtenstein appreciates having been authorised to adopt a number of Swiss methods and Swiss emission factors.

1.1.2 Background information on climate change

In recent years, various research programs on the effects of global climate warming in the Alpine region have been conducted, e.g. CH2014-Impacts (2014) and CH2011 (2011). In November 2018, the “Climate Scenarios for Switzerland” CH2018 (NCCS 2018) were published. The CH2018 scenarios are more detailed compared to previous studies and particularly more regionally differentiated.

The historic development and projections indicate that noticeable effects are to be expected. Liechtenstein published “Facts and figures about the climate in Liechtenstein” showing expected temperature and precipitation in the year 2060 (OE 2020h). The results of the expected impacts of climate change have primarily been studied in Switzerland, which is beside Austria one of the two neighbouring countries of Liechtenstein, and draw to a large extent on the findings of reports prepared by the Swiss Advisory Body on Climate Change (OcCC 2007; OcCC 2008; OcCC 2012) and the findings by the CH2018 “Climate Scenarios for Switzerland” (NCCS 2018), CH2014-Impact study (CH2014-Impacts 2014), the CH2011 (CH2011 2011) report and the Swiss Academies Report no. 11 (SCNAT 2016). Also, results of a report of the International Bodensee Conference have been considered with specific findings for Liechtenstein (IBK 2007).

In 2013 and 2018, the Swiss Federal Office for the Environment FOEN and MeteoSwiss (the Federal Office of Meteorology and Climatology) published a report, which shows the numerous indicators that demonstrate the changes in the climate in Switzerland, whether in the cryosphere, the hydrosphere, vegetation, human health, the economy or the society (FOEN/MeteoSwiss 2013, FOEN/MeteoSwiss 2018). Impacts are analysed quantitatively in the CH2014-Impacts (2014) study. The results are also representative for Liechtenstein (OE 2020h). In addition, a climate risk analysis has been done for the alpine region of Switzerland (INFRAS/Egli Engineering 2015) in particular for the canton of Uri. The conditions in Liechtenstein are comparable to the Swiss Alps. The results can therefore give valuable insights about climate change related future risks.

1.1.2.1 Impacts

The Office of Environment (OE) Liechtenstein published a booklet with facts and figures about climate change in 2020 (OE 2020h). The mean annual temperature of Liechtenstein (location Vaduz) is 10.6°C for the current standard reference period 1991-2020 The mean annual temperature increased by 1.2°C compared to the reference period 1961-1990 (MeteoSwiss, 2022). Figure 1-2 shows a time series of the temperature deviation in the years 1901-2019 from the mean temperature in Liechtenstein (1961-1990). The symbols are maps of Liechtenstein (see Figure 1-1 for details).

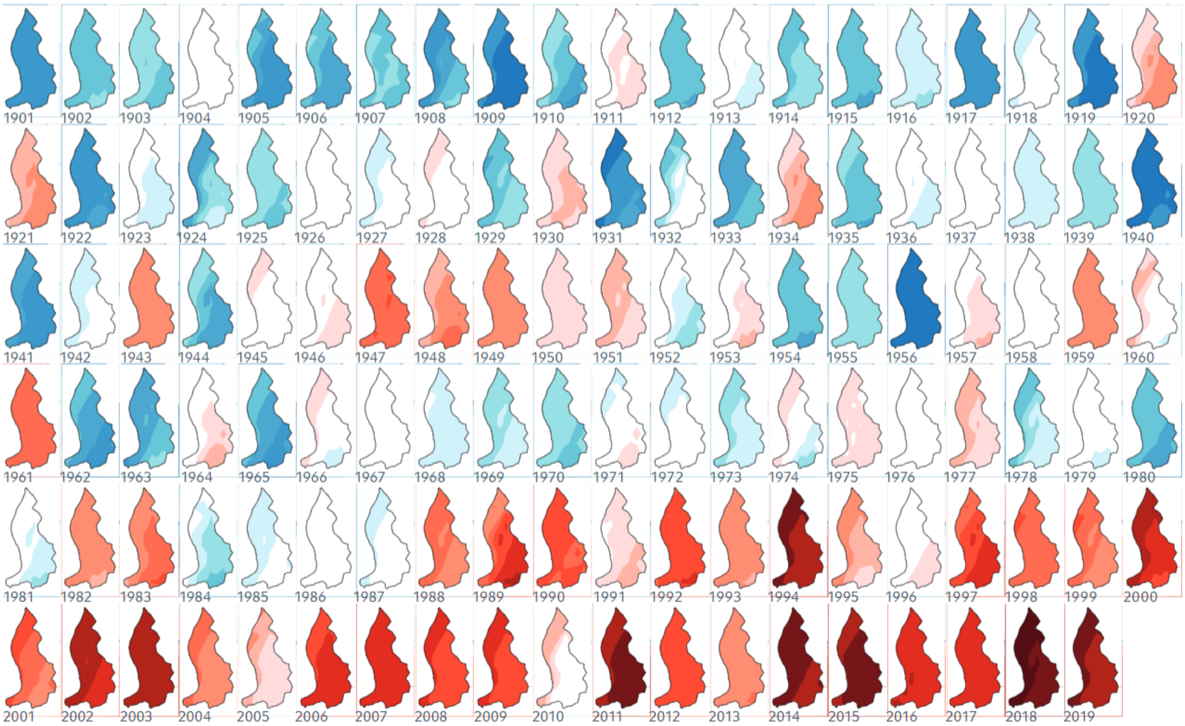


Figure 1-2 Deviation from mean annual temperature (mean of 1961-1990) in the principality of Liechtenstein between 1901 and 2019. Positive deviations are marked in red (max. +2.5°C), negative deviations in blue (min -2.5°C). Data: OE (2020h).

For the Principality of Liechtenstein, no long records of temperature measurements exist. The measurement station in Vaduz (Liechtenstein)[1] is only in operation since 1971. However, there are two measurement stations in Switzerland close to the border of Liechtenstein, Sargans (3 km up the Rhine valley from the border) and Bad Ragaz (5 km from the border), with temperature measurements since 1871. The temperature time series of Vaduz since 1971 shows high similarities to those of Sargans and Bad Ragaz. Since the beginning of the measurements in 1871, the temperature in Sargans and Bad Ragaz has increased by around 1.9°C. Since 1971, the number of summer days has increased from about 40 to about 50 days while the frosty days[2] have declined from around 90 to around 80. These results most probably also apply to the valley regions of Liechtenstein. Between the reference period 1961-1990 and 1981-2010, Liechtenstein's annual mean temperature has risen by 0.7°C. This increase is up to three times higher as the world-wide temperature increase and has been observed in the other Alpine countries as well. Associated with the warming, the zero-degree isotherm has also risen by several hundred meters and the vegetation period has been extended by three to four weeks. Phenological observations show that the biological beginning of spring has been advancing by 1.5 to 2.5 days per decade. Further details are described in a specific chapter of Liechtenstein's Adaptation strategy (Government 2018).

[1] The station at Vaduz is part of the SwissMetNet, the official meteorological monitoring network of the Swiss Federal Office of Meteorology and Climatology (MeteoSwiss).
[2] Frosty day: Temperature falls below 0°C.

According to the Swiss Climate Change Scenarios CH2018 (NCCS 2018), the future climate of Liechtenstein is expected to change significantly from the present and past conditions. In the scenario RCP8.5 (without mitigation measures) the mean temperature will increase by 2-3°C between today until 2060. In the scenario RCP2.6 (with ambitious mitigation measures) the mean temperature will increase by 0.5-2°C between today until 2060. Figure 1-4 illustrates the past and expected future changes in seasonal mean temperature over north-eastern Switzerland.

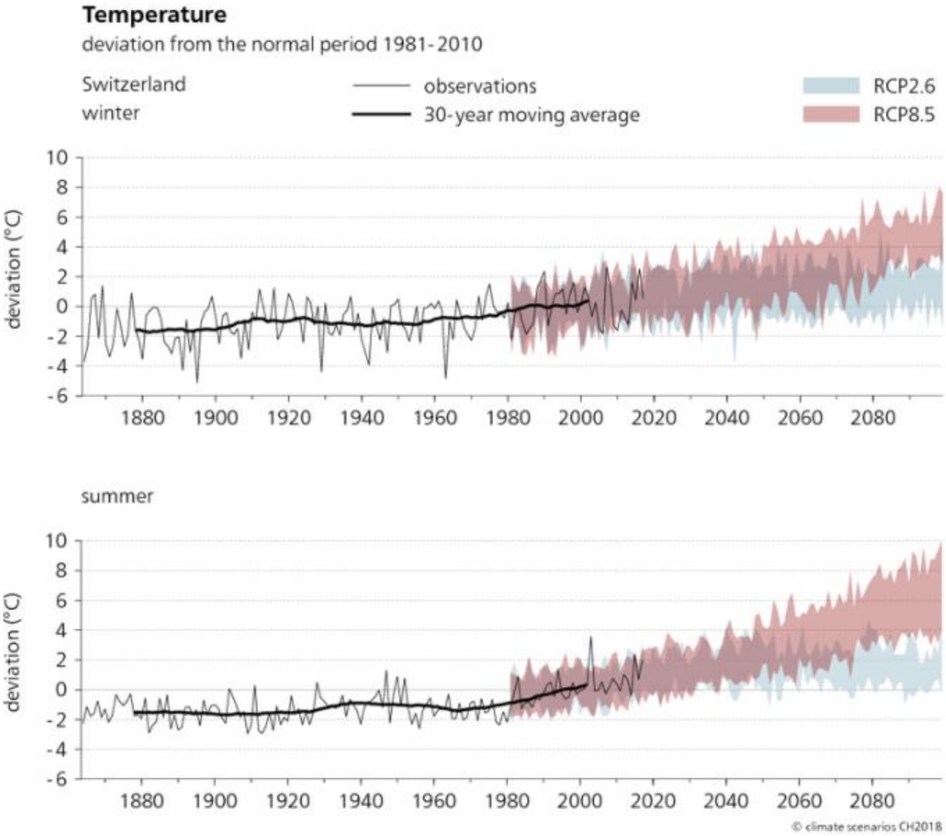


Figure 1-3 Past and expected future changes in seasonal temperature (°C) over north-eastern Switzerland for the scenario RCP2.6 (with mitigation measures) and RCP8.5 (without mitigation measures). The changes are depicted relative to the reference period 1981-2010 (from NCCS 2018).

Summer mean precipitation is projected to decrease by 16%, in the scenario RCP8.5. Mean precipitation in winter is expected to increase by 25% (Figure 1-4).

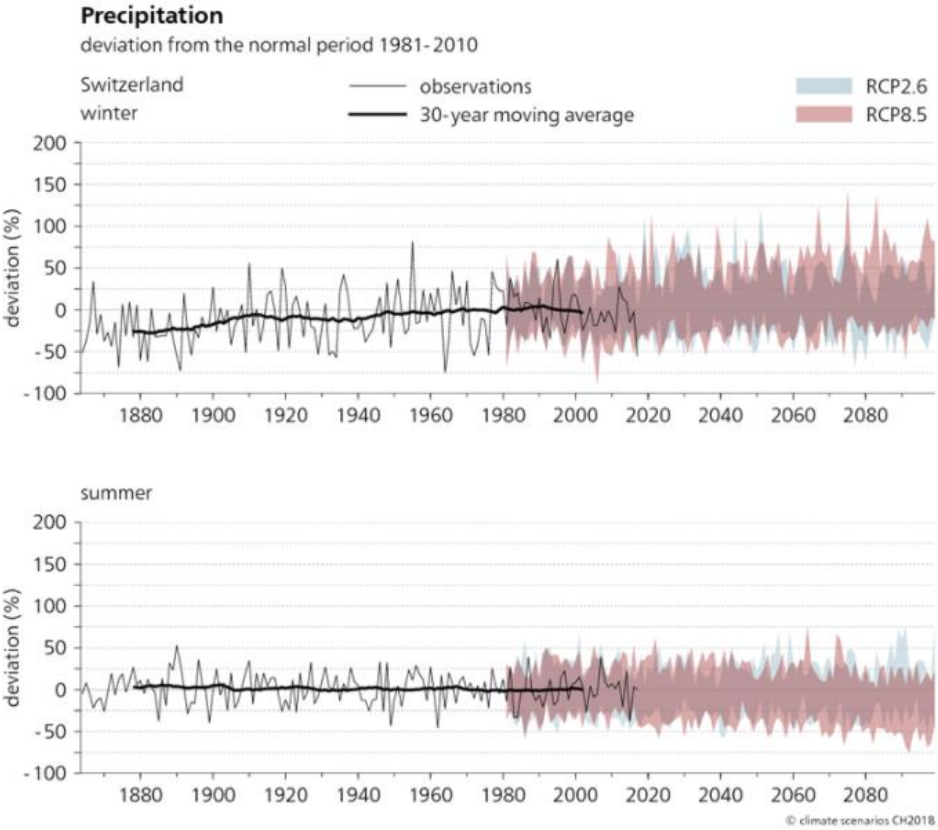


Figure 1-4 Past and expected future changes in seasonal precipitation (%) over north-eastern Switzerland for the scenario RCP2.6 (with mitigation measures) and RCP8.5 (without mitigation measures). The changes are depicted relative to the reference period 1981-2010 (from NCCS 2018).

For the year 2085, the expected changes in annual mean temperature and precipitation are represented in Figure 1-5 in a spatial resolution of 2 km.

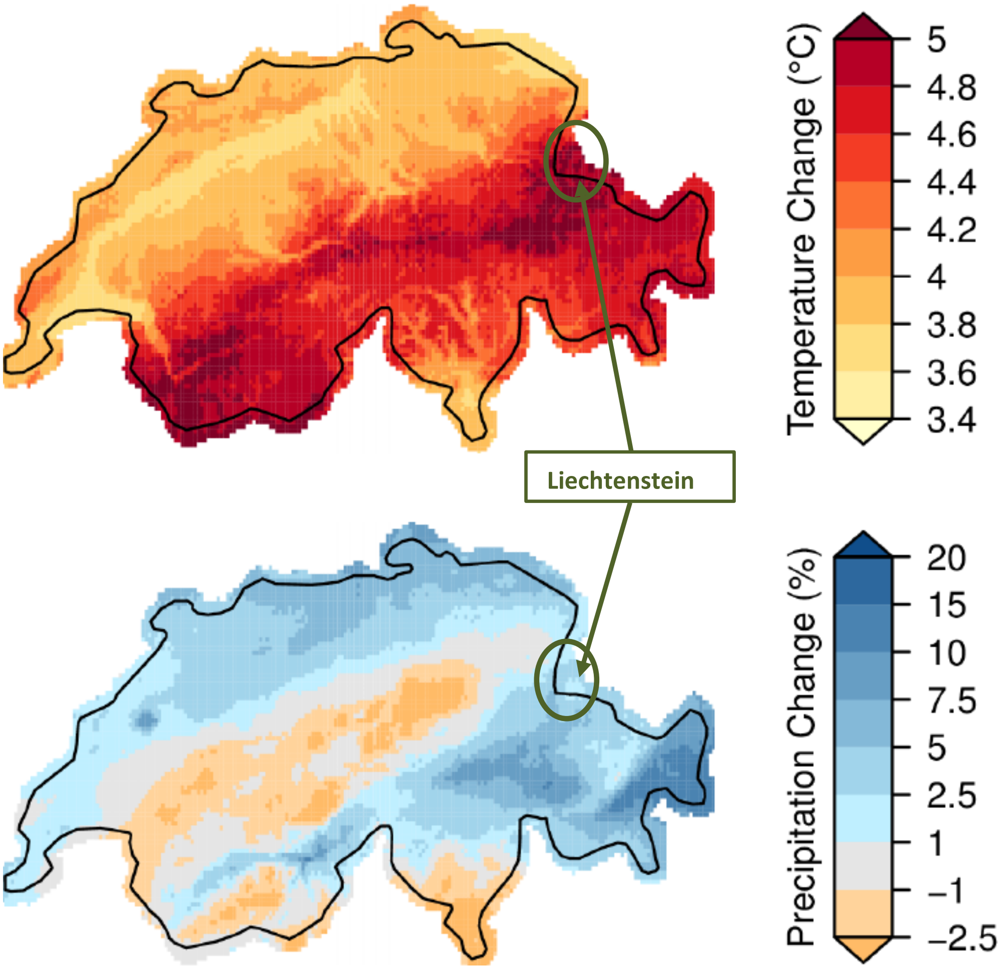


Figure 1-5 Ensemble median changes in annual mean temperature (upper map) and annual mean precipitation (lower map) for the “unabated emissions scenario” period 2085 in the high-resolution grid of 2 km for Switzerland and Liechtenstein (NCCS 2018).

Along with these changes in the mean temperature and precipitation, the nature of extreme events is also expected to change towards more frequent, intense and longer-lasting summers and heat waves (accompanied with drought events) with respect to the reference period 1981-2010. The number of summer days is expected to increase from 42 summer days per year to 75 in 2060 in the valley regions. The number of frost days is expected to decrease from 80 days to 50 days in 2060 (OE 2020h). In addition, a shift from solid (snow) to liquid (rain) precipitation is expected, which would increase flood risk primarily in the lowlands (NCCS 2018). The warming trend and changing precipitation patterns are also expected to have significant effects on ecosystems. The Biodiversity Monitoring Switzerland reports that climate change impacts are being observed even within short time periods. For instance, typical alpine vascular plants have shifted their distribution in the uphill direction during the past few years and phenological observations show that the vegetation period increased by 2 to 4 weeks since 1970 (OE 2020h).

The expected increase in intensity of storms and reduction of snowfall and snow cover duration are particularly important for alpine areas. Tourism, infrastructure and forestry are particularly affected due to more frequent floods, landslides and debris flows and an increased risk of avalanches. Liechtenstein's adaptation strategy describes the expected effects (Government 2018). A specific risk analysis for the alpine canton Uri in Switzerland shows increasing risks for infrastructures because of rising flood and landslide intensity as well as an increasing number of hot days for the lower parts of the canton with significant impacts on human health (INFRAS/Egli Engineering 2015). The climate-related risks for Liechtenstein are expected to be similar.

1.1.2.2 Vulnerability assessments

The following general effects can be expected as a consequence of further increasing CO_2 concentrations and the associated rise in temperature (Government 2018):

Health: the increase in intensity of heat waves in combination with high tropospheric ozone concentrations represents the greatest risk that climate change poses to human health. Another important health risk of climate change is the occurrence of vector-borne diseases. There is still high uncertainty about how future climate change will trigger further health issues.

Biodiversity, Ecosystems: a temperature increase changes the composition of forest and grassland vegetation and biodiversity in general. For instance, deciduous trees may become more important than today. Also, natural hazards (e.g. storms, avalanches, and debris flows) may have negative effects on forest and vegetation. The invasive, non-native species are an additional risk for ecosystems.

Natural hazards: changes in weather patterns may lead to an increased risk of floods in winter and droughts in summertime. A high flood risk exists particularly in the narrow Alpine valleys (mountain streams), where various protective measures (e.g. rock fall barriers and water course corrections) become vital. A further danger is posed by the Rhine: Although regulated, the river may endanger the intensively used valley floor in the event of a flood.

Tourism: within the next decades Liechtenstein's tourism sector, such as the economically important recreation resorts in Malbun and Steg, will have to deal with great challenges caused by climate change related developments in Liechtenstein's ecosystems. Especially winter tourism will be affected by higher temperatures, which cause a rise of the freezing level and will lead to a shift of the snow line towards higher altitudes.

Agriculture, energy production, water management: A rise in temperature may have negative effects on the productivity of grain cultivation in the long term (e.g. increased risk of draughts) but could also bring positive effects (e.g. longer vegetation period). The production of hydropower will be influenced by changing precipitation patterns. Overall, increased competition for water resources (hydropower production, agriculture, industry, tourism, nature conservation) can be expected.

The international engagement of the insurance sector will likely suffer the most severe negative consequences from an increase in the probability of losses.

1.1.2.3 Adaptation/mitigation

The projected consequences of an ongoing climate change require the immediate implementation of the so called Two-Pillar-Strategy – Mitigation (Pillar1) and Adaptation (Pillar 2).

Mitigation: reduction of greenhouse gas emissions can only be achieved if concrete measures are implemented in due time. Liechtenstein has launched a set of measures to address the problem of growing greenhouse gas emissions such as the most recent energy strategy 2030 and energy vision 2050 (Government 2020), Emissions Trading Act (Government 2012), Energy Efficiency Act (Government 2008), CO_2-Act (Government 2013), Environmental Protection Act (Government 2008a), National Transport Policies, National Climate Protection Strategy (Government 2015), Climate Vision 2050 (Government 2020a) and Action Plan on Air (OEP 2007e). Liechtenstein's climate policy goal is to achieve its "Nationally Determined Contribution" (NDC) under the Paris Agreement. On 23 April 2015, Liechtenstein submitted its "Intended Nationally Determined Contribution (INDC)" to the UNFCCC, which aims at a reduction of greenhouse gases by 40% by 2030 compared to 1990 (Government 2015a). A long-term climate strategy has been recently elaborated for Liechtenstein (Government 2023). The Climate Strategy 2050 includes a definition of the increase in the emission reduction target for 2030 and concrete measures for all sectors in order to achieve the target and the target of the Climate Vision 2050 (climate neutrality by 2050). With the adoption of the new Climate Strategy 2050 in December 2022, the Parliament of Liechtenstein approved the increase of the reduction target for 2030 to 55% below 1990 levels. The revision of article 4 paragraph 1 of the Emissions Trading Act reflecting the target increase will come into force on 1st of July 2023. In course of the year, Liechtenstein will accordingly communicate its updated Nationally Determined Contribution to the UNFCCC.

Adaptation: it is already known that certain consequences related to climate change will become irreversible. Therefore, the second pillar deals with the question of how these future threats could be addressed and how potential future damages can be limited or even avoided. Liechtenstein's Climate Change Adaptation strategy is published and available in German language only (Government 2018). An update for the adaption strategy is foreseen for 2023.

Natural hazard: Liechtenstein has established so called "Geological Risk Maps" with a special focus on residential areas. These maps provide regional information on specific risks from avalanches, rockfall and landslides and flooding.

Agriculture: identified adaptation measures are the selection of plant breeds that are suitable under expected future climatic conditions and selecting suitable plant breeds. However, the use of genetically modified crops is not foreseen. Irrigation of agricultural fields will increase resulting in conflicts with other public interests, especially during longer draught periods.

Forestry: increase of draught periods and subsequent damages caused by insects, pathogens (viruses, bacteria, fungus), fire or storms will lead to a decrease of the protective functions of forests in Liechtenstein. Adaptation measures already implemented are the conversion of spruce and fir stocks into mixed deciduous and coniferous forests.

Tourism: in this sector, further efforts need to be considered within the next years. The production of artificial snow, as currently practiced, is not considered to be a sustainable solution to address the lack of snow in skiing resorts. Various municipalities and institutions have already introduced new options for winter and summer tourism in order to counter potential revenue losses. Thereby, the focus lies on strategies to promote a "gentle tourism".

1.1.3 Background information on greenhouse gas inventory

1.1.3.1 Framework

In 1995, the Principality of Liechtenstein ratified the United Nations Framework Convention on Climate Change (UNFCCC). Furthermore, Liechtenstein ratified the Kyoto Protocol (both commitment periods) to the UNFCCC in 2004 and the Paris Agreement in 2017.

1.1.3.2 Submissions of National Communications and Biennial Reports

In 1995, 1998, 2002, 2006, 2010, 2014, 2017 and 2022, Liechtenstein submitted its National Communication Reports (NC1 to NC8) to the secretariat of the UNFCCC.

In 2013, 2016, 2017,2019, and 2022 Liechtenstein submitted Biennial reports BR1, BR2, BR3, BR4, BR5 to the secretariat. For BR2, a revised version was submitted in early 2017.

The latest reviews were conducted for the NC7 (FCCC/IDR 2018) and BR4 (FCCC/TRR 2021). For both reports, the ERT states that the reporting is complete, transparent and thus adhering to the UNFCCC reporting guidelines on NCs and BRs.

1.1.3.3 Former submissions of Greenhouse Gas Inventories

First commitment period (2008-2012) of Kyoto Protocol

In 2005, the first Greenhouse Gas Inventory of Liechtenstein was submitted in the Common Reporting Format (CRF) without National Inventory Report. From 2006-2014 Liechtenstein annually submitted its Greenhouse Gas Inventory together with the National Inventory Report prepared under the UNFCCC and under the Kyoto Protocol (OEP 2006-2011, OEP 2006a, 2007a, 2007b, 2012b, OE 2013-2014).

Second commitment period (2013-2020) of Kyoto Protocol

During its October 2014 session, the Liechtenstein Parliament approved the second commitment period of the Kyoto Protocol accepting a **20% reduction until 2020**.

The submission of the Greenhouse Gas Inventory and National Inventory Report in 2015 was postponed and submitted in 2016. From 2016-2022 Liechtenstein annually submitted its Greenhouse Gas Inventory together with the National Inventory Report prepared under the UNFCCC and under the Kyoto Protocol (OE 2016a, OE 2016c, OE 2016d, OE 2017-2022).

Reviews of former Greenhouse Gas Inventories

Liechtenstein's greenhouse gas inventory was subject to in-country reviews in the years 2007 and 2013. Furthermore, centralized reviews took place in 2008, 2009, 2010, 2011, 2012, 2014, 2016, 2018, 2020 and 2022. The review of the GHG inventories and National Inventory Reports 2015 and 2016 took place simultaneously in September 2016 due to the postponed submission in 2015. In response to the Potential Problems formulated in the course of the review of the 2022 annual submission of Liechtenstein, Liechtenstein corrected an error in the preparation of emission data in sector 1B and submitted updated CRF tables in November 2022 (OE 2022g).

1.2 National circumstances and institutional arrangements

1.2.1 National Entity and National Inventory System (NIS)

As part of a comprehensive project, the Government mandated its Office of Environment (OE) in 2005 to design and establish the National Inventory System (NIS) in order to ensure full compliance with the reporting requirements.

Figure 1-6 gives a schematic overview of the institutional setting of the process of inventory preparation within the NIS.

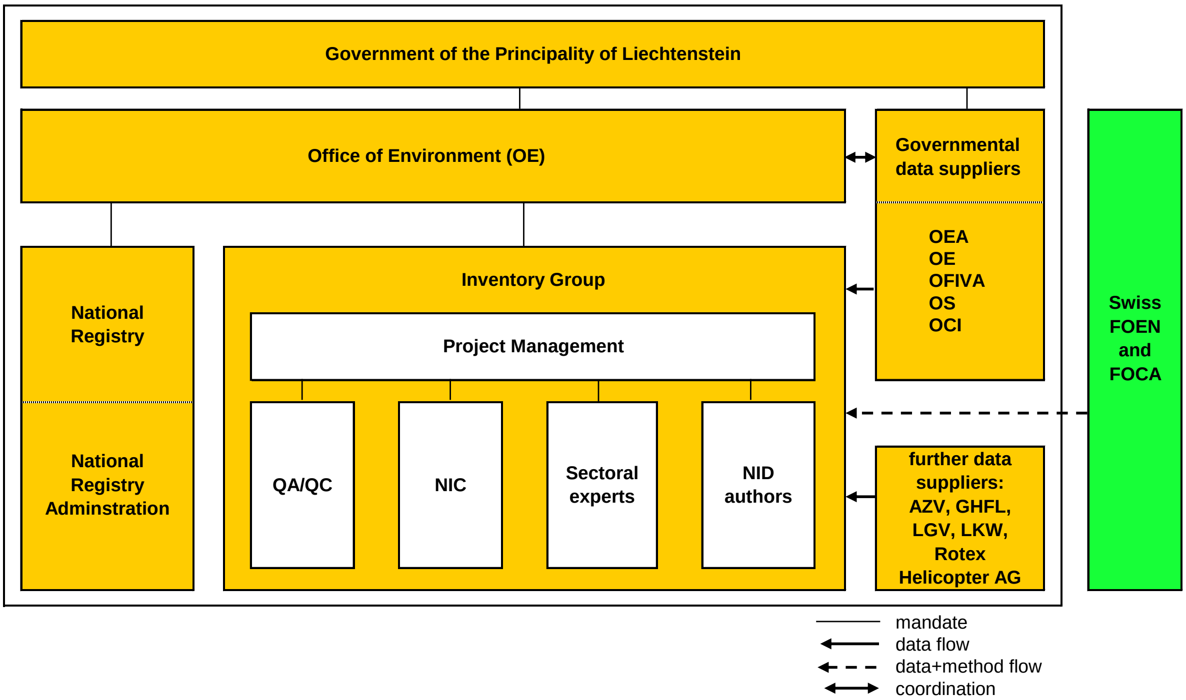


Figure 1-6 National Inventory System: Institutional setting and data suppliers. OE: Office of Environment; OEA: Office of Economic Affairs; OFIVA: Office of Food Inspections and Veterinary Affairs; OS: Office of Statistics: OCI: Office of Construction and Infrastructure; AZV: Liechtenstein's wastewater administration union; GHFL: Corporate society for the Storage of Gas Oil in the Principality of Liechtenstein; LGV: Liechtenstein's gas utility; LKW: Liechtenstein's electric power company; FOEN: Swiss Federal Office of the Environment; FOCA: Swiss Federal Office of Civil Aviation.

The Government of the Principality of Liechtenstein bears the overall responsibility for the NIS. By Liechtenstein's Emission Trading Act (Emissionshandelsgesetz, Government 2012), the Office of Environment (OE) is in charge of establishing emission inventories and is therefore also responsible for all aspects concerning the establishment of the National Inventory System (NIS) under the Paris Agreement. Please note that the Office of Environment was reorganised in 2013. The Office of Agriculture (OA), the Office of Forest, Nature and Land Management (OFNLM) and the Office of Environmental Protection (OEP) were merged to the Office of Environment (OE). The former Office of Land Use Planning (SLP) was reorganised in 2013 and the Local Land Use Planning Bureau is now incorporated into the Office of Construction and Infrastructure (OCI).

The Office of Environment (OE) is in charge of compiling the emission data, bears overall responsibility for Liechtenstein's national greenhouse gas inventory and is acting as the national registry administrator. Its project manager and national focal point is:

Karin Jehle
Gerberwerg 5, P.O. Box 684, 9490 Vaduz, Principality of Liechtenstein
karin.jehle@llv.li; Tel.: +423 236 6196

She also coordinates in cooperation with the director of the OE the data flow from the governmental data suppliers to the inventory group.

The inventory group consists of the project manager, who is also the National Inventory Compiler (NIC), the Quality Manager (QA/QA) and several external experts: sectoral specialists for modelling the greenhouse gas emissions and removals and the NID authors.

In addition to the OE, the Office of Economic Affairs (OEA), the Office of Statistics (OS) and the Office of Construction and Infrastructure (OCI) participate directly in the compilation of the inventory. Several other administrative and private institutions are involved in inventory preparation.

1.2.2 Inventory preparation process

1.2.2.1 Overview of inventory planning, preparation and management

Inventory planning, preparation, and management are well-established in Liechtenstein and follow an annual cycle according to an official schedule (Table 1-1). The planning of the inventory starts with the initial reporting meeting in June where the head of the inventory group and quality manger, the project manager and NIC as well as the emission modeler and the NID authors participate. At the initial meeting, the work is scheduled and priorities with regard to inventory development are set. Decisions regarding planned improvements are taken using the latest key category analysis to prioritize the enhancements. Source and sink categories which are key categories and hence need an additional improvement because of the recommendation by the ERT are usually planned to implement in the next annual submission (priority 1) unless specified otherwise. All other potential improvements are planned to implement (priority 2) depending on available resources (see IDP in chp. 10.4, Table 10-4). The entire data compilation process lasts from June to October. Normally, the UN review is conducted in September. The findings of the ERT typically lead to corrections of errors or to modifications in the methods. In October, another meeting of the core group takes place, where potential improvements of the inventory are analysed. Decisions about modifications are taken and the progress of data compilation is discussed. The compilation includes multiple quality control activities, in particular quality checks of different versions of the reporting tables (CRF) from October to December. At the end of this process, improvements are realised, the final version of inventory data is generated, and the inventory development plan (IDP) is updated.

Due to the transition to the new UNFCCC and IPCC guidelines, the inventory cycles for submissions 2015 and 2016 deviated uniquely. From 2017 on, the cycle corresponds to the description above again.

After inventory preparation, the NID is passed through a multistage quality control cycle too (see Table 1-1). NID authors, the emission modeler, the head of the inventory group, the project manager as well as additional people of the Office of Environment (OE) and sector experts review the drafts of the NID mutually. Thus, a maximum of quality assurance can be achieved. If the internal review suggests large revisions, they are taken up in the inventory development plan for future improvements. Archiving of inventory material is made after submission by the OE and sectoral experts, by the contributing authors and by the QA/QC officer.

Table 1-1 Annual cycle of inventory planning, preparation and management.

Process	Month											
	June	July	August	September	October	November	December	January	February	March	April	May
Initial meeting	■											
Data compilation	■	■	■	■	■							
CRF as 1st draft version					■							
QC of the CRF 1st draft version					■							
CRF as complete draft						■						
QC of the complete CRF draft						■						
Final CRF version						■	■					
Preparation of the NIR				■	■	■	■	■	■	■		
1st draft version NIR							■					
QC 1st draft version NIR								■				
2nd draft version NIR										■		
QC 2nd draft version NIR										■		
Final version NIR										■		
Submission final NIR and final CRF's											■	
Official UN review process			■	■								
Archiving												■

1.2.2.2 Data collection and processing

Data is supplied by governmental and external data suppliers.

Among the governmental data suppliers are:

- Office of Economic Affairs (OEA)
- Office of Statistics (OS)
- Office of Construction and Infrastructure (Local Land Use Planning Bureau)
- Office of the Environment (OE)

Further data suppliers are:

- Liechtenstein’s Gas Utility / Liechtensteinische Gasversorgung (LGV)
- Electric power company / Liechtensteinische Kraftwerke (LKW)
- Abwasserzweckverband (AZV)
- Heliport Balzers (Rotex Helicopter AG)
- Swiss Federal Office for the Environment (FOEN)
- Swiss Federal Office of Civil Aviation (FOCA)

In former years, the cooperative society for the storage of gas oil in the Principality of Liechtenstein (Genossenschaft für Heizöl-Lagerhaltung im Fürstentum Liechtenstein, GHFL) delivered data about the annual storage of fuels. However, the cooperative society was closed in 2008.

Cooperation for data collection with the Swiss Federal Office for the Environment

The Swiss Federal Office for the Environment (FOEN) is the agency that has the lead within the Swiss federal administration regarding climate policy and its implementation. The FOEN and Liechtenstein’s OE cooperate in the inventory preparation.

- Due to the Customs Union Treaty of the two states, the import statistics in the Swiss overall energy statistics (SFOE 2022) also includes the fossil fuel consumption of the Principality of Liechtenstein, except for gas consumption of Liechtenstein, which is excluded from SFOE (2022). FOEN therefore corrects its fuel consumption data by subtracting Liechtenstein’s liquid fuel consumption from the data provided in the Swiss overall energy statistics to avoid double-counting. To that aim, OE calculates its energy consumption and provides FOEN with the data.
- FOEN, on the other hand, provides a number of methods and emission factors to OE, mainly for transportation, agriculture, LULUCF, F-gases, and industrial processes and product use. Liechtenstein has benefited to a large extent from the methodological support by the inventory core group within the FOEN and its willingness to share data and spreadsheet-tools in an open manner. Its kind support is herewith highly appreciated.

Figure 1-7 illustrates the simplified data flow leading to the CRF tables required for reporting under the UNFCCC and the Paris Agreement. For roles and responsibilities of the contributors see Figure 1-6.

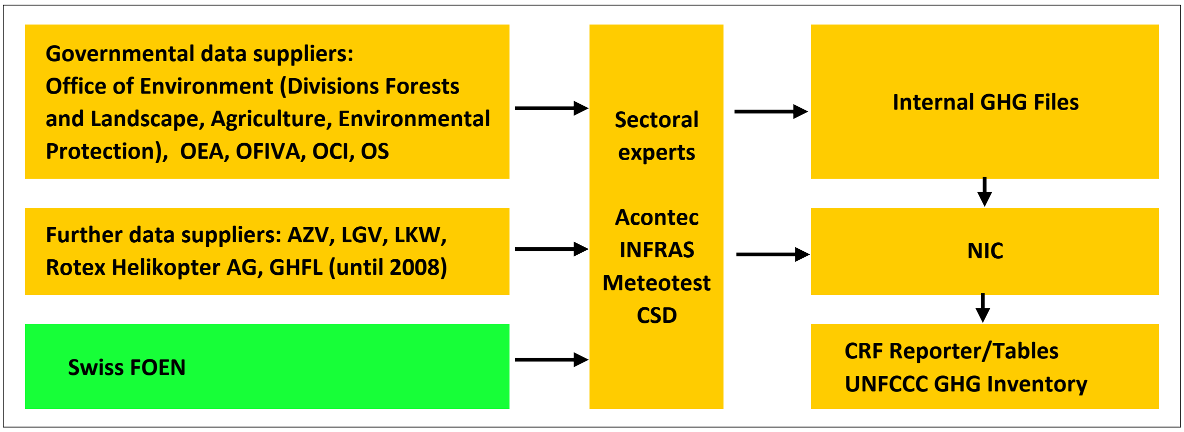


Figure 1-7 Data suppliers and data collection for setting up the UNFCCC GHG Inventory (see Glossary for abbreviations).

1.2.2.3 Treatment of confidentiality issues

In Liechtenstein, all activity data and emission factors are publicly available and not subject to confidentiality treatment. However, some emission factors used from Switzerland might see confidentiality restrictions in the Swiss NID and thus also for this report.

1.2.3 Documentation and archiving of information

The electronic files of Liechtenstein's GHG inventory are all saved by the backup system of Liechtenstein's administration.

Every computer belonging to the administration, including the computers of the Office of Environment, are connected to a central network. The data of the server systems, file-clusters and database servers are being saved in a tape-library. For safety reasons, the tape-library is not in the computing centre but in the national police building: In case of a total loss of the computing centre, the data are still available.

There are several backups

- daily incremental, saved up to one month (4 weeks),
- Weekly full backup, saved up to two months,
- Monthly full backup, saved up to one year.

The backup files are being initialised via scheduler of the master server. The data are written via network onto one of the LTO 2 Drives (tape). The master server manages the handling of the tapes. Backups are checked daily via Activity Monitor. If a backup is not carried out, it may be caught up manually. Since daily restores of user data are carried out, there is a guarantee for keeping the data readable.

For archiving reasons, the backup tapes are being doubled four times a year. The duplicates are not being overwritten for five years.

Also, the data generated in the NID compilation process such as the NID itself, QA/QC documents, KCA files, uncertainty analysis, review documents are archived by INFRAS within its archiving system that is maintained in the ISO 9001:2015 quality management system by INFRAS (SQS 2021). The administration of Liechtenstein has also a backup system in place and automatic backups are stored for five years. Hard copy files are stored in the archive for 10 years. CRF reporter software stores the data as well and the GHG inventory file is accessible from the UNFCCC website. Two hard copies of the NID are sent to the national library each year.

Finally, the entire information exchange by email between all people involved in updating the NID 2023 is stored in PST format.

Therefore, archiving practices are in line with paragraph 16(a) of the annex to decision 19/CMP.1

1.2.4 Processes for official consideration and approval of inventory

QA/QC activities and the inventory submission are coordinated by the Office of Environment and documented in the checklists shown in Annex 4. The final GHG-inventory is presented to the Director of the Office of Environment, who is also the quality manger, and to the project manager/NIC for official approval. The submission is coordinated and carried out by the project manager/NIC.

1.3 Brief general description of methodologies and data sources used

1.3.1 General description

The emissions are mainly calculated based on the standard methods and procedures of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) as adopted by the UNFCCC in its Decision 24/CP.19 (UNFCCC 2014).

The emissions are modelled by using country-specific activity data. Country-specific emission factors are applied if available. A number of default emission factors from IPCC are used. For a majority of emission sources, however, emission factors are adopted from the Swiss GHG inventory after checking their applicability. In those cases, the emission factors are reported as country-specific. It is noteworthy that there is a very close relationship between Liechtenstein and Switzerland based on the Customs Union Treaty between the two countries (see chp. 1.1.1). The Customs Union Treaty with Switzerland has a significant impact on environmental and fiscal strategies. Many Swiss environmental provisions and climate-protection regulations are also applicable in Liechtenstein or are implemented into Liechtenstein law on the basis of specific international treaty rules. **Therefore, a number of emission factors are adopted from Switzerland assuming that the Swiss emission factors actually represent the emission standards more accurately than default emission factors.** This assumption especially holds for:

- the sector Energy due to the same fuel quality standards and regulations and standards for exhaust gases of combustion and motor vehicles,

- the emission of F-gases due to similar product and consumer's attitude,
- agricultural emissions due to similar stock farming and cultivation of land,
- the sector LULUCF due to – again – similar geographic, meteorological and climatic circumstances for forestry, cropland, grassland and wetlands.

In the following paragraphs, a short summary of the methods used is given for each sector.

1 Energy

- Emissions from 1A Fuel combustion: Activity data is taken from the National Energy Statistics (including consistency modifications) and from census for the fuel sales of gasoline and diesel oil. The methods are country-specific.
- Emissions from 1B Fugitive emissions from fuels: The Swiss method is applied corresponding to country-specifics.

2 Industrial processes and product use

- HFC and PFC emissions from 2F1 Refrigeration and air conditioning are reported and are calculated with the rule of proportion applied on the Swiss emissions using country-specific activity data as representative for the conversion (e.g. no. of inhabitants).
- SF_6 emissions from 2G1 Electrical equipment are reported based on country-specific data.
- N_2O emissions from 2G3 product uses are reported and are calculated with the rule of proportion applied on the Swiss emissions using country-specific activity data (no. of inhabitants) as representative for the conversion.
- CO and NMVOC emissions from 2D3b Road paving with asphalt and 2D3c Asphalt roofing are estimated from the Swiss emissions using the number of inhabitants as a reference value for the rough estimate of Liechtenstein's emissions
- NMVOC emissions from 2D3 Other are delineated from the Swiss emissions using the number of inhabitants as a reference value for the rough estimate of Liechtenstein's emissions.
- Other emissions from industrial processes and product use (CO_2, CH_4, N_2O) are not occurring.

3 Agriculture

- Emissions are reported for 3A Enteric fermentation, 3B Manure management and 3D Agricultural soils by applying Swiss methods (country-specific) combined with Liechtenstein specific activity data as far as available.

4 LULUCF

- Emissions and removals are reported for 4A to 4G, 4(III) and 4(IV). Most of the methods and the emission factors are adopted from Switzerland, for forest land also country-specific data from Liechtenstein's National Forest Inventory are used.

5 Waste

- Emissions for 5A Solid waste disposal, 5B Biological treatment of solid waste and 5D Wastewater treatment and discharge are estimated according to IPCC (2006) with country-specific activity data.
- Emissions for 5C Incineration and open burning of waste a country-specific method is used, based on CORINAIR, adapted from the Swiss NIR (FOEN 2022).

1.3.2 Specific assumptions for the year 2021

For the modelling of its emissions, Liechtenstein uses several emission factors originating from the Swiss GHG inventory. At the time of inventory preparation, the emissions 2021 of the Swiss inventory 2022 were available as projections in the EMIS (Swiss Emission Information System) database of the Swiss Federal Office for the Environment dated from April 2022 corresponding to the emission data which Switzerland submitted in April 2022 in its NIR to the UNFCCC (FOEN 2022). This data for the year 2021 is used, for example, in category 2F.

Table 1-2 Notation keys for applied methods and emission factors 2021 (see also CRF tables Summary3s1, Summary3s2). Legend: D = IPCC default; CS = country-specific; M = model; T1, T2, T3 = Tier 1, 2, 3; NA = not applicable.

GREENHOUSE GAS SOURCE AND SINK CATEGORIES (CO_2, CH_4, and N_2O)	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
1. Energy	**T1, T2**	**CS, D**	**T1, T2, T3**	**CS, D**	**T1, T2, T3**	**CS, D**
A. Fuel combustion	T1, T2	CS, D	T1, T2, T3	CS, D	T1, T2, T3	CS, D
1. Energy industries	T2	CS, D	T2	CS	T1, T2	CS, D
2. Manufacturing industries and construction	T1, T2	CS, D	T1, T2	CS	T1, T2	CS, D
3. Transport	T1, T2	CS, D	T2, T3	CS, D	T2, T3	CS, D
4. Other sectors	T1, T2	CS, D	T1, T2	CS	T1, T2	CS, D
B. Fugitive emissions from fuels	NA	NA	T3	CS	NA	NA
2. Oil and natural gas	NA	NA	T3	CS	NA	NA
2. Industrial processes and product use	**NA**	**NA**	**NA**	**NA**	**CS**	**CS**
A. Mineral industry	NA	NA				
D. Non-energy products from fuels & solvent use	T1	D	NA	NA	NA	NA
G. Other product manufacture and use	NA	NA	NA	NA	CS	CS
3. Agriculture	**T1**	**D**	**T2**	**CS, D, M**	**T1, T3**	**CS, D**
A. Enteric fermentation			T2	CS, M		
B. Manure management			T2	CS, D, M	T3	CS, D
D. Agricultural soils					T1, T3	CS, D
H. Urea application	T1	D				
4. Land use, land-use change and forestry	**T2**	**CS, D**	**NA**	**NA**	**T2**	**D**
A. Forest land	T2	CS	NA	NA	NA	NA
B. Cropland	T2	CS	NA	NA	T2	D
C. Grassland	T2	CS	NA	NA	T2	D
D. Wetlands	T2	CS	NA	NA	T2	D
E. Settlements	T2	CS	NA	NA	T2	D
F. Other land	T2	CS	NA	NA	T2	D
G. Harvested wood products	T2	D				
5. Waste	**T2**	**CS**	**T2, T3**	**CS, D**	**T2, T3**	**CS, D**
A. Solid waste disposal	NA	NA	T2	D		
B. Biological treatment of solid waste			T2	CS	T2	CS
C. Incineration and open burning of waste	T2	CS	T2	CS	T2	D
D. Waste water treatment and discharge			T3	CS, D	T3	CS, D
6. Other *(as specified in summary 1.A)*	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**

GREENHOUSE GAS SOURCE AND SINK CATEGORIES (F-GASES)	HFCs		PFCs		SF_6	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
2. Industrial processes and product use	**CS**	**CS**	**CS**	**CS**	**CS**	**CS**
F. Product uses as ODS substitutes	CS	CS	CS	CS	NA	NA
G. Other product manufacture and use	NA	NA	NA	NA	CS	CS
6. Other *(as specified in summary 1.A)*	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**

Note: The CRF Tables Summary3s1 and 3s2 do not always display the correct notation keys for the applied methods and emission factors, which is the reason why the information above has been adapted manually where necessary and may deviate in some positions from information given in the CRF Tables.

1.3.3 Reference approach for the energy sector

Liechtenstein carried out the reference approach to estimate energy consumption and CO_2 emissions for the energy sector. The results are shown in chp. 3.2.1.

1.4 Brief Description of Key Categories

The key category analysis (KCA) is performed based on the automatic KCA implemented in the CRF Reporter Software. The software indicates to every source and sink category whether it is key or not (CRF Table7). The method corresponds to an Approach 1 level and trend assessment methodology with the proposed threshold of 95% as recommended by the 2006 IPCC Guidelines (IPCC 2006).

The analyses lead to four results:

- Base year 1990 level assessment without LULUCF categories
- Base year 1990 level assessment with LULUCF categories
- Reporting year 2021 level and trend assessment without LULUCF categories
- Reporting year 2021 level and trend assessment with LULUCF categories

To every source and sink category identified as key, the corresponding emission or sink is attributed. The data of the four analyses is shown in Table 1-3 to Table 1-6.

An Approach 2 level and trend assessment has not been carried out in the current submission. The identified key categories and especially new key categories are analysed in more detail in order to identify the reasons for category being key as well as possible needs for improvement.

1.4.1 KCA excluding LULUCF categories

For 2021, among a total of 196 categories (excluding LULUCF categories), eleven have been identified as Approach 1 key categories by the CRF Reporter Software (see CRF Table7 of the reporting tables) with an aggregated contribution of 96.6% of the national total emissions (see Table 1-3). Ten categories are key categories according to level assessment and also ten according to trend assessment.

Within those eleven key categories, seven stem from the energy sector, contributing 79.9% to total CO_2 equivalent emissions in 2021. The other key categories are from the sectors Agriculture (three categories, contribution 12.4%) and Industrial Processes and Product Use IPPU (one category, contribution 4.3%).

The three major sources, all from the energy sector, sum up to a contribution of 65.2% of the national total emissions:

- 1A3b Road transportation, CO_2
- 1A4 Other sectors, gaseous fuels, CO_2
- 1A4 Other sectors, liquid fuels, CO_2

Compared to newest inventory year of the previous submission (reporting year 2020), the following change has occurred in the KCA for the reporting year 2021 of the current submission:

- 1A2 Fuel combustion – Manufacturing Industries and Construction – Gaseous Fuels – CO_2 is – in addition to level – newly also a key category according to trend assessment

Table 1-3 List of Liechtenstein's Approach 1 key categories 2021 excluding LULUCF. Sorted by share of total emissions.

Key Category Analysis 2021 (excluding LULUCF) IPCC Source Categories (and fuels, if applicable)	GHG	Emissions 2021 [kt CO2eq]	Share of Total Emissions	Cumulative Total	Result of Assessment
1.A.3.b Road Transportation	CO2	55.46	30.2%	30.2%	KC Level, KC Trend
1.A.4 Other Sectors - Gaseous Fuels	CO2	38.42	20.9%	51.0%	KC Level, KC Trend
1.A.4 Other Sectors - Liquid Fuels	CO2	26.07	14.2%	65.2%	KC Level, KC Trend
3.A Enteric Fermentation	CH4	15.87	8.6%	73.9%	KC Level, KC Trend
1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO2	12.94	7.0%	80.9%	KC Level, KC Trend
1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO2	10.20	5.5%	86.4%	KC Level, KC Trend
2.F.1 Refrigeration and Air conditioning	F-gases	7.86	4.3%	90.7%	KC Level, KC Trend
3.D.1 Direct N2O Emissions From Managed Soils	N2O	3.91	2.1%	92.8%	KC Level, KC Trend
1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CO2	2.54	1.4%	94.2%	KC Level, KC Trend
3.B Manure Management	CH4	3.06	1.7%	95.9%	KC Level
1.B.2.b Fugitive Emissions from Fuels - Oil and Natural Gas - Natural Gas	CH4	1.36	0.7%	96.6%	KC Trend

For the base year 1990, the level key category analysis is given in Table 1-4 below. There are seven level key categories. The following change has occurred in the KCA compared to the previous submission:

- 3B Manure management, CH_4 is not a key category anymore (excl. LULUCF)

Table 1-4 List of Liechtenstein's Approach 1 key categories 1990 excluding LULUCF. Sorted by share of total emissions.

Key Category Analysis 1990 (excluding LULUCF) IPCC Source Categories (and fuels, if applicable)	GHG	Emissions 1990 [kt CO_2eq]	Share of Total Emissions	Cumulative Total	Result of Assessment
1.A.4 Other Sectors - Liquid Fuels	CO2	76.71	33.4%	33.4%	KC Level
1.A.3.b Road Transportation	CO2	75.29	32.8%	66.2%	KC Level
1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO2	20.99	9.1%	75.3%	KC Level
3.A Enteric Fermentation	CH4	15.59	6.8%	82.1%	KC Level
1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO2	15.20	6.6%	88.7%	KC Level
1.A.4 Other Sectors - Gaseous Fuels	CO2	10.21	4.4%	93.2%	KC Level
3.D.1 Direct N2O Emissions From Managed Soils	N2O	4.20	1.8%	95.0%	KC Level

Throughout the sectoral chapters 3 - 7, the corresponding key categories excluding LULUCF are documented for each source.

1.4.2 KCA including LULUCF categories

According to the 2006 IPCC Guidelines (IPCC 2006), the key category analysis including LULUCF categories is conducted on the full GHG inventory in order to identify additional key categories. The KCA including LULUCF categories is performed as an automatic step by the CRF Reporter.

The Approach 1 key category analysis for the year 2021 including LULUCF categories consists of a total of 223 categories, whereof 17 are key categories (see Table 1-5). Five categories are identified key from the LULUCF sector and contribute a total of 8.1% to total emissions:

- 4A1 Forest land remaining forest land, CO_2
- 4B1 Cropland remaining cropland, CO_2
- 4C2 Land converted to grassland, CO_2
- 4E2 Land converted to settlements, CO_2
- 4G Harvested wood products, CO_2

Furthermore, one additional category from the agriculture sector is key when performing the KCA for the full inventory (including LULUCF categories):

- 3B Manure management, N_2O

Compared to newest inventory year of the previous submission (reporting year 2020), the following changes have occurred in the KCA for the reporting year 2021 of the current submission:

- 1A2 Fuel combustion – Manufacturing Industries and Construction – Gaseous Fuels – CO_2 is – in addition to level – newly also a key category according to trend assessment
- 3B Manure Management (N_2O) is not a (trend) key category anymore
- 4E2 Land Converted to Settlements (CO_2) is not a (trend) key category anymore

In the KCA 1990 including LULUCF categories, three key categories contributing 4.0% to total emissions are identified from the LULUCF sector (see Table 1-6):

- 4B1 Cropland remaining cropland, CO_2
- 4E2 Land converted to settlements, CO_2
- 4G Harvested wood products, CO_2

Additionally, one category from the agriculture sector is key when performing the KCA for the full inventory (including LULUCF categories):

- 3B Manure management, CH_4

Table 1-5 List of Liechtenstein's Approach 1 key categories 2021 including LULUCF. Sorted by share of total emissions.

Key Category Analysis 2021 (including LULUCF) **IPCC Source Categories (and fuels, if applicable)**	GHG	Emissions 2021 abs. values [kt CO2eq]	Share of Total Emissions	Cumulative Total	Result of Assessment
1.A.3.b Road Transportation	CO2	55.46	26.6%	26.6%	KC Level, KC Trend
1.A.4 Other Sectors - Gaseous Fuels	CO2	38.42	18.5%	45.1%	KC Level, KC Trend
1.A.4 Other Sectors - Liquid Fuels	CO2	26.07	12.5%	57.6%	KC Level, KC Trend
3.A Enteric Fermentation	CH4	15.87	7.6%	65.2%	KC Level, KC Trend
1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO2	12.94	6.2%	71.5%	KC Level, KC Trend
1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO2	10.20	4.9%	76.4%	KC Level, KC Trend
2.F.1 Refrigeration and Air conditioning	F-gases	11.98	5.8%	82.1%	KC Level, KC Trend
4.A.1 Forest Land Remaining Forest Land	CO2	7.86	3.8%	85.9%	KC Level, KC Trend
3.D.1 Direct N2O Emissions From Managed Soils	N2O	3.94	1.9%	87.8%	KC Level, KC Trend
4.B.1 Cropland Remaining Cropland	CO2	3.91	1.9%	89.7%	KC Level, KC Trend
3.B Manure Management	CH4	3.06	1.5%	91.1%	KC Level
4.E.2 Land Converted to Settlements	CO2	2.65	1.3%	92.4%	KC Level
1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels	CO2	2.54	1.2%	93.6%	KC Level, KC Trend
4.C.2 Land Converted to Grassland	CO2	2.17	1.0%	94.7%	KC Level, KC Trend
3.B Manure Management	N2O	1.39	0.7%	95.3%	KC Level
1.B.2.b Fugitive Emissions from Fuels - Oil and Natural Gas - Natural Gas	CH4	1.36	0.7%	96.0%	KC Trend
4.G Harvested Wood Products	CO2	0.17	0.1%	96.1%	KC Trend

Table 1-6 List of Liechtenstein's Approach 1 key categories 1990 including LULUCF. Sorted by share of emissions.

Key Category Analysis 1990 (including LULUCF) **IPCC Source Categories (and fuels, if applicable)**	GHG	Emissions 1990 abs. values [kt CO_2eq]	Share of Total Emissions	Cumulative Total	Result of Assessment
1.A.4 Other Sectors - Liquid Fuels	CO2	76.71	31.6%	31.6%	KC Level
1.A.3.b Road Transportation	CO2	75.29	31.0%	62.6%	KC Level
1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels	CO2	20.99	8.6%	71.2%	KC Level
3.A Enteric Fermentation	CH4	15.59	6.4%	77.7%	KC Level
1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels	CO2	15.20	6.3%	83.9%	KC Level
1.A.4 Other Sectors - Gaseous Fuels	CO2	10.21	4.2%	88.1%	KC Level
3.D.1 Direct N2O Emissions From Managed Soils	N2O	4.20	1.7%	89.9%	KC Level
4.B.1 Cropland Remaining Cropland	CO2	4.18	1.7%	91.6%	KC Level
3.B Manure Management	CH4	3.28	1.4%	92.9%	KC Level
4.E.2 Land Converted to Settlements	CO2	2.82	1.2%	94.1%	KC Level
4.G Harvested Wood Products	CO2	2.69	1.1%	95.2%	KC Level

1.5 Brief general description of QA/QC plan and implementation

1.5.1 Quality assurance and quality control

For the submission 2008, the QA/QC activities had been documented for the first time through the use of checklists. These lists are now updated for the current submission and are shown in Annex 4. The classification of the QA/QC activities follows the IPCC Guidelines (IPCC 2006). According to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories the major elements of a QA/QC and verification system are:

- Participation of an inventory compiler who is also responsible for coordinating QA/QC and verification activities and definition of roles/responsibilities within the inventory;
- A QA/QC plan;
- General QC procedures that apply to all inventory categories;
- Category-specific QC procedures;
- QA and review procedures;
- QA/QC system interaction with uncertainty analyses;
- Verification activities;

- Reporting, documentation, and archiving procedures.

Please note that Liechtenstein's QA/QC system accounts for the **specific circumstances of the Principality of Liechtenstein:** Due to the small size of the State, not every process, data flow and arrangement needs to be established by a formal agreement due to short "distances" within the administration and due to a high degree of acquaintance between the people involved. Therefore, the National System manages with little number of written documents.

The QA/QC activities are coordinated by Mr. Stefan Hassler, the Director of the Office of Environment (e-mail: stefan.hassler@llv.li, phone: +423 236 61 97). The QA/QC activities are organised within the Inventory Group, see National Inventory System depicted in Figure 1-6.

The following people are involved in the QA/QC activities:

- NIC / project manager,
- Sectoral experts,
- NID authors.

Operational tasks are delegated to the NID lead author. She distributes checklists to the project manager being also the National Inventory Compiler, to the sectoral experts and to other NID authors. They fill in the procedures that they carried out. The lists are then sent back to the quality manager, who confirms the performance of the QA/QC activities. The activities are documented in the NID (see Annex 4).

The quality management shall enable the party to principally fulfil the reporting requirements. Specifically, it shall ensure and improve the quality of GHG inventory that means a continuous improvement **of transparency, consistency, comparability, completeness and confidence.** In detail, it serves

- for providing checks to ensure data integrity, correctness and completeness;
- to identify errors and omissions;
- to reduce the uncertainties of the emission estimates;
- to document and archive inventory material.

The QA/QC activities are well established and are part of the entire inventory process. Specific quality assurance activities (QA; ensuring the quality of the inventory, determining conformity of procedures and identifying areas of improvement) and quality control activities (QC; generic quality checks related to calculations, data processing, completeness, and documentation) are described in the QA/QC plan in Annex A4.1. All activities are planned and documented in checklists (see Annexes A4.2 for QC and A4.3 for QA activities). Special attention in the QA/QC activities are given to emissions from key categories.

1.5.2 Inventory development plan (IDP)

Liechtenstein maintains an inventory development plan (IDP). The IDP summarises all issues detected from internal and external QA/QC activities (in particular recommendations and encouragements made by the expert review team ERT) as well as possible planned improvements of the inventory. Planned improvements are prioritised according to the latest key category analysis and with regard to the uncertainty analyses (see chp. 10.4).

The latest review of Liechtenstein's greenhouse gas inventory took place in September 2022. The findings of the ERT were published in February 2023 in the report of the individual review of the annual submission of Liechtenstein submitted in 2022 (FCCC/ARR 2023).

The following table shows the planned improvements from the IDP that have been realised for the current submission. Planned improvements for future submissions, improvements that will not be implemented and improvements that have already been implemented are documented in the sector chapters and summarised in chp. 10.4 of this NID.

Reference	Identified Issues, e.g. recommendations or planned improvements	Status	Comment/Reason NID	Sector
ARR 2020, ID#G.10, ARR 2022 ID#G.5	Update CRF table 9 and annex 5 to the NIR to include information on where emissions from light- and heavy-duty trucks are accounted for and information justifying the assumption that emissions for category 3.I (other carbon-containing fertilizers) are insignificant in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines.	Implemented in submission 2023	Liechtenstein included a documentation of the notation key used in CRF table 1.A.(a)s3 in the NIR of submission 2021 (see chp. 3.2.7.2 - Methodology - Road transportation). Liechtenstein populated Table 9 and added information regarding category 3.I in chapter 1.7. of the NID in submission 2023.	0 General
Internal decision	Update of CO2 emissions from lubricant use (2D1) based on updated data from Switzerland's GHG inventory.	Implemented in submission 2023	At the time of the inventory preparation in submission 2022, CO2 emissions from lubricant use for 2020 were not yet available from Switzerland's GHG inventory. Therefore, in submission 2022 Liechtenstein derived the emissions factor per capita based on Switzerland's emissions reported for 2019. In the next submission, emissions from 2D1 in 2020 were updated based on the updated emissions from Switzerland's GHG inventory.	2 IPPU

Reference	Identified Issues, e.g. recommendations or planned improvements	Status	Comment/Reason NID	Sector
ARR 2022 ID#I.2	2.F.4 Aerosols -HFCs The Party reported in CRF Table2(II)B-Hs2 emissions of HFC134a from stocks of metered dose inhalers for the time series of 1997-2019. For inventory year 2020, emissions were reported as "NO". During the review, the Party clarified that due to an error in the data preparation, the emissions of HFC134a for inventory year 2020 were not included in the CRF tables. Include the emissions of HFC134a associated with metered dose inhalers for 2020 in the next inventory submission.	Implemented in submission 2023	Liechtenstein included the emissions of HFC134a for 2020 in the submission 2023.	2 IPPU
ARR 2022 ID#A.6	3B: The Party reported in its NIR (p.176) that the EFs applied to estimate N2O emissions from liquid/slurry manure management systems were updated and adjusted in the 2020 submission in accordance with the information presented in the Netherlands' GHG inventory (van Bruggen et al., 2014). Namely, Liechtenstein applied N2O EFs of 0.002 kg N2O-N (kg N excreted)-1 for a liquid/slurry system with a natural crust cover and a liquid/slurry system without a natural crust cover (versus the default EFs of 0.005 and 0.00 N2O-N (kg N excreted)-1, respectively, in table 10.21 of the 2006 IPCC Guidelines). The ERT noted that the implementation of the updated N2O EFs has resulted in a significant increase in N2O emissions from liquid/slurry manure management systems (e.g. from 0.0003 kt N2O in 2017, as reported in the 2019 submission, to 8.34 kt N2O in 2017, as reported in the 2020 submission). The ERT recommends that the Party provide the information in its NIR to justify the applicability of the N2O EF values it uses, which were developed by researchers of the Netherlands, to the national circumstances of Liechtenstein for the entire reporting period and, if a justification is not possible, consider using the default values of the N2O EFs reported in table 10.21 of the 2006 IPCC Guidelines (vol. 4, chap. 10) to calculate N2O emissions from liquid/slurry manure management systems.	Implemented in submission 2023	The party is in the view that "downgrading" to a tier 1 method would be a clear step back and would harm the overall consistency of the agriculture model. Furthermore, the party wants to state that it cannot be in the spirit of the UNFCCC to push parties towards using a tier 1 approach instead of a tier 2 approach. The party explained in its NID that this emission factor is used in the Swiss inventory as well, and has been evaluated by a Swiss expert for its application for Liechtenstein. Furthermore, as suggested by the ERT in the ARR 2022, the party documented in its NID an unpublished source (Bretscher 2020) confirming the conclusion of the Swiss inventory expert.	3 Agriculture

Reference	Identified Issues, e.g. recommendations or planned improvements	Status	Comment/Reason NID	Sector
ARR 2022 ID#L.4	The ERT recommends that the Party improve in the NIR the methodological description for the LULUCF sector by including specific information, such as tier level, carbon stocks and calculation formula, for each carbon pool and land-use category; for example, in NIR sections 6.5.2.2 and 6.6.2.2, under (a) and (b), the calculation formula, including conversion time and carbon stocks, could be described.	Implemented in submission 2023	The party improved the description of the methods in chapters 6.5.2, 6.6.2, 6.7.2, 6.8.2 and 6.9.2.	4 LULUCF
ARR 2022 ID#L.8	The Party did not include in CRF table 4.Gs2 data for sawn wood production, import and export for the entire time series – values for 1960 to 1989 are missing. The ERT recommends that the Party fill any blank cells in the CRF tables with values or appropriate notation keys.	Implemented in submission 2023	Date for the years 1961-1989 were filled in. There are no import/export data for 1960 available.	4 LULUCF
Internal decision, ARR 2022, IDW.11	5.D Wastewater treatment and discharge - CH4: The ERT recommends that the Party correct the error in the calculation of the AD for sewage gas losses for 2006 – 2020 and related CH4 emissions from wastewater treatment and discharge and report the revised estimates in the next annual submission.	Implemented in submission 2023	There was a wrong cell reference in calculation AD for sewage gas losses, starting from the year 2005. The mistake was corrected in Submission 2023	5 Waste
ARR 2022, ID#W.10	5.A Solid waste disposal on land - CH4: The ERT recommends that the Party correct the value of DOCf in CRF table 5.A so that it is consistent with the value reported in the NIR (0.5), which is the correct value.	Implemented in submission 2023	In Submission 2022 the DOCf value = 15.40 in CRF table 5.A was wrong. However, the correct value for DOCf = 0.5 value was applied in estimating the CH4 emissions. Mistake was corrected in Submission 2023.	5 Waste

1.5.3 Verification activities

Verification activities were conducted in various steps of the development of the inventory. As Liechtenstein compiles its inventory in close collaboration with Switzerland concerning the methods and models used, continuous comparison between the two inventories take place.

In many cases the same emission factors as in the Swiss NID are applied. Therefore, those factors are checked when copied from the Swiss NID and correlation thus depends on activity data. As both countries have similar methodologies, comparable economic structure, similar liquid/gaseous fuels mixes and vehicle fleet composition, the comparison of total per capita CO_2 emission indicates completeness of source categories:

- If the national total emissions (without LULUCF) of the two countries are compared, very similar and highly correlated trends are found. In 1990, Liechtenstein's emissions were 0.43% of the Swiss emissions. After a slight increase between 1993 and 2009, this share is 0.39% in 2016. In the same years, the share of inhabitants slightly changed from 0.43% to 0.45%. This may be interpreted as a simple form of verification, since

Liechtenstein has used the same or similar methods and EF for many sectors, in which activity data is linked to the number of inhabitants. (Simultaneously, it shows that the per capita emissions in Liechtenstein were reduced more strongly in Liechtenstein than in Switzerland.)

- Another indirect verification may be derived from the ambient air pollutant concentration measurements. Liechtenstein is integrated in a monitoring network of the Eastern cantons of Switzerland (www.ostluft.ch). The results are commonly analysed and published (OSTLUFT 2022). They show that the local air pollution levels of NO_2, O_3 and PM10 in Liechtenstein vary in the same range as in the Swiss neighbouring measurement sites (FOEN 2022c).

1.6 General uncertainty assessment

1.6.1 Approach 1

In the current inventory, Approach 1 uncertainty is evaluated with level (2021, 1990) and trend (1990-2021) analyses. Approach 1 is based on propagation of error. Uncertainty in the emission level in 2021 and in the trend between the reporting year (2021) and the base year (1990) is estimated for the inventory total and for the single source categories and gases using uncertainty ranges of corresponding activity data and emission factors. All uncertainties are given as half of the 95% confidence interval divided by the mean and expressed as a percentage (approximately two standard deviations) as suggested by the 2006 IPCC Guidelines (IPCC 2006).

As in previous submissions, a simplified uncertainty analysis has been carried out. The simplification means that uncertainty analysis individually accounts for the key categories, whereas the rest of the categories were aggregated by gas and treated as four “rest” categories CO_2, CH_4, N_2O and F-gases, to which a semi-quantitative uncertainty (see below, Table 1-7) was attributed.

In the automatic KCA of the CRF Reporter, the aggregation level of the categories is not identical to the aggregation level as applied in previous uncertainty analyses. Therefore, a small number of categories, for which the uncertainty is available, had to be aggregated in a preparing step by Gaussian error propagation, to the level of the corresponding key category (see Annex A2.1 for further information).

Results of the uncertainty analyses are used for prioritizing the improvements of national inventory accuracy.

1.6.2 Uncertainty estimates

Data on uncertainties is not provided explicitly for most emission sources and sinks by the OE. Therefore, the authors and the involved expert of Acontec generated first estimates of uncertainties based on uncertainty data from the Swiss NID (FOEN 2023) and expert estimates.

All uncertainty figures are to be interpreted as corresponding to half of the 95% confidence interval. Distributions are symmetric for Approach 1 analysis.

For key categories, individual uncertainties are used. Those are described in the respective sector chapters. For the remaining categories, qualitative estimates of uncertainties are applied. The terms used are “high”, “medium” and “low” data quality. To each term, quantitative uncertainties as shown in Table 1-7 are used. They are motivated by the comparison of uncertainty analyses of several countries carried out by De Keizer et al. (2007), as presented at the 2nd Internat. Workshop on Uncertainty in Greenhouse Gas Inventories (Vienna 27-28 Sep 2007).

Table 1-7 Semi-quantitative uncertainties (95% level) for categories, for which no explicit uncertainty is known. Note that there is no source of NF_3 in Liechtenstein, therefore no values are indicated.

Gas	Uncertainty category	Relative 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%
HFC	medium	20%
PFC	medium	20%
SF_6	medium	20%

Note that uncertainties in the GWP values were not taken into account in the inventory uncertainty estimates.

1.6.3 Results of Approach 1 uncertainty evaluation

The quantitative uncertainty analysis Approach 1 has been carried out following the 2006 IPCC Guidelines Approach 1 methodology (IPCC 2006, vol. 1, chp. 3, Table 3.2).

Details on uncertainty estimates of specific sources are provided in the sub-sections on "Uncertainties and Time-Series Consistency" in each of the chapters on source categories.

Uncertainty of national total CO_2eq emissions **excluding LULUCF:** The Approach 1 level uncertainty for the year 2021 is estimated to be 5.17%, trend uncertainty (1990-2021) is 4.80% (see Table 1-8). The level uncertainty for the year 1990 amounts 7.02% (see Table 1-9). Uncertainty of national total CO_2eq emissions **including LULUCF**: The Approach 1 level uncertainty for the year 2021 is estimated to be 6.10%, trend uncertainty (1990-2021) is 5.26% (see Table 1-10). The level uncertainty for the year 1990 amounts 6.93% (see Table 1-11).

Compared to the **previous submission in 2022 (reporting year 2020),** the results of the current Approach 1 analyses show lower uncertainties for the assessment excluding LULUCF and higher uncertainties for the assessment including LULUCF.

- Level uncertainty 2020 (previous submission): 5.50% (excluding LULUCF) and 5.83% (including LULUCF)
- Trend uncertainty 1990-2020 (previous submission): 4.97% (excluding LULUCF) and 5.08% (including LULUCF)

The results for the uncertainty analysis for the year 2021 excluding and including LULUCF categories are similar to the previous submission, since both, the emissions (per sectors) and the uncertainty estimates per category have remained similar. However, the following changes occur:

- Overall uncertainty for 2021 excluding LULUCF categories is 0.3 percentage points lower than in the previous submission for the level assessment and 0.2 percentage points lower for the trend assessment. On the one hand this decrease is driven by a decrease in N_2O emissions due to lower GWP used for N_2O in this submission (AR5) than in the previous submission (AR4). On the other hand, a decrease in emissions in 1A4 liquid fuels compensated by an increase in 1A4 gaseous fuels leads to a lower uncertainty, as the combined uncertainty for 1A4 liquid fuels is higher than the one for 1A4 gaseous fuels.
- Overall uncertainty for 2021 including LULUCF is 0.3 percentage points higher than in the previous submission for the level assessment and 0.2 percentage points higher for the trend assessment. This increase is a result of the higher sink activity in category 4A1.

The overall uncertainty in Liechtenstein is to some extent determined by the high activity data uncertainty of liquid fuels. This is due to the fact that Liechtenstein, forming a customs and monetary union with Switzerland, has no own customs statistics of imports of oil products, and activity data has to be based on inquiries with suppliers, being of heterogeneous quality.

Table 1-8 Approach 1 level (2021) and trend (1990-2021) uncertainty excluding LULUCF.

A					B	C	D	E	F	G	H	I	J	K	L	M
IPCC Source category					**Gas**	**Base year emissions or removals**	**Year 2021 emissions or removals**	**AD unc.**	**EF unc.**	**Comb. unc.**	**Contr. to variance by Category in 2021**	**Type A sensi-tivity**	**Type B sensi-tivity**	**Unc. in trend in nat. emissions introduced by EF unc.**	**Unc. in trend in nat. emissions introduced by AD unc.**	**Unc. intro-duced into the trend in total national emissions**
(categories excluding LULUCF)						kt CO_2 eq	kt CO_2 eq	%	%	%	-	%	%	%	%	-
1A1	**1. Energy**	A. Fuel combustion activities	1. Energy industries	Gaseous F.	CO_2	0.12	2.54	5.0	0.4	5.0	0.005	0.01	0.01	0.00	0.08	0.006
1A2	**1. Energy**	A. Fuel combustion activities	2. Manufacturing industries & construction	Liquid F.	CO_2	20.99	10.20	20.0	0.1	20.0	1.229	0.03	0.04	0.00	1.26	1.577
1A2	**1. Energy**	A. Fuel combustion activities	2. Manufacturing industries & construction	Gaseous F.	CO_2	15.20	12.94	5.0	0.4	5.0	0.124	0.00	0.06	0.00	0.40	0.159
1A3b	**1. Energy**	A. Fuel combustion activities	3. Transp.; b. Road Transp.		CO_2	75.29	55.46	9.5	0.1	9.5	8.159	0.02	0.24	0.00	3.23	10.464
1A4	**1. Energy**	A. Fuel combustion activities	4. Other Sectors	Liquid F.	CO_2	76.71	26.07	15.8	0.1	15.8	5.041	0.15	0.11	0.01	2.54	6.465
1A4	**1. Energy**	A. Fuel combustion activities	4. Other Sectors	Gaseous F.	CO_2	10.21	38.42	4.0	0.3	4.0	0.686	0.13	0.17	0.04	0.94	0.877
1B2b	**1. Energy**	B. Fugitive Emissions from Fuels	2. Oil and Natural Gas; b. Nat. Gas		CH_4	0.41	1.36	35.4	35.4	50.0	0.137	0.00	0.01	0.16	0.30	0.113
2F1	**2. IPPU**	F. Product uses as substitutes for ODS	1. Refrigeration and air conditioning		F-gases	0.00	7.86	10.7	10.7	15.1	0.417	0.03	0.03	0.37	0.52	0.401
3A	**3. Agriculture**	A. Enteric Ferment.			CH_4	15.59	15.87	6.5	16.9	18.1	2.444	0.01	0.07	0.25	0.63	0.460
3B	**3. Agriculture**	B. Manure Management			CH_4	3.28	3.06	6.5	54.0	54.4	0.821	0.00	0.01	0.10	0.12	0.025
3D1	**3. Agriculture**	D. Agricul-tural Soils	1. Direct Soil Emissions		N_2O	4.20	3.91	16.9	94.1	95.6	4.131	0.00	0.02	0.22	0.41	0.215
non-key rest					CO_2	0.45	0.26	7.1	7.1	10.0	0.000	0.00	0.00	0.00	0.01	0.000
non-key rest					CH_4	2.26	1.52	21.2	21.2	30.0	0.061	0.00	0.01	0.03	0.20	0.040
non-key rest					N_2O	4.93	4.25	56.6	56.6	80.0	3.425	0.00	0.02	0.08	1.48	2.202
non-key rest					F-gases	-	0.18	14.1	14.1	20.0	0.000	0.00	0.00	0.01	0.02	0.000
Total						**229.64**	**183.90**				**26.68**					**23.01**
										Percentage uncertainty in total inventory:	**5.17**				*Trend uncertainty:*	**4.80**

Table 1-9 Approach 1 level (1990) uncertainty excluding LULUCF.

A					B	C	E	F	G	H
IPCC Source category					**Gas**	**Base year emissions or removals**	**AD unc.**	**EF unc.**	**Comb. unc.**	**Contr. to variance by Category in 1990**
(categories excluding LULUCF)						kt CO_2 eq	%	%	%	-
1A2		A. Fuel combustion activities	2. Manufacturing industries & construction	Liquid F.	CO_2	20.99	20.0	0.1	20.0	3.343
1A2		A. Fuel combustion activities	2. Manufacturing industries & construction	Gaseous F.	CO_2	15.20	5.0	0.4	5.0	0.110
1A3b		A. Fuel combustion activities	3. Transp.; b. Road Transp.		CO_2	75.29	9.5	0.1	9.5	9.641
1A4		A. Fuel combustion activities	4. Other Sectors	Liquid F.	CO_2	76.71	15.8	0.1	15.8	27.988
1A4		A. Fuel combustion activities	4. Other Sectors	Gaseous F.	CO_2	10.21	4.0	0.3	4.0	0.031
3A	**3. Agriculture**	A. Enteric Fermentation			CH_4	15.59	6.5	16.9	18.1	1.514
3D1	**3. Agriculture**	D. Agricul-tural Soils	1. Direct Soil Emissions		N_2O	4.20	16.9	94.1	95.6	3.055
non-key rest					CO_2	0.57	7.1	7.1	10.0	0.001
non-key rest					CH_4	5.95	21.2	21.2	30.0	0.604
non-key rest					N_2O	4.93	56.6	56.6	80.0	2.950
non-key rest					F-gases	0.00	14.1	14.1	20.0	0.000
Total						**229.64**				**49.24**
							Percentage uncertainty in total inventory:			**7.02**

Table 1-10 Approach 1 level (2021) and trend (1990-2021) uncertainty including LULUCF.

A					B	C	D	E	F	G	H	I	J	K	L	M
IPCC Source category					Gas	Base year emissions or removals	Year 2021 emissions or removals	AD unc.	EF unc.	Comb. unc.	Contr. to variance by Category in 2021	Type A sensitivity	Type B sensitivity	Unc. in trend in nat. emissions introduced by EF unc.	Unc. in trend in nat. emissions introduced by AD unc.	Unc. intro-duced into trend in total national emissions
(categories including LULUCF)						kt CO_2 eq	kt CO_2 eq	%	%	%	-	%	%	%	%	-
1A1	1. Energy	A. Fuel combustion activities	1. Energy industries	Gaseous F.	CO_2	0.12	2.54	5.0	0.4	5.0	0.005	0.01	0.01	0.00	0.08	0.006
1A2			2. Manufacturing ind. & constr.	Liquid F.	CO_2	20.99	10.20	20.0	0.1	20.0	1.226	0.03	0.04	0.00	1.22	1.478
				Gaseous F.	CO_2	15.20	12.94	5.0	0.4	5.0	0.124	0.00	0.05	0.00	0.39	0.149
1A3b			3. Transport; b. Road Transportation		CO_2	75.29	55.46	9.5	0.1	9.5	8.134	0.01	0.23	0.00	3.13	9.810
1A4			4. Other Sectors	Liquid F.	CO_2	76.71	26.07	15.8	0.1	15.8	5.025	0.14	0.11	0.01	2.46	6.061
				Gaseous F.	CO_2	10.21	38.42	4.0	0.3	4.0	0.684	0.13	0.16	0.04	0.91	0.822
1B2b		B. Fugitive Emissions from Fuels	2. Oil, nat. gas, other em. from energy prod.		CH_4	0.41	1.36	35.4	35.4	50.0	0.137	0.00	0.01	0.16	0.29	0.107
2F1	2. IPPU	F. Prod. uses as subst. for ODS	1. Refriger. & air cond.		F-gases	0.00	7.86	10.7	10.7	15.1	0.416	0.03	0.03	0.35	0.50	0.376
3A	3. Agriculture	A. Enteric Ferment.			CH_4	15.59	15.87	6.5	16.9	18.1	2.437	0.02	0.07	0.27	0.61	0.445
3B		B. Manure Managem.			CH_4	3.28	3.06	6.5	54.0	54.4	0.818	0.00	0.01	0.12	0.12	0.028
					N_2O	1.22	1.39	31.4	152.9	156.1	1.387	0.00	0.01	0.29	0.26	0.150
3D1		D. Agricultural Soils	1. Dir. Soil Em.		N_2O	4.20	3.91	16.9	94.1	95.6	4.118	0.00	0.02	0.26	0.39	0.221
4A1	4. LULUCF	A. Forest Land	1. Forest land remaining forest land		CO_2	0.11	-11.98	2.7	46.7	46.8	9.252	0.05	0.05	2.37	0.19	5.677
4B1		B. Cropland	1. Cropland remaining cropland		CO_2	4.18	3.94	30.8	23.0	38.4	0.677	0.00	0.02	0.07	0.72	0.529
4C2			2. Land con-verted to grassland		CO_2	0.45	2.17	13.6	51.0	52.8	0.388	0.01	0.01	0.39	0.18	0.185
4E2		E. Settle-ments	2. Land con-verted to settlements		CO_2	2.82	2.65	19.4	33.7	38.9	0.313	0.00	0.01	0.07	0.31	0.098
4G		G. HWP			CO_2	-2.69	0.17	50.0	54.8	74.2	0.005	0.01	0.00	0.52	0.05	0.275
non-key rest					CO_2	2.85	3.25	7.1	7.1	10.0	0.031	0.00	0.01	0.03	0.14	0.020
					CH_4	2.26	1.52	21.2	21.2	30.0	0.061	0.00	0.01	0.02	0.19	0.037
					N_2O	3.98	3.20	56.6	56.6	80.0	1.935	0.00	0.01	0.03	1.08	1.168
					F-gases	-	0.18	14.1	14.1	20.0	0.000	0.00	0.00	0.01	0.02	0.000
Total						**237.18**	**184.19**				**37.17**					**27.64**
							Percentage uncertainty in total inventory:				**6.10**				*Trend uncertainty:*	**5.26**

Table 1-11 Approach 1 level (1990) uncertainty including LULUCF.

A					B	C	E	F	G	H
IPCC Source category					**Gas**	**Base year emissions or removals**	**AD unc.**	**EF unc.**	**Comb. unc.**	**Contr. to variance by Category in 1990**
(categories including LULUCF)						kt CO_2 eq	%	%	%	-
1A2		A. Fuel combustion activities	2. Manufacturing industries & construction	Liquid F.	CO_2	20.99	20.0	0.1	20.0	3.134
1A2		A. Fuel combustion activities	2. Manufacturing industries & construction	Gaseous F.	CO_2	15.20	5.0	0.4	5.0	0.103
1A3b		A. Fuel combustion activities	3. Transp.; b. Road Transp.		CO_2	75.29	9.5	0.1	9.5	9.039
1A4		A. Fuel combustion activities	4. Other Sectors	Liquid F.	CO_2	76.71	15.8	0.1	15.8	26.238
1A4		A. Fuel combustion activities	4. Other Sectors	Gaseous F.	CO_2	10.21	4.0	0.3	4.0	0.029
3A	**3. Agriculture**	A. Enteric Ferment.			CH_4	15.59	6.5	16.9	18.1	1.420
3B	**3. Agriculture**	B. Manure Management			CH_4	3.28	6.5	54.0	54.4	0.567
3D1	**3. Agriculture**	D. Agricul-tural Soils	1. Direct Soil Emissions		N_2O	4.20	16.9	94.1	95.6	2.864
4B1	**4. LULUCF**	B. Cropland	1. Cropland remaining cropland		CO_2	4.18	30.8	23.0	38.4	0.460
4E2	**4. LULUCF**	E. Settle-ments	2. Land con-verted to settlements		CO_2	2.82	19.4	33.7	38.9	0.214
4G	**4. LULUCF**	G. HWP			CO_2	-2.69	50.0	54.8	74.2	0.707
non-key rest					CO_2	3.52	7.1	7.1	10.0	0.022
non-key rest					CH_4	2.67	21.2	21.2	30.0	0.114
non-key rest					N_2O	5.20	56.6	56.6	80.0	3.072
non-key rest					F-gases	0.00	14.1	14.1	20.0	0.000
Total						**237.18**				**47.98**
						Percentage uncertainty in total inventory:				**6.93**

The level uncertainties are also evaluated by gas according to the results of the Approach 1 uncertainty assessment excluding LULUCF for the year 2021.

Table 1-12 Level uncertainties by gas 2021 for the total national emissions excluding LULUCF.

Gas	Emissions 2021 (excluding LULUCF) kt CO2 eq	Mean absolute uncertainty kt CO2 eq	Mean relative uncertainty
CO2	145.88	7.18	5%
CH4	21.81	3.42	16%
N2O	8.16	5.06	62%
F-gases	8.05	1.19	15%
Total	**183.90**	**9.5**	**5.17%**

Please note that the current results of the Approach 1 uncertainty analysis for GHG emissions from key categories in Liechtenstein do not (fully) take into account the following factors that may further increase uncertainties:

- Correlations that exist between source categories that have not been considered.
- Uncertainties due to the assumption of constant parameters, e.g. of constant net calorific values for fuels for the entire period since 1990.
- Uncertainties due to methodological shortcomings, such as differences between sold fuels and actually combusted fuels (stock-changes in residential tanks) for liquid fossil fuels.

1.6.4 Results of Approach 2 uncertainty evaluation in previous submission

An Approach 2 uncertainty analysis was not conducted in the current submission for the latest reporting year. However, Approach 2 uncertainty results from a previous submission (reporting year 2020, see box below) show that the resulting uncertainties with Approach 1 for the reporting year 2021 are in a similar range as with previous Approach 2 results. In terms of trend uncertainty, the results of Approach 2 show higher uncertainties than the results of Approach 1. Positive correlations for activity data and emission factors between the base year and the latest reporting year tend to increase trend uncertainty when assessed with Approach 2 with a Monte Carlo simulation.

Results of the Approach 2 uncertainty analysis for the reporting year 2020:

The Approach 2 level uncertainty (2020) in the national total annual CO_2 equivalent emissions **excluding LULUCF** was 4.92% (95% confidence interval from -4.88% to 4.96%), trend uncertainty (1990-2020) was 6.25%.

The Approach 2 level uncertainty (2020) in the national total annual CO_2 equivalent emissions **including LULUCF** was 5.28% (95% confidence interval from -5.26% to 5.31%), trend uncertainty (1990-2020) was 6.42%.

1.7 General Assessment of completeness

1.7.1 Information on completeness

Liechtenstein’s current GHG inventory is complete for all gases concerning the Paris Agreement.

Explanations for using the notation keys “NE” and “IE” are provided in CRF table 9.

1.7.2 Description of insignificant categories

The use of other carbon-containing fertilisers (3I) was not estimated (NE) for Liechtenstein, as the emissions are below the threshold of significance in accordance with paragraph 37(b) of the UNFCCC Annex I Inventory reporting guidelines.

1.7.3 Total aggregate emissions considered insignificant

The total GHG-emissions excluding LULUCF in 2021 are 183.90 kt CO_2 eq. The significance threshold for aggregated emissions equals to 0.92 kt CO_2 eq.

The emissions from UAN application in category 3I are very likely <0.005 kt CO_2 in the year 2021 (1% of emissions of source category 3H Urea application), which means that it accounts for less than 0.001% of total GHG emissions (excl. LULUCF) and is well below the significance threshold.

1.8 Metrics

The NID and reporting tables CRF are prepared using the 100-year time-horizon global warming potential (GWP_{100}) values from the IPCC Fifth Assessment Report (AR5) (Myhre et al. 2013), implemented in the CRF reporter released by the secretariat at the end of January 2023.

1.9 Summary of any flexibility applied

No flexibility applied.

2. Trends in greenhouse gas emissions and removals

This chapter provides an overview of Liechtenstein's GHG emissions and removals as well as their trends in the period 1990–2021.

2.1 Description of emission and removal trends for aggregated GHG emissions and removals

Liechtenstein's greenhouse gas emissions in the year 2021 amount to 183.9 kt CO_2 equivalent (CO_2eq) excluding LULUCF sources or sinks (including LULUCF: 184.2 kt CO_2eq). This refers to 4.68 t CO_2eq per capita.

Total emissions in 2021 (excl. LULUCF) have declined by 19.9% compared to 1990. Compared to 2020, they increased by 1.68%. When including LULUCF categories, total emissions decreased by 0.79% between 2020-2021 and by 22.3% between 1990-2021.

Among the different greenhouse gases, CO_2 accounts for the largest share of total emissions. Table 2-1 shows the emissions for individual gases and sectors in Liechtenstein for the year 2021. The most important emission sources are fuel combustion activities in the Energy sector. Emissions of CH_4 and N_2O mainly originate from the sector 3 Agriculture, and F-gas emissions stem from the sector 2 Industrial processes and product use (IPPU) by definition. The table also provides information about international bunkers.

Table 2-1 Summary of Liechtenstein's GHG emissions by gas and sector in CO_2 equivalent (kt). Numbers may not add to totals due to rounding.
Note that the current inventory (submission 2023) uses for the first time the global warming potentials (GWP_{100}) from the Fifth Assessment Report (AR5) of the IPCC (Myhre et al. 2013).

Emissions 2021	**CO_2**	**CH_4**	**N_2O**	**HFCs**	**PFCs**	**SF_6**	**Total**
	CO_2 equivalent (kt)						
1 Energy	145.7	1.82	0.88	-	-	-	148.4
2 IPPU	0.11	NO	0.13	7.99	0.001	0.05	8.3
3 Agriculture	0.04	18.9	6.57	-	-	-	25.5
5 Waste	0.01	1.06	0.59	-	-	-	1.7
Total (excluding LULUCF)	**145.9**	**21.8**	**8.16**	**7.99**	**0.001**	**0.05**	**183.9**
4 LULUCF	-0.1	NO	0.34	-	-	-	0.3
Total (including LULUCF)	**145.8**	**21.8**	**8.50**	**7.99**	**0.001**	**0.05**	**184.2**
International Bunkers	*0.96*	*0.0002*	*0.01*	-	-	-	*0.97*

A breakdown of Liechtenstein's total emissions by gas is shown in Figure 2-1 below. Figure 2-2 shows the contributions of each sector to the different greenhouse gases.

Accounting for 79.3% of the total emissions in 2021 (excluding emissions from LULUCF), CO_2 is the most dominant greenhouse gas emitted in Liechtenstein. CH_4 emissions represent 11.9% and N_2O emissions 4.4% of the total emissions.

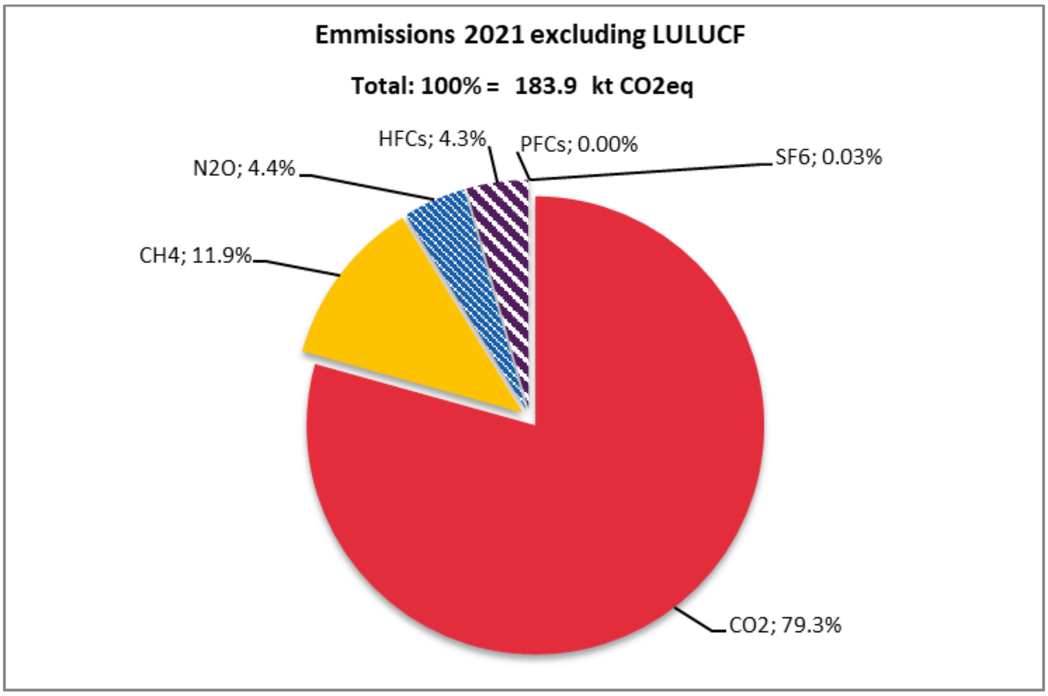


Figure 2-1 Liechtenstein's GHG emissions by gases excluding LULUCF emissions.

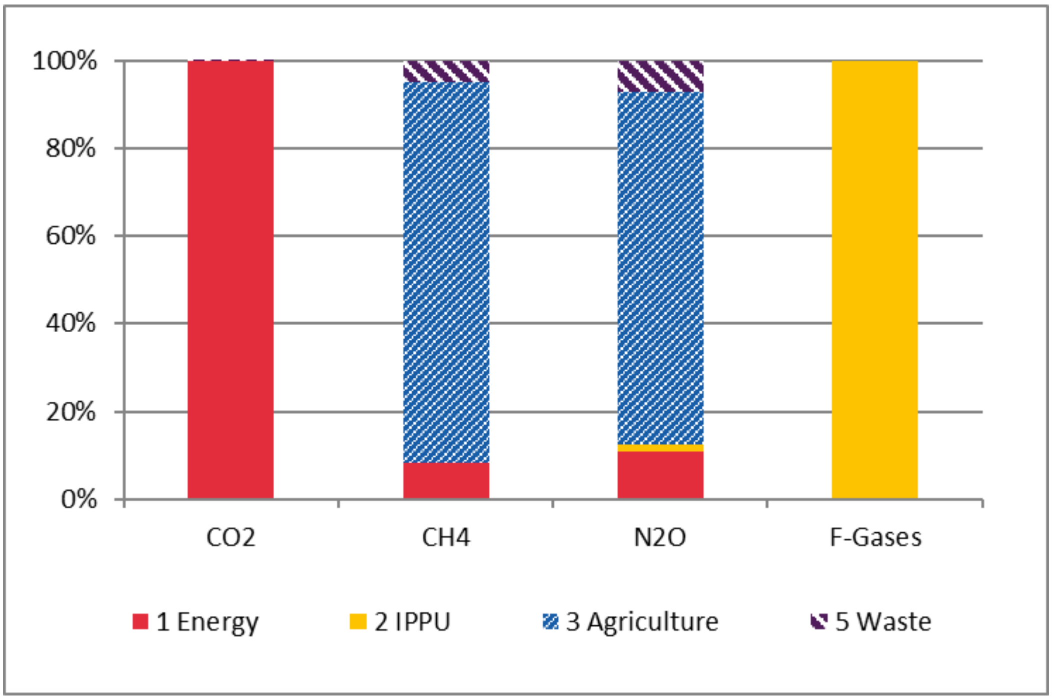


Figure 2-2 Relative contributions of the individual sectors (excluding LULUCF) to GHG emissions in 2021.

2.2 Description of emission and removal trends by sector and by gas

2.2.1 Emission trends by gas

Emission trends 1990–2021 by gas are summarised in Table 2-2 and in Figure 2-3.

Table 2-2 Summary of Liechtenstein's GHG emissions in CO_2eq (kt) by gas. The last column shows the percentage change in emissions in 2021 as compared to the base year 1990. HFC emissions have increased by about a factor of 83'200 in 2021 compared to 1990.
Note that the current inventory (submission 2023) uses for the first time the global warming potentials (GWP_{100}) from the Fifth Assessment Report (AR5) of the IPCC (Myhre et al. 2013).

Greenhouse Gas Emissions	**1990**	**1995**	**2000**	**2005**	**2010**
	CO_2 equivalent (kt)				
CO_2 emissions incl. net CO_2 from LULUCF	206.2	209.2	241.7	238.0	211.4
CO_2 emissions excl. net CO_2 from LULUCF	199.0	204.2	216.9	229.0	190.8
CH_4 emissions incl. CH_4 from LULUCF	21.5	20.1	18.7	20.8	21.4
CH_4 emissions excl. CH_4 from LULUCF	21.5	20.1	18.7	20.8	21.4
N_2O emissions incl. N_2O from LULUCF	9.4	9.3	8.8	8.5	8.6
N_2O emissions excl. N_2O from LULUCF	9.1	9.1	8.4	8.1	8.3
HFCs	0.0	1.1	3.5	6.3	8.3
PFCs	NO	0.0	0.0	0.1	0.1
SF_6	NO	NO	0.1	0.3	0.0
Unspecified mix of HFCs and PFCs	NO	NO	NO	NO	NO
NF_3	NO	NO	NO	NO	NO
Total (including LULUCF)	237.2	239.7	272.7	273.9	249.8
Total (excluding LULUCF)	229.6	234.4	247.6	264.5	228.8

Greenhouse Gas Emissions	**2012**	**2013**	**2014**	**2015**	**2016**
	CO_2 equivalent (kt)				
CO_2 emissions incl. net CO_2 from LULUCF	209.9	209.7	178.3	171.6	159.8
CO_2 emissions excl. net CO_2 from LULUCF	185.3	192.5	161.3	159.8	149.8
CH_4 emissions incl. CH_4 from LULUCF	22.3	21.3	21.5	21.3	21.4
CH_4 emissions excl. CH_4 from LULUCF	22.3	21.3	21.5	21.3	21.4
N_2O emissions incl. N_2O from LULUCF	8.8	8.6	8.5	8.5	8.4
N_2O emissions excl. N_2O from LULUCF	8.5	8.2	8.1	8.2	8.0
HFCs	9.1	9.0	9.3	9.4	9.0
PFCs	0.0	0.0	0.0	0.0	0.0
SF_6	0.0	0.2	0.1	0.0	0.0
Unspecified mix of HFCs and PFCs	NO	NO	NO	NO	NO
NF_3	NO	NO	NO	NO	NO
Total (including LULUCF)	**250.1**	**248.8**	**217.7**	**210.8**	**198.7**
Total (excluding LULUCF)	**225.2**	**231.3**	**200.3**	**198.6**	**188.3**

Greenhouse Gas Emissions	**2017**	**2018**	**2019**	**2020**	**2021**	**1990-2021**
	CO_2 equivalent (kt)					**%**
CO_2 emissions incl. net CO_2 from LULUCF	167.1	164.9	161.0	146.4	145.8	-29.3%
CO_2 emissions excl. net CO_2 from LULUCF	155.8	143.0	149.0	141.9	145.9	-26.7%
CH_4 emissions incl. CH_4 from LULUCF	20.9	21.2	21.9	22.1	21.8	1.2%
CH_4 emissions excl. CH_4 from LULUCF	20.9	21.2	21.9	22.1	21.8	1.2%
N_2O emissions incl. N_2O from LULUCF	8.4	8.5	8.6	8.5	8.5	-9.5%
N_2O emissions excl. N_2O from LULUCF	8.0	8.1	8.3	8.2	8.2	-10.6%
HFCs	9.3	9.4	9.1	8.6	8.0	see caption
PFCs	0.0	0.0	0.0	0.0	0.0	-
SF_6	0.0	0.1	0.0	0.1	0.1	-
Unspecified mix of HFCs and PFCs	NO	NO	NO	NO	NO	-
NF_3	NO	NO	NO	NO	NO	-
Total (including LULUCF)	**205.6**	**204.1**	**200.7**	**185.7**	**184.2**	**-22.3%**
Total (excluding LULUCF)	**193.9**	**181.7**	**188.3**	**180.9**	**183.9**	**-19.9%**

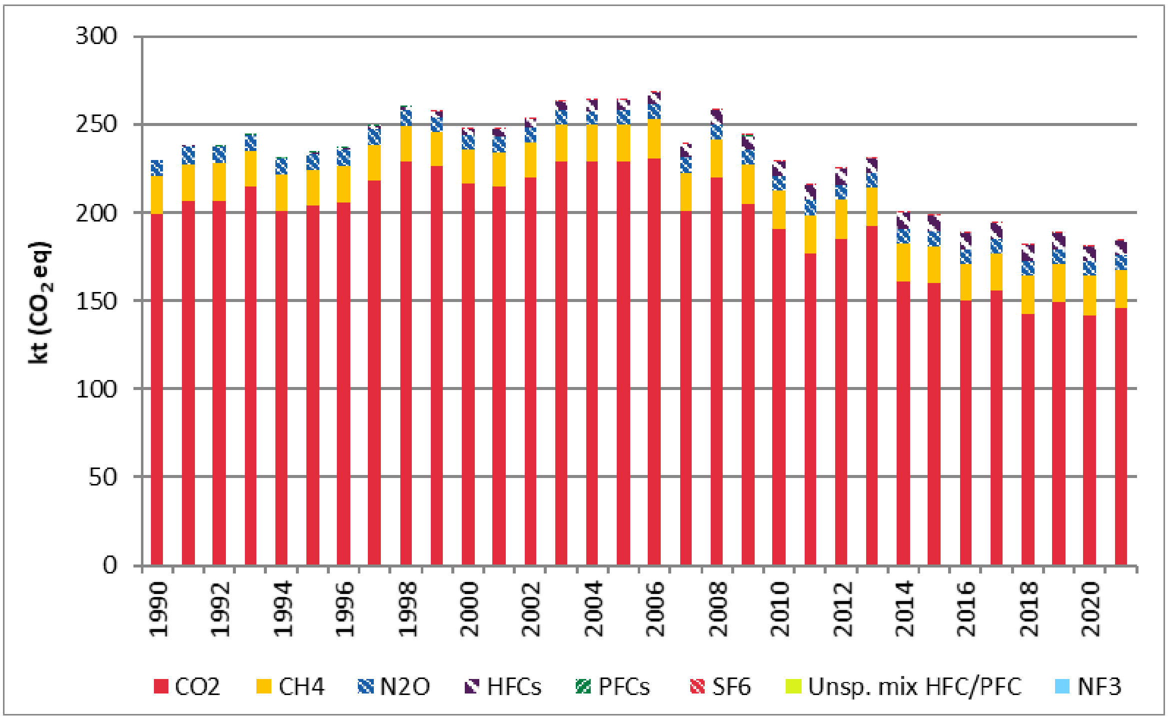


Figure 2-3 Trend of Liechtenstein's greenhouse gas emissions by gases. CO_2, CH_4 and N_2O correspond to the respective total emissions excluding LULUCF. Note that NF_3 emissions are not occurring.

As shown in Table 2-2 and Figure 2-3, total emissions excluding and including LULUCF emissions are clearly below base year emissions. Emissions have increased after 1990, reaching a maximum in 2006. From then onwards, a decreasing trend starts to develop. Emission trends for the individual gases can be described as follows:

- Total emissions (in CO_2eq) excluding LULUCF sources or sinks decreased by 19.9% from 1990 to 2021.
- Total emissions (in CO_2eq) including LULUCF show a decrease of 22.3% in 2021 compared to 1990 levels.
- CO_2 emissions (excluding net CO_2 from LULUCF) have declined by 26.7% between 1990 and 2021. In comparison to the previous reporting year 2020, CO_2 emissions (excluding net CO_2 from LULUCF) increased by 2.8% in 2021. In general, the most important drivers of net CO_2 emissions are fuel prices and winter temperatures (heating degree days), influencing the source categories contributing to a large share of CO_2 emissions under 1A Fuel combustion (1A2 Manufacturing industries and construction, 1A3 Transport and 1A4 Other sectors). The latest developments are also influenced by changes in the CO_2 levy and by the Covid pandemic (see chp. 2.2.2). The share of CO_2 emissions decreased from 86.6% in 1990 to 79.3% in 2021 (excl. LULUCF).
- CH_4 emissions (excluding CH_4 from LULUCF) have increased by 1.2% since 1990. Compared to 2020, CH_4 emissions (excluding LULUCF) show a decrease by 1.2% in 2021. The major reason for the emission development is the variation in numbers of livestock (in particular cattle), which strongly influence CH_4 emissions from enteric fermentation. Livestock numbers have been reduced between 1990-2000 and have

increased again since (however, still being below the 1990 level). The share of CH_4 increased from 9.4% in 1990 to 11.9% in 2021 (excl. LULUCF).

- N_2O emissions (excluding N_2O from LULUCF) have declined by 10.6% in 2021 compared to 1990. Compared to 2020, N_2O emissions (without LULUCF) in 2021 decreased by 0.2%. The main source of N_2O emissions is agriculture (manure management and agricultural soils). The share of N_2O increased from 4.0% (1990) to 4.4% (2021).
- HFC emissions increased due to their role as substitutes for CFCs. SF_6 emissions originate from electrical transformation stations and play a minor role for the total of the synthetic gases (F-gases). PFC emissions are occurring since 1997 and are increasing on a low level. The share of the sum of all F-gases (within total emissions excl. LULUCF) increased from 0.00004% (1990) to 4.4% (2021).

2.2.2 Emission trends by sector

Table 2-3 shows emission trends for all major source and sink categories. As the largest share of emissions originated from sector 1 Energy, the table shows the contributions of the source categories attributed to it in more detail (1A1-1A5, 1B).

Table 2-3 Summary of Liechtenstein's GHG emissions by source and sink categories in CO_2eq (kt). The last column shows the percent change in emissions in 2021 compared to the base year 1990.

Source and Sink Categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	CO_2 equivalent (kt)									
1 Energy	**201.3**	**208.9**	**209.7**	**217.8**	**203.8**	**207.0**	**208.9**	**221.4**	**232.3**	**229.7**
1A1 Energy industries	0.2	0.8	1.9	2.0	1.8	2.1	2.6	2.5	2.9	2.9
1A2 Manufacturing ind. & constr.	36.3	35.9	36.3	37.6	35.6	35.7	35.7	37.6	40.3	39.8
1A3 Transport	76.9	90.2	89.5	87.4	80.0	82.0	83.3	86.9	86.6	90.7
1A4 Other sectors	87.6	81.4	81.4	90.3	85.8	86.6	86.5	93.6	101.7	95.4
1A5 Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9
2 IPPU	**0.6**	**0.6**	**0.6**	**0.7**	**0.9**	**1.6**	**1.8**	**2.2**	**2.7**	**3.2**
3 Agriculture	**26.0**	**26.0**	**25.3**	**24.2**	**24.3**	**24.1**	**24.3**	**24.0**	**23.5**	**22.5**
5 Waste	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**
Total (excluding LULUCF)	***229.6***	***237.2***	***237.3***	***244.4***	***230.7***	***234.4***	***236.7***	***249.2***	***260.2***	***257.1***
4 LULUCF	**7.5**	**-8.1**	**2.7**	**-0.5**	**18.6**	**5.3**	**-2.9**	**8.4**	**0.7**	**-0.4**
Total (including LULUCF)	***237.2***	***229.1***	***240.1***	***243.8***	***249.3***	***239.7***	***233.8***	***257.6***	***260.9***	***256.7***

Source and Sink Categories	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	CO_2 equivalent (kt)									
1 Energy	**220.1**	**217.8**	**223.1**	**232.4**	**232.0**	**231.6**	**233.8**	**203.4**	**222.3**	**208.1**
1A1 Energy industries	2.8	2.9	2.5	2.8	3.0	3.1	2.9	2.6	2.9	3.0
1A2 Manufacturing ind. & constr.	36.4	36.4	37.9	41.2	39.8	39.1	40.5	33.9	36.3	27.5
1A3 Transport	91.5	88.1	84.1	83.8	82.3	81.9	79.3	83.4	87.9	81.9
1A4 Other sectors	88.4	89.4	97.6	103.5	105.8	106.3	109.9	82.3	93.9	94.5
1A5 Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	0.9	1.0	1.0	1.1	1.2	1.2	1.3	1.3	1.3	1.2
2 IPPU	**4.0**	**4.8**	**5.5**	**6.1**	**6.7**	**7.1**	**7.4**	**8.2**	**8.7**	**8.2**
3 Agriculture	**21.9**	**23.0**	**23.4**	**23.5**	**23.5**	**24.2**	**25.3**	**25.6**	**25.8**	**25.7**
5 Waste	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**	**1.7**
Total (excluding LULUCF)	***247.6***	***247.3***	***253.6***	***263.7***	***264.0***	***264.5***	***268.2***	***238.9***	***258.6***	***243.8***
4 LULUCF	**25.1**	**2.2**	**3.1**	**7.1**	**9.3**	**9.3**	**14.1**	**23.2**	**25.3**	**22.4**
Total (including LULUCF)	***272.7***	***249.5***	***256.7***	***270.8***	***273.2***	***273.9***	***282.3***	***262.1***	***283.9***	***266.2***

Source and Sink Categories	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	CO_2 equivalent (kt)									
1 Energy	**193.5**	**179.4**	**188.0**	**195.2**	**163.7**	**162.3**	**152.3**	**158.3**	**145.5**	**151.6**
1A1 Energy industries	3.3	3.1	2.8	3.0	2.5	2.0	2.2	2.1	2.2	3.4
1A2 Manufacturing ind. & constr.	26.1	23.6	25.7	26.4	27.3	27.6	25.9	27.7	24.6	24.1
1A3 Transport	77.7	76.9	79.9	79.6	73.8	61.8	60.4	60.8	58.8	57.3
1A4 Other sectors	85.2	74.7	78.3	84.9	58.9	69.5	62.5	66.4	58.6	65.4
1A5 Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1B Fugitive emissions from fuels	1.3	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
2 IPPU	**8.7**	**9.1**	**9.4**	**9.5**	**9.7**	**9.7**	**9.3**	**9.6**	**9.7**	**9.4**
3 Agriculture	**24.9**	**25.7**	**26.0**	**24.8**	**25.2**	**25.0**	**25.1**	**24.4**	**24.9**	**25.7**
5 Waste	**1.7**	**1.8**	**1.7**	**1.7**	**1.6**	**1.6**	**1.6**	**1.6**	**1.6**	**1.6**
Total (excluding LULUCF)	***228.8***	***215.9***	***225.2***	***231.3***	***200.3***	***198.6***	***188.3***	***193.9***	***181.7***	***188.3***
4 LULUCF	**21.0**	**24.7**	**25.0**	**17.5**	**17.4**	**12.2**	**10.4**	**11.7**	**22.3**	**12.4**
Total (including LULUCF)	***249.8***	***240.6***	***250.1***	***248.8***	***217.7***	***210.8***	***198.7***	***205.6***	***204.1***	***200.7***

Source and Sink Categories	2020	2021	1990-2021
	CO_2eq (kt)		%
1 Energy	**144.4**	**148.4**	**-26.3%**
1A1 Energy industries	2.4	2.6	1410%
1A2 Manufacturing ind. & constr.	22.8	23.2	-36%
1A3 Transport	52.7	56.1	-27%
1A4 Other sectors	65.1	65.2	-26%
1A5 Other	NO	NO	-
1B Fugitive emissions from fuels	1.3	1.4	234%
2 IPPU	**8.9**	**8.3**	**1273%**
3 Agriculture	**25.9**	**25.5**	**-1.9%**
5 Waste	**1.6**	**1.7**	**-3.9%**
Total (excluding LULUCF)	***180.9***	***183.9***	***-19.9%***
4 LULUCF	**4.8**	**0.3**	**-96.2%**
Total (including LULUCF)	***185.7***	***184.2***	***-22.3%***

A graphical representation of the data in the table above is given in Figure 2-4. For more details on the development of the emissions of sector 1 Energy see chp. 3.

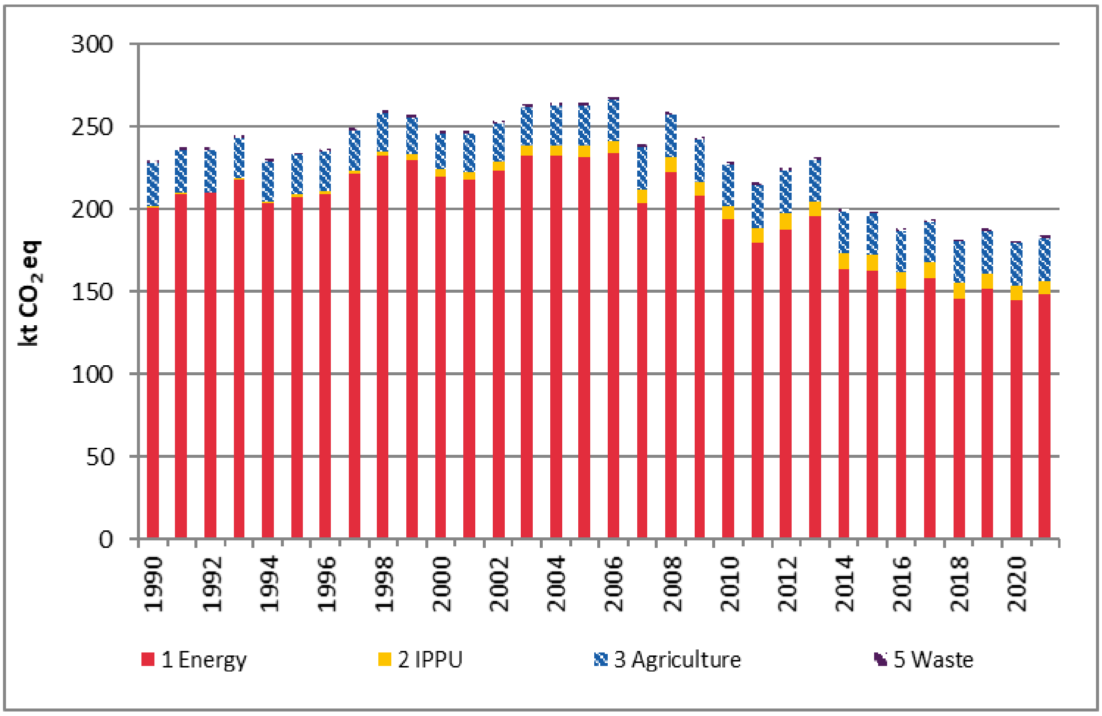


Figure 2-4 Trend of Liechtenstein's greenhouse gas emissions by main source categories in CO_2eq (kt) (excl. net CO_2 from LULUCF).

The following emission trends are observed in the sectors:

Sector 1 Energy

In 2021, 80.7% of Liechtenstein's GHG emissions (excluding LULUCF) originate from sector 1 Energy, which is 0.9 percentage points more than in 2020. The share of sector 1 Energy in the total emissions declined by 6.9 percentage points since 1990. Also, the total emissions of the sector 1 Energy clearly decreased in comparison to 1990 levels (by 26.3%). The source categories within sector 1 Energy show the following trends between 1990 and 2021:

- 1A1 Energy industries: Since 1990, Liechtenstein's gas-grid has been extended and natural gas has replaced gas oil as the main heating fuel in buildings. Total emissions have increased by about a factor of 15 since 1990.
- 1A2 Manufacturing industries and construction: Total emissions from this source category have declined by 36.0% since 1990. Gaseous fuels are the more important energy carrier in Liechtenstein in 2021. In 2021, emissions from gaseous fuels decreased by 14.9% compared to 1990 and increased by 11.5% compared to 2020. Liquid fuel emissions decreased by 51.3% compared to 1990.
- 1A3 Transport: Up to 2006, fuel consumption in road transportation was mostly in line with a general development of road-vehicle kilometres of all vehicle categories. Total

emissions started decreasing since 2012. Between 2020 and 2021, emissions of 1A3 increased by 6.4% due to the Covid pandemic. In 2020 working from home reduced motorized private transport and thus the emissions in sector 1A3. In 2021 traffic volumes increased again and as a result also the emission in sector 1A3 increased compared to 2020. The overall trend shows a decrease of 27.0% (1990-2021). The decrease is mainly related to fuel tourism (see chp. 3.2.7.2; SFOE 2018).

1A4 Other sectors: GHG emissions in source category 1A4 have slightly increased by 0.2% compared to the previous reporting year 2020. An important driver of emissions from category 1A4 are heating degree days, which generally correlate well with the use of heating fuels. Various emission reduction measures in Liechtenstein are influencing the fuel consumption. For instance, the increase in the CO_2 levy in 2016, which caused an increase in sales of gas oil in 2015 and a reduced apparent consumption in 2016 and subsequently again an increase in 2017. The fuel levy was further increased in 2018. Also, in 2018, the relative reduction of sales of gas oil is stronger than the relative decrease of heating degree days, and, vice versa, the increase of gas oil sales in 2019 is higher as it would have been expected due to the increase of heating degree days. Another example is the installation of a district heating pipeline in 2009, which is one factor leading to the stronger declining trend of the CO_2 emissions in comparison to the trend in heating degree days. The observed difference in the trends of CO_2 emissions and heating degree days is an indication of a decoupling between heating activities and CO_2 emissions.

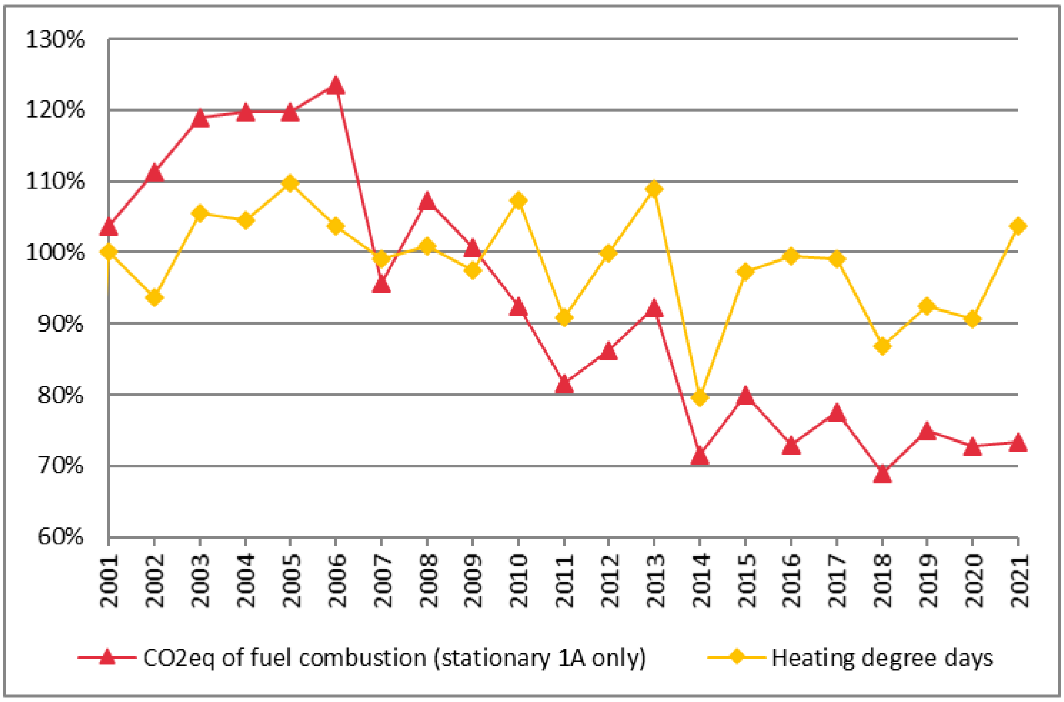


Figure 2-5 Relative trend for CO_2 emissions from 1A Fuel Combustion compared with the number of heating degree days. The drop of emissions in 2007 is driven by high oil and gas prices.

- 1A5 Other (mobile): Liechtenstein does not have any emissions under source category 1A5 because Liechtenstein has no army.
- 1B Fugitive emissions from fuels: In parallel with the installation and subsequent extension of Liechtenstein's gas supply network since 1990, fugitive emissions have strongly increased over the period 1990-2021 (233.9%).

Sector 2 Industrial processes and product use

Due to the lack of heavy industry within the borders of Liechtenstein, there are only small sources of F-gases and emissions are on a low level. Still, the use of F-gases has increased substantially throughout the period 1990-2021, which leads to a relative increase of emissions in sector 2 approximately by a factor of 14. The most important source category is 2F Product uses as substitutes for ozone-depleting substances (ODS) due to the replacement of CFCs with HFCs. The main factor influencing the increase in HFC emissions in refrigeration and air conditioning are the increasing population of Liechtenstein (35.4% increase in 2021 compared with 1990), the increasing number of households in Liechtenstein (+69%), the increasing number of persons employed in the industrial and service sectors (+110%) and the increasing number of registered cars (+81%).

Sector 3 Agriculture

In 2021, emissions are below the 1990 level by 1.9%. The main parameter influencing CH_4 and N_2O emissions from agriculture are animal numbers (in particular cattle and swine). A second relevant development in enteric fermentation is the increasing productivity of dairy cattle (high-yield cattle), which results in higher (per animal) emission factors. The emissions from manure management also closely follow the development of the cattle population. Under the agricultural soils category, the emissions from animal manure applied to soils is the most important subcategory and also depends on the cattle population number, as well as a change in husbandry systems from stall towards loose housing systems (in the course of the agricultural policy reforms during the 1990s and the early twenty-first century).

Sector 4 LULUCF

Figure 2-6 shows CO_2 emissions or removals by sources and sinks from LULUCF categories in Liechtenstein. The dominant categories when looking at the changes in CO_2 emissions are gain and loss of living biomass in forests. There is a considerable annual variation of loss of living biomass in forests dependent on the wood harvesting rate and storm events. The reasons for the relatively high net CO_2 emissions in 1990 and 2000 are the European storms Vivian (February 1990) and Lothar (December 1999), respectively, which caused great damages in the forest stands and markedly increased harvesting. In January 1994, the Rhine valley and especially Liechtenstein was hit by a strong foehn storm with large wind throws (see http://www.sturmarchiv.ch).

In a medium-term perspective, harvesting rates in Liechtenstein's forests appeared to expand between 2001 and 2008 mainly due to increased use of energy wood. Harvesting rates started to decline after 2012 due to the international and domestic economic framework conditions. In 2018, harvesting rates were relatively high due to salvage logging on areas affected by storms and pests.

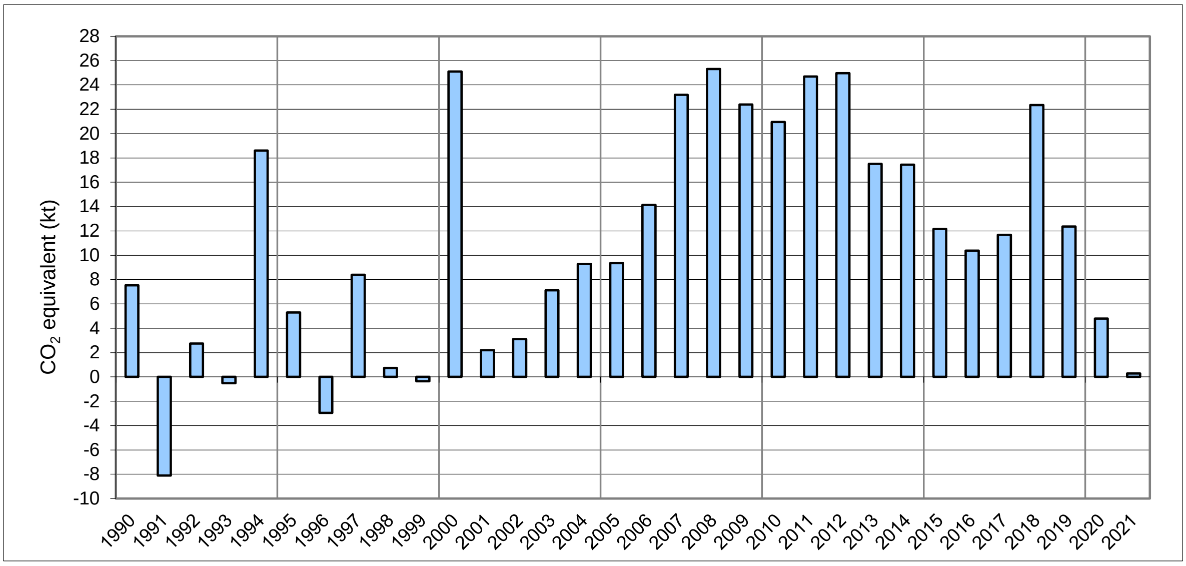


Figure 2-6 Liechtenstein's CO_2 emissions/removals of source category 4 LULUCF in kt CO_2 equivalent.

Sector 5 Waste

In Liechtenstein, only little emissions occur from the sector Waste, since all municipal solid waste is exported to a Swiss incineration plant. The waste sector shows a decrease between 1990 and 2021 (3.9%). The development of the greenhouse gas emissions is dominated by source category 5D Wastewater treatment and discharge. In source category 5D Wastewater treatment and discharge, sewage gas has only been used as fuel for boilers or co-generation up to 2014. Since then, all sewage gas is upgraded and supplied to the gas grid, which results in significant lower greenhouse gas emissions in this source category. In source category 5A Solid waste disposal, a steady decrease of greenhouse gas emissions can be observed due to stopped landfilling in 1974.

2.2.3 Emission trends for precursor greenhouse gases and SO_2

Liechtenstein is member to the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) and submits data on air pollutants including indirect GHG. The submission in 2023 will take place at the end of April 2023, and **the overview and results provided below are from the submission to CLRTAP in 2022**. (Therefore, results for 2021 are not yet available.)

For the precursor substances NO_x, CO and NMVOC as well as for the gas SO_2, data from the current state of knowledge in air pollution reporting is shown in Table 2-4 (Acontec 2023). The system boundaries for the road transportation sector categories are not the same as under the UNFCCC reporting since Liechtenstein uses, the territorial approach under the CLRTAP and the sales principle for the UNFCCC reporting, which restricts the comparability of the two data sets. In particular, there would be inconsistencies within activity data and accordingly within implied emission factors of the results of the two approaches. Therefore, the data is not reported in CRF table 6.

Table 2-4 Development of NO_x, CO, NMVOC and SO_x emissions (in t) as of submission 2021 (OE 2022f).

Precursor gases and SO_2	1990	1995	2000	2005	2010
	tonnes				
NO_x	622	578	543	501	403
CO	1'572	968	783	598	540
NMVOC	1'311	837	571	396	359
SO_x	117	73	46	35	20

Precursor gases and SO_2	2011	2012	2013	2014	2015
	tonnes				
NO_x	394	387	381	356	341
CO	540	531	489	483	486
NMVOC	355	354	342	335	326
SO_x	17	15	14	9.3	9.4

Precursor gases and SO_2	2016	2017	2018	2019	2020	1990-2020
	tonnes					%
NO_x	313	293	278	261	238	-62%
CO	465	442	465	438	391	-75%
NMVOC	320	313	309	311	309	-76%
SO_x	7.6	7.4	6.5	6.7	5.7	-95%

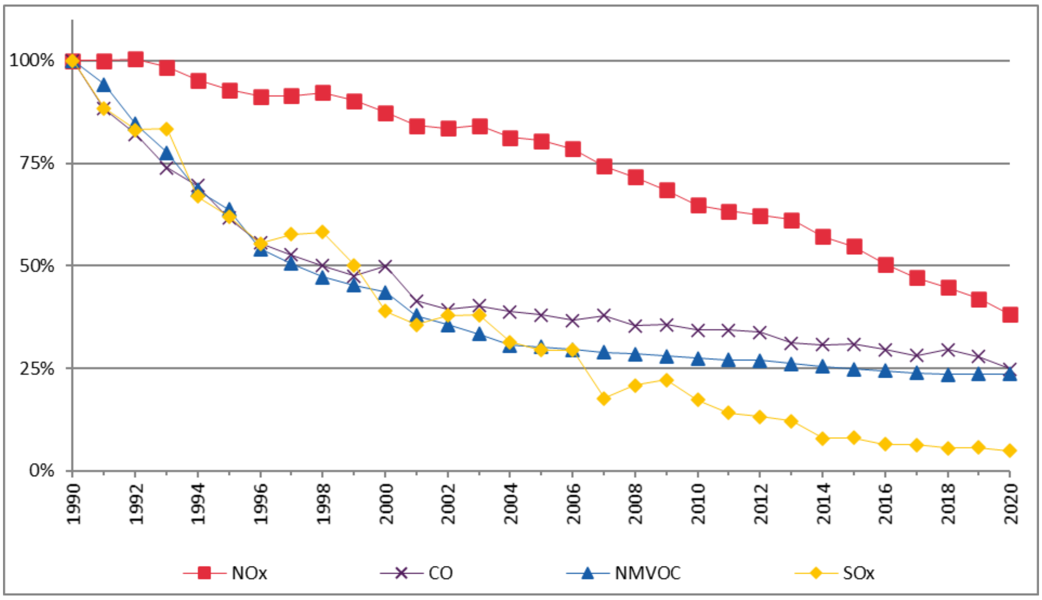


Figure 2-7 Trend of NO_x, CO, NMVOC and SO_x emissions as of CLRTAP submission 2022 (OE 2022f).

The complete CLRTAP Inventory data can be found on the internet (see OE 2022f):
https://www.ceip.at/status-of-reporting-and-review-results/2022-submission

3. Energy (CRT sector 1)

3.1 Overview of the sector

This chapter contains information about the greenhouse gas emissions of sector 1 Energy. In Liechtenstein, the sector 1 Energy is the most relevant greenhouse gas source. 148.4 kt CO_2 equivalents were emitted within this sector in 2021, which corresponds to 80.7% of total emissions (183.9 kt CO_2 equivalent, excluding LULUCF). The emissions of the time period 1990–2021 are depicted in Figure 3-1.

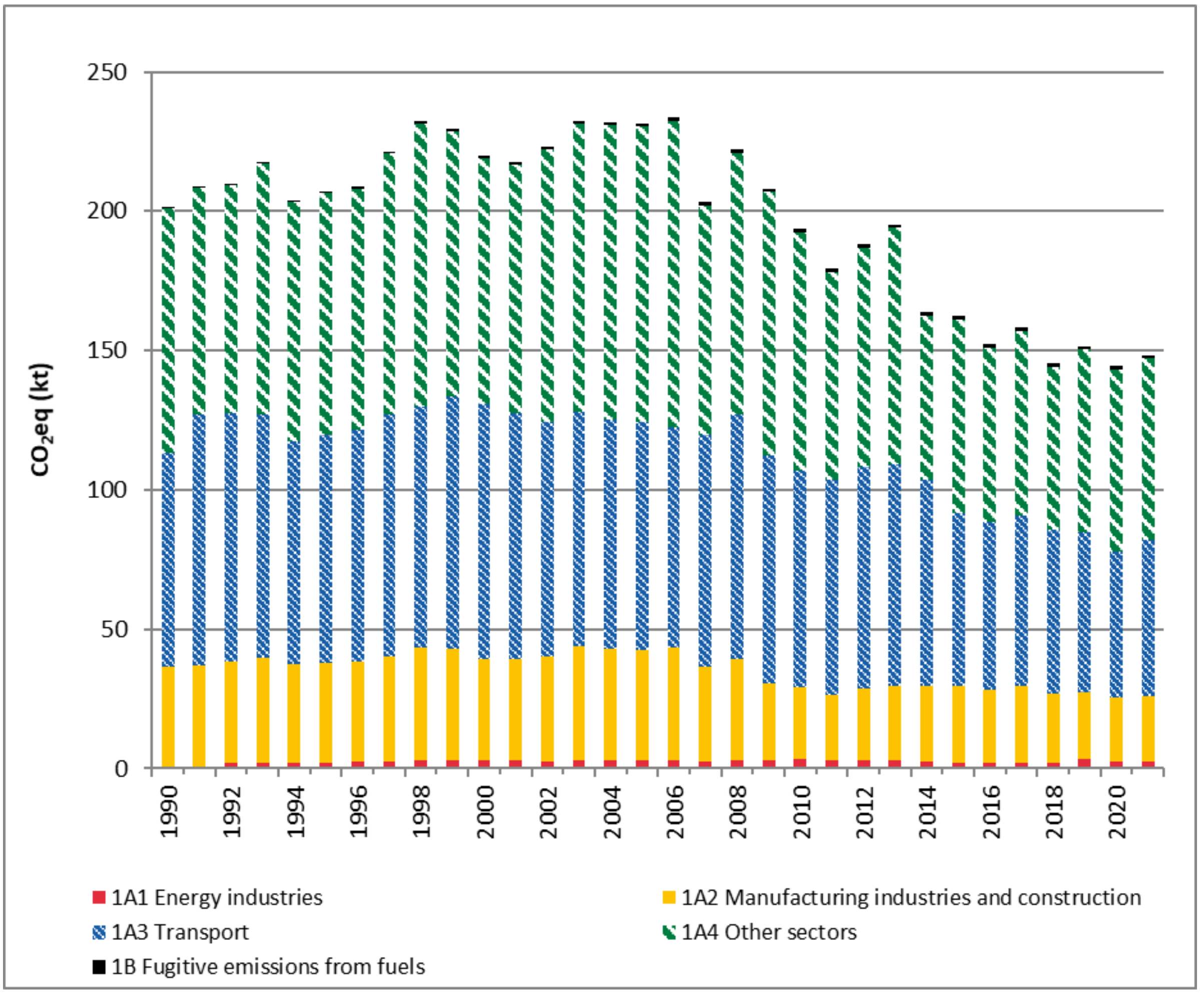


Figure 3-1 Liechtenstein's GHG emissions of the sector 1 Energy by sub-sectors. Note that there are no emissions in sub-sector 1A5.

Table 3-1 summarises the emissions from sector 1 Energy by individual gases 1990–2021. The numbers do neither include emissions from international bunkers (aviation) nor CO_2 emissions from biomass burning since none of those are accounted for in the UNFCCC.

Table 3-1 GHG emissions of sector 1 Energy by gas in CO_2 equivalent (kt) and the relative change (last column).

Gas	1990	1995	2000	2005	2010
	CO_2 equivalent (kt)				
CO_2	198.7	204.0	216.6	228.7	190.6
CH_4	1.4	1.5	1.7	2.0	1.9
N_2O	1.1	1.6	1.7	0.9	1.0
Sum	**201.3**	**207.0**	**220.1**	**231.6**	**193.5**

Gas	2012	2013	2014	2015	2016
	CO_2 equivalent (kt)				
CO_2	185.1	192.3	161.1	159.6	149.6
CH_4	1.9	1.9	1.8	1.8	1.8
N_2O	1.0	1.0	0.9	0.9	0.9
Sum	**188.0**	**195.2**	**163.7**	**162.3**	**152.3**

Gas	2017	2018	2019	2020	2021	1990-2021
	CO_2 equivalent (kt)					%
CO_2	155.6	142.8	148.8	141.8	145.7	-26.7%
CH_4	1.8	1.8	1.9	1.8	1.8	27.3%
N_2O	0.9	0.9	0.9	0.8	0.9	-23.3%
Sum	**158.3**	**145.5**	**151.6**	**144.4**	**148.4**	**-26.3%**

Table 3-2 shows more details of the emissions of sector 1 Energy in 2021. The table includes emissions from international bunkers (aviation) and from biomass burning in two separate rows, which are both not accounted for under the UNFCCC.

Table 3-2 Summary of sector 1 Energy, emissions in kt CO_2 equivalent (rounded values).

Emissions 2021	**CO_2**	**CH_4**	**N_2O**	**Total**	
Sources	**CO_2 equivalent (kt)**				**%**
1 Energy	**145.7**	**1.8**	**0.9**	**148.4**	***100.0%***
1A Fuel Combustion	**145.7**	**0.5**	**0.9**	**147.1**	***99.1%***
1A1 Energy industries	2.5	0.0	0.0	2.6	***1.7%***
1A2 Manufacturing industries and construction	23.1	0.0	0.1	23.2	***15.6%***
1A3 Transport	55.5	0.1	0.5	56.1	***37.8%***
1A4 Other sectors	64.5	0.3	0.3	65.2	***43.9%***
1A5 Other	NO	NO	NO	NO	-
1B Fugitive emissions from fuels	**0.0**	**1.4**	**NO,NA**	**1.4**	***0.9%***
International Bukers	**1.0**	**0.0**	**0.0**	**1.0**	-
CO_2 Emissions from Biomass	**21.1**	**-**	**-**	**21.1**	-

Emissions from sector 1 Energy may be characterised as follows:

- Concerning the total emissions (CO_2 eq) from sector 1 Energy, a trend of -26% can be observed between 1990 and 2021. From 2020 to 2021 emissions increased by 3%. This increase is mainly caused by an increase in emission in sector 1A3 transport. In 2020 traffic volume was reduced due to the restrictions related to the COVID-19 pandemic. The emissions of the sector 1 Energy reached a minimum level in 2020. In 2021 traffic volumes increased again and as a result also the emission from sector 1A3 increased compared to 2020.
- The three source categories 1A2, 1A3 and 1A4 dominate the emissions of sector 1 Energy and cover altogether 97.3% (144.5 kt CO_2 eq) of total emissions of sector 1.
  - 1A3 Transport accounts for 37.8% of the emissions in 2021.
  - 1A4 Other sectors (commercial/institutional, residential) contributes to 43.9% of the total energy-related emissions.
  - 1A2 Manufacturing industries and construction contributes to 15.6% of the emissions.
  - 1A1 Energy industries and 1B Fugitive emissions only play a minor role. In 2021, they cover 1.7% and 0.9%, respectively, of the total sector 1 emissions.
- The only occurring bunker emissions originate from a helicopter base in Balzers, Liechtenstein. Only few flights are domestic, most of them are business flights to Switzerland and Austria, producing bunker emissions of 1.0 kt CO_2 eq.
- CO_2 emissions from biomass add up to 21.1 kt. They originate from use of biofuels in transport, wood burning (heating) and the burning of sewage gas (heating, power) as well as the consumption of biogas produced from sewage gas, which is fed into the general gas network.

- The far most important gas emitted from source category 1 Energy is CO_2. It accounts for 98.7% of the category in 1990 and for 98.2% in 2021.
- In 2021, CH_4 emissions accounted for 1.2% of total emissions in the sector 1 Energy. The increasing trend since 1990 (+27.3%) is a result of the increase in consumption of natural gas and the subsequent increase of fugitive emissions of methane (increase by 233.9%). The CH_4 emissions of source category 1A4 have increased by 10% since 1990. The CH_4 emissions from road transportation show a reduction of 87.5%, mainly due to the growing number of gasoline passenger cars with catalytic converters.
- N_2O emissions accounted for 0.6% of the total sector 1 Energy emissions in 1990 and for 0.6% in 2021.

The Liechtenstein greenhouse gas inventory identifies 7 key categories within the energy sector (key category analysis excluding LULUCF categories, see Chapter 1.4). The emissions in 1990 and 2021 of these categories are depicted in Figure 3-2. In 2021, CO_2 emissions from 1A3b Road Transportation are most dominant.

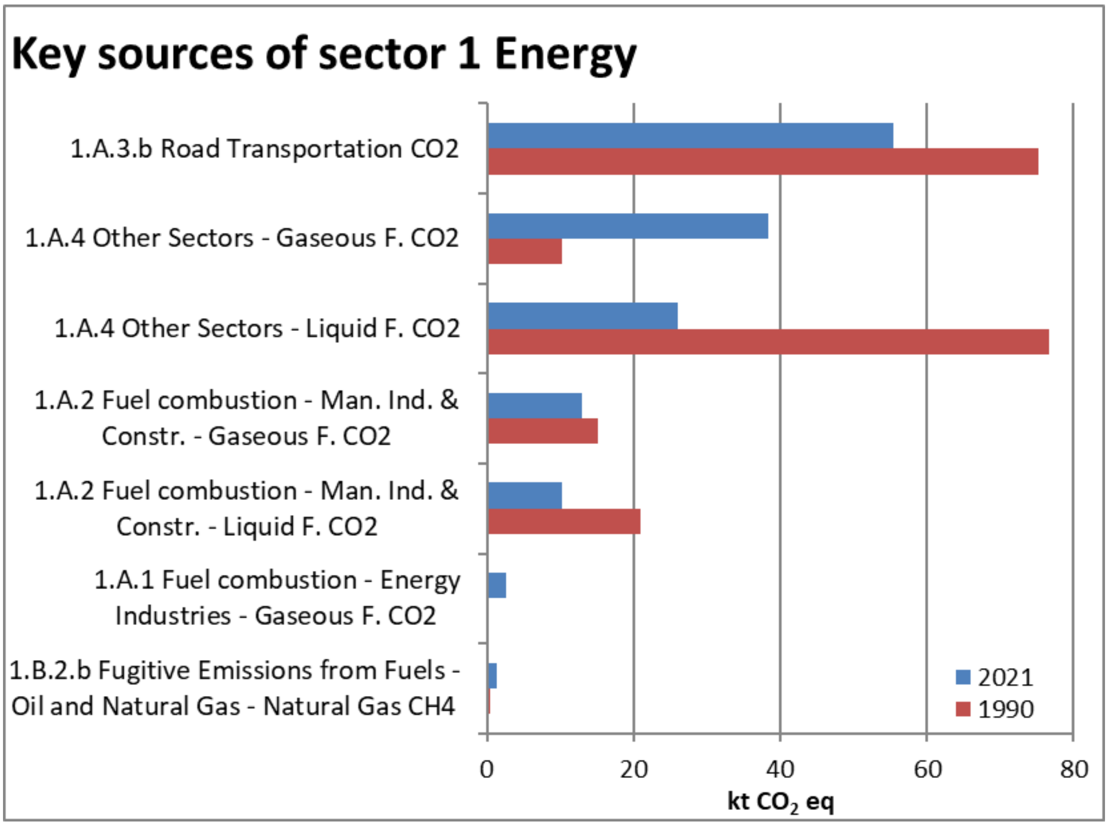


Figure 3-2 Key sources in the energy sector (KCA excl. LULUCF). Emissions in CO_2 equivalents (kt) per key source category in 2021 and in the base year 1990.

3.2 Fuel combustion (1A)

3.2.1 Comparison of the sectoral approach with the reference approach

The reference approach uses Tier 1 methods for the different source categories of the sector 1 Energy, whereas the national (sectoral) approach uses specific methods for the different source categories. For the inventory of the Framework Convention, the Kyoto Protocol and the Paris Agreement the sectoral approach is used. The reference approach is only used for controlling purposes (quality control).

Due to the close relations with Switzerland, Liechtenstein is characterized by similar economic structures, the same quality of liquid/gaseous fuels and a similar vehicle fleet composition. Therefore, a large number of emission factors, especially for CO_2, are taken from the Swiss greenhouse gas inventory. The oxidation factor is set to 1.0 because the combustion installations in Liechtenstein have very good combustion properties. Combined emissions of CO and unburnt VOC range between 0.1 and 0.3% of CO_2 emissions for oil and gas combustion. The assumption of complete oxidation is also in line with the 2006 IPCC Guidelines that recommend the use of an oxidation factor of 1.0 (IPCC 2006).

Coal is not burnt anymore since 2012. For coal, an oxidation factor of 1.0 was used as a conservative assumption and because the consumed amount was negligible. This is consistent with the information and assumptions from Switzerland's greenhouse gas inventory.

Conversion factors (TJ/unit) and carbon emission factors (t C/ TJ) for the reference approach in submission 2023 have been taken from Table 3-5 (see CRF Table1.A(b)) and are therefore identical to the ones used for the sectoral approach.

The apparent consumption, the net carbon emissions and the effective CO_2 emissions are calculated for the reference approach as described in the reporting table CRF Table 1A(b). Data is taken from the energy statistics as described in chapter 3.2.4.2. The reference approach covers the CO_2 emissions of all imported fuels minus exported fuels (e.g. natural gas by the gas network).

Table 3-3 and Figure 3-3 show the differences between reference and sectoral (national) approaches 1990–2021. Energy consumption differs by 0.0% in 2021, whereas CO_2 emissions show a difference of 1.69% in 2021.

The difference of the CO_2 emissions between the reference and the sectoral approach can be explained by different measurement methods of the two approaches. There are small differences in CO_2 emissions, since the reference approach does not account for biomass content of natural gas, gasoline and diesel. Consequently, the CO_2 emissions resulting from the reference approach are higher as in the sectoral approach, which accounts for the share of biomass in these fuels.

In Liechtenstein the share of biomass in gasoline and diesel is increasing since around 1995. Therefore, the differences between the two approaches are increasing, too.

The energy consumption is identical between the two approaches, since the sectoral approach is also based on total energy consumption according to the national energy statistics (OS 2022a), which is split into the different sectors.

In addition, small differences in CO_2 emissions are due to the fact that a small fraction of the gas consumed is not burnt but lost in the distribution network. The reference approach does not account for these losses and assumes complete burning of the natural gas, therefore leading to higher total emissions. Consequently, the emissions according to the reference approach, are higher as compared to the sectoral approach results.

Table 3-3 Differences in energy consumption and CO_2 emissions between the reference and the sectoral (national) approach. The difference is calculated according to [(RA-SA)/SA] 100% with RA = reference approach, SA = sectoral (national) approach. For calculating the difference in energy consumption between the two approaches, data reported as “apparent” energy consumption (excluding non-energy use, reductants and feedstocks) are used for the reference approach.

Difference between reference and sectoral approach					
	1990	**1995**	**2000**	**2005**	**2010**
	percent (%)				
Energy consumption	0.00	0.00	0.00	0.00	0.00
CO_2 emissions	0.01	0.03	0.05	0.08	0.13
	2012	**2013**	**2014**	**2015**	**2016**
	percent (%)				
Energy consumption	0.00	0.00	0.00	0.00	0.00
CO_2 emissions	0.18	0.18	0.29	0.52	0.86
	2017	**2018**	**2019**	**2020**	**2021**
	percent (%)				
Energy consumption	0.00	0.00	0.00	0.00	0.00
CO_2 emissions	1.25	1.73	1.68	1.69	1.59

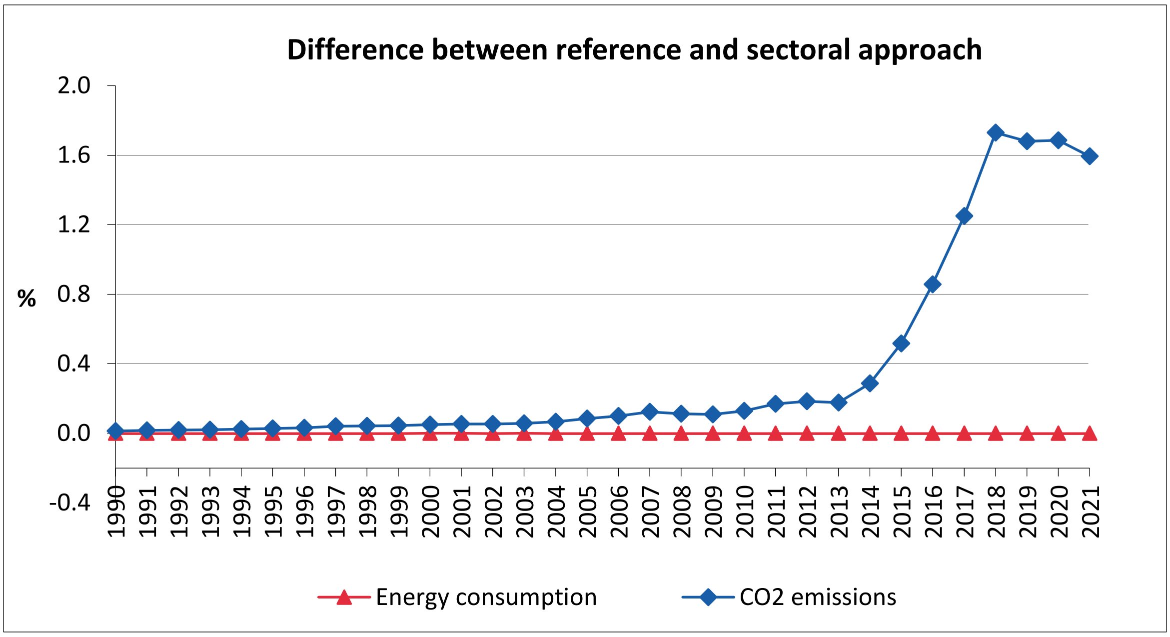


Figure 3-3 Time series for the differences between reference and sectoral approach. Numbers are taken from the table above.

Recalculation in the Reference Approach

- For gasoline and diesel, emission factors of CH_4 and N_2O were updated based on Switzerland's Handbook of emission factors version 4.2 for the entire time series (INFRAS 2022, INFRAS 2022a). This leads to a recalculation of CH_4 and N_2O emissions.

Further recalculations in the energy sector are documented in the respective sectoral chapters (1A1, 1A2, 1A3 and 1A4).

3.2.2 International bunker fuels (1D)

For Liechtenstein, the only source of international bunker emissions is civil aviation originating from one helicopter base "Heliport Balzers" Total emissions of civil aviation are calculated as described in section 3.2.7.2 using a Tier 1 method. For the year 2021, the effective consumption for domestic and international flights was provided by the operating company of the helicopter base (see Table 3-4).

Total kerosene consumption is based on collected data for the year 1995 and for the years since 2001 (Rotex Helicopter AG 2006, 2007, …, 2022). For the years 1990-1994, the collected data for total kerosene consumption in 1995 is used as a constant value since no other data is available. For the years 1996-2000, total kerosene consumption is linearly interpolated between the data collected for 1995 and for 2001. Surveys were conducted for the years 1995, 2001 and 2002 in order to estimate domestic fuel consumption in Liechtenstein (Rotex Helicopter AG 2006). For the years 1990-1994, the survey results for domestic kerosene consumption in 1995 are used as a constant value since no other data is available. For the years 1996-2000 and 2003-2011, total kerosene consumption is linearly interpolated between the survey results for 1995 and 2001 and for the survey result 2002 and collected data 2012, respectively. Since 2012, data on domestic kerosene consumption is collected (Rotex Helicopter AG 2012-2022).

Kerosene consumption for international flights (international bunkers aviation) is calculated by subtracting domestic consumption from total consumption for the entire time series.

In 2021, there are only three helicopters stationed in Liechtenstein. Activity data is highly dependent on the annual demand for these helicopters. Thus, emissions change significantly in years with high or low demand for flying (passengers and freight transportation). In 2021 kerosene consumption increases slightly compared to 2020 due to higher flight activities.

Marine bunker emissions are not occurring.

Table 3-4 Kerosene (civil aviation) based on sales principle: Total kerosene consumption, domestic flights (reported under 1A3a) and International flights (bunker, memo item). International flights are calculated by subtracting kerosene consumed in domestic aviation from total kerosene consumption. Data source for surveys (highlighted in blue) and collected data (highlighted in green): Rotex Helicopter AG (Rotex Helicopter AG 2006-2022).

Year	**Civil aviation - Kerosene (TJ)**			
	Total	1A3a Domestic aviation	Information on data for total and domestic aviation	International bunkers aviation
1990	6.87	1.03	*Constant values (equal to survey from 1995)*	5.84
1991	6.87	1.03		5.84
1992	6.87	1.03		5.84
1993	6.87	1.03		5.84
1994	6.87	1.03		5.84
1995	6.87	1.03	*Total consumption: collected data; Domestic aviation: Survey*	5.84
1996	7.04	1.04	*Linear interpolation (between survey from 1995 and from 2001)*	6.00
1997	7.21	1.05		6.16
1998	7.39	1.06		6.33
1999	7.56	1.07		6.49
2000	7.74	1.08		6.66
2001	7.91	1.09	*Total consumption: collected data; Domestic aviation: Survey*	6.82
2002	7.26	1.14		6.12
2003	7.93	1.11	*Total consumption: collected data; Domestic aviation: linear interpolation (between survey from 2002 and collected data from 2012)*	6.82
2004	5.68	1.08		4.60
2005	7.67	1.04		6.62
2006	12.32	1.01		11.31
2007	12.18	0.98		11.20
2008	11.93	0.95		10.98
2009	14.21	0.92		13.29
2010	12.46	0.89		11.57
2011	13.34	0.86		12.48
2012	16.10	0.83	*Collected data*	15.28
2013	15.18	0.74		14.44
2014	17.05	0.85		16.20
2015	17.16	0.81		16.36
2016	13.14	0.56		12.59
2017	12.09	0.35		11.75
2018	15.38	0.40		14.98
2019	16.48	1.14		15.34
2020	13.65	0.81		12.83
2021	14.02	0.84		13.18

3.2.3 Feedstocks and non-energy use of fuels

Energy data are taken from Liechtenstein's energy statistics (OS 2022a). These statistics account for production, imports, exports, transformation and stock changes. Hence, all figures for energy consumption in Liechtenstein correspond to apparent consumption figures.

No bitumen and lubricants are produced in Liechtenstein. Bitumen is imported for road paving, and NMVOC emissions from bituminous materials are related to road paving and to asphalt roofing. Regarding the use of bitumen, the amount is calculated based on Swiss import, export and production data (FOEN 2022b). The total amount of apparent consumption in Liechtenstein and Switzerland is split proportional to the length of paved roads in Liechtenstein (630 km in 2017, OS 2017e) and Switzerland (71'520 km in 2015, SFSO 2017e) respectively. A constant split is applied, since the road length does not show a strong variation from year to year.

The amount of lubricants used in Liechtenstein is estimated based on the Swiss import and export and production data (FOEN 2022b). The total amount of apparent consumption in Liechtenstein and Switzerland is split proportional to the number of inhabitants in Liechtenstein and Switzerland respectively (see Table 4-4).

3.2.4 Country-specific issues

3.2.4.1 CO_2 emission factors and net calorific values (NCV)

The CO_2 emission factors and the net calorific values (NCV) used for the calculation of the emissions 2020 of sector 1 Energy are shown in Table 3-5. Except for gasoline, diesel and kerosene, emission factors are assumed constant for the entire time series. The time series of gasoline, diesel and kerosene are shown in Table 3-6.

Table 3-5 CO_2 emission factors and net calorific values (NCV) for fuels in 2021. Except for gasoline, diesel and kerosene emission factors are assumed constant for the entire time series. The time series of gasoline, diesel and kerosene are shown in Table 3-6.

Fuel	CO2 Emission Factor 2020		Net calorific values (NCV)
	t CO_2 / TJ	t CO_2 / t	TJ / t
Hard coal	92.7	2.60	0.0281
Gas oil	73.7	3.16	0.0429
Natural gas	56.1	-	-
Gasoline	73.8	3.14	0.0426
Diesel oil	73.3	3.15	0.0430
Propane/Butane (LPG)	65.5	3.01	0.0460
Jet kerosene	72.8	3.13	0.0430
Alkylate gasoline	69.3	2.95	0.0425
Biofuel (vegetable oil)	73.3	2.76	0.0376
Biodiesel	73.3	2.79	0.0380
Bioethanol	73.8	1.96	0.0265
Sewage gas	100.5	1.93	0.0192

Table 3-6 CO_2 emission factors of gasoline, diesel and kerosene 1990-2021. For bioethanol, the same emission factors are applied as for gasoline and for biodiesel the same emission factors are applied as for diesel.

Fuel	unit	1990	1995	2000	2005	2010
Gasoline	t CO_2/TJ	73.9	73.9	73.9	73.9	73.8
Diesel	t CO_2/TJ	73.6	73.6	73.6	73.5	73.4
Kerosene	t CO_2/TJ	73.2	73.2	73.1	73.0	72.9
Fuel	**unit**	**2012**	**2013**	**2014**	**2015**	**2016**
Gasoline	t CO_2/TJ	73.8	73.8	73.8	73.8	73.8
Diesel	t CO_2/TJ	73.3	73.3	73.3	73.3	73.3
Kerosene	t CO_2/TJ	72.8	72.8	72.8	72.8	72.8
Fuel	**unit**	**2017**	**2018**	**2019**	**2020**	**2021**
Gasoline	t CO_2/TJ	73.8	73.8	73.8	73.8	73.8
Diesel	t CO_2/TJ	73.3	73.3	73.3	73.3	73.3
Kerosene	t CO_2/TJ	72.8	72.8	72.8	72.8	72.8

Data sources of NCV

The NCV of Jet kerosene and Alkylate gasoline are taken from the Swiss overall energy statistics of the year 2000 (SFOE 2001). The NCV of hard coal, gas oil, gasoline, diesel oil and LPG are taken from the former energy statistic of Liechtenstein (OS 2021a). For bioethanol and biodiesel, the NCV are taken from the Handbook of Emission Factors for Road Transport HBEFA 4.1 (INFRAS 2022a).

In 1998, 2008 and 2011 the NCV have been confirmed by measurement campaigns for liquid fuels (EMPA 1999, Intertek 2008, Intertek 2012) and show that NCVs are almost constant over the whole reporting period. The authors of the measurements write in their report, that only small deviations were found, which are within the range of uncertainties in the measurements.

Data sources of CO_2 emission factors

The CO_2 emission factors of fossil fuels are taken from the Swiss overall energy statistics of the year 2000 (SFOE 2001) with the following exceptions:

- Emission factors of diesel oil and kerosene are taken from the measurement campaign mentioned above (EMPA 1999, Intertek 2008, Intertek 2012),
- Emission factors of gasoline, diesel, bioethanol and biodiesel are taken from INFRAS (2022a).
- The emission factor of LPG is based on FOEN 2022
- The emission factor of natural gas is taken from the IPCC 2006 Guidelines (IPCC 2006).
- The emission factor of sewage gas assumes that 35% of the volume of the sewage gas is CO_2 and 65% CH_4.

Note that the emissions factors for CH_4 and N_2O are not only dependent on the fuel type but on the technology as well. Therefore, they are not integrated in Table 3-5 but are shown in the corresponding sectors and categories.

3.2.4.2 Energy statistics (activity data)

National energy statistics and modifications

In general, the data is taken from Liechtenstein's energy statistics (OS 2022a, OS 2022b). Some additional data sources are used as it is explained in the following sections. The results are summarised in Table 3-7.

The following modifications on the original energy statistics data have been carried out for this submission:

Gas oil

The consumption of gas oil in Liechtenstein's energy statistics reflects the amount of gas oil supplied annually to customers in Liechtenstein by oil transport and distribution companies, such as:

- Direct delivery of gas oil from Switzerland to Liechtenstein: the information provided by Switzerland includes delivery to end consumers and delivery to the main storage facility.
- Delivery from Liechtenstein's main storage facility: information from Liechtenstein's storage facility and its delivery to end consumers.

The delivery from the main storage facility is therefore counted twice in the energy statistics 1990-2008. In order to avoid this double counting, the values have been corrected by subtracting the amount of gas oil supplied from Switzerland to the storage facility from the overall amount of gas oil supplied, as provided by the energy statistics. Note that the storage facility was closed in 2008 (see below). Data on the amount of gas oil supplied to Liechtenstein's storage facility was collected from the Cooperative Society for the Storage of Gas Oil in the Principality of Liechtenstein (GHFL 2007, GHFL 2008). The actual consumption of gas oil in Liechtenstein is calculated based on the total amount supplied according to national energy statistics minus supply of the stock (see Table 3-8).

Table 3-7 Time series of Liechtenstein's fuel consumption based on the sales principle, including bunker fuel consumption (kerosene only) and biomass. Data sources: OS (2022a, OS 2022b), OEP (2006c), OEP (2008) and Rotex Helicopter AG (2006–2022).

Fuel	**1990**	**1995**	**2000**	**2005**	**2010**
	TJ				
Gasoline	819	903	977	774	594
Diesel	250	230	298	369	475
Gas Oil	1’264	1’058	925	980	693
Natural Gas	455	742	960	1’284	1’079
LPG	13.3	8.1	5.5	3.7	5.3
Hard Coal	1.04	0.73	0.67	0.25	0.06
Kerosene (domestic)	1.030	1.030	1.080	1.045	0.888
Sum	**2’804**	**2’944**	**3’168**	**3’411**	**2’848**
1990=100%	100%	105%	113%	122%	102%
Kerosene (bunker)	5.84	5.84	6.66	6.62	11.57
Biomass					
Wood	42.9	36.2	87.9	90.1	182.9
Sewage gas	15.6	17.0	21.7	20.8	22.2
Biofuel	0.0	0.0	0.3	1.0	1.5
Sum biomass	**58.5**	**53.2**	**109.9**	**111.9**	**206.7**

Fuel	**2012**	**2013**	**2014**	**2015**	**2016**
	TJ				
Gasoline	583	563	510	410	384
Diesel	556	578	556	498	518
Gas Oil	634	686	470	569	452
Natural Gas	971	1’030	856	914	908
LPG	4.1	3.9	3.6	3.7	3.6
Hard Coal	0.00	0.00	0.00	0.00	0.00
Kerosene (domestic)	0.83	0.74	0.85	0.81	0.56
Sum	**2’749**	**2’862**	**2’397**	**2’395**	**2’266**
1990=100%	98%	102%	85%	85%	81%
Kerosene (bunker)	15.28	14.44	16.20	16.36	12.59
Biomass					
Wood	202.8	172.5	187.0	209.4	202.5
Sewage gas	22.8	24.3	1.0	0.5	1.8
Biofuel	2.5	2.4	3.9	7.9	13.4
Sum biomass	**228.1**	**199.2**	**191.9**	**217.8**	**217.7**

Fuel	**2017**	**2018**	**2019**	**2020**	**2021**	**1990-2021**
	TJ					%
Gasoline	376	369	363	326	341	-58%
Diesel	546	531	514	493	523	109%
Gas Oil	487	395	491	477	408	-68%
Natural Gas	953	884	896	863	963	112%
LPG	3.5	3.8	3.6	3.7	3.4	-75%
Hard Coal	0.00	0.00	0.00	0.00	0.00	-100%
Kerosene (domestic)	0.35	0.40	1.14	0.81	0.84	-18%
Sum	**2’366**	**2’183**	**2’268**	**2’163**	**2’240**	**-20%**
1990=100%	84%	78%	81%	77%	80%	
Kerosene (bunker)	11.75	14.98	15.34	12.83	13.18	126%
Biomass						
Wood	189.1	225.4	206.9	163.9	158.9	270%
Sewage gas	2.5	1.8	1.4	0.5	0.9	-94%
Biofuel	21.5	27.9	28.1	26.7	25.3	-
Sum biomass	**213.0**	**255.1**	**236.5**	**191.1**	**185.1**	**216%**

Table 3-8 Total supply of gas oil as provided by Liechtenstein's energy statistics and fraction of supply that is supplied to Liechtenstein's stock (and may be further supplied to final consumers). Gas oil consumption 1 is the difference of total supply minus stock supply: (Consumption 1 = Total supply - Supplied to stock).
This consumption is then corrected for actual density, resulting in consumption 2. The latter is then used for Liechtenstein's GHG Inventory. (Consumption 2 = Consumption 1 * 0.845 / 0.840).

	Total supply	Supplied to stock	Consumption 1	Assumed density	Consumption	Actual density	Consumption 2	Consumption
Source	Energy Statistics	GHFL 2008	Calculated	OS-LIE	Calculated	FOEN 2011	Calculated	Calculated
Year	Gas oil [t]	Gas oil [t]	Gas oil [t]	Gas oil [t/m^3]	Gas oil [m^3]	Gas oil [t/m^3]	Gas oil [t]	Gas oil [TJ]
1990	35'484	5'813	29'671	0.840	35'323	0.845	29'848	1'272
1991	29'240	3'207	26'033	0.840	30'991	0.845	26'188	1'116
1992	26'083	961	25'122	0.840	29'907	0.845	25'271	1'077
1993	28'531	792	27'739	0.840	33'023	0.845	27'904	1'189
1994	26'931	1'380	25'551	0.840	30'418	0.845	25'704	1'095
1995	25'004	159	24'845	0.840	29'578	0.845	24'993	1'065
1996	23'053	0	23'053	0.840	27'444	0.845	23'190	988
1997	26'443	200	26'243	0.840	31'241	0.845	26'399	1'125
1998	28'701	520	28'181	0.840	33'549	0.845	28'349	1'208
1999	24'774	45	24'729	0.840	29'439	0.845	24'876	1'060
2000	21'931	216	21'715	0.840	25'851	0.845	21'844	931
2001	21'098	435	20'663	0.840	24'599	0.845	20'786	885
2002	24'218	859	23'359	0.840	27'808	0.845	23'498	1'001
2003	24'871	116	24'755	0.840	29'471	0.845	24'903	1'061
2004	24'036	0	24'036	0.840	28'614	0.845	24'179	1'030
2005	23'100	98	23'002	0.840	27'383	0.845	23'139	986
2006	24'231	278	23'953	0.840	28'516	0.845	24'096	1'030
2007	14'549	352	14'197	0.840	16'902	0.845	14'282	611
2008	18'120	0	18'120	0.840	21'571	0.845	18'228	779
2009	20'368	0	20'368	0.840	24'248	0.845	20'489	876
2010	16'212	0	16'212	0.840	19'300	0.845	16'309	697
2011	14'183	0	14'183	0.840	16'885	0.845	14'267	610
2012	14'830	0	14'830	0.840	17'655	0.845	14'918	638
2013	15'986	0	15'986	0.840	19'031	0.845	16'081	690
2014	10'957	0	10'957	0.840	13'044	0.845	11'022	473
2015	13'263	0	13'263	0.840	15'789	0.845	13'342	572
2016	10'535	0	10'535	0.840	12'542	0.845	10'598	455
2017	11'358	0	11'358	0.840	13'521	0.845	11'426	490
2018	9'197	0	9'197	0.840	10'949	0.845	9'252	397
2019	11'449	0	11'449	0.840	13'630	0.845	11'517	494
2020	11'108	0	11'108	0.840	13'224	0.845	11'174	479
2021	9'511	0	9'511	0.840	11'323	0.845	9'568	410

In 2008, the storage facility was closed. From 2008 onwards, the amount supplied to the storage facility is therefore zero.

Gas oil supply is measured in volume units (litres, m^3) and later reported to the Office of Environment in mass units (t). This conversion is made with a (rounded) density of 0.840 t/m^3, whereas the more precise density is 0.845 t/m^3 (FOEN 2011). Therefore, the Consumption 1 is corrected accordingly, resulting in Consumption 2, as is shown in Table 3-8. Using country-specific net calorific values provided by the Energy statistics of Liechtenstein (OS 2021a), the actual consumption in energy units results as used in Liechtenstein's GHG inventory. See also Table 3-5.

Natural gas

Natural gas consumption as published in the energy statistics (OS 2022a) is based on net natural gas imports. The amount of natural gas leaking from the distribution network (reported under 1B2b) and which is not burned at the final consumer's combustion system, is subtracted from the net imports in order to determine final consumption in 1A.

Gasoline / Diesel oil

A census, carried out by the Office of Economic Affairs (OEA), revealed that values for fuel consumption have large uncertainties. A number of distributors of gasoline and diesel annually report the amount of gasoline and diesel provided to domestic gasoline stations. Since not all distributors are known (they may origin from any Swiss gasoline station and may differ every year), the census may not provide a complete statistic. Therefore, in 2000, the Office of Environmental Protection started a second survey of all public gasoline stations. The results of this new census can be considered as a complete survey of all gasoline and diesel oil sold to passenger cars (including "fuel tourism") for the years 2000-2016. For the years 1990-1999 (diesel: 1990-2001), data compiled by OEA were collected in their original units (mass and volume units were used) and transformed into energy units by using the related densities and NCV (see Table 3-5). To ensure quality of time-series consistency an outlier and implied emission factor check was carried out as described in 2006 IPCC Guidelines. Both checks revealed that the time series 1990-2021 are consistent.

The data from the energy statistics is used for **gasoline** consumption in 1990. For the years 1991-1999, a moving average over three years is applied (e.g. 1991: arithmetic mean of 1990, 1991 and 1992). Since 2000, the values of the second survey are used (OE 2022e). The resulting time series is shown in Table 3-7 in row “gasoline”.

For **diesel oil** the amount sold at gasoline stations does not yet cover the whole amount consumed.

- There are private diesel stations, which are not part of the OE census covering only publicly accessible gasoline stations. The holders of these private stations are mainly transport companies with heavy duty vehicles, construction companies with construction vehicles and farmers with agricultural machinery/vehicles. As the diesel oil containers are subject to registration, the holders of these private diesel stations are known by the OEA. Based on this registration data, the OE (by that time called OEP) started an additional census of the diesel consumption by these private stations in 2002 (OEP 2006c, OE 2022e).
- Finally, consumption from the agriculture sector is calculated based on the following information sources:
    - Until 2005: Farmers declared their purchase of diesel fuel and claimed refund of the fuel levy at the General Directorate of Swiss Customs, which was the collecting and refunding institution of fuel levies for fuel purchase in Switzerland and Liechtenstein, and which provided to the OEP information about the amount declared annually by Liechtenstein’s farmers. For simplification reasons, Switzerland has ceased the refunding system.

- Since 2005: The OEP/OE collects consumption data directly at the level of individual farmers by conducting a specific survey. In winter 2007 the survey was carried out for the first time. The survey provided consumption data for 2005, which was also available from the former method practised by the General Directorate of Swiss Customs. This allowed a quality control check. Since the difference was only 1% (OEP 2006c), both methods are of equal and very high quality. The census is now being repeated annually.

The OEP/OE census for diesel oil therefore consists of three parts: diesel oil of public gasoline stations (in improved census since 2000), diesel oil consumption of private stations (in census since 2002) and diesel oil consumption by farmers (data available for all years since 1990). The sum of these three data sources, as available since 2002, corresponds to the total diesel oil consumption.

For diesel oil the value in 1990 is taken from the energy statistics. For the years 1991-2001, a moving average over three years is applied (e.g. 1991: arithmetic average of 1990, 1991, 1992), because of low data quality. Since 2002, the values of the OEP/OE census are used, because for these years, data of high quality is available. The resulting time series is shown in Table 3-7 in row “diesel”.

Kerosene

The effective kerosene consumption of the only helicopter base at Balzers is reported in detail for the years 2001-2021 (see Rotex Helicopter AG 2006, -2022) and separated in domestic and international/bunker consumption using the method described in section 3.2.2. Less detailed information is available for 1995. For all other years in the reporting period, adequate assumptions were made (see section 3.2.7.2).

Bunker

Bunker kerosene consumption see section 3.2.2.

Biomass

A description of the methodology for calculating CO_2 emissions from the combustion of biomass and the consumption of biofuels is included in the relevant chapters 3.2.5.2 (1A1 Energy industries), 3.2.6.2 (1A2 Manufacturing industries and construction), 3.2.7.2 (1A3 Transport), 3.2.8.2 (1A4 Other sectors) and 7 (Waste sector).

CO_2 emissions from biomass do not account for the national total emissions and are therefore reported as memo items only.

Energy statistics and contribution to the IPCC source categories

Gas oil

There is currently no data on the specific contribution of source categories 1A2, 1A4a and 1A4b to total gas oil consumption in 1A Fuel combustion available. Therefore, the following shares are estimated based on expert judgement for all years from 1990 to 2021: The Energy Statistics of Liechtenstein (e.g. OS 2022a) only indicates the total consumption of gas oil. That means the distribution between the different sectors had to be evaluated by experts for all years from 1990 until 2021. The experts of Liechtenstein assume that 60% of the gas oil consumption can be attributed to the commercial and institutional sources (1A4a), 20% to the manufacturing industries and construction companies (1A2) and the remaining 20% to residential sources (1A4b). As there has not been any significant change in the different sources regarding gas oil consumption nor any switch from the gas oil consumption from one sector to the other, constant shares are assumed between 1990 and 2021.

Table 3-9 Estimated share of source categories in total consumption of gas oil in 1A Fuel combustion (assumed constant for the entire time series).

Source category		Share in consumption of gas oil
1A2	Manufaturing industries and contruction	20%
1A4a	Other sectors - Commercial/institutional	60%
1A4b	Other sectors - Residential	20%
Total 1A		100%

Natural gas

The data on total consumption of natural gas in Liechtenstein is provided by the gas utility (LGV 2022) and published in the national energy statistics (OS 2022a).

For the partition of natural gas consumption between the different combustion activities in 1A, only limited data is available. Even though the gas utility publishes statistics of natural gas consumption of different groups of its customers, the definition of these groups is not fully in line with IPCC source categories. Therefore, the following attribution is applied:

Table 3-10 Applied allocation between IPCC source categories and categories in Liechtenstein's natural gas (NG) consumption statistics.

IPCC source category		Corresponding category in NG statistics	
		(English)	*(German)*
1A1a	Public electricity and heat production	Co-generation	Blockheizkraftwerke
1A2	Manufacturing industries and construction	Industry	Industrie
1A3b	Road transportation	Fuel for transportation	Treibstoff
1A4a	Other sectors - Commercial/institutional	Services	Gewerbe/Dienstleistungen und öffentliche Hand
1A4b	Other sectors - Residential	Residential/households	Wohnungen/Haushalt

Gasoline

The entire amount of gasoline sold is attributed to 1A3b Road transportation.

Alkylate gasoline is attributed 20% to 1A4b Residential and 80% to 1A4c Agriculture/ forestry/fishing. This attribution is based on an expert estimate, which takes into account that most of the alkylate gasoline is used in forestry. Since 2011, data are provided by an annual census of diesel and gasoline sales in Liechtenstein.

The amount of alkylate sold (activity data) was surveyed in a census in 2011 encompassing all selling stations and consumers (OEP 2011c). Since 2012 data on alkylate gasoline are provided by an annual census about diesel and gasoline sales in Liechtenstein. Before 2011, no data on alkylate gasoline consumption are available. Therefore, the data of the year 2011 is extrapolated to 1995 in order to create a complete time series. To calculate the time series until 1995, when selling of alkylate gasoline in Liechtenstein started, the development of consumption of the two biggest consumers were analysed. Based on this trend, the total sales estimated for Liechtenstein were linearly extrapolated back to 1996. For the first year (1995), it is assumed that only 50% of the amount of 1996 was sold, since purchasing only started in second half of 1995. Before 1995 no alkylate gasoline was used in Liechtenstein.

Diesel oil

The diesel consumption, which is derived from three different data sources (census of private diesel fuel tanks, National Energy Statistics and census of diesel oil consumption in the agricultural sectors as described above), is attributed to the source categories based on the following assumptions.

Table 3-11 Data sources for the diesel consumption and its attribution to IPCC source categories for the period 1990-2021 (Acontec 2006).

Data source	1A3b Road transportation	1A4c Other sectors - Agriculture/forestry/ fishing	1A2g Other - Off-road vehicles and machinery	Sum
Census gasoline stations	100%	0%	0%	100%
Private diesel fuel tanks agriculture	0%	100%	0%	100%
Private diesel fuel tanks industry	70%	0%	30%	100%

Please note that for the Swiss greenhouse gas inventory, the data for source category 1A Fuel combustion from the Swiss Overall Energy Statistics is corrected for the gas oil consumption in Liechtenstein (FOEN 2022). In the Swiss GHG inventory, the gas oil consumption in Liechtenstein is subtracted from the fuel consumption provided by the Swiss Overall Energy Statistics (that includes Liechtenstein's consumption). Therefore, a potential overestimation (underestimation) of fuel consumption in Liechtenstein is fully compensated by a related underestimation (overestimation) of fuel consumption in Switzerland.

Additional information on energy consumption

In order to increase the transparency, additional comprehensive data on energy consumption, shares of fuels and their development before 1990 and post-1990 are given in this chapter according to the recommendation of the ERT. Figure 3-4 and Table 3-12 from Liechtenstein's energy statistics 2001 (OS 2001) illustrate the evolution of the energy demand in Liechtenstein between 1964 and 2001. Natural gas consumption started only in the mid-1980s.

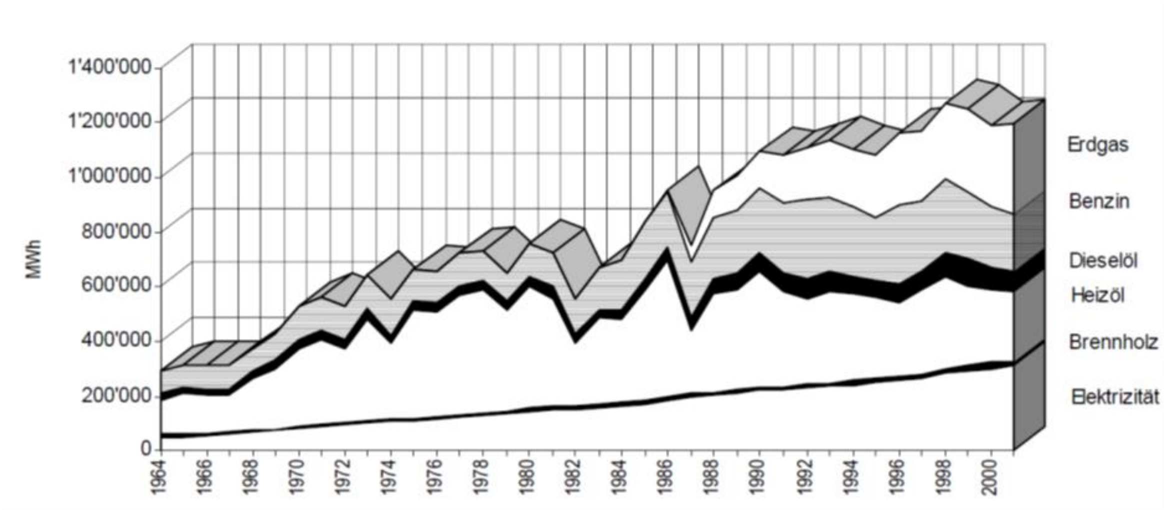


Figure 3-4 Liechtenstein's energy consumption and fuel shares 1964-2001 (OS 2001) in MWh. From top to bottom, the following fuels are shown: natural gas (Erdgas), gasoline (Benzin), diesel (Dieselöl), gas oil (Heizöl), wood (Brennholz), electricity (Elektrizität).

The electricity production 1990-2001 is given in Table 3-15 and documents the increasing relevance and shares of the natural gas consumption. In 1990, only one natural gas electricity production plant was in operation with a very small production. Older official numbers about the effective electricity production numbers are unfortunately not available. Nevertheless, the numbers indicate that the thermal power plant was installed shortly before 1990. This is also confirmed by an official publication of the Swiss gas organisation (Erdgas Schweiz, see Gasette 2014) about the renovation of the thermal power plant in Triesen (Liechtenstein) after more than 20 years of operation. As per official information from the Office of Environment (OE), the thermal power plant at Triesen was installed between 1989 and 1991 (first only one engine, the second engine was installed in 2000).

Table 3-12 Energy consumption 1964-2001 in MWh (OS 2001). The headers are from left to right: year (Jahr), electricity (Elektrizität), wood (Brennholz), coal (Kohle), gas oil (Heizöl), diesel (Dieselöl), gasoline (Benzin), natural gas (Erdgas), liquid gas (Flüssiggas), total (Total), energy consumption per inhabitant (Verbrauch je Einwohner). *) Consumption, **) Import

Jahr	Elektrizität* (MWh)[1]	Brennholz* (MWh)[2]	Kohle** (MWh)[3]	Heizöl** (MWh)[4]	Dieselöl** (MWh)[4,6]	Benzin** (MWh)[4]	Erdgas** (MWh)[5]	Flüssiggas** (MWh)[4]	TOTAL (MWh)	Verbrauch (MWh) je Einwohner
1964	48'008	13'007	11'396	123'801	22'904	84'880	-	.	303'995	15.9
1965	52'416	11'679	10'175	144'895	24'120	81'662	-	.	324'947	16.8
1966	56'102	9'680	8'425	135'603	25'440	84'514	-	.	319'763	16.1
1967	61'077	8'127	7'570	135'921	20'188	88'031	-	.	320'914	15.7
1968	67'542	7'150	1'718	188'230	25'993	80'730	-	.	371'362	17.5
1969	72'936	6'415	2'414	221'344	30'950	97'639	-	.	431'697	20.6
1970	81'730	4'974	4'197	286'201	33'159	124'336	-	.	534'597	25.0
1971	90'205	4'868	1'626	311'409	32'690	119'477	-	.	560'275	25.6
1972	96'377	4'153	1'474	273'818	33'501	122'647	-	.	531'971	23.7
1973	104'598	4'062	2'638	370'211	41'234	124'145	-	.	646'888	27.9
1974	108'639	6'546	2'638	274'601	32'089	130'398	-	.	554'910	23.4
1975	110'434	5'495	1'644	401'263	29'676	115'263	-	.	663'774	27.7
1976	117'675	4'885	1'198	385'138	31'365	114'864	-	.	655'126	27.1
1977	125'571	4'487	334	441'294	32'620	121'692	-	10'484	736'481	29.8
1978	132'655	4'991	1'064	449'510	36'546	104'731	-	12'643	742'139	29.3
1979	137'883	6'287	988	372'071	30'582	103'741	-	14'397	665'948	25.8
1980	144'955	11'625	1'661	443'941	37'863	121'175	-	27'101	788'320	31.3
1981	151'393	13'927	2'556	389'538	44'149	125'309	-	35'058	761'929	29.2
1982	152'065	14'024	1'038	229'320	34'774	126'871	-	28'957	587'048	22.3
1983	155'928	15'166	731	315'312	30'320	152'252	-	29'297	699'006	26.4
1984	163'813	15'120	1'074	302'185	35'647	182'093	-	32'642	732'575	27.5
1985	171'234	12'411	1'005	402'985	44'913	205'279	-	33'277	871'104	32.2
1986	182'414	15'212	699	500'256	48'184	200'490	3'316	31'788	982'358	35.9
1987	196'093	11'852	500	232'765	49'975	202'000	57'889	21'575	772'648	27.9
1988	203'943	10'111	423	358'878	58'847	222'536	100'974	6'338	962'050	34.1
1989	214'283	8'449	466	366'686	58'124	233'613	124'785	3'581	1'009'987	35.5
1990	221'176	12'407	304	420'929	69'417	233'050	140'705	3'684	1'101'673	37.9
1991	224'944	8'583	282	346'817	67'648	260'837	170'770	2'256	1'082'137	36.8
1992	233'000	12'376	338	309'409	75'887	288'369	191'330	4'291	1'115'000	37.3
1993	234'762	11'239	311	338'451	74'124	267'672	206'522	3'364	1'136'444	37.5
1994	241'159	14'186	221	319'434	61'602	252'767	209'830	2'621	1'101'820	36.0
1995	252'593	10'471	215	296'574	63'460	229'090	229'370	2'254	1'084'027	35.1
1996	259'303	9'715	155	273'432	68'058	288'913	262'318	2'703	1'164'597	37.4
1997	263'372	11'803	163	313'640	66'066	258'271	254'441	1'938	1'169'694	37.3
1998	283'639	13'202	170	340'423	87'166	267'017	280'459	1'989	1'274'065	39.8
1999	295'031	14'490	90	293'844	101'850	239'545	301'711	1'619	1'248'180	38.5
2000	302'018	25'419	195	260'123	79'646	223'819	296'992	1'530	1'189'742	36.2
2001	313'450	15'553	106	250'243	76'397	212'314	328'647	1'084	1'197'794	35.9

1 *Bis 1994: Verbrauch im Landesnetz. Ab 1995 Verbrauch im Inland*
2 *Forstamtlicher Rechenschaftsbericht (Forstamtliches Jahr: 1. Juli - 30. Juni) (Holzverwertung)*
3 *Erhebung bei den Liechtensteiner Händlern*
4 *Erhebung bei den Liechtenstein beliefernden Grossisten*
5 *Meldungen der Liechtensteinischen Gasversorgung*
* *Verbrauch*
** *Import*

Table 3-13 Electricity production and the increasing natural gas consumption of Liechtenstein 1990-2001 (OS 2001). The headers are from left to right: year (Jahr), hydropower (Wasserkraft), natural gas (Erdgas), biogas (Biogas), photovoltaics (Fotovoltaik), total (Total). All numbers are given in MWh. Notes: 1) in operation since 1995, 2) in operation since 2000.

Jahr	Wasserkraft					Erdgas	Biogas	Fotovoltaik	Total
	Lawena und Samina	Jenny-Spoerry	Schlosswald 1	Letzana 2	Steia 2	Blockheiz-kraftwerke	Blockheiz-kraftwerke		
1990	54'674	738	.	.	.	123	.	.	55'535
1991	53'777	961	.	.	.	928	58	.	55'724
1992	59'655	2'061	.	.	.	2'309	871	.	64'896
1993	64'880	2'638	.	.	.	2'272	871	8	70'669
1994	61'339	2'503	.	.	.	2'243	1'070	18	67'173
1995	64'854	3'035	1'812	.	.	2'458	873	32	73'064
1996	59'516	2'752	1'991	.	.	3'080	1'082	40	68'461
1997	58'170	2'596	1'974	.	.	2'859	1'236	63	66'898
1998	63'826	2'380	1'985	.	.	3'352	1'302	71	72'916
1999	66'963	3'003	2'180	.	.	3'018	1'341	74	76'579
2000	71'492	2'308	2'280	495	10	2'960	1'424	66	81'035
2001	70'872	1'973	2'223	981	219	2'874	1'392	69	80'603

3.2.5 Energy industries (1A1)

3.2.5.1 Category description: Energy industries (1A1)

Key category information 1A1

CO_2 from the combustion of Gaseous Fuels in Energy Industries (1A1) is a key category regarding level and trend.

According to IPCC guidelines, source category 1A1 Energy industries comprises emissions from fuels combusted by fuel extraction and energy producing industries. In Liechtenstein, source category 1A1 includes only emissions from the production of heat and/or electricity for sale to the public in 1A1a Public electricity and heat production. Petroleum refining (1A1b) and Manufacture of solid fuels and other energy industries (1A1c) do not occur (see Table 3-14).

Table 3-14 Specification of source category 1A1 Energy industries

1A1	Source	Specification
1A1a	Public electricity and heat production	This source consists of natural gas or biogas used for public co-generation units.
1A1b	Petroleum refining	Not occurring in Liechtenstein.
1A1c	Manufacture of solid fuels and other energy industries	Not occurring in Liechtenstein.

In 2021, 26% of Liechtenstein's electricity consumption was produced domestically and 74% was imported (see Table 3-15). In absolute values, the electricity consumption 2021 amounts to around 418 GWh. This corresponds to an increase of 3.8% compared to 2020. Domestic electricity generation increased by 3.0%. The electricity imports increased by 4.1% compared to 2020.

Table 3-15 Electricity consumption, generation and imports in Liechtenstein (OS 2022b).

Electricity consumption, generation and imports in Liechtenstein 2021	**MWh**	**Share**
Total electricity consumption in Liechtenstein	417'595	100%
Electricity generation in Liechtenstein 2021	106'777	26%
Hydro power	73'720	18%
Natural gas co-generation	2'358	0.6%
Biogas co-generation	36	0.0%
Photovoltaic	30'663	7.3%
Electricity imports in Liechtenstein 2021	310'818	74%

Liechtenstein's domestic electricity generation is dominated by hydroelectric power plants (see Figure 3-5). Other electricity sources are photovoltaic plants as well as fossil and biogas fuelled combined heat and power generation plants.

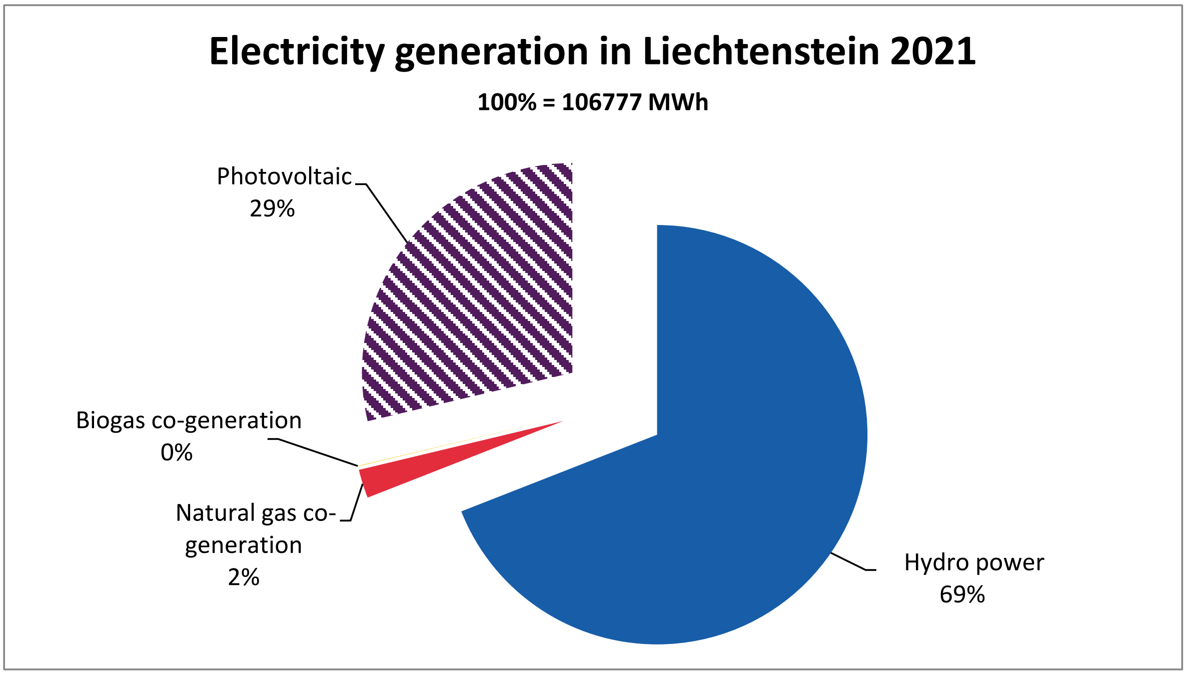


Figure 3-5 Structure of electricity generation in Liechtenstein 2021. Data source: Energy Statistics 2021 (OS 2022b).

Renewable sources account for 97.8% of domestic electricity generation in Liechtenstein. Compared to 2020, the electricity produced by photovoltaic plants has increased by 3.2%. Photovoltaic is thus representing 29% of the total domestic electricity production in 2021.

Waste incineration plants do not exist in Liechtenstein and municipal solid waste is exported to Switzerland for incineration. Therefore, no heat and/or electricity production from waste incineration plants is occurring in Liechtenstein.

As discussed above, electricity generation is based on natural gas and biogas co-generation. Therefore, source category 1A1 includes only emissions from gaseous fuels and biogas from wastewater treatment plants.

3.2.5.2 Methodological issues: Energy industries (1A1)

Methodology

For fuel combustion in 1A1a Public electricity and heat production, the only occurring source within 1A1 Energy industries, a Tier 2 method is used for calculation of emissions of CO_2 and CH_4. For emissions of N_2O from natural gas a Tier 1 method is applied. Aggregated fuel consumption data from the Energy Statistics of Liechtenstein (OS 2022a) is used to calculate emissions. As mentioned above, only natural gas and biomass (sewage gas) are occurring within this source category 1A1a. The wastewater treatment plant (WWTP) uses only biogas for electricity generation and no additional fuels are used to combust the biogas. In addition, the WWTP applies lubricants. Corresponding emissions are reported under 2D1 (see chp. 4.5).

The sources are characterised by similar industrial combustion processes and the same emission factors for all processes of this source category are applied.

Emission factors

Natural gas

The CO_2 emission factor of natural gas corresponds to the IPCC default value (IPCC 2006). The CH_4 emission factor of natural gas is country-specific and representative for engines used in Switzerland and Liechtenstein (lean fuel-air-ratio). Hence, emission factors have been taken from Switzerland (SAEFL 2005e), see Table 3-16. The N_2O emission factor corresponds to the default value from IPCC (2006).

Biomass

Country-specific emission factors for biogas from wastewater treatment plants are taken from SAEFL (2005e). The emission factor of biogenic CO_2 has been adapted to take into account CO_2 being present in the biogas as a product of fermentation already prior to combustion. The following table presents the emission factors used in 1A1a.

Table 3-16 Emission factors for 1A1a Public electricity and heat production in energy industries for 2021 (public co-generation).

Source/fuel	CO_2 [t/TJ]	CO_2 biogenic [t/TJ]	CH_4 [kg/TJ]	N_2O [kg/TJ]
1A1a Public electricity and heat production				
Natural gas	56.1	NO	25.0	0.1
Biomass (Biogas from WWTP)	NO	56.1	25.0	0.1
Biomass (Sewage gas)	NO	100.5	6.0	11.0

Activity data

Activity data on natural gas consumption (in TJ) for Public electricity and heat production (1A1a) is extracted from the energy statistics (OS 2022a). Activity data on sewage gas consumption from wastewater treatment plants is provided by plant operators (for data see section 7.5.2). In 2021, natural gas accounts for 96% of energy consumption in source category public electricity and heat fuel consumption. Table 3-17 documents the activity data of heat fuel consumption in Liechtenstein for fossil fuels (natural gas) and biomass (sewage gas). Natural gas consumption increased by a factor of about 21 from 1990 to 2021. The rapid increase in the years 1990 – 1992 is due to the significant expansion of the natural gas network and increasing number of connections within Liechtenstein. This increase in natural gas consumption and the related increase in emissions is the reason why gaseous fuels of 1A1 is a key category regarding trend.

Biomass consumption increased from 1990 to 2014. Between 2013 and 2014 there is a strong decrease in biomass consumption, as sewage gas is processed to biogas since November 2013. The biogas produced is fed to the general gas network. While in 1990, biomass contributed with 88% to electricity production and heat fuel consumption, it only represents about 4% in 2021.

Table 3-17 Activity data for natural gas and biomass consumption in 1A1a Public electricity and heat production.

Source/fuel	1990	1995	2000	2005	2010
1A1a Public electricity and heat production	TJ				
Natural gas	2.16	35.64	47.52	54.00	56.16
Biomass	15.57	16.98	21.70	20.82	22.24

Source/fuel	2012	2013	2014	2015	2016
1A1a Public electricity and heat production	TJ				
Natural gas	48.24	52.13	44.24	36.02	38.16
Biomass	22.79	24.40	2.13	1.39	2.63

Source/fuel	2017	2018	2019	2020	2021	1990-2021
1A1a Public electricity and heat production	TJ					%
Natural gas	37.26	38.32	60.17	42.90	45.30	1997%
Biomass	3.38	2.85	3.06	1.76	2.07	-87%

3.2.5.3 Uncertainty assessment and time-series consistency

Uncertainties are analysed on an aggregated level for the entire source category 1A since no customs statistics exist that would provide reliable data on fuel imports into Liechtenstein. The aggregated uncertainty analysis is presented in chapter 3.2.10.

3.2.5.4 Category-specific QA/QC and verification

Information about category-specific QA/QC activities and verification processes are provided in chapter 3.2.11.

3.2.5.5 Category-specific recalculations

No category-specific recalculations were carried out.

3.2.5.6 Category-specific planned improvements

There are no category-specific planned improvements for the next submission.

3.2.6 Manufacturing industries and construction (1A2)

3.2.6.1 Category description: Manufacturing industries and construction (1A2)

Key category information 1A2
CO_2 from the combustion of gaseous fuels in manufacturing industries and construction (1A2) is a key category regarding level and trend.
CO_2 from the combustion of liquid fuels in manufacturing industries and construction (1A2) is a key category regarding both level and trend.

In source category 1A2 Manufacturing industries and construction only 1A2e Food processing, beverages and tobacco and 1A2g Other - Non-road vehicles and other machinery occur in Liechtenstein. In the category 1A2e all emissions from the combustion of fuels in stationary boilers, gas turbines and engines are included as well as on-site production of heat and electricity.

Since 2021, no companies in Liechtenstein are participating in the European Emission Trading Scheme (EU-ETS).

Table 3-18 Specification of source category 1A2 Manufacturing industries and construction

1A2	Source	Specification
1A2a	Iron and steel	Not occurring in Liechtenstein.
1A2b	Non-ferrous metals	Not occurring in Liechtenstein.
1A2c	Chemicals	Not occurring in Liechtenstein.
1A2d	Pulp, paper and print	Not occurring in Liechtenstein.
1A2e	Food processing, beverages and tobacco	Contains emissions of the food processing, beverages and tobacco industry such as meat production, milk products, convenience food, etc.
1A2f	Non-metallic minerals	Not occurring in Liechtenstein.
1A2g	Other non-road machinery	Contains emissions of non-road machinery in construction and industry.

3.2.6.2 Methodological issues: Manufacturing industries and construction (1A2)

Methodology

Food processing, beverages and tobacco (1A2e)

A top-down method based on aggregated fuel consumption data from the energy statistics of Liechtenstein (OS 2022a) is used to calculate emissions under 1A2e. The emission sources are characterised by rather similar industrial combustion processes and thus homogeneous emission factors can be assumed. Therefore, a top-down approach is appropriate and identical emission factors for each fuel type are applied for these source categories. The unit of emission factors refers to fuel consumption (in TJ). In addition, the industrial sector is rather small in Liechtenstein and therefore, the energy use for heating is an important emission source within this category. An oxidation factor of 100% is assumed for all combustion processes and fuels because technical standards for combustion installations in Liechtenstein are relatively high (see section 3.2.1).

Other – Non-road machinery (1A2g)

A Tier 2 method is used for non-road machinery in construction and industry. It is assumed that 30% of Liechtenstein’s diesel consumption is attributed to activity from construction vehicles and machinery as well as industrial non-road vehicles and machinery (see Table 3-11). Emission factors are taken from the Swiss non-road study (INFRAS 2015).

Emission factors

Food processing, beverages and tobacco (1A2e)

CO_2 emission factors and NCV values of gas oil are country-specific and have been determined based on the Swiss overall energy statistics of the year 2000 (SFOE 2001). In 1998, 2008 and 2011, the values have been confirmed by measurement campaigns of NCV and carbon content of fuels (EMPA 1999, Intertek 2008, Intertek 2012). For further information, see chapter 3.2.4.1. For the N_2O emissions, the default emission factors from IPCC 2006 have been used.

CO_2 and CH_4 emissions from combustion of natural gas are also calculated using the IPCC default emission factors (IPCC 2006**)**. For biogas produced from sewage gas the same emission factors are used as for natural gas. Table 3-19 shows the emission factors used for the sources in category 1A2.

Other – Non-road machinery (1A2g)

The CO_2 emission factor of diesel taken from Switzerland. For three years, measurements are available (EMPA 1999, Intertek 2008, Intertek 2012), for the other years the emission factor is interpolated or kept constant, see Table 3-6.

The N_2O and CH_4 emission correspond to the implied emission factors of Switzerland's Handbook of Emission Factors of non-road vehicles (INFRAS 2015) for the whole time series.

Emission factors of biodiesel are assumed to be equal to the emission factors of fossil diesel in 1A2g.

Table 3-19 Emission factors for sources in 1A2 in 2021.

Source/fuel	CO_2 [t/TJ]	CO_2 biogenic [t/TJ]	CH_4 [kg/TJ]	N_2O [kg/TJ]
1A2e Food processing, beverages and tobacco				
Gas oil	73.7	-	1.0	0.6
Natural gas	56.1	-	1.0	0.1
Biomass (Biogas from WWTP)		56.1	1.0	0.1
1A2g Other off-road vehicles and machinery				
Diesel	73.3	-	0.4	3.3
Biodiesel		73.3	0.4	3.3

Activity data

Food processing, beverages and tobacco (1A2e)

Activity data on gas oil consumption are based on aggregated fuel consumption data from the energy statistics of Liechtenstein (OS 2022a). It is further assumed that 20% of Liechtenstein's gas oil consumption can be attributed to the food processing, beverages and tobacco industry.

Activity data on consumption of natural gas is provided by Liechtenstein's gas utility (LGV 2022). Data are taken from OS (2022a).

In Liechtenstein, no heavy industries with high furnaces or other processes are occurring. Industries in Liechtenstein using fuels are of minor importance and consist mainly of small businesses. The Industry sector includes machinery, equipment manufacturing, production of dental products, transport equipment and food production but most of the manufacturing processes depend on electric energy and steam generation. Since 2009, steam is imported from the waste incineration plant in Buchs (Switzerland) and is not produced on-site from fossil fuels. Fuel consumption of source category 1A2e is mostly determined by the heating activities by Liechtenstein's companies.

Other – Non-road machinery (1A2g)

Activity data includes the consumption of diesel oil from non-road machineries in construction and industry. Diesel is blended with a small share of biodiesel. The share of biodiesel is assumed to be identical to the share of biodiesel in Switzerland. For Switzerland, the share of biodiesel is determined based on data from the Swiss customs statistic, which is applied in Switzerland's road transportation model (INFRAS 2022).

It is assumed that the fleet composition in Liechtenstein is similar to the Swiss fleet composition (vehicle category, size class, age distribution). The resulting disaggregated fuel consumption of source category 1A2g for the entire time series is given in the table below.

Table 3-20 Activity data of Liechtenstein's fuel consumption in 1A2e Food processing, beverages and tobacco as well as in 1A2g Other non-road vehicles and machinery.

Source/fuel	**1990**	**1995**	**2000**	**2005**	**2010**	
1A2e Food processing, beverages and tobacco			TJ			
Gas oil	252.8	211.7	185.0	196.0	138.6	
Natural gas	270.9	317.4	351.5	375.5	218.8	
Biomass (Biogas from WWTP)	NO	NO	NO	NO	NO	
1A2g Other off-road vehicles and machinery						
Diesel	32.1	29.7	40.2	48.0	47.6	
Biodiesel	NO	NO	0.04	0.14	0.16	
Source/fuel	**2012**	**2013**	**2014**	**2015**	**2016**	
1A2e Food processing, beverages and tobacco			TJ			
Gas oil	126.8	137.2	94.0	113.8	90.4	
Natural gas	208.2	206.7	276.5	258.6	260.2	
Biomass (Biogas from WWTP)	NO	0.3	6.8	6.3	5.8	
1A2g Other off-road vehicles and machinery						
Diesel	62.6	62.6	65.4	62.7	62.8	
Biodiesel	0.23	0.20	0.37	0.76	1.40	
Source/fuel	**2017**	**2018**	**2019**	**2020**	**2021**	**1990-2021**
1A2e Food processing, beverages and tobacco			TJ			%
Gas oil	97.5	78.9	98.2	95.3	81.6	-68%
Natural gas	277.9	256.5	227.2	206.9	230.6	-15%
Biomass (Biogas from WWTP)	6.6	6.9	6.3	6.0	6.0	-
1A2g Other off-road vehicles and machinery						
Diesel	65.7	58.7	55.2	56.4	57.0	78%
Biodiesel	2.40	2.97	2.85	2.83	2.31	-

Table 3-20 documents the decrease of gas oil consumption by 68% from 1990 to 2021. This decrease is correlated with the extension of the natural gas network in Liechtenstein which led to a corresponding substitution of gas oil as the main heating fuel in buildings (see also chapter 3.2.5.2). The consumption of liquid fuels showed a sharp decrease in 2007 followed by an increase in 2008 and 2009 and another decrease in 2010 and 2011 which are discussed below under source category 1A4 Other sectors. A similar development is observed between 2017 and 2019.

Between 1990 and 2021 the consumption of gaseous fuels decreased by 15% including a sharp decrease in 2009. This significant decrease in the natural gas consumption can be explained by the installation of the new district heating pipeline. This new district heating facility, installed in 2009, delivers heat from the onsite waste incineration plant in Buchs (Switzerland). Related emissions are occurring in Switzerland and therefore reported in the inventory of Switzerland. Between 2017 and 2021 the district heating network was further expanded. Fluctuations in the natural gas consumption are a result of the changing heating needs in cold or warm winters.

This shift in fuel mix is the reason for CO_2 emissions from liquid fuels and gaseous fuels in category 1A2 being key categories with regards to the trend 1990-2021. Between 2013 and 2014, there is a strong increase in biomass consumption, as sewage gas is processed to biogas since November 2013. The biogas produced is fed to the general gas network thus leading to an increase in biomass consumption in source category 1A2e. In addition, the biodiesel which is blended with regular diesel contributes to an increase in biomass consumption in source category 1A2g.

3.2.6.3 Uncertainty assessment and time-series consistency

Uncertainties are analysed on an aggregated level for the entire source category 1A since no customs statistics exist that would provide reliable data on fuel imports into Liechtenstein. The aggregated uncertainty analysis is presented in chapter 3.2.10.

3.2.6.4 Category-specific QA/QC and verification

Information about category-specific QA/QC activities and verification processes are provided in chapter 3.2.11.

3.2.6.5 Category-specific recalculations

No category-specific recalculations were implemented.

3.2.6.6 Category-specific planned improvements

According to Liechtenstein's inventory development plan no future improvements are planned under source-category 1A2.

3.2.7 Transport (1A3)

3.2.7.1 Category description: Transport (1A3)

Key category information 1A3b

CO_2 from the combustion of fuels in Road transportation (1A3b) is a key category regarding both level and trend.

This source category contains road transport and national civil aviation. Civil aviation in fact is only a very small contribution resulting from only one helicopter base in Liechtenstein. Railway is not producing emissions (see below). Navigation and other transportation are not occurring in Liechtenstein. Further non-road transportation is included in source categories 1A2g Other non-road machinery and 1A4c Other sectors non-road transport in agriculture and forestry.

Table 3-21 Specification of Liechtenstein's source category 1A3 Transport.

1A3	Source	Specification
1A3a	Domestic aviation	Helicopters only.
1A3b	Road transportation	Light and heavy motor vehicles, coaches, two-wheelers.
1A3c	Railways	Fully electrified system, but no electricity infeed, no diesel locomotives, switchyard
1A3d	Domestic navigation	Not occurring in Liechtenstein.
1A3e	Other transportation	Not occurring in Liechtenstein.

3.2.7.2 Methodological issues: Transport (1A3)

Methodology

__Domestic aviation (1A3a)__

A Tier 1 method was applied for the calculation of emissions (for additional information, see activity data or chp. 3.2.2). Liechtenstein’s emissions are calculated based on fuel consumption, flying hours and fleet composition of the single helicopter base “Heliport Balzers”. Emission factors are constant for the entire time series (see Table 3-22).

Activity data partly consists of surveys and collected data from the helicopter company Rotex Helicopter AG. For years where no data was available, constant values or interpolations were used.

Note that these emissions are also reported in the Swiss GHG inventory. Since Switzerland and Liechtenstein form a customs union, all imports of kerosene appear in the Swiss overall energy statistics. The Swiss Federal Office of Civil Aviation (FOCA) carries out an extended Tier 3a method to determine the domestic (and bunker) emissions of civil aviation. Within this calculation, all fuel consumption of helicopters is accounted for. The helicopter basis in Balzers is included in the Swiss modelling scheme. All resulting emissions from helicopters are reported in the Swiss inventory as domestic emissions. The amount of emissions from the Balzers helicopter base is very small compared to the total of all other Swiss helicopter emissions. Therefore, Switzerland refrains from subtracting the small contribution of emissions from its inventory. Nevertheless, for Liechtenstein these emissions are not negligible.

Road transportation (1A3b)

The emissions are calculated with a Tier 2 method (top-down) as suggested by 2006 IPCC Guidelines (IPCC 2006). The CO_2 emission factors are derived from the carbon content of fuels (see Table 3-5 and Table 3-6) similar as in the Swiss GHG inventory (FOEN 2022). For CH_4 and N_2O, country-specific emission factors from Switzerland's road transportation model (INFRAS 2022) are applied. The activity data corresponds to the amounts of gasoline and diesel fuel sold in Liechtenstein (sales principle). These data are taken from the national energy statistics modified as mentioned in Chapter 3.2.4.2.

Since the energy statistic of Liechtenstein (OS 2022a) provides only data on total fuel consumption, it is not possible to split emissions according to vehicle type under 1A3bi-1A3biv. Therefore, total emissions from road transport are reported under 1A3bi using implied emission factors accounting for all vehicle types. For the other vehicle categories no emissions are reported under 1A3bii – 1 A3biv and the notation key IE is applied.

Note that a large number of Austrian and German citizens are working in Liechtenstein (2021: 41'352 registered employees, and about 23'249 commuters, whereof 41.1% are non-Swiss citizens, see OS 2022f) and buying part of their gasoline in Liechtenstein. The method of reporting the fuel sold at all gasoline stations in the country guarantees that indeed the sales principle is applied and not a territorial principle as might be the case by applying a traffic model, which, for Liechtenstein, would considerably underestimate the fuel sold. This statement only holds up to 2014 as long as prices were higher in Austria as compared to Liechtenstein and Switzerland (which both have the same price due to the Customs Union Treaty). The discontinuation of Switzerland's minimum exchange rate on 15 January 2015, resulted in a strong appreciation of the Swiss franc, which led to a switch in the direction of fuel tourism (SFOE 2018).

Railways (1A3c)

There is a railway line crossing the country, where Austrian and Swiss railways are passing by. Liechtenstein has no own railway. The railway line is owned and maintained by the Austrian Federal Railway. The line in Liechtenstein is fully electrified. There are no diesel sales to railway locomotives, therefore there are no GHG emissions occurring.

Domestic navigation (1A3d)

Domestic navigation is not occurring in Liechtenstein, since there are no lakes. The river Rhine is not navigable on the territory of Liechtenstein. Therefore, no emissions are occurring in this sector.

Other Transportation (1A3e)

Fuel consumption by equipment supporting pipeline transportation activities of natural gas and ground activities in airports do not occur in Liechtenstein.

Emissions factors

Domestic aviation (1A3a)

The emission factors used for emission calculations of 1A3a Domestic aviation are illustrated in Table 3-22. The CO_2 emission factor for kerosene is taken from Table 3-5 (SFOE/FOEN 2014). The CH_4 and N_2O emission factors are default values given by IPCC (2006).

Table 3-22 Emission factors used for estimating emissions of helicopters. The values are used for the entire time series 1990-2021.

Source/fuel	CO_2 [t/TJ]	CH_4 [kg/TJ]	N_2O [kg/TJ]
1A3a Domestic aviation (helicopters only)			
Kerosene	72.8	0.5	2.0

Road transportation (1A3b)

CO_2

- CO_2 emission factors for fossil gasoline, diesel oil, bioethanol and biodiesel: The emission factors are adopted from Switzerland’s road transportation model (INFRAS 2022) (see Table 3-5 and Table 3-6 in chp. 3.2.4.1), which is also applied in Switzerland’s GHG inventory. The fleet composition of Liechtenstein is very similar to Switzerland. Accordingly, in Liechtenstein’s inventory a weighted average emission factor from all vehicle categories in Switzerland (passenger cars, light duty vehicles, motorcycles, heavy duty vehicles, buses, coaches) is used for each fuel type.
- CO_2 emission factor for natural gas: emission factor corresponds to the IPCC default value (IPCC 2006).
- CO_2 emission factors for biogas: Since 2013, Liechtenstein produces biogas from sewage gas treatment and uses a part of this biogas in road transportation. The emission factors are equal to natural gas.
- CO_2 emission factors for vegetable oil: In the past, there was one distributor in Liechtenstein who imported biofuels in the years 2007-2009, mixed them with other fuel types and then sold the fuel. The emission factor is assumed to be identical to conventional diesel. In 2010, the production of biofuels ceased. Note that this is not considered to be a “production of biofuels” and thus in CRF Table 1A(b) there is only data provided for import and export of the biogenic compounds of the fuel. The fuel was based on recycling of waste vegetable oil consisting mainly of canola. A small fraction of fossil diesel oil was added to the vegetable fuel. The fossil fraction is contained in the diesel sold and therefore has not to be accounted again. The biogenic

fraction is not reported under 1A3b but under Memo items “biomass” for respective years. Please note that this holds only for emissions from vegetable oil. CO_2 emissions of biofuels (bioethanol and biodiesel) are reported under 1.A.3.b under biomass, but are not accounted in that category. Thus, they are not part of the totals presented in Table 1s1, cell B23, but instead under Memo items Table1s2, cell B33.

- The CO_2 emission factor for lubricants (used in a blend with gasoline for motorcycles) stems from the IPCC 2006 Guidelines (IPCC 2006).

CH_4, N_2O

- CH_4, N_2O for gasoline, diesel oil, biodiesel and bioethanol: the emission factors from Switzerland’s road transportation model for the whole period 1990-2021 (INFRAS 2022). The road transportation model applies the emission factors from Switzerland’s Handbook of Emission Factors version 4.2 (INFRAS 2022a). Note that the regulation for emission concepts of the two countries is identical: Switzerland and Liechtenstein adopt the same limit values for pollutants on the same schedule as the countries of the European Union. The fleet composition of the two countries, the CO_2 emissions of light motor vehicles (passenger cars, light duty vehicles, motorcycles) and the emissions of heavy motor vehicles (heavy duty vehicles, buses, coaches) are similar in Liechtenstein and Switzerland. A quantitative analysis based on Switzerland’s road transportation model (INFRAS 2004, Annex A5) and of Liechtenstein (OEP 2002, Table 7, p. 16) reveals that the contribution of light motor vehicles to the CO_2 emissions of the total (light and heavy motor vehicles) is 80% in Liechtenstein and 85% in Switzerland. Note that these results are derived based on the territorial principle. From the viewpoint of the sales principle, both numbers would be higher due to fuel tourism, but in Liechtenstein, the increase would be stronger since fuel tourism was more pronounced in Liechtenstein than in Switzerland. It can therefore be expected that if fuel tourism was considered, the two figures 80% and 85% would converge even more. This comparison underpins the applicability of Swiss implied emission factors for Liechtenstein. Annual variation in the implied emission factors may reach a few percent. But the deviation of the emission total of source category 1A3b is very small.
- CH_4, N_2O emission factors for natural gas: For CH_4 and N_2O the emission factor from Switzerland’s road transportation model is used (INFRAS 2022).
- CH_4, N_2O emission factors for biogas: For biogas from sewage gas treatment, implied emission factors 1A3b for natural gas are used (see Table 3-23).
- Production of liquid biofuel occurred only from 2007 to 2009. For this period, CH_4, N_2O emission factors for biofuel are assumed to be identical to those of fossil diesel used in 1A3b Road transportation.
- CH_4 and N_2O emission factors for lubricants (used in a blend with gasoline for motorcycles) are assumed to be identical to CH_4 and N_2O emission factors of gasoline.

Annex A5.1 provides explanations on the origin of the Swiss emission factors for road transportation.

Table 3-23 Emission factors for fossil fuels road transport.

Gas	unit	1990	1995	2000	2005	2010
				Gasoline		
CO_2	t/TJ	73.9	73.9	73.9	73.9	73.8
CH_4	kg/TJ	29.99	17.88	13.75	10.53	8.26
N_2O	kg/TJ	3.52	5.10	4.80	1.67	1.02
				Diesel		
CO_2	t/TJ	73.6	73.6	73.6	73.5	73.4
CH_4	kg/TJ	2.55	2.02	1.35	0.87	0.59
N_2O	kg/TJ	0.57	0.67	0.90	1.25	2.21
				Gaseous fuels		
CO_2	t/TJ	NA	NA	NA	56.1	56.1
CH_4	kg/TJ	NA	NA	NA	91.65	33.70
N_2O	kg/TJ	NA	NA	NA	1.14	3.76
				Lubricants		
CO_2	t/TJ	73.3	73.3	73.3	73.3	73.3
CH_4	kg/TJ	29.99	17.88	13.75	10.53	8.26
N_2O	kg/TJ	3.52	5.10	4.80	1.67	1.02

Gas	unit	2012	2013	2014	2015	2016
				Gasoline		
CO_2	t/TJ	73.8	73.8	73.8	73.8	73.8
CH_4	kg/TJ	7.62	7.28	6.88	6.61	6.64
N_2O	kg/TJ	0.84	0.76	0.71	0.68	0.66
				Diesel		
CO_2	t/TJ	73.3	73.3	73.3	73.3	73.3
CH_4	kg/TJ	0.72	0.80	0.91	1.12	1.46
N_2O	kg/TJ	2.52	2.61	2.71	2.82	2.96
				Gaseous fuels		
CO_2	t/TJ	56.1	56.1	56.1	56.1	56.1
CH_4	kg/TJ	34.06	32.28	31.21	27.42	25.76
N_2O	kg/TJ	3.07	3.15	3.32	3.48	3.51
				Lubricants		
CO_2	t/TJ	73.3	73.3	73.3	73.3	73.3
CH_4	kg/TJ	7.62	7.28	6.88	6.61	6.64
N_2O	kg/TJ	0.84	0.76	0.71	0.68	0.66

Gas	unit	2017	2018	2019	2020	2021	1990-2021
				Gasoline			%
CO_2	t/TJ	73.8	73.8	73.8	73.8	73.8	0%
CH_4	kg/TJ	6.48	6.30	6.00	5.91	5.93	-80%
N_2O	kg/TJ	0.65	0.64	0.64	0.70	0.68	-81%
				Diesel			
CO_2	t/TJ	73.3	73.3	73.3	73.3	73.3	0%
CH_4	kg/TJ	1.82	2.10	2.30	2.33	2.48	-3%
N_2O	kg/TJ	3.11	3.25	3.36	3.49	3.56	523%
				Gaseous fuels			
CO_2	t/TJ	56.1	56.1	56.1	56.1	56.1	-
CH_4	kg/TJ	24.11	23.07	21.87	20.08	18.66	-
N_2O	kg/TJ	3.63	3.52	3.51	4.01	3.49	-
				Lubricants			
CO_2	t/TJ	73.3	73.3	73.3	73.3	73.3	0%
CH_4	kg/TJ	6.48	6.30	6.00	5.91	5.93	-80%
N_2O	kg/TJ	0.65	0.64	0.64	0.70	0.68	-81%

Table 3-24 Emission factors for biofuels used in road transport. The CO_2 emission factor refers to biogenic emissions. Liquid biofuel from waste vegetable oil was produced from 2007-2009 (not shown in table, see CRF reporting tables for full time series), the corresponding CO_2, CH_4 and N_2O emission factors are assumed to be identical to those of fossil diesel.

Gas	unit	1990	1995	2000	2005	2010
		Bioethanol				
CO_2	t/TJ	73.9	73.9	73.9	73.9	73.8
CH_4	kg/TJ	29.99	17.88	13.75	10.53	8.26
N_2O	kg/TJ	3.52	5.10	4.80	1.67	1.02
		Biodiesel				
CO_2	t/TJ	73.6	73.6	73.6	73.5	73.4
CH_4	kg/TJ	2.55	2.02	1.35	0.87	0.59
N_2O	kg/TJ	0.57	0.67	0.90	1.25	2.21
		Biogas (since 2013)				
CO_2	t/TJ	NA	NA	NA	NA	NA
CH_4	kg/TJ	NA	NA	NA	NA	NA
N_2O	kg/TJ	NA	NA	NA	NA	NA

Gas	unit	2012	2013	2014	2015	2016
		Bioethanol				
CO_2	t/TJ	73.8	73.8	73.8	73.8	73.8
CH_4	kg/TJ	7.62	7.28	6.88	6.61	6.64
N_2O	kg/TJ	0.84	0.76	0.71	0.68	0.66
		Biodiesel				
CO_2	t/TJ	73.3	73.3	73.3	73.3	73.3
CH_4	kg/TJ	0.72	0.80	0.91	1.12	1.46
N_2O	kg/TJ	2.52	2.61	2.71	2.82	2.96
		Biogas (since 2013)				
CO_2	t/TJ	NA	56.1	56.1	56.1	56.1
CH_4	kg/TJ	NA	32.28	31.21	27.42	25.76
N_2O	kg/TJ	NA	3.15	3.32	3.48	3.51

Gas	unit	2017	2018	2019	2020	2021	1990-2021
		Bioethanol					%
CO_2	t/TJ	73.8	73.8	73.8	73.8	73.8	-0.1%
CH_4	kg/TJ	6.48	6.30	6.00	5.91	5.93	-80.2%
N_2O	kg/TJ	0.65	0.64	0.64	0.70	0.68	-80.8%
		Biodiesel					
CO_2	t/TJ	73.3	73.3	73.3	73.3	73.3	-0.4%
CH_4	kg/TJ	1.82	2.10	2.30	2.33	2.48	-3.0%
N_2O	kg/TJ	3.11	3.25	3.36	3.49	3.56	523.0%
		Biogas (since 2013)					
CO_2	t/TJ	56.1	56.1	56.1	56.1	56.1	-
CH_4	kg/TJ	24.11	23.07	21.87	20.08	18.66	-
N_2O	kg/TJ	3.63	3.52	3.51	4.01	3.49	-

Activity data

Domestic aviation (1A3a)

The operating company of the helicopter base “Heliport Balzers” provided data on fuel consumption for 1995, 2001–2021 as well as domestic fuel consumption for 2012–2021 (Rotex Helicopter AG 2006 -2022). The fleet consists of three helicopters. Details for the kerosene consumption are described in chp. 3.2.2, the part of domestic consumption is shown in Table 3-25.

Table 3-25 Activity data for 1A3a Domestic aviation: kerosene consumption 1990-2021 in TJ (only domestic consumption without international bunker fuels). See also Table 3-4.

Source/fuel	1990	1995	2000	2005	2010	
1A3a Domestic aviation (helicopters only)	TJ					
Kerosene (domestic)	1.03	1.03	1.08	1.04	0.89	
Source/fuel	**2012**	**2013**	**2014**	**2015**	**2016**	
1A3a Domestic aviation (helicopters only)	TJ					
Kerosene (domestic)	0.83	0.74	0.85	0.81	0.56	
Source/fuel	**2017**	**2018**	**2019**	**2020**	**2021**	**1990-2021**
1A3a Domestic aviation (helicopters only)	TJ					%
Kerosene (domestic)	0.35	0.40	1.14	0.81	0.84	-18%

Road transportation (1A3b)

The amount of gasoline and diesel fuel sold in Liechtenstein serve as activity data for the calculation of the CO_2 emissions (see Table 3-26).

For gaseous fuels, the amount reported by gasoline stations is used. Since 1997 the imported diesel is blended with a small share of biodiesel and since 2010 the imported gasoline is blended with a small share of bioethanol. The shares are assumed to be equal to the share determined for Switzerland (INFRAS 2022).

The biofuel consumption of vegetable oil produced in Liechtenstein occurred only between 2007 and 2009. Since 2013, Liechtenstein produces biogas from sewage gas treatment and uses a part of this biogas in road transportation.

Table 3-26 Time series of activity data for 1A3b Road transportation. Vegetable oil was used between 2007 and 2009 (not shown in table, see CRF reporting table for full time series) and biogas is used since 2013.

Fuel	1990	1995	2000	2005	2010
	TJ				
Gasoline	819	903	977	773	593
Diesel	200	184	239	301	407
Natural Gas	NO	NO	NO	32.4	59.4
Lubricants (1A3biv)	0.0025	0.0022	0.0018	0.0015	0.0011
Biogas	NO	NO	NO	NO	NO
Bioethanol	NO	NO	NO	NO	0.01
Biodiesel	NO	NO	0.2	0.8	1.3
Sum	**1'020**	**1'086**	**1'216**	**1'107**	**1'061**
1990=100%	100%	107%	119%	109%	104%

Fuel	2012	2013	2014	2015	2016
	TJ				
Gasoline	582	562	508	406	379
Diesel	477	494	471	414	428
Natural Gas	23.4	23.0	19.5	17.4	9.5
Lubricants (1A3biv)	0.0011	0.0007	0.0008	0.0008	0.0008
Biogas	NO	0.03	0.48	0.43	0.21
Bioethanol	0.65	0.71	1.00	2.45	3.07
Biodiesel	1.58	1.46	2.40	4.53	8.63
Sum	**1'084**	**1'080**	**1'002**	**844**	**828**
1990=100%	106%	106%	98%	83%	81%

Fuel	2017	2018	2019	2020	2021	1990-2021
	TJ					%
Gasoline	370	362	356	318	331	-60%
Diesel	445	424	411	390	422	110%
Natural Gas	5.6	7.0	5.4	2.8	2.5	-
Lubricants (1A3biv)	0.0008	0.0014	0.0014	0.0011	0.0011	-56%
Biogas	0.13	0.19	0.15	0.08	0.06	-
Bioethanol	3.76	4.38	4.95	4.99	6.59	-
Biodiesel	14.74	19.41	19.19	17.69	15.42	-
Sum	**839**	**817**	**797**	**733**	**777**	**-24%**
1990=100%	82%	80%	78%	72%	76%	

The Office of Environmental Protection (OEP) conducted a study in the year 2002 in order to estimate the territorial fuel consumption based on kilometres travelled (OEP 2002). This approach is substantiated by a model which uses input data from transport statistics and traffic counting. The CO_2 emissions were more than 40% lower in the base year and 30% lower in 2004 than the emissions reported in respective GHG inventories. The differences between this result and the statistics of fuel sales are explained by fuelling of (mainly) Austrian cars due to lower gasoline prices in Liechtenstein. Moreover, the differences show the importance of collecting sales numbers as activity data for Liechtenstein and not using data derived from the territorial principle (as mentioned above in this chapter, the fuel tourism decreased significantly in 2015 due changing of the exchange rate between Swiss francs (Liechtenstein's currency) and Euros (Austria's currency).

Note that the consumption of lubricants is included in the global gasoline sales reported in the national energy statistics.

3.2.7.3 Uncertainties and time-series consistency

Uncertainties are analysed on an aggregated level for the entire source category 1A since no customs statistics exist that would provide reliable data on fuel imports into Liechtenstein. The aggregated uncertainty analysis is presented in chapter 3.2.10.

3.2.7.4 Category-specific QA/QC and verification

Information about category-specific QA/QC activities and verification processes are provided in chapter 3.2.11.

3.2.7.5 Category-specific recalculations

The following recalculations lead to minor changes in CH_4 and N_2O emissions:

- 1A3b: In this submission the latest version of the Handbook Emission Factors for Road Transport (HBEFA 4.2) is used (INFRAS 2022a). Hence, CH_4 and N_2O emission factors for gasoline, diesel and natural gas were updated for the complete time series.

3.2.7.6 Category-specific planned improvements

No category-specific improvements are planned.

3.2.8 Other sectors (commercial/institutional, residential, agriculture/forestry/fishing) (1A4)

3.2.8.1 Category description: Other sectors (1A4)

Key category information 1A4

CO_2 from the combustion of gaseous and of liquid fuels in Other Sectors (1A4) are key categories regarding both level and trend.

Source category 1A4 Other sectors comprises emissions from fuels combusted in commercial and institutional buildings, in households, as well as emissions from fuel combustion for grass drying and non-road machinery in agriculture.

Table 3-27 Specification of source category 1A4 Other sectors.

1A4	Source	Specification
1A4a	Commercial/institutional	Emissions from fuel combustion in commercial and institutional buildings.
1A4b	Residential	Emissions from fuel combustion in households.
1A4c	Agriculture/forerstry/fishing	Emissions from fuel combustion of agricultural machineries.

3.2.8.2 Methodological issues: Other sectors (1A4)

Methodology

Commercial/institutional (1A4a) and residential (1A4b)

For fuel combustion in commercial and institutional buildings (1A4a) as well as in households (1A4b), a Tier 2 method is used and cross-checked with the estimate on the gas oil consumption based on expert judgement (see sub-section 3.2.4.2 energy statistics and contribution to the IPCC source categories). A top-down method based on aggregated fuel consumption data from the energy statistics of Liechtenstein (OS 2022a) is used to calculate emissions. The sources of source category 1A4a and 1A4b are characterised by rather similar combustion processes and therefore, the same emission factors are implemented. An oxidation factor of 100% is assumed for all combustion processes and fuels (see chp. 3.2.1).

Agriculture/forestry/fishing (1A4c)

For source category 1A4c, a Tier 1 method is used. Emissions stem from fuel combustion in agricultural machinery. Emission factors are taken from the Swiss non-road online database (INFRAS 2015). The activity data is derived from the information provided by the General Directorate of Swiss Customs (refunding institution of fuel levies until 2005) and by OEP census (OEP 2012c). For more details, see section 3.2.4.2, paragraph gasoline/diesel oil.

Emission factors

Commercial/institutional (1A4a) and residential (1A4b)

CO_2 emission factors and NCV values are country-specific (see Table 3-5 and chp. 3.2.4.1 for details).

Liechtenstein is a very small country and strongly linked with Switzerland on several aspects. Therefore, the technology providers are mostly the same for both countries and it can be assumed, that the technologies used as well as the consumption properties are the same.

The coal emission factor for CO_2 refers to the emission factor of hard coal in Switzerland (Cemsuisse 2010). As Liechtenstein is a small neighbouring country of Switzerland, it is assumed that similar coal is used as in Switzerland. The N_2O emission factor is taken from the IPCC 2006 Guidelines and the CH_4 emission factor is taken from Switzerland's National Inventory Report 2022 (FOEN 2022).

The country-specific emission factors for CO_2 emissions from gas oil and Liquefied Petroleum Gas (LPG) are taken from Switzerland's National Inventory Report 2022 (FOEN 2022). Emission factors of CH_4 and N_2O are taken from the IPCC 2006 Guidelines (Vol. 2, Chp. 2, Table 2.4 and 2.5). For biogas, the same emission factors are used as for natural gas.

The CO_2, CH_4 and N_2O emission factors for natural gas is taken from IPCC 2006 Guidelines (Vol. 2, Chp. 2, Table 2.4 and 2.5).

The CO_2, CH_4 and N_2O emission factors for alkylate gasoline is taken from IPCC 2006 Guidelines (Vol. 2, Chp. 3, Table 3.3.1).

The CO_2 and N_2O emission factors for combustion of wood are taken from IPCC 2006 Guidelines (Vol. 2, Chp. 2, Table 2.4). The CH_4 emission factor for combustion of wood is derived from FOEN 2022a. They are based on air pollution control and laboratory measurements and literature. For small wood combustion installations in 1A4b, a weighted emission factor is applied based on the share of different types of wood firing boilers (Acontec 2018a).

Table 3-28 Emission factors for 1A4a and 1A4b: Commercial/institutional and residential in Other sectors for the year 2021.

Source/fuel	CO_2 fossil [t/TJ]	CO_2 biogenic [t/TJ]	CH_4 [kg/TJ]	N_2O [kg/TJ]
1A4a/b Other sectors - Commercial/institutional and Residential				
Gas oil	73.7	-	10.0	0.6
LPG	65.5	-	5.0	0.1
Alkylate gasoline	69.3	-	140.0	0.4
Coal	92.7	-	300.0	1.5
Natural gas	56.1	-	5.0	0.1
Biomass (Biogas from WWTP)	-	56.1	5.0	0.1
Biomass (Wood combustion 1A4a)	-	112.0	10.0	4.0
Biomass (Wood combustion 1A4b)	-	112.0	73.6	4.0

Agriculture/forestry (1A4c)

The CO_2, CH_4 and N_2O emission factors for diesel used in non-road vehicles and machinery (agriculture and forestry) are country-specific and are taken from Switzerland's database of non-road vehicles (INFRAS 2015). As Liechtenstein is a small neighbouring country of Switzerland with similar agricultural features like topography, climate, machinery (same regulation for Euro classes), it is assumed that the same emission factor can be applied as for the Swiss inventory.

For biodiesel the same emission factors are used as for fossil diesel.

The CO_2, CH_4 and N_2O emission factors for alkylate gasoline is taken from IPCC 2006 Guidelines (Vol. 2, Chp. 3, Table 3.3.1).

Table 3-29 Emission factors for 1A4c: Other sectors – Agriculture/forestry for the year 2021.

Source/fuel	CO_2 fossil [t/TJ]	CO_2 biogenic [t/TJ]	CH_4 [kg/TJ]	N_2O [kg/TJ]
1A4c Other sectors - Agriculture/forestry				
Diesel	73.3	-	1.0	3.0
Biodiesel	73.3	-	1.0	3.0
Alkylate gasoline	69.3	-	140.0	0.4

Activity data

Commercial/institutional (1A4a) and residential (1A4b)

Activity data on fuel consumption (TJ) are based on aggregated fuel consumption data from the energy statistics of Liechtenstein (OS 2022a). A description of the modifications and the disaggregation of data from energy statistics are provided in section 3.2.4.2.

Activity data for consumption of alkylate gasoline have been determined by a census carried out by the Office of Environment (OE 2022e). 20% of alkylate gasoline is allocated to households and reported in 1A4b Residential whereas 80% of alkylate gasoline is allocated to agriculture and forestry and reported in 1A4c.

The resulting disaggregation is given in the table below.

Table 3-30 Activity data in 1A4a Commercial/institutional and 1A4b Residential. Biomass consumption comprises consumption of biogas from wastewater treatment plants and consumption of wood.

Source/fuel	1990	1995	2000	2005	2010
	TJ				
1A4a Commercial/institutional	**938.28**	**877.25**	**901.85**	**1'054.00**	**799.90**
Gas oil	758.40	635.05	555.03	587.93	415.84
LPG	13.29	8.14	5.52	3.68	5.34
Natural gas	140.84	212.33	288.54	408.34	268.97
Coal	NO	NO	NO	NO	NO
Biomass	25.75	21.73	52.75	54.05	109.76
1A4b Residential	**312.23**	**403.38**	**493.86**	**646.39**	**687.40**
Gas oil	252.80	211.68	185.01	195.98	138.61
Alkylate gasoline	NO	0.05	0.10	0.11	0.13
Natural gas	41.22	176.43	272.91	414.01	475.43
Coal	1.04	0.73	0.67	0.25	0.06
Biomass	17.17	14.49	35.17	36.03	73.18

Source/fuel	2012	2013	2014	2015	2016
	TJ				
1A4a Commercial/institutional	**768.32**	**792.29**	**529.41**	**645.60**	**561.29**
Gas oil	380.39	411.48	282.03	341.39	271.17
LPG	4.14	3.86	3.63	3.68	3.63
Natural gas	262.08	273.12	128.39	170.73	161.40
Coal	NO	NO	NO	NO	NO
Biomass	121.71	103.83	115.36	129.81	125.09
1A4b Residential	**636.85**	**681.70**	**565.83**	**639.13**	**620.03**
Gas oil	126.80	137.16	94.01	113.80	90.39
Alkylate gasoline	0.13	0.12	0.16	0.12	0.20
Natural gas	428.78	474.83	387.37	430.90	438.68
Coal	NO	NO	NO	NO	NO
Biomass	81.14	69.60	84.29	94.32	90.75

Source/fuel	2017	2018	2019	2020	2021	1990-2021
	TJ					%
1A4a Commercial/institutional	**588.32**	**538.53**	**567.10**	**539.98**	**519.02**	**-45%**
Gas oil	292.35	236.73	294.70	285.92	244.81	-68%
LPG	3.50	3.82	3.59	3.68	3.36	-75%
Natural gas	174.91	158.49	140.78	147.81	171.06	21%
Coal	NO	NO	NO	NO	NO	-
Biomass	117.56	139.49	128.04	102.57	99.80	288%
1A4b Residential	**640.90**	**604.66**	**656.06**	**637.21**	**672.38**	**115%**
Gas oil	97.45	78.91	98.23	95.31	81.60	-68%
Alkylate gasoline	0.20	0.12	0.12	0.15	0.12	-
Natural gas	456.84	424.07	462.20	462.88	513.75	1146%
Coal	NO	NO	NO	NO	NO	-
Biomass	86.41	101.56	95.51	78.87	76.90	348%

Since 1990, gas oil consumption decreased by approximately 68% for 1A4a and 1A4b. The significant decline in 2007, followed by an increase of the gas oil consumption between

2008 and 2009 and another decrease in 2010 and 2011, are caused by two different reasons: First, special fluctuation of prices for fossil fuels and second warm winters with low number of heating degree days. As stock changes in residential fuel tanks are not taken into account, high prices of fossil fuels therefore led to a smaller apparent consumption of fossil fuels in 2007, when stocks were depleted, and higher apparent consumption in 2008, when fuel tanks were refilled. In 2009, the lower prices raised the demand of gas oil and the launch of the CO_2 levy on January 1, 2010 induced the commercial consumers to refill their fuel tanks at the end of 2009.

In 2012, the cold winter (high number of heating degree days) led to a small increase of gas oil consumption in these source categories 1A4a and 1A4b. Due to the further increase in the CO_2 levy by 1st January, 2016, again an increase in sales of gas oil was observed in 2015, which leads to a reduced apparent consumption of gas oil in 2016. The same pattern can be observed again between 2017 and 2019, due to another increase in the CO_2 levy on January 1 in 2018. In 2021 gas oil consumption decreased again due to an increase in gas oil prices in 2021. The decrease in gas oil consumption is partly compensated by an increase in natural gas consumption. The total energy consumption in 1A4b increased from 2020 to 2021 due to a higher number of heating degree days.

This shift in fuel mix is the reason for CO_2 emissions from the use of gaseous and liquid fuels in category 1A4a and 1A4b being key categories regarding level and trend.

Among other factors, the increase in consumption of harvested wood as fuel (as documented in the wood harvesting statistics of Liechtenstein, OE 2022b) contributes to the strong increase in biomass consumption since 1990.

Agriculture/forestry/fishing (1A4c)

The activity data related non-road machinery is shown in Table 3-31. Besides diesel, the consumption of alkylate gasoline is also accounted for (20% in 1A4b and 80% in 1A4c). The consumption of alkylate gasoline in 2019 has been derived from an annual census carried out by the Office of Environment (OE 2022e).

Table 3-31 Activity data in 1A4c Agriculture/forestry/fishing.

Source/fuel	**1990**	**1995**	**2000**	**2005**	**2010**	
1A4c Other Sectors - Agriculture/forestry			TJ			
Alkylate gasoline	NO	0.20	0.41	0.46	0.50	
Diesel	17.91	16.84	17.50	18.19	18.46	
Biodiesel	NO	NO	0.02	0.05	0.07	
Source/fuel	**2012**	**2013**	**2014**	**2015**	**2016**	
1A4c Other Sectors - Agriculture/forestry			TJ			
Alkylate gasoline	0.51	0.47	0.62	0.47	0.80	
Diesel	14.32	19.55	16.19	15.57	14.43	
Biodiesel	0.05	0.07	0.09	0.19	0.34	
Source/fuel	**2017**	**2018**	**2019**	**2020**	**2021**	**1990-2021**
1A4c Other Sectors - Agriculture/forestry			TJ			%
Alkylate gasoline	0.82	0.49	0.48	0.60	0.50	-
Diesel	15.18	21.90	21.34	23.17	23.87	33%
Biodiesel	0.59	1.13	1.12	1.19	0.98	-

3.2.8.3 Uncertainty assessment and time-series consistency

Uncertainties are analysed on an aggregated level for the entire source category 1A since no customs statistics exist that would provide reliable data on fuel imports into Liechtenstein. The aggregated uncertainty analysis is presented in chapter 3.2.10.

3.2.8.4 Category-specific QA/QC and verification

Information about category-specific QA/QC activities and verification processes are provided in chapter 3.2.11.

3.2.8.5 Category-specific recalculations

No category-specific recalculations were implemented.

3.2.8.6 Category-specific planned improvements

According to Liechtenstein's inventory development plan, no future improvements are planned under source-category 1A4.

3.2.9 Other (1A5)

3.2.9.1 Category description: Other (1A5)

Emissions of category 1A5 do not occur in Liechtenstein.

3.2.10 Uncertainties and time-series consistency 1A

3.2.10.1 Uncertainties – Fuel combustion activities (1A)

For the current submission, a simplified uncertainty analysis has been carried out as described in chp. 1.6. Uncertainties were accounted individually for the key categories, whereas the rest of the sources was aggregated by gas and treated as four "rest" categories (CO_2, CH_4, N_2O, F-gases) with mean uncertainties according to Table 1-7. The key categories 1A1 gaseous fuels, 1A2 liquid fuels, 1A2 gaseous fuels, 1A3b, 1A4 liquid fuels, 1A4 gaseous fuels are treated individually, whereas the remaining categories are included in the "rest" categories with mean uncertainty.

Uncertainty in aggregated fuel consumption activity data (1A)

Liechtenstein and Switzerland form a customs and monetary union governed by a customs treaty. Therefore, no customs statistics exist that would provide reliable data on (liquid and solid) fuel imports into Liechtenstein. However, the data on fuel consumption originates at the aggregated level of sales figures. It is disaggregated using simple expert judgement leading to the consumption in households as well as different industry and services sectors (see Section 3.2.4.2, energy statistics and contribution to the IPCC source categories). For liquid fuels, the uncertainties have been estimated for four fuel types separately, because methods to determine fuel consumption and associated uncertainties differ for each fuel type (see also section 1.6.3 and 3.2.4.2).

Details about the uncertainty analysis of the activity data (fuel consumption) in 1A are based on expert judgements. Dominant to overall uncertainty is liquid fuel consumption. Since import customs statistics of oil products do not exist, this data is based on surveys with oil suppliers, carried out earlier by OEA and in recent years by OEP/OE.

Comparing different liquid fuels, the uncertainty for gasoline is lowest because activity data is based on surveys at all filling stations in Liechtenstein and the uncertainty is estimated to be 10%. Diesel consumption is also based on surveys at filling stations, but small unknown quantities may be imported directly from construction companies and farmers. Therefore, the uncertainty is estimated to be 15% for diesel. The uncertainty for gas oil and LPG consumption is estimated to be the highest among liquid fuels, because fuel is provided by direct delivery to homes by several companies, which is more difficult to monitor. Their uncertainties are estimated to be 20%.

Uncertainty of gaseous fuels is estimated to be 5% as the quantities of gas can be determined on a detailed level. Solid fuels and biomass fuels have a relatively high uncertainty of 20%.

Uncertainty of CO_2 emission factors in Fuel combustion activities (1A)

Liechtenstein and Switzerland form a customs and monetary union governed by a customs treaty. Therefore, all gas oil is supplied by Swiss suppliers and no taxation accrues at the borders for the import to Liechtenstein. It is therefore assumed that fuel has the same properties as the fuels sold on the Swiss market. Therefore, the emission factors and their uncertainties have been taken from Switzerland, and are documented in the Swiss NID (FOEN 2023):

In 2013, a large measurement campaign was carried out in Switzerland to determine the CO_2 emission factors of the dominant liquid fuels (SFOE/FOEN 2014). Based on the standard deviation of these measurements relative uncertainties were derived (FOEN 2023). Liechtenstein adopts these uncertainty estimates for the uncertainty analysis. The following uncertainties have been applied for the emission factors:

- Natural gas (1A1, 1A2, 1A4): U(EF CO_2) = 0.4%
- Liquid fuels (1A2, 1A4): U(EF CO_2) = 0.08%
- Gasoline (1A3b): U(EF CO_2) = 0.13%
- Diesel oil (1A3b): U(EF CO_2) = 0.07%

Note that 1A3b/CO_2 is not differentiated in the KCA of the CRF Reporter by fuel type but is considered as a key category as sum of gasoline and diesel oil. For the uncertainty analysis, the uncertainty of the aggregated category has to be calculated via error propagation from the uncertainty inputs given above: AD 10% and 15% for gasoline and diesel oil respectively and EF (CO_2) 0.13% and 0.07%. Annex 2shows the procedure for uncertainty aggregation. The results are:

1A3b/CO_2: U(AD) = 9.4%, U(EF) = 0.07%.

Analogously, the uncertainties of the aggregated key categories 1A4 liquid fuels, 1A4 gaseous fuels are derived:

1A4 liquid/CO_2: U(AD) = 15.8%, U(EF) = 0.06%

1A4 gaseous/CO_2: U(AD) = 4.0%, U(EF) = 0.32%

All the non-key categories of 1A (1A1a/CH_4, 1A1a/N_2O, 1A2e/CH_4 etc.) are summed up in the rest categories CH_4, N_2O to which medium uncertainties are attributed (see explanation in chapter 1.6).

3.2.10.2 Consistency and completeness 1A - Fuel combustion activities

Consistency

The applied methods for the calculations of Liechtenstein's GHG emissions are the same for the years 1990-2021. The entire time series are therefore consistent.

Completeness

The emissions for the entire time series 1990–2021 have been calculated and reported. The data on emissions of the Kyoto gases for sector 1 Energy (CO_2, CH_4, N_2O) are also complete.

3.2.11 Category-specific QA/QC and verification of Fuel combustion activities (1A)

General QA/QC activities

The category-specific QA/QC activities have been carried out as mentioned in section 1.5also including triple checks of Liechtenstein's reporting tables (CRF tables). The triple check includes a detailed comparison of current and last year emissions by two NID authors and by the specialist from the Office of Environment. In addition, the activity data has been cross checked with the data in Liechtenstein's energy statistics (OS 2022a).

Road transportation (1A3b)

The international project for the update of the emission factors for road vehicles is overseen by a group of external and international experts that guarantees an independent quality control. Updated emission factors for Switzerland's road transport emissions were published in 2022 (INFRAS 2022a). The same emission factors are used for Liechtenstein.

The results have undergone large plausibility checks and comparisons with earlier estimates.

The emission factors for CH_4 and N_2O used for the modelling of 1A3b Road transportation are taken from the handbook of emission factors HBEFA 4.2 (INFRAS 2022a), which is also applied in Germany, Austria, the Netherlands and Sweden.

3.2.12 Category-specific recalculations

All recalculations carried out for source categories 1A1 – 1A5 are listed in corresponding sub-chapters 3.2.5.5 to 3.2.8.5. No other recalculations have been performed.

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

3.3.1 Fugitive emissions from solid fuels (1B1)

Fugitive emissions from category 1B1 Fugitive emissions from solid fuels do not occur in Liechtenstein.

3.3.2 Fugitive emissions from oil and natural gas and other emissions from energy production (1B2)

3.3.2.1 Category description: Fugitive emissions from oil and natural gas and other emissions from energy production (1B2)

Key category information 1B2b
Source category 1B2b Fugitive emissions of CH_4 from natural gas is a key category regarding trend.

Intentional or unintentional release of greenhouse gases may occur during the extraction, processing and delivery of fossil fuels to the point of final use. These are known as fugitive emissions (IPCC 2006). According to the IPCC guidelines (IPCC 2006), the term fugitive emissions in 1B2 cover all greenhouse gas emissions from oil and gas systems except contributions from fuel combustion. Oil and natural gas systems comprise all infrastructure required to produce, collect, process or refine and deliver natural gas and petroleum products to market. The system begins at the well head, or oil and gas source, and ends at the final sales point to the consumer (IPCC 2006).

In Liechtenstein, only emissions from gas pipelines occur. Table 3-32 shows the sources for which fugitive emissions are accounted for.

Fuel consumption by equipment supporting pipeline transportation activities of natural gas and ground activities in airports do not occur in Liechtenstein.

Table 3-32 Specification of source category 1B2 Fugitive emissions from oil and natural gas and other emissions from energy production.

1B2	Source	Specification
1B2a	Oil	Not occurring in Liechtenstein.
1B2b	Natural gas	Emissions from gas pipelines only.
1B2c	Venting and flaring	Not occurring in Liechtenstein.
1B2d	Other	Not occurring in Liechtenstein.

3.3.2.2 Methodological issues: Fugitive emissions from oil and natural gas and other emissions from energy production (1B2)

Methodology

For source 1B2b Natural gas, the emissions of CH_4 leakages from gas pipelines are calculated with a Tier 3 method. The method considers the length, type and pressure of the gas pipelines. The distribution network components (regulators, shut off fittings and gas meters), the losses from maintenance and extension as well as the end user losses are taken into account. NMVOC leakages are not estimated. For the calculation of the fugitive emissions of the transmission pipelines data in Table 3-36 and Table 3-37 are considered. Regarding density, NCV and share of methane within natural gas, the following values are applied for the entire time series:

- Net calorific value (NCV): 36.3 MJ/m^3 (under norm conditions of 0°C and 1013 mbar)
- Density of methane: 0.717 kg/m^3 (under norm conditions of 0°C and 1013 mbar)
- Content of methane in natural gas: 92.6%

According to expert information of Liechtenstein's gas utility (LGV), the losses identified within the NID are generally overestimated as the natural gas pipeline has a very high quality based on its new pipeline system compared to other natural gas systems. For the calculation approach the points below have to be considered:

- In Liechtenstein's approach, the total amount of natural gas transported through the pipeline is not relevant. For the estimation of the fugitive emissions, the amount of natural gas transported is not used and only the length as well as the type and pressure of the gas pipelines are considered.
- Additionally, several aspects as for example the emissions of the components at the household connection, emissions from the network maintenance as well as from

components in the transmission pipeline (e.g. valves) are also considered in Liechtenstein's calculation (see Table 3-34).

Therefore, the calculation is defined as **the length of the pipeline (km of pipeline) x emission factor of losses (EF / km of pipeline).** Additionally, losses of the household connections as well as different components in the transmission pipeline (in % of the leakage per pipeline calculated) are added as well.

Within the reporting tables (CRF), the data for distribution is included in the energy unit GJ. Therefore, the emissions calculations described above are at the end converted into energy unit GJ in order to provide the data needed in the CRF.

Emission factors

The emission factors for gas distribution losses (source 1B2b) depend on the type and pressure of the natural gas pipeline (see Table 3-33) and are taken from literature. Batelle (1994) provides specific emission factors for different sources of fugitive emissions based on measurements of 1989 in Germany. Specific data for Switzerland (and Liechtenstein) is provided by a study of Xinmin (2004).

Liechtenstein is a very small country and strongly linked with Switzerland in several aspects. Therefore, the technology providers are mostly the same for both countries and it can be assumed that the technologies used are the same. Therefore, the CH_4 emission factors are assumed to be applicable also for Liechtenstein.

Table 3-33 CH_4 emission factors for 1B2b Fugitive emissions from natural gas in 2021 (Battelle 1994, Xinmin 2004). For HDPE (polyethylene) 1-5 bar, the upper value shows the assumption for 1993 and previous years while the lower value (italic) shows the value for 2001 and following years. Data between 1993 and 2001 are linearly interpolated between the two values.

Source/fuel	< 100 mbar [m^3/h/km]	1-5 bar [m^3/h/km]	> 5 bar [m^3/km*year]	Gas meters [m^3/number*year]
1B2b Fugitive emissions from natural gas				
Steel cath.	-	-	249	-
HDPE (polyethylene)	0.0080	0.0024	-	-
		0.0006		
Gas meters	-	-	-	5.11

Table 3-34 provides background information on the natural gas losses at gas meters and at end users, which are provided as shares in terms of natural gas volumes used in industry and "other" (=households and services) respectively as documented in Table 3-37. The CH_4 emissions from gas meters are accounted for by applying an emission factor of 5.11 m^3 CH_4 per gas meter and year (Batelle 1994). Losses at end users are estimated based on expert assumptions.

Table 3-34 Natural gas losses at end users as additional information (Battelle 1994, S.114).

Source/fuel		**1990-2021**
1B2b Fugitive emissions from natural gas	Unit	
Losses end user (Gas meters)	m^3/(gas meter*year)	5.11
Losses end user (Installations) households, services	%	0.06
Losses end user (Installations) Industry	%	0.06

The fugitive emissions of CO_2 from natural gas are calculated by using a country-specific emission factor based on measurements of the gas composition in 2016 and 2017 (Acontec 2018b). It amounts to 0.78% of the total volume of natural gas. The emission factor is assumed constant for the entire time series.

Table 3-35 CO_2 emission factors for 1B2b Fugitive emissions from natural gas. A constant emission factor is used for the entire time series.

Source/fuel		**1990-2021**
1B2b Fugitive emissions from natural gas	Unit	
Fugitive CO_2 Emissions from natural gas	Vol %	0.78%

Activity data

The activity data such as length and type of the pipelines in the distribution network for the calculation of methane leaks have been extracted from the annual reports of Liechtenstein's Gas Utility (LGV 2022, edition 2021 includes data up to 2021). The emissions are attributed on one hand to the activity data of the steel cath. pipelines of >5 bar pressure as part of the transmission of natural gas and on the other hand to pipelines of the distribution network (HDPE pipelines).

Table 3-36 Activity data for 1B2 Fugitive emissions from oil and natural gas and other emissions from energy production. Activity data include the length of natural gas pipelines and the number of connections to customers.

Source/fuel		1990	1995	2000	2005	2010
1B2b Fugitive emissions from natural gas	**Unit**					
Steel cath. > 5 bar	km	26.3	26.3	26.3	26.6	26.6
HDPE (Polyethylene) 1-5 bar	km	28.5	29.5	37.3	45.6	51.0
HDPE (Polyethylene) < 100 mbar	km	67.0	135.9	206.0	276.3	312.8
Connections	number	479	1’398	2’460	3’464	4’116

Source/fuel		2012	2013	2014	2015	2016
1B2b Fugitive emissions from natural gas	**Unit**					
Steel cath. > 5 bar	km	26.7	26.7	26.7	26.7	26.7
HDPE (Polyethylene) 1-5 bar	km	51.6	51.9	52.1	52.1	52.1
HDPE (Polyethylene) < 100 mbar	km	323.8	328.8	336.1	341.2	347.0
Connections	number	4’311	4’337	4’411	4’486	4’491

Source/fuel		2017	2018	2019	2020	2021	1990-2021
1B2b Fugitive emissions from natural gas	**Unit**						%
Steel cath. > 5 bar	km	26.7	26.7	26.7	26.7	26.7	1%
HDPE (Polyethylene) 1-5 bar	km	52.1	52.1	52.1	52.1	51.6	81%
HDPE (Polyethylene) < 100 mbar	km	352.0	355.6	360.7	363.5	366.8	447%
Connections	number	4’571	4’651	4’715	4’758	4’768	895%

Table 3-36 documents the continuous increase of Liechtenstein’s gas supply network since 1990. By 2020, the number of connections installed have increased by about a factor of 10 compared 1990.

Table 3-37 Natural gas volumes of Liechtenstein’s natural gas distribution network as additional information.

Source/fuel	Unit	1990	1995	2000	2005	2010
1B2b Fugitive emissions from natural gas						
Natural gas volume industry	Mio. m^3	7.5	8.8	9.7	10.4	6.0
Natural gas volume other	Mio. m^3	5.1	11.7	16.8	25.1	23.7
Sum natural gas volume	Mio. m^3	**12.6**	**20.5**	**26.5**	**35.4**	**29.8**

Source/fuel	Unit	2012	2013	2014	2015	2016
1B2b Fugitive emissions from natural gas						
Natural gas volume industry	Mio. m^3	5.8	5.7	7.6	7.1	7.2
Natural gas volume other	Mio. m^3	21.1	22.7	16.0	18.1	17.9
Sum natural gas volume	Mio. m^3	**26.8**	**28.4**	**23.6**	**25.2**	**25.1**

Source/fuel	Unit	2017	2018	2019	2020	2021	1990-2021
1B2b Fugitive emissions from natural gas							%
Natural gas volume industry	Mio. m^3	7.7	7.1	6.3	5.7	6.4	-15%
Natural gas volume other	Mio. m^3	18.6	17.3	18.5	18.1	20.2	298%
Sum natural gas volume	Mio. m^3	**26.3**	**24.4**	**24.7**	**23.9**	**26.6**	**112%**

3.3.2.3 Uncertainties and time-series consistency

Uncertainty in fugitive CH_4 emissions from natural gas pipelines in 1B2

The combined uncertainty of emissions of CH_4 from 1B2 (which is a key category regarding trend) is estimated based on expert judgement.

For the current submission, a simplified uncertainty analysis has been carried out as described in chp. 1.6. Uncertainties were accounted individually only for the key categories, whereas the rest of the sources was aggregated by gas and treated as four "rest" categories (CO_2, CH_4, N_2O, F-gases) with mean uncertainties according to Table 1-7. Since emissions of CO_2 from 1B2 is not a key category, its uncertainties are accounted in the "rest" categories with mean uncertainty, which is 10% combined uncertainty for CO_2 emissions.

The time series are consistent.

3.3.2.4 Category-specific QA/QC and verification

The category-specific QA/QC activities have been carried out as mentioned in sections 1.5 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2020 and for the changing rates 2020/2021).

3.3.2.5 Category-specific recalculations

No category-specific recalculations were carried out.

3.3.2.6 Category-specific planned improvements

No category-specific improvements are planned.

3.4 CO_2 transport and storage (1C)

Category 1C is not occurring in Liechtenstein.

4. Industrial processes and product use (CRT sector 2)

4.1 Overview of sector

Industrial processes and product use (IPPU) covers greenhouse gas emissions occurring from industrial processes, from the use of products, and from non-energy uses of fossil fuel carbon. According to IPCC guidelines (IPCC 2006), emissions within this sector comprise greenhouse gas emissions as by-products from industrial processes and also emissions of synthetic greenhouse gases during production, use and disposal. Emissions from fuel combustion in industry are reported in source category 1A2.

Only GHG emissions of two IPCC source categories among the IPPU sector occur in Liechtenstein. Sources in the following source categories do not occur in Liechtenstein at all:

- Mineral industry (2A)
- Chemical industry (2B)
- Metal industry (2C)
- Electronics industry (2E)
- Other (2H)

GHG emissions from 2F Product uses as ODS substitutes, in particular HFC and PFC emissions from 2F1 Refrigeration and air conditioning, HFC emissions from 2F2 Foam blowing agents and from 2F4 Aerosols, as well as from 2G Other product manufacture and use (including N_2O emissions from 2G3a Medical applications and 2G3b Other propellant for pressure and aerosol products), are reported under source category 2 IPPU. In addition, SF6 emissions from 2G1 Electrical equipment and CO_2 emissions from 2D1 Lubricant use are reported. NF_3 emissions are not occurring.

The emissions of source category 2 Industrial processes and product use have increased from 1990 to 2014. Since 2018 they show a decreasing tendency (Table 4-1 and Figure 4-1).

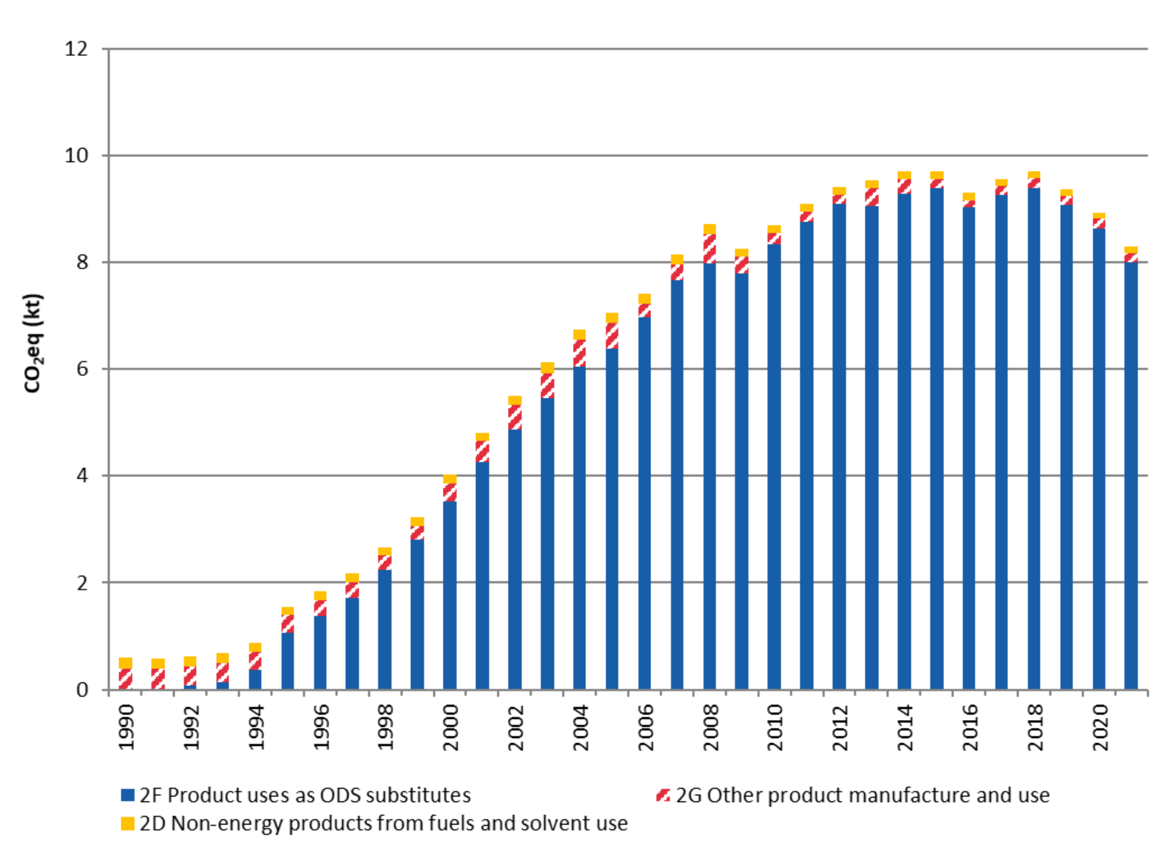


Figure 4-1 Liechtenstein's GHG emissions of sector 2 Industrial processes and product use. Note that there are no emissions in sectors 2A, 2B, 2C, 2E and 2H.

The most relevant emissions are those of HFCs followed by N_2O, SF_6 and PFC emissions, which are of minor importance. The use of HFC started to be relevant in 1992 when these substances were introduced as substitutes for CFCs.

The total emissions of sector 2 Industrial processes and other product use (IPPU) account for 8.3 kt CO_2 equivalent in 2021. Emissions of the IPPU sector play therefore a minor role in Liechtenstein's inventory and contribute to 4.5% to the total emissions excluding LULUCF. 8.0 kt CO_2 equivalent were emitted in sector 2F Product uses as ODS substitutes and another 0.2 kt CO_2 equivalent in sector 2G Other product manufacture and use and 0.1 kt CO_2 equivalent in sector 2D Non-energy products from fuels and solvent use. The total emissions in the IPPU sector increased by a factor of 14 since 1990. This trend is in particular dominated by the increase in HFC emissions. CO_2 emissions decreased by 45% and N_2O emissions decreased by 68% between 1990 and 2021.

From 2020 to 2021, the total F-gas emissions decreased by 7.3%, HFC emissions decreased by 7.4%, PFC emissions decreased by 4.5% and SF_6 emissions increased by 3.8%.

Further details on the methodological approach used for the calculation of emissions from source category 2D, 2F and 2G are documented in Annex A5.3.

Table 4-1 GHG emissions of sector 2 Industrial processes and product use by gases in CO_2 equivalent (kt) and the relative change (last column).

Gas	1990	1995	2000	2005	2010
	CO2 equivalent (kt)				
CO_2	0.2	0.16	0.17	0.20	0.15
N_2O	0.40	0.32	0.24	0.22	0.18
F-Gases	0.00	1.07	3.62	6.64	8.36
Sum	**0.60**	**1.55**	**4.03**	**7.06**	**8.69**

Gas	2012	2013	2014	2015	2016
	CO2 equivalent (kt)				
CO_2	0.14	0.14	0.14	0.14	0.14
N_2O	0.17	0.15	0.15	0.14	0.13
F-Gases	9.10	9.24	9.40	9.42	9.04
Sum	**9.41**	**9.53**	**9.69**	**9.69**	**9.30**

Gas	2017	2018	2019	2020	2021	1990-2021
	CO2 equivalent (kt)					%
CO_2	0.13	0.12	0.12	0.11	0.11	-45%
N_2O	0.12	0.12	0.13	0.13	0.13	-68%
F-Gases	9.30	9.45	9.11	8.68	8.05	8378144%
Sum	**9.56**	**9.70**	**9.36**	**8.92**	**8.29**	**1273%**

4.2 Mineral industry (2A)

Greenhouse gas emissions from category 2A are not occurring in Liechtenstein.

4.3 Chemical industry (2B)

Greenhouse gas emissions from category 2B are not occurring in Liechtenstein.

4.4 Metal industry (2C)

Greenhouse gas emissions from category 2C are not occurring in Liechtenstein.

4.5 Non-energy products from fuels and solvent use (2D)

4.5.1 Category description: Non-energy products from fuels and solvent use (2D)

Key category information 2D
Source category 2D "Non-energy products from fuels and solvent use" is not a key category.

Source category 2D comprises emissions of CO_2 from lubricant use. Other direct greenhouse gas emissions from source category 2D are not occurring in Liechtenstein.

Table 4-2 Specification of source category 2D Non-energy products from fuels and solvent use.

2D	Source	Specification
2D1	Lubricant use	Emissions of CO_2 from primary usage of lubricants in machinery and vehicles

4.5.2 Methodological issues: Non-energy products from fuels and solvent use (2D)

4.5.2.1 Methodology

Lubricant use (2D1)

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 are primarily used for their lubricating properties and associated CO_2 emissions are therefore considered as non-combustion emissions reported in 2D1 Lubricant use.

Liechtenstein estimates the emissions from lubricant use in Switzerland by assuming that emissions in Liechtenstein are proportional to the number of inhabitants.

4.5.2.2 Emission factors

Lubricant use (2D1)

The emission factors of CO_2 from lubricant 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.

Based on CO_2 emissions in source category 2D1 in Switzerland and the number of inhabitants in Switzerland the following emission factors per inhabitant for Liechtenstein are derived.

Table 4-3 Emission factors for 2D1 Non-energy products from fuels and solvents.

Emission factors 2D Non-energy products from fuels and solvents		1990	1995	2000	2005	2010	
Inhabitants Switzerland	number	6'712'000	7'041'000	7'184'000	7'437'000	7'825'000	
Emissions 2D1 Switzerland	kt	47.0	36.2	37.0	42.7	32.6	
2D1 EF CO_2 from Lubricant use - CO_2	kg/inhabitant	7.00	5.14	5.15	5.74	4.17	
Emission factors 2D Non-energy products from fuels and solvents		**2012**	**2013**	**2014**	**2015**	**2016**	
Inhabitants Switzerland	number	7'997'000	8'089'000	8'189'000	8'282'000	8'373'000	
Emissions 2D1 Switzerland	kt	30.1	31.5	31.7	30.5	30.2	
2D1 EF CO_2 from Lubricant use - CO_2	kg/inhabitant	3.76	3.90	3.87	3.68	3.60	
Emission factors 2D Non-energy products from fuels and solvents		**2017**	**2018**	**2019**	**2020**	**2021**	**1990-2021 %**
Inhabitants Switzerland	number	8'452'000	8'514'000	8'575'000	8'638'000	8'705'000	30%
Emissions 2D1 Switzerland	kt	29.5	27.0	26.1	23.5	25.0	-47%
2D1 EF CO_2 from Lubricant use - CO_2	kg/inhabitant	3.49	3.17	3.05	2.73	2.87	-59%

4.5.2.3 Activity data

Lubricant use (2D1)

The amount of lubricants used in Liechtenstein is based on import, export and production data from Switzerland (FOEN 2022b). The amount used in Liechtenstein is assumed to be proportional to the number of inhabitants in Switzerland and Liechtenstein respectively.

Table 4-4 Number of inhabitants of Liechtenstein as proxy for activity data calculations of emissions under source category 2D1.

Number of inhabitants for AD calculation	1990	1995	2000	2005	2010	
	Number of inhabitants					
Liechtenstein	29'032	30'923	32'863	34'905	36'149	
Number of inhabitants for AD calculations	**2012**	**2013**	**2014**	**2015**	**2016**	
	Number of inhabitants					
Liechtenstein	36'838	37'129	37'366	37'623	37'810	
Number of inhabitants for AD calculations	**2017**	**2018**	**2019**	**2020**	**2021**	**1990-2021 %**
	Number of inhabitants					
Liechtenstein	38'114	38'380	38'749	39'055	39'315	35%

4.5.3 Uncertainties and time-series consistency

For the current submission, a simplified uncertainty analysis has been carried out as described in chp. 1.6. Uncertainties were accounted individually only for the key categories, whereas the rest of the sources was aggregated by gas and treated as four "rest" categories (CO_2, CH_4, N_2O, F-gases) with mean uncertainties according to Table 1-7. Since 2D1 is not a key category, its uncertainties are accounted in the "rest" categories with mean uncertainty, which is 10% combined uncertainty for CO_2 emissions.

The time series are consistent.

4.5.4 Category-specific QA/QC and verification

The category-specific QA/QC activities are documented in section 1.5.

4.5.5 Category-specific recalculations

The following recalculation was implemented:

- 2D1: The emission factor for lubricants use was updated for the years 2019 and 2020, since updated data on CO_2 emissions from lubricant use in Switzerland was available (FOEN 2022b).

4.5.6 Category-specific planned improvements

No category-specific improvements are planned.

4.6 Electronic industry (2E)

4.6.1 Category description: Electronic industry (2E)

Greenhouse gas emissions from category 2E are not occurring in Liechtenstein.

4.7 Product uses as ODS substitutes (2F)

4.7.1 Category description: Product uses as ODS substitutes (2F)

Key category information 2F1
Source category 2F1 aggregated F-gases from Refrigeration and Air conditioning is a key category regarding level and trend.

Source category 2F comprises HFC and PFC emissions from consumption of the products listed below. Other applications are not occurring in Liechtenstein.

Table 4-5 Specification of source category 2F Product uses as substitutes for ODS.

2F	Source	Specification
2F1	Refrigeration and air conditioning	Emissions from Refrigeration and Air Conditioning Equipment (inclusive heat pumps and tumble dryers)
2F2	Foam blowing agents	Emissions from foam blowing, incl. Polyurethan spray
2F3	Fire protection	Not occurring in Liechtenstein.
2F4	Aerosols	Emissions from use as aerosols, incl. Metered dose inhalers
2F5	Solvents	Not occurring in Liechtenstein.
2F6	Other applications	Not occurring in Liechtenstein.

4.7.2 Methodological issues: Product uses as ODS substitutes (2F)

4.7.2.1 Methodology

Data on HFC and PFC emissions are not available for Liechtenstein. Therefore, these emissions are derived from data from Switzerland's national inventory database EMIS (FOEN 2022a) as a best estimate.

In order to derive Liechtenstein's emissions under source category 2F, the most relevant source categories were determined using a relative threshold in a first step. Every single emission source given in Switzerland's national inventory database EMIS was analysed with respect to a threshold, which is defined by the following methodology:

For every single emission source and gas, the contribution to the total GHG emissions of the respective source category at the level of 2F1, 2F2 and 2F4 is calculated. A threshold of 10% is defined and applied per sub-category (2F1, 2F2 and 2F4). Only emission sources and gases that contribute more than 10% to a given sub-category are considered to be relevant for Liechtenstein's GHG inventory under source category 2F. Emissions that account for less than 10% in the Swiss inventory in the respective sub-category are neglected, since they likely originate from an emissions source that does not occur in Liechtenstein.

For the emission sources identified as relevant by applying the 10% threshold in the Swiss GHG inventory, emissions in Liechtenstein are estimated by applying the rule of proportion. They are calculated based on the emissions reported by Switzerland and specific indicators such as the number of inhabitants or the number of employees. The Swiss emissions are then divided by the Swiss indicators in order to get Swiss-specific emissions per inhabitant or per employee etc. and are then multiplied by the corresponding indicator of Liechtenstein. This underlying assumption allows an estimate of emissions under source category 2F. As it can be assumed that the consumption patterns for industry, service sector and household sector of Liechtenstein are very similar to Switzerland, this approach will result in reliable figures for Liechtenstein. Further details on the methodological approach used for the calculation of emissions from source category 2F are documented in Annex A5.3.

Refrigeration and air conditioning (2F1)

In the Swiss Inventory PFC emissions, under 2F1, result from Commercial Refrigeration and Transport Refrigeration. More details of the underlying data models are documented in the Switzerland's National Inventory Report 2022 (FOEN 2022).

Manufacturing of refrigeration and air conditioning equipment is not occurring in Liechtenstein. Disposal of retired equipment falling under the categories of Domestic Refrigeration, Mobile Air Conditioning and Transport Refrigeration is collected mostly through a single recycling company in Liechtenstein (Elkuch Recycling AG). The recycling company collects and exports the equipment to Switzerland or Austria without recovering of F-gases in the refrigeration or Air Conditioning units. Nevertheless, Liechtenstein's emissions are estimated on basis of the rule of proportion applied onto the sum of emissions for Switzerland including manufacturing, product life emissions and disposal losses. For more precision, the rule of proportion should be restricted to product life emissions and the Swiss manufacturing emissions and disposal losses should be excluded from the calculation. Since the manufacturing emissions in Switzerland are of low relative importance, this bias is neglected. The inclusion of emissions from manufacturing and disposal is a conservative estimate for Liechtenstein. As the statistical basis for a more detailed analysis is not available, the effect is also neglected and the conservative estimation is accepted.

The following methodological explanation is taken from Switzerland's National Inventory Report 2022 (FOEN 2022), citations are written in italics. It is considered as valid for Liechtenstein as well, since Liechtenstein's data are based on Switzerland's national inventory database EMIS (FOEN 2022a):

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*
- *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 based on the bottom-up calculations of stock as given in the example of mobile air conditioning in Annex A3.2 in FOEN 2022).

The total bulk refrigerant for commercial and industrial application is split considering the typical use of refrigerant blends and information on commercial and industrial equipment provided to FOEN (Carbotech 2022). Parameters for commercial and industrial applications are given in Table 4 47 in FOEN 2022. 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.

Table 4-6 Indicators used in calculating Liechtenstein's emissions for source category 2F1 on basis of Switzerland's emissions by applying rule of proportion.

Application	**Refrigerant**	**Base value**	**Indicator for calculation by rule of proportion**
Domestic Refrigeration	HFC-134a	Total emissions reported for Switzerland	Number of households
Commercial Refrigeration	HFC-125 HFC-134a HFC-143a C_3F_8	Total emissions reported for Switzerland	Number of persons employed in industrial and service sector
Transport Refrigeration	HFC-125 HFC-134a HFC-143a	Total emissions reported for Switzerland	Number of inhabitants
Industrial Refrigeration	Included in commercial refrigeration		
Stationary Air Conditioning	HFC-32 HFC-125 HFC-134a HFC-143a	Total emissions reported for Switzerland	Number of persons employed in industrial and service sector
Mobile Air Conditioning	HFC-134a	Total emissions reported for Switzerland (cars, trucks, railway)	Number of registered cars

Foam blowing agents (2F2)

As manufacturing of foams is not occurring in Liechtenstein, only emissions during life of product and disposal are considered. Emissions under source category 2F2 are related to hard foams only. For soft foams, manufacturing using HFC is not occurring in Switzerland or Liechtenstein. As soft foam emissions are only occurring during production, emissions from soft foams are NO.

More details of the underlying data models are documented in Switzerland's National Inventory Report 2022 (FOEN 2022), given below.

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.

A 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 A5.1 in FOEN 2022) 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 2022).

Aerosols (2F4)

To restrict the complexity of the estimation model for Liechtenstein, gases with very low emissions in Switzerland are neglected, as described above. The relevance of the absolute emission amounts reported under 2F4 is very low and therefore, inaccuracies in the estimation model are considered negligible.

More details of the underlying data models are documented in Switzerland's National Inventory Report 2022 (FOEN 2022), given below.

The Tier 2a emission model for Aerosol / metered dose inhalers is based on a top-down approach using import statistics for HFCs.

4.7.2.2 Emission factors

Refrigeration and air conditioning (2F1)

Liechtenstein's emissions are estimated based on specific emission factors described above (e.g. emissions per inhabitant, emissions per employee, emissions per car, etc.) and the corresponding indicators. Underlying emission factors are taken from Switzerland's national inventory database EMIS (FOEN 2022a). The following explanations are taken from Switzerland's National Inventory Report 2022 (FOEN 2022):

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.*

The following table displays the detailed model parameters used for the present submission. Changes of model parameters within the period 1990 to 2020 are indicated with values in brackets. The parameters in brackets are applied for the inventory 2020. 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 (UBA 2005, UBA 2007, Schwarz 2001, Schwarz and Wartmann 2005). 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 4-7 Typical values of lifetime, charge and emission factors used in the model calculations for 1990 to 2020 for refrigeration and air conditioning equipment. Changes of model parameters within this time period are indicated with the new value in brackets (for example a charge of 4.7–7.5 kg was applied for heat pumps until 2000 and a lower charge of 2.8–4.5 kg from 2000 onwards). A linear interpolation is applied for the product life emission factor of commercial and industrial refrigeration, stationary air conditioning and for the emission factor of mobile air conditioning within the given time period (FOEN 2022).

Equipment type	Product life time	Initial charge of new product	Manufacturing emission factor	Product life emission factor	Charge at end of life *)	Export of retiring equipment **)	Disposal loss emission factor ***)
	[a]	[kg]	[% of initial charge]	[% per annum]	[% of initial charge of new product]	[% of retiring equipment]	[% of remaining charge]
Domestic refrigeration	16	0.1	NO	0.5	92	0-5	19 ****)
Commercial refrigeration	8	NR	0.5	Sinking from 12.5 in 1990 to 7.8 in 2015	80-90	NE	21
Industrial refrigeration	15	NR	0.5	Sinking from 10 in 1990 to 5 in 2015	75-90	NE	15
Transport refrigeration: trucks/vans	10	1.8-7.8	1.5	15	86	90	28
Transport refrigeration: wagons	16	NR	NO	10	100	NE	28
Stationary air conditioning: direct cooling systems	15	NR	3 (2005: 1)	Sinking from 10 in 1995 to 4 in 2010	74-89	NE	28
Stationary air conditioning: indirect cooling systems	15	NR	1	Sinking from 6 in 1995 to 4 in 2010	85-89	NE	19
Stationary air conditioning: heat pumps	15	4.7-7.5 (2000: 2.8-4.5)	3 (2005: 1)	2	86	NE	19
Stationary air conditioning: tumble dryers	15	0.4	0.5	2	74	NE	19
Mobile air conditioning: cars	15	Sinking from 0.84 1990 to 0.55 in 2014	NO	8.5	58	31-72 (2016: 48)	50
Mobile air conditioning: truck/van cabins	12	1.1	NO	10 (2010: 8.5)	69-73	90 trucks 50 vans	50
Mobile air conditioning: buses	12	7.5	NO	20 (2001: 15)	100	50	50
Mobile air conditioning: trains	16	20	NO	5.5	100	50	20

*) 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 of HFC and PFC 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

Foam blowing agents (2F2)

Liechtenstein’s emission factors are the derived indicators described above (e.g. emissions per inhabitant, emissions per employee, emissions per car, etc.). The underlying emission factors are provided by Switzerland’s national inventory database EMIS (FOEN 2022a). The following explanations are taken from Switzerland’s National Inventory Report 2022 (FOEN 2022):

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 4-8 Typical values on lifetime, charge and emission factors used in model calculations for foam blowing (from FOEN 2022).

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 is HFC free in Switzerland.

** 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).

Aerosols (2F4)

Liechtenstein’s emissions are estimated based on specific emission factors described above (e.g. emissions per inhabitant, emissions per employee, emissions per car, etc.) and the corresponding indicators. Underlying emission factors are taken from Switzerland’s national inventory database EMIS (FOEN 2022a). The following explanations are taken from Switzerland’s National Inventory Report 2022 (FOEN 2022):

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.

4.7.2.3 Activity data

Refrigeration and air conditioning (2F1)

Activity data for Liechtenstein is calculated based on activity data for Switzerland with the methodology as described above. The following figures have been used for the indicators:

Table 4-9 Figures used as indicators for calculation of activity data by applying rule of proportion.

	1990		2021	
Number of households				
Liechtenstein	10'556	Source: National census 1990 (OEA 2010)	17’833	Source: National census 2010 with trend extrapolation (OEA 2010)
Switzerland	2'841'850	Source: National census 1990 (SFSO 2005)	3’917’379	Source: Population and Households Statistics (SFSO 2022e)
Conversion Factor CH→LIE	0.371%		0.455%	
Number of employees in industrial and service sector				
Liechtenstein	19'554	Source: Employment statistics Liechtenstein (OS 2022e)	41’078	Source: Employment statistics Liechtenstein (OS 2022e)
Switzerland	3'658'406	Source: Employment statistics Switzerland (SFSO 2022b)	4'963'519	Source: Employment statistics Switzerland (SFSO 2022b)
Conversion Factor CH→LIE	0.534%		0.828%	
Number of registered passenger cars				
Liechtenstein	16'891	Source: Statistical Yearbook Liechtenstein (OS 2022c)	30'538	Source: Statistical Yearbook Liechtenstein (OS 2022c)
Switzerland	2'985'397	Source: National motorcar statistics for Switzerland (SFSO 2022c)	4'688'235	Source: National motorcar statistics for Switzerland (SFSO 2022c)
Conversion factor CH→LIE	0.566%		0.651%	

Foam blowing agents (2F2)

Activity data for Liechtenstein is calculated based on activity data for Switzerland with the methodology described above. The following figures have been used for the indicators:

Table 4-10 Figures used as indicator for calculation of activity data by applying rule of proportion (see also Table 4-4).

Number of inhabitants in 2020		
Liechtenstein	39'315	Source: OS 2022d
Switzerland	8'705'000	Source: SFSO 2022d
Conversion Factor CHE→LIE	0.452%	

Emissions from the foam blowing subcategory have been declining from 2009 to 2010. There are mainly two reasons for this: firstly, the only Swiss producer of PU-Sprays ceased the use of HFC in 2009 completely. This caused a significant decline in respective emissions. Secondly, a small but continuous declining trend of HFC content in imported goods from Germany can be observed.

Aerosols (2F4)

Activity data for Liechtenstein is calculated based on the number of inhabitants of Switzerland and Liechtenstein based on the methodology as described above. The figures as shown in Table 4-10 have been used as a proxy.

4.7.3 Uncertainties and time-series consistency

There is only one key category as determined by the CRF Reporter from this sector: 2F1/aggregate F-gases. The combined uncertainty is based data from the Swiss GHG inventory 2022 (FOEN 2022) for HFC, which were derived from a Monte Carlo simulation. It amounts to 15.1%. Since 99% of the F-gases emissions are caused by HFC, this value is applied.

For the emissions of F-gases of non-key categories, an uncertainty of 20% is assumed (Table 1-7).

The methods for calculating the emissions are consistent for the entire time series.

4.7.4 Category-specific QA/QC and verification

The category-specific QA/QC activities have been carried out as mentioned in section 1.5 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2020 and for the changing rates 2020/2021).

Under 2F3, emissions from Fire protection are reported as not occurring since no emissions are occurring in this sector within Switzerland. The application of HFC, PFC and SF6 in fire extinguishers is prohibited by law in Switzerland. For the 2010 GHG inventory of Liechtenstein (OEP 2012b) validity of this assumption was examined with industry representatives also for Liechtenstein. They confirmed that there is neither production nor disposal or known stocking of fire extinguishers using HFC, PFC or SF_6. Therefore, it can be assumed that the notation key NO is correct for Liechtenstein.

4.7.5 Category-specific recalculations

Switzerland's GHG inventory 2023 was not yet available for Liechtenstein's submission 2023. For Switzerland, the following recalculations have been carried out in submission 2022, which also influence Liechtenstein's emission time series reported in Submission 2023:

- 2F2: A correction of roundings was made, using two decimal places as applied for other emission factors.

In addition, the following recalculations lead to minor changes in HFC and PFC emissions:

- 2F1 Refrigeration and air conditioning: An error was corrected in the calculation of the conversion factor (activity data) in 2F1 commercial refrigeration, leading to changes in the activity data in the complete time series.
- 2F1 Refrigeration and air conditioning: Since a new household statistic is available for Switzerland (SFSO 2022e) the activity data (number of households) has changed from 2012-2020.
- 2F1 Refrigeration and air conditioning: Since the number of employees in industrial and service sector in Switzerland was updated based on newest available data (SFSO 2022b) the activity data (number of employees) has changed from 2010-2020.
- 2F1 Refrigeration and air conditioning: Since the number of registered passenger cars in Switzerland was updated based on newest available data (SFSO 2022c) the activity data (number of registered PC) has changed from 1995-2004.

4.7.6 Category-specific planned improvements

There are no category-specific planned improvements for the next submission

4.8 Other product manufacture and use (2G)

4.8.1 Source category description: Other product manufacture and use (2G)

Key category information 2G

Source category 2G "Other product manufacture and use" is not a key category.

According to the IPCC guidelines (IPCC 2006) N_2O for anaesthetic use is supplied in steel cylinders and used during anaesthesia for two reasons: a) as an anaesthetic and analgesic and as b) a carrier gas for volatile fluorinated hydrocarbon anaesthetics such as isoflurane, sevoflurane and desflurane. The anaesthetic effect of N_2O is additive to that of the fluorinated hydrocarbon agents. N_2O is also used as a propellant in aerosol products primarily in food industry. Typical usage is to make whipped cream, where cartridges filled with N_2O are used to blow the cream into foam (IPCC 2006).

Liechtenstein emission sources of 2G Other product manufacture and use are given in Table 4-11.

Table 4-11 Specification of source category 2G Other product manufacture and use.

2G	Source	Specification
2G1	Electrical equipment	SF6 emissions used in electrical equipment and released due to disposal.
2G2	SF_6 and PFCs from other product use	Not occuring in Liechtenstein.
2G3	N_2O from product uses	N_2O emissions from anaesthesia use in hospitals as well as N_2O emissions from the use of aerosol cans.
2G4	Other	Not occuring in Liechtenstein.

Source category 2G comprises emissions from SF6 in electrical equipment as well as N_2O emissions from product applications hospitals (anaesthesia) and households (aerosol cans). Other emissions do not occur in Liechtenstein or are not significant.

4.8.2 Methodological issues: Other product manufacture and use (2G)

4.8.2.1 Methodology

Electrical equipment

The only SF_6 emissions in Liechtenstein arise from the transformers operated by the utility Liechtensteinische Kraftwerke (LKW). The LKW reports on activity data and emissions with a Tier 3 method. A complete mass balance analysis is conducted by LKW on installation level, which was reconfirmed by LKW in 2011. No production of equipment with SF_6 is occurring.

N_2O from product use

Data availability in Liechtenstein is very limited. In order to estimate emissions for Liechtenstein, the specific emissions per inhabitant in Switzerland are used as a proxy: emissions from the source category 2G in Liechtenstein are the product of the specific emissions per inhabitant in Switzerland and the number of inhabitants in Liechtenstein. This basis allows an estimate of emissions. The rationale behind this approach is that the general characteristics for determining emissions are generally very similar in Liechtenstein and Switzerland (e.g. use of similar products). Further details on the methodological approach used for the calculation of emissions of N_2O from product use are documented in Annex A5.3.

4.8.2.2 Emission factors

Electrical equipment

Emission factors for this source category are based on industry information (LKW) and fluctuate over time due to differences in the gas imports per year, installations of F-gas equipment and differences in refill amounts of SF_6 gases (see Table 4-12).

N_2O from product use

Emission factors for N_2O, which correspond to the specific emissions per inhabitant, are taken from Switzerland's national inventory database EMIS (FOEN 2022a). Specific emission factors are derived for 2G3a Medical applications and 2G3b Other propellant for pressure and aerosol products. Table 4-12 illustrates the resulting implied emission factor on aggregated level for the entire source category 2G3. The rationale behind the methodology for source category 2G is that the general characteristics of Liechtenstein and Switzerland determining emissions are similar. As regulatory frameworks, technical standards and legal principles (threshold values, etc.) in the manufacture and use of electrical equipment sector of Liechtenstein correspond to Swiss standards, it is justified to adopt Switzerland's country-specific methodology and/or emission factors. Therefore, specific emissions per inhabitant in Switzerland (FOEN 2022a) are used as a proxy for Liechtenstein.

Table 4-12 Emission factors of Liechtenstein's SF_6 emissions under source category 2G1 and N_2O emissions under 2G3 for the time series 1990-2021.

Emission factors 2G Other product manufacture and use	1990	1995	2000	2005	2010	
2G1 Electrical equipment - SF_6 product life factor (% per annum)	NO	NO	0.360	0.403	0.033	
2G3 N_2O from product uses - N_2O (g/inhabitant)	52.0	39.5	27.0	23.8	18.7	
Emission factors 2G Other product manufacture and use	**2012**	**2013**	**2014**	**2015**	**2016**	
2G1 Electrical equipment - SF6 product life factor (% per annum)	0.001	0.201	0.130	0.041	0.016	
2G3 N_2O from product uses - N_2O (g/inhabitant)	17.4	14.8	14.8	14.0	12.8	
Emission factors 2G Other product manufacture and use	**2017**	**2018**	**2019**	**2020**	**2021**	**1990-2021 %**
2G1 Electrical equipment - SF6 product life factor (% per annum)	0.049	0.074	0.050	0.057	0.054	-
2G3 N_2O from product uses - N_2O (g/inhabitant)	12.3	12.3	12.2	12.2	12.2	-77%

4.8.2.3 Activity data

Table 4-4 illustrates the numbers of inhabitants of Liechtenstein and Switzerland for the entire time series. The number of inhabitants is used to derive Liechtenstein's activity data under source category 2G3.

Table 4-13 Activity data of source category 2G Other product manufacture and use. (Number of inhabitants see also Table 4-4.)

Activity data 2G Other product manufacture and use	1990	1995	2000	2005	2010	
2G1 Electrical equipment - SF_6 amount in operating systems (average annual stocks) in kt	NO	NO	0.0011	0.0028	0.0031	
2G3 N_2O from product uses - number of inhabitants	29'032	30'923	32'863	34'905	36'149	
Emission factors 2G Other product manufacture and use	**2012**	**2013**	**2014**	**2015**	**2016**	
2G1 Electrical equipment - SF_6 amount in operating systems (average annual stocks) in kt	0.0037	0.0038	0.0039	0.0040	0.0040	
2G3 N_2O from product uses - number of inhabitants	36'838	37'129	37'366	37'623	37'810	
Emission factors 2G Other product manufacture and use	**2017**	**2018**	**2019**	**2020**	**2021**	**1990-2021 %**
2G1 Electrical equipment - SF_6 amount in operating systems (average annual stocks) in kt	0.0040	0.0041	0.0041	0.0041	0.0042	-
2G3 N_2O from product uses - number of inhabitants	38'114	38'380	38'749	39'055	39'315	35%

Electrical equipment

Activity data is based on industry information. Before 1995/1996 a different technology was applied, which did not use SF_6 (see Table 4-13). SF_6 emissions show an increasing trend. Since only one company is involved (LKW), individual changes in emissions become evident. Variability could also be a result of changing reporting periods and/or changes (reductions) in actual maintenance and repair interventions.

N_2O from product use & Other

The activity data is the number of inhabitants in Liechtenstein and is provided in Table 4-4. The number of inhabitants in Liechtenstein is taken from OS 2022d. Data on the Swiss inhabitants (see Table 4-9) are taken from SFSO 2022d.

4.8.3 Uncertainties and time-series consistency

For the current submission, a simplified uncertainty analysis has been carried out as described in chp. 1.6Uncertainties were accounted individually only for the key categories, whereas the rest of the sources was aggregated by gas and treated as four "rest" categories (CO_2, CH_4, N_2O, F-gases) with mean uncertainties according to Table 1-7. Since 2G is not a key category, its uncertainties are accounted in the "rest" categories with mean uncertainty, which is 20% combined uncertainty for SF_6 emissions.

The time series are consistent.

4.8.4 Category-specific QA/QC and verification

The category-specific QA/QC activities have been carried out as mentioned in section 1.5including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2020 and for the changing rates 2020/2021).

For the inventory 2010 (OEP 2012b), the sum of SF_6 emissions reported by Liechtenstein for 1996-2010 for the former source category 2F8 Electrical Equipment as potential and actual emissions have been checked with the "Liechtensteinische Kraftwerke" (LKW 2010) and were confirmed to be plausible in view of the installation-based data from the electrical equipment operated by the "Liechtensteinische Kraftwerke".

4.8.5 Category-specific recalculations

The following recalculation leads to minor changes in N_2O emissions:

- 2G3 N_2O from product use: An error was corrected in the calculation of the emission factor in 2G3, leading to minor changes in N_2O emissions in the complete time series.

4.8.6 Category-specific planned improvements

No category-specific improvements are planned.

4.9 Other (2H)

4.9.1 Category description: Other (2H)

Emissions from category 2H are not occurring in Liechtenstein.

5. Agriculture (CRT sector 3)

5.1 Overview of sector

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

- Enteric fermentation (3A) – CH_4 emissions from domestic livestock
- Manure management (3B) – CH_4 and N_2O emissions
- Agricultural soils (3D) – N_2O, NO_x, CO, and NMVOC emissions
- Urea application (3H) – CO_2 emissions

Categories 3C Rice cultivation, 3E Prescribed burning of savannas, 3F Field burning of agricultural residues and 3G Liming do not occur in Liechtenstein and are therefore not reported. Please also note that in line with IPCC Guidelines CO_2 emissions from energy use in agriculture are reported under sector 1 Energy Other sectors (1A4c).

Liechtenstein's emissions within sector 3 Agriculture are calculated according to the Swiss agriculture model. The ERT considered this approach as appropriate in its Annual Review Report 2014 (FCCC/ARR 2014) in paragraph 60. Country-specific activity data such as livestock, agricultural area, harvest or milk yield are updated on a yearly basis. Specific parameters and variables of the model are revised at 5-year intervals with latest Swiss values and data. The effort for updating the model at an annual basis is not feasible for a small country such as Liechtenstein (see planned improvements in chp. 10.4). The latest update has been conducted for submission 2020.

Greenhouse gas emissions from agriculture amount to 25.5 kt CO_2 equivalents in 2021, which is a contribution of 13.9% to the total of Liechtenstein's greenhouse gas emissions (excluding LULUCF). Main agricultural sources of greenhouse gases in 2020 were enteric fermentation emitting 15.9 kt CO_2eq, followed by agricultural soils with 5.2 kt CO_2eq, manure management with 4.5 kt CO_2eq and urea application with 0.04 kt CO_2eq. A decrease of 1.9% can be observed between 1990 and 2021 regarding overall emissions from agriculture (see Table 5-1 and Figure 5-1). A period of decreasing emissions between 1990-2000 turned into an increasing trend from 2001-2008. From 2009 on, emissions are fluctuating without showing a clear trend. Compared to the previous reporting year, emissions have decreased between 2020 and 2021 by around 1.4%.

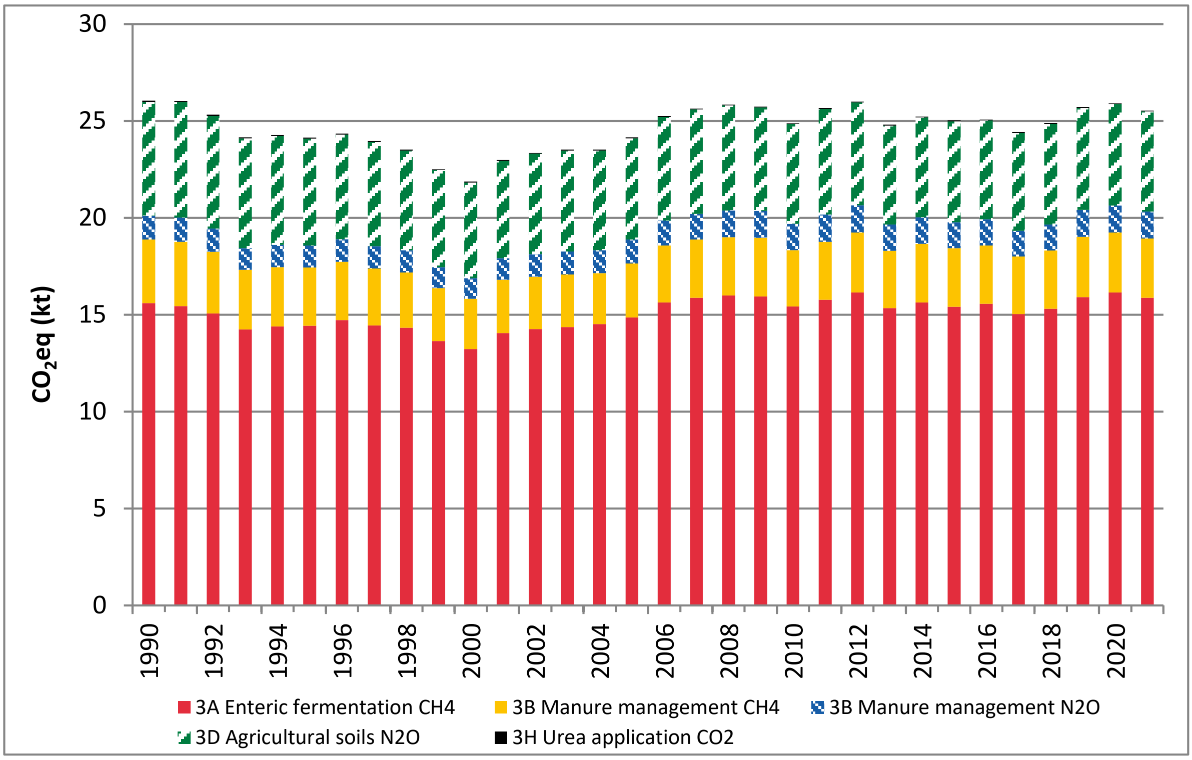


Figure 5-1 Liechtenstein's GHG emissions of the sector 3 Agriculture by sub-sectors. Note that emissions in sub-sectors 3C, 3E, 3F, 3G, 3I are not occurring.

Table 5-1 shows the emission trends for CO_2, CH_4 and N_2O within sector 3 Agriculture. CO_2 emissions, which originate from urea application only, decreased by 29.0% in 2021 compared to 1990. The development of urea application is similar as in Switzerland (see Swiss inventory, FOEN 2022, chp. 5.1). CH_4 emissions are slightly above 1990 levels (+0.3%). N_2O emissions decreased by 7.6% between 1990 and 2021. Both, CH_4 and N_2O emissions, are highly dependent on the development and the shares of different animal populations (see also Figure 5-5).

Table 5-1 GHG emissions of sector 3 Agriculture by gas in CO_2 equivalent (kt) and the relative change since 1990 (last column).

Gas	1990	1995	2000	2005	2010
	CO_2 equivalent (kt)				
CO_2	0.06	0.05	0.05	0.05	0.04
CH_4	18.87	17.44	15.83	17.64	18.32
N_2O	7.10	6.65	5.99	6.47	6.52
Sum	**26.04**	**24.14**	**21.86**	**24.16**	**24.88**

Gas	2012	2013	2014	2015	2016
	CO_2 equivalent (kt)				
CO_2	0.04	0.04	0.04	0.05	0.04
CH_4	19.23	18.30	18.66	18.43	18.58
N_2O	6.72	6.47	6.52	6.55	6.44
Sum	**26.00**	**24.80**	**25.22**	**25.03**	**25.06**

Gas	2017	2018	2019	2020	2021	1990-2021
	CO_2 equivalent (kt)					%
CO_2	0.04	0.05	0.05	0.04	0.04	-29.0%
CH_4	18.00	18.31	19.02	19.25	18.93	0.3%
N_2O	6.38	6.54	6.65	6.62	6.57	-7.6%
Sum	**24.42**	**24.89**	**25.71**	**25.91**	**25.53**	**-1.9%**

There are three key categories of the inventory belonging to the sector 3 Agriculture (key category analysis excluding LULUCF categories). Those categories are displayed in Figure 5-2, including emission levels for the base year 1990 and the reporting year 2021.

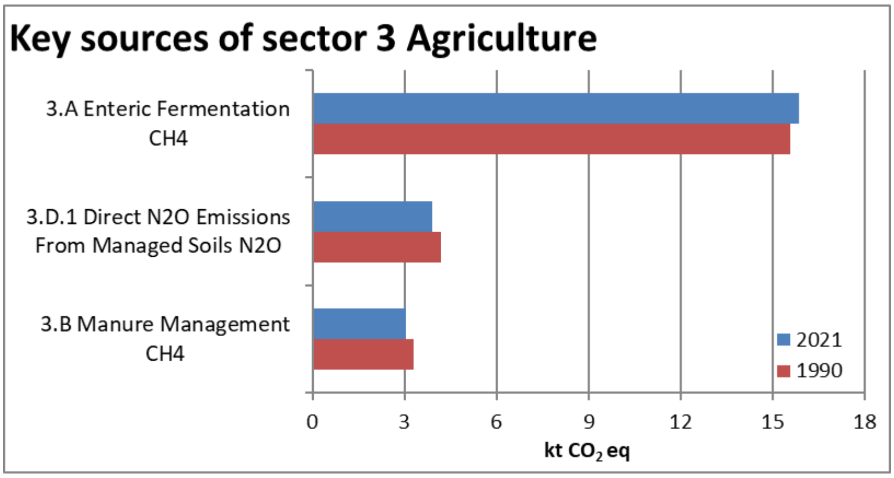


Figure 5-2 Key categories from agriculture (KCA excl. LULUCF). Emissions in CO_2 equivalents (kt) per key source category in 2021 and in the base year 1990.

5.2 Enteric fermentation (3A)

5.2.1 Category description: Enteric fermentation (3A)

Key category information 3A
CH_4 emissions from 3A Enteric fermentation are a key category by level and trend.

This emission source comprises the domestic livestock population cattle, sheep, swine, and other livestock such as goats, horses, mules and asses, and poultry (see Table 5-2).

As illustrated in Figure 5-1, CH_4 emissions from source category 3A Enteric fermentation have decreased between 1990 and 2000 and then increased again from 2001 to 2012. From then on, emissions show fluctuations without a clear trend. The emission development is highly correlated with the cattle population number, as emissions from cattle contribute to over 90% of the enteric fermentation emissions. A second relevant development in 3A Enteric fermentation is the increasing productivity of dairy cattles (high-yield cattle), which results in higher (per animal) emission factors.

Table 5-2 Specification of source category 3A Enteric fermentation.

3A	**Source**	**Specification**
3A1	Cattle	Mature dairy cattle Other mature cattle Growing cattle (fattening calves, pre-weaned calves, breeding cattle 1st year, breeding cattle 2nd year, breeding cattle 3rd year, fattening cattle)
3A2	Sheep	Fattening sheep Milksheep
3A3	Swine	Swine
3A4a	Goats	Goats
3A4b	Horses	Horses < 3 years Horses > 3 years
3A4c	Mules and Asses	Mules and Asses
3A4d	Poultry	Poultry

5.2.2 Methodological issues: Enteric fermentation (3A)

According to the decision tree in the 2006 IPCC Guidelines (IPCC 2006) chp. 10, Fig. 10.2, a Tier 2 approach was applied for CH_4 emissions from domestic livestock. As for previous submissions, Liechtenstein adopted the methodology of Switzerland (see chp. 5.1) to calculate emissions originating from source category 3A Enteric fermentation.

Detailed Swiss-specific data on nutrient requirements, feed intake and CH_4 conversion rates for specific animals and feed types were used. For mature dairy cattle, a detailed feeding model was applied, predicting gross energy intake based on animal performance and diet chemical composition. The methane conversion rate (Y_m) for mature dairy cattle was derived from a series of studies representing Swiss-specific feeding conditions.

Activity data used for estimating emissions from 3A Enteric fermentation is country specific.

5.2.2.1 Emission factors

All emission factors applied for source category 3A Enteric fermentation are based on the country-specific emission factors of Switzerland from the inventory submission 2019 (FOEN 2019, p. 277). The method is based on the IPCC 2006 Guidelines (IPCC 2006), equation 10.21:

$$EF = \frac{GE \cdot (Y_m \div 100) \cdot 365\ days/year}{55.65\ MJ/kg\ CH_4}$$

Where:

EF = annual CH_4 emission factor (kg/head/year)

GE = gross energy intake (MJ/head/day)

Y_m = methane conversion rate: fraction of gross energy in feed converted to CH_4 (%)

55.65 MJ/kg = energy content of methane.

The parameters used for estimating the emission factors are described in the following sections. Find detailed data for the estimation of emission factors in AnnexA5.2.

Gross energy intake (GE) (compare FOEN 2019, page 277)

For calculating the gross energy intake (GE), country-specific methods based on available data on requirements of net energy, digestible energy and metabolisable 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 5-3. The respective conversion factors are given in Table 5-3.

For each **cattle category,** 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, specific requirements were calculated following the feeding recommendations for Switzerland provided in RAP (1999) and Morel et al. (2015). These RAP recommendations are also used by the Swiss farmers as a basis for their cattle feeding regimes and for filling in application forms for direct payments; they are therefore considered to be appropriate.

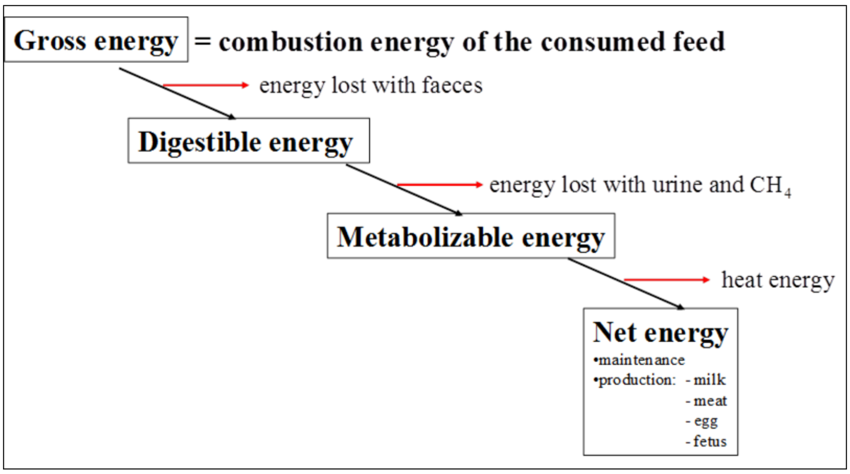


Figure 5-3 Levels of feed energy conversion (Soliva 2006a).

Table 5-3 Conversion factors used for the 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.

Livestock Category		**Conversion Factors**	
Mature Dairy Cattle		NEL to GE	0.339
Other Mature Cattle		NEL to GE	0.265
Growing Cattle	*Fattening Calves*	*ME to GE*	0.939
	Pre-Weaned Calves	*NEL to GE*	0.299
	Breeding Cattle 1st Year	*NEL to GE*	0.332
	Breeding Cattle 2nd Year	*NEL to GE*	0.313
	Breeding Cattle 3rd Year	*NEV to GE*	0.313
	Fattening Cattle	*NEV to GE*	0.383
Sheep	*Fattening Sheep*	*NEV to GE*	0.350
	Milksheep	*NEL to GE*	0.287
Swine		DE to GE	0.682
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

Gross energy intake of **mature dairy cattle** is primarily dependent on animal performance, i.e. body weight and milk yield. Accordingly, the respective GE was assessed with a detailed model within the Swiss GHG inventory (Agroscope 2014c). Using the respective model outputs, simple linear regression equations were applied to estimate GE of mature dairy cattle for Liechtenstein. It was assumed that no differences exist concerning body weight and feeding strategies between Switzerland and Liechtenstein. Hence, the resulting linear regression given below and in Figure 5-4 includes only milk yield as driving parameter:

milk production per head per year ≤ 6’030 kg:
GE = 0.0251 MJyr/kg/day * Milk + 136.3 MJ/head/day

milk production per head per year > 6’030 kg:
GE = 0.0148 MJyr/kg/day *Milk + 199.54 MJ/head/day

Where:

GE = gross energy intake (MJ/head/day)

Milk = amount of milk produced (kg/head/year)

To achieve yearly milk yields higher than 6’030 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 dependency. Due to the increasing ratio of net energy to gross energy the increase of GE with increasing milk yields is lower above 6’030 kg*year^{-1}. In Liechtenstein, this transition occurred around 1997.

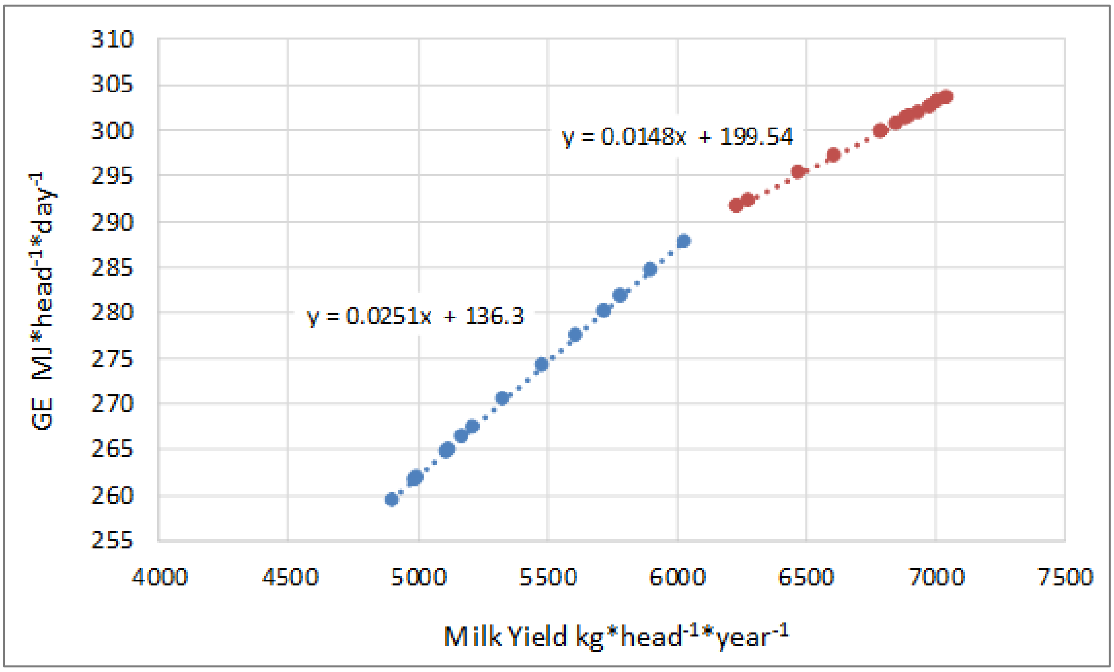


Figure 5-4 Linear regressions relating gross energy intake (GE) to milk yield for mature dairy cattles for Switzerland (based on FOEN 2019).

In Liechtenstein, milk production (see Table 5-4) of mature dairy cattle increased from 5’792 kg per head and year in 1990 (18.99 kg per head for 305 days) to 7’241 kg per head and year in 2021 (23.74 kg per head for 305 days). Statistics of annual milk production are provided by Liechtenstein’s Office for Food-control and Veterinary (Amt für Lebensmittelkontrolle und Veterinärwesen) in corporation with the Division of Agriculture of the Office of Environment. Milk production includes marketed milk, milk consumed by calves on farms and milk sold outside the commercial industry. It should be noted that daily milk yield refers to milk production during lactation (305 days) and not during the whole year (365 days). Accordingly, milk production and energy requirement for lactation was zero during the two remaining months when the cows are dry.

Table 5-4 Average daily milk production during lactation in Liechtenstein. The unit kg/head/day does not refer to a full year, but only to 305 days (energy requirement for lactation is assumed zero during the two months when cows are dry).

Milk Production Cattle		**1990**	**1995**	**2000**	**2005**	**2010**
Population Size Mature Dairy Cattle	head	2’850	2’643	2’440	2’489	2’425
Lactation Period	day	305	305	305	305	305
Milk Yield Mature Dairy Cattle	kg/head/day	18.99	19.19	20.72	22.24	21.87
Milk Yield Other Mature Cattle	kg/head/day	8.20	8.20	8.20	8.20	8.20

Milk Production Cattle		**2012**	**2013**	**2014**	**2015**	**2016**
Population Size Mature Dairy Cattle	head	2’456	2’363	2’367	2’299	2’232
Lactation Period	day	305	305	305	305	305
Milk Yield Mature Dairy Cattle	kg/head/day	22.40	22.19	22.16	22.73	23.09
Milk Yield Other Mature Cattle	kg/head/day	8.20	8.20	8.20	8.20	8.20

Milk Production Cattle		**2017**	**2018**	**2019**	**2020**	**2021**
Population Size Mature Dairy Cattle	head	2’246	2’271	2’332	2’311	2’231
Lactation Period	day	305	305	305	305	305
Milk Yield Mature Dairy Cattle	kg/head/day	23.15	23.55	24.53	24.09	23.74
Milk Yield Other Mature Cattle	kg/head/day	8.20	8.20	8.20	8.20	8.20

For **other mature cattle** and **growing cattle** Liechtenstein determines GE based on the same approach as Switzerland. The method is based on the feeding requirements according to RAP (1999) and Morel et al. (2015). In the calculation of the net energy (NE), 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. The method is described in detail in Soliva (2006a). NE is further subdivided into NE for lactation (NEL) and NE for growth (NEV) (see Table 5-3). For some of the growing cattle categories NEL is used, rather than NEV that would seem logical. 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 metabolisable energy (ME). See Figure 5-3 and Table 5-3 for more details on NEL and NEV.

The gross energy intake for **other mature cattle** is significantly higher than IPCC default values, since the category "other mature cattle" only includes mature cows that produce offspring for meat (so-called "suckler cows" or "mother cows"). Milk production of other mature cattle is 2500 kg per head and year (305 days of lactation) and has not changed over the inventory time period (Morel et al. 2015).

The gross energy intake of **growing cattle** corresponds to the weighted average GE of all sub-categories displayed in Table 5-5 (in italics). No methane is generated from milk. Energy intake from milk or milk products is still considered when estimating methane emission factors from enteric fermentation of calves. The GE for all six sub-categories are constant over time and based on the respective estimates in the Swiss Inventory (FOEN 2019). In the case of breeding cattle 1st year and fattening cattle, no further disaggregation was conducted as in the Swiss inventory. Since the composition of the young cattle category changed over time (e.g. more pre-weaned calves, see Table 5-7), the average gross energy intake for growing cattle also changes slightly.

Table 5-5 Gross energy intake per head of different livestock groups. Disaggregated categories not contained in the CRF-Tables are displayed in italic.

Gross Energy Intake	**1990**	**1995**	**2000**	**2005**	**2010**	**2012**	**2013**	**2014**
	MJ/head/day							
Cattle	643.4	642.2	651.6	657.0	655.9	656.4	656.3	657.1
Mature Dairy Cattle	281.7	283.2	293.1	299.9	298.2	300.7	299.7	299.6
Other Mature Cattle	250.6	250.6	250.6	250.6	250.6	250.6	250.6	250.6
Growing Cattle (weighted average)	111.1	108.4	107.9	106.5	107.0	105.2	106.0	106.9
Fattening Calves	*47.1*	*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*	*60.1*
Breeding Cattle 1st Year	*75.4*	*75.4*	*75.4*	*75.4*	*75.4*	*75.4*	*75.4*	*75.4*
Breeding Cattle 2nd Year	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*
Breeding Cattle 3rd Year	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*
Fattening Cattle	*103.7*	*103.7*	*103.7*	*103.7*	*103.7*	*103.7*	*103.7*	*103.7*
Sheep	22.5	22.5	22.5	22.5	22.5	22.5	22.5	22.5
Swine	28.1	28.1	28.1	28.1	28.1	28.1	28.1	28.1
Goats	25.4	25.4	25.4	25.4	25.4	25.4	25.4	25.4
Horses (weighted average)	107.5	107.7	108.0	108.2	108.3	107.9	108.2	108.3
Horses <3 years	*101.4*	*101.4*	*101.4*	*101.4*	*101.4*	*101.4*	*101.4*	*101.4*
Horses >3 years	*109.0*	*109.0*	*109.0*	*109.0*	*109.0*	*109.0*	*109.0*	*109.0*
Mules and Asses	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6
Poultry 1)	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3

Gross Energy Intake	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
	MJ/head/day						
Cattle	659.1	662.4	661.0	662.8	667.0	665.9	664.2
Mature Dairy Cattle	302.1	303.8	304.0	305.9	310.3	308.3	306.7
Other Mature Cattle	250.6	250.6	250.6	250.6	250.6	250.6	250.6
Growing Cattle (weighted average)	106.4	108.1	106.4	106.3	106.1	107.1	106.9
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 Cattle 1st Year	*75.4*	*75.4*	*75.4*	*75.4*	*75.4*	*75.4*	*75.4*
Breeding Cattle 2nd Year	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*
Breeding Cattle 3rd Year	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*	*143.6*
Fattening Cattle	*103.7*	*103.7*	*103.7*	*103.7*	*103.7*	*103.7*	*103.7*
Sheep	22.5	22.5	22.5	22.5	22.5	22.5	22.5
Swine	28.1	28.1	28.1	28.1	28.1	28.1	28.1
Goats	25.4	25.4	25.4	25.4	25.4	25.4	25.4
Horses (weighted average)	108.2	108.5	108.6	108.6	108.5	108.5	108.6
Horses <3 years	101.4	101.4	101.4	101.4	101.4	101.4	101.4
Horses >3 years	*109.0*	*109.0*	*109.0*	*109.0*	*109.0*	*109.0*	*109.0*
Mules and Asses	39.6	39.6	39.6	39.6	39.6	39.6	39.6
Poultry 1)	1.3	1.3	1.3	1.3	1.3	1.3	1.3

1) Poultry data is not Gross Energy intake (GE) but Metabolizable Energy intake (ME)

Energy requirements and GE intake of **sheep, swine, goats** and **poultry** were obtained from the respective estimates of the Swiss Farmers Union (SBV 2018, Giuliani 2018). These estimates are not officially published anymore in the statistical yearbooks (e.g. SBV 2014) but are still available from background data and are based on the same method as earlier published energy requirement statistics (e.g. SBV 2007).

Gross energy intake for **horses** and **mules** and **asses** were estimated by Stricker (2012), mainly based on Meyer and Coenen (2002).

Resulting estimates of gross energy intakes are provided in Table 5-5.

Methane conversion rate (Y_m) (compare FOEN 2019 page 283)

For the methane conversion rate (Y_m), only limited country-specific data exist. The same approach as in the Swiss inventory was applied for all animal categories. All values for Y_m for the different livestock categories and the corresponding data sources are shown in Table 5-6.

Table 5-6 Methane conversion rates (Y_m) for different livestock groups in 2021. Disaggregated categories are displayed in italic.

Livestock category	**Methane conversion rate (Y_m)**	**Sources**
Cattle		
Mature Dairy Cattle	6.9%	Adopted based on 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))
Other Mature Cattle	6.5%	Table 10.12 in IPCC (2006)
Growing Cattle	6.2%	Weighted average
Fattening Calves	*0.0%*	*Based on Tables 10.12 and 10A.2 in IPCC (2006) (where suitable, weighted averages)*
Pre-Weaned Calves	*4.1%*	
Breeding Cattle 1st Year	*6.5%*	
Breeding Cattle 2nd Year	*6.5%*	
Breeding Cattle 3rd Year	*6.5%*	
Fattening Cattle	*6.4%*	
Sheep	5.9%	Weighted according to the population structure of Switzerland due to missing data on the sheep population structure in Liechtenstein
Lambs < 1 year	*4.5%*	*Table 10.13 in IPCC (2006)*
Mature sheep	*6.5%*	*Table 10.13 in IPCC (2006)*
Swine	0.6%	Crutzen et al. (1986) and Minonzio et al. (1998)
Goats	6.0%	Martínez-Fernández et al. (2014) and Fernández et al. (2013)
Horses	2.45%	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)
Mules and Asses	2.45%	
Poultry	0.16%	Country-specific value (Switzerland) evaluated in an in vivo trial with broilers (Hadorn and Wenk 1996)

For fattening calves, a methane conversion rate of 0% is applied. According to IPCC (2006), this is suitable for fattening calves which are fully fed with milk. Some small amounts of roughage may be administered towards the end of the fattening period. However, methane production from this roughage is considered minimal as the animals are generally barely capable to digest it. Accordingly, the CH_4 conversion rate (Ym) of 0% is adequate.

5.2.2.2 Activity data

The activity data was obtained from Liechtenstein's Office for Food-control and Veterinary (Amt für Lebensmittelkontrolle und Veterinärwesen) in cooperation with the Division of

Agriculture of the Office of Environment. Annual data are available for the livestock categories mature dairy cattle, sheep, goats and swine for the whole time-series. For all the other livestock categories data are available for the years 1990 and 2000 as well as for 2002 onward. Data in between was interpolated. From 2002 onward, data for all livestock categories is available on an annual basis. Any deviation from FAO figures is due to the fact that **Liechtenstein is not a FAO member** and has no obligation to report livestock numbers to FAO. Consequently, FAO makes its own estimates regarding Liechtenstein livestock numbers.

Activity data (population sizes) are provided in Table 5-7.

Table 5-7 Activity data for Liechtenstein (data sources: Division of Agriculture).

Population size	**1990**	**1995**	**2000**	**2005**	**2010**	**2012**	**2013**	**2014**
	1000 head							
Cattle	6.33	5.86	4.95	5.57	5.99	6.29	6.01	6.21
Mature Dairy Cattle	2.85	2.64	2.44	2.49	2.43	2.46	2.36	2.37
Other Mature Cattle	0.02	0.05	0.07	0.36	0.38	0.54	0.46	0.45
Growing Cattle (weighted average)	3.46	3.17	2.43	2.72	3.19	3.29	3.18	3.40
Fattening Calves	*0.05*	*0.08*	*0.11*	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*
Pre-Weaned Calves	*0.02*	*0.04*	*0.01*	*0.27*	*0.28*	*0.40*	*0.34*	*0.33*
Breeding Cattle 1st Year	*1.14*	*1.06*	*0.65*	*0.60*	*0.81*	*0.79*	*0.79*	*0.88*
Breeding Cattle 2nd Year	*0.90*	*0.70*	*0.54*	*0.68*	*0.81*	*0.79*	*0.78*	*0.87*
Breeding Cattle 3rd Year	*0.63*	*0.58*	*0.34*	*0.35*	*0.46*	*0.45*	*0.44*	*0.49*
Fattening Cattle	*0.72*	*0.73*	*0.77*	*0.74*	*0.74*	*0.79*	*0.75*	*0.75*
Sheep	2.78	2.63	2.98	3.06	3.66	3.80	3.52	3.58
Swine	3.25	2.43	1.99	1.70	1.69	1.74	1.66	1.71
Goats	0.17	0.15	0.16	0.32	0.43	0.39	0.27	0.28
Horses (weighted average)	0.17	0.16	0.16	0.27	0.34	0.33	0.30	0.31
Horses <3 years	*0.03*	*0.03*	*0.02*	*0.03*	*0.03*	*0.05*	*0.03*	*0.03*
Horses >3 years	*0.13*	*0.14*	*0.14*	*0.24*	*0.30*	*0.28*	*0.27*	*0.28*
Mules and Asses	0.07	0.13	0.22	0.14	0.15	0.18	0.17	0.18
Poultry	4.44	6.25	8.06	10.45	12.92	12.53	13.03	12.68

Population size	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**1990-2021**
	1000 head							%
Cattle	6.03	6.23	5.79	5.89	6.12	6.39	6.27	-1%
Mature Dairy Cattle	2.30	2.23	2.25	2.27	2.33	2.31	2.23	-22%
Other Mature Cattle	0.47	0.41	0.43	0.45	0.49	0.48	0.50	2375%
Growing Cattle (weighted average)	3.27	3.59	3.11	3.17	3.30	3.60	3.55	3%
Fattening Calves	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*	*0.08*	50%
Pre-Weaned Calves	*0.34*	*0.30*	*0.32*	*0.33*	*0.36*	*0.36*	*0.36*	2327%
Breeding Cattle 1st Year	*0.83*	*0.98*	*0.79*	*0.80*	*0.83*	*0.95*	*0.94*	-18%
Breeding Cattle 2nd Year	*0.82*	*0.97*	*0.78*	*0.79*	*0.82*	*0.94*	*0.93*	3%
Breeding Cattle 3rd Year	*0.47*	*0.55*	*0.44*	*0.45*	*0.47*	*0.53*	*0.53*	-17%
Fattening Cattle	*0.73*	*0.70*	*0.71*	*0.72*	*0.75*	*0.74*	*0.72*	0%
Sheep	3.89	4.05	4.12	3.99	3.88	3.83	4.23	52%
Swine	1.75	1.79	1.88	1.77	1.72	1.47	1.63	-50%
Goats	0.29	0.33	0.36	0.43	0.43	0.51	0.54	218%
Horses (weighted average)	0.30	0.27	0.26	0.24	0.25	0.24	0.23	36%
Horses <3 years	*0.03*	*0.02*	*0.01*	*0.01*	*0.02*	*0.01*	*0.01*	-64%
Horses >3 years	*0.27*	*0.25*	*0.24*	*0.23*	*0.24*	*0.22*	*0.21*	61%
Mules and Asses	0.16	0.17	0.16	0.23	0.22	0.23	0.23	211%
Poultry	12.50	12.83	12.46	12.92	15.01	15.44	20.64	365%

Total number of cattle decreased by about a fifth between 1990 and the beginning of the new millennium, grew again between 2000 and 2012 and from then on has stabilised with slight fluctuations. Other mature cattle have grown in number due to an increasing meat demand from extensive livestock production. Swine population has decreased with one drastic drop between 2003 and 2004 caused by a disease. The increase in the poultry population between 1990 and 2007 is a result of two new poultry farms that were established in Liechtenstein. Another poultry farm was established in 2020, which explains the increase of poultry in 2021. Figure 5-5 illustrates the development of the sizes of Liechtenstein's animal populations.

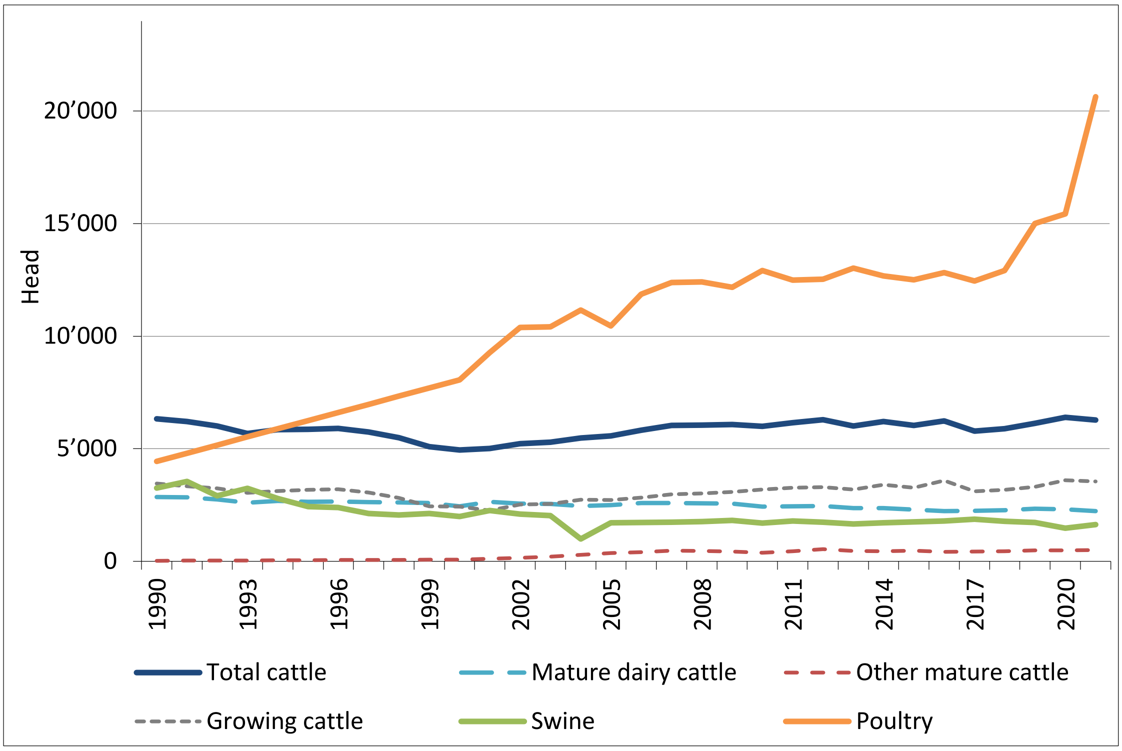


Figure 5-5 Development of population size of main animal categories (Division of Agriculture).

5.2.3 Uncertainties and time-series consistency

Uncertainties of emission factors and activity data are taken from ART (2008) and were determined for the Swiss GHG inventory. Since the same model is applied for Liechtenstein's GHG inventory, the uncertainties are adopted for Liechtenstein, too. ART (2008) was updated with current activity and emission data of the Swiss inventory (FOEN 2019) and completed with default uncertainties from the 2006 IPCC Guidelines (IPCC 2006). The arithmetic mean of the lower and upper bound uncertainty was used for activity data (6.5%) and for emission factors (16.9%), resulting in a combined uncertainty of 18.1% for Approach 1 analysis.

The time series 1990–2021 are consistent. The following issues should be considered:

- Liechtenstein has only very small animal populations that can fluctuate considerably due to establishment or cessation of farms or agricultural activities.

- Gross energy intakes of some of the aggregated animal categories reveal some fluctuations during the inventory period due to varying shares of the sub-categories.
- Gross energy intakes as well as the implied emission factor for mature dairy cattle increase, mainly as a result of higher milk production (Table 5-4).

5.2.4 Category-specific QA/QC and verification

The category-specific QA/QC activities were carried out as mentioned in section 1.5 including triple checks of Liechtenstein's reporting tables (CRF tables). The triple check includes a detailed comparison of current and previous submission data for the base year 1990 and for the year 2020 as well as an analysis of the increase or decrease of emissions between 2020 and 2021 in the current submission.

In addition to the overall triple check a separate internal technical documentation of Liechtenstein's model is available (Bretscher 2019, in German only). The manual also ensures transparency and retraceability of the calculation methods and data sources. Supplementary, a quality control was done by Acontec and INFRAS by a countercheck of the calculation sheets.

Further QA/QC activities are also documented in the Swiss NIR (see FOEN 2019 page 287). The respective conclusions are equally valid for Liechtenstein since the methods used are an adaptation of the Swiss model version. Bottom-up inventory estimates in Switzerland agree well with several atmospherically CH_4 measurements, thus verifying the methodological approach applied in the inventory.

The SE, the NIC and the NID author report their QC activities in a checklist (see Annex).

5.2.5 Category-specific recalculations

There were no category-specific recalculations.

5.2.6 Category-specific planned improvements

It is planned that Liechtenstein's agriculture model will be updated every 5 years with latest Swiss values and data. The effort updating the model annually is not feasible for a small country such as Liechtenstein. The latest update has been done for the submission 2020.

5.3 Manure management (3B)

5.3.1 Category description: Manure management (3B)

Key category information 3B
CH_4 emissions from 3B Manure Management are a key category by level.

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, goats, horses, mules and asses, and poultry (see Table 5-8). Five (CH_4) respectively four (N_2O) different manure management systems are considered including indirect N_2O emissions from manure management (see Table 5-9). The total emissions from source category 3B Manure management closely follow the development of the cattle population. Most significant contributors to CH_4 emissions in 2021 are cattle with approximately 86%. To N_2O emissions, cattle and sheep contribute significant shares of around 71% and 17%, respectively (direct emissions only). Approximately 63% of the total N_2O emissions attributed to source category 3B Manure management originate from indirect N_2O emissions.

Table 5-8 Specification of source category 3B Manure Management according to livestock.

3B	**Source**	**Specification**
3B1	Cattle	Mature dairy cattle Other mature cattle Growing cattle (fattening calves, Pre-weaned calves, breeding cattle 1st year, breeding cattle 2nd year, breeding cattle 3rd year, fattening cattle)
3B2	Sheep	Fattening sheep Milk sheep
3B3	Swine	Piglets Fattening pig over 25 kg Dry sows Nursing sows Boars
3B4	Other livestock	Goats Horses (Horses < 3 years, Horses > 3 years) Poultry Mules and Asses

Table 5-9 Specification of source category 3B Manure Management according to manure management system. Note that the encoding items 3B6a, 3B6b, 3B6e are an auxiliary convention in Switzerland's EMIS database, which is also used in Liechtenstein's emission model.

3B	Source	Specification	
3B6a	Direct emissions	Liquid systems	
3B6b		Solid storage and dry lot	
3B / 3D		Pasture, range and paddock	
3B6e		Other	Deep litter
			Poultry system
3B5a	Indirect emissions	Atmospherical deposition	
3B5b		Leaching and run-off	

5.3.2 Methodological issues: Manure management (3B)

5.3.2.1 Methodology

As in previous submissions, Liechtenstein adopted the methodology of Switzerland (for further information see chp. 5.1) in order to calculate emissions originating from source category 3B Manure management. The calculation is based on methods described in the 2006 IPCC Guidelines (CH_4: IPCC 2006 equation 10.23; N_2O: IPCC 2006 equation 10.25).

CH_4 emissions from Manure management were generally estimated using a Tier 2 methodology. For cattle a more detailed method was applied, estimating volatile solids (VS) excretion based on gross energy intake estimates as used for Enteric fermentation. Methane conversion factors (MCF) are from IPCC 2006 Guidelines (solid storage, pasture range and paddock, anaerobic digesters, poultry manure), from country-specific data sources (deep litter) or were modelled according to Mangino et al. (2001) (liquid systems, anaerobic digesters).

N_2O emissions from source category 3B Manure management were estimated using a country-specific Tier 3 methodology (adopted from Switzerland). Activity data used for estimating the emissions is collected specifically for Liechtenstein (see Table 5-10, Table 5-7, and additional information below). Detailed country-specific data on nitrogen excretion rates, manure management system distribution and nitrogen volatilisation were applied in accordance with the Swiss inventory. Emission factors for direct N_2O emissions (i.e. EF_3 in equation 10.25, IPCC 2006, Vol. 4, chp 1.5), are based on default values provided in IPCC 2006 Guidelines. The emission factor for indirect emissions from atmospheric deposition is based on Bühlmann et al. (2015) and 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 the calculation of CH_4 and N_2O emissions, slightly different livestock sub-categories were used (see Table 5-10). The livestock categories reported in the CRF tables are the same, but the respective sub-categories as a basis for the calculation are different. The categorization for the estimation of CH_4 emissions had to be adapted to data available for energy requirements, while the categorisation for the estimation of N_2O emissions is determined by the respective categorisation of the Swiss inventory (AGRAMMON, Kupper et al. 2018, Flisch et al. 2009). 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 3rd year or fattening cattle according to their purposes.

Table 5-10 Livestock categories for estimating CH_4 and N_2O emissions from source category 3B Manure management.

<table>
<tr><th>3B</th><th colspan="2">CH₄</th><th colspan="2">N₂O</th></tr>
<tr><td rowspan="3">Cattle</td><td colspan="2">Mature Dairy Cattle</td><td colspan="2">Mature Dairy Cattle</td></tr>
<tr><td colspan="2">Other Mature Cattle</td><td colspan="2">Other Mature Cattle</td></tr>
<tr><td>Growing Cattle</td><td>Fattening Calves
Pre-Weaned Calves
Breeding Cattle 1st year
Breeding Cattle 2nd year
Breeding Cattle 3rd year
Fattening Cattle</td><td>Growing Cattle</td><td>Fattening Calves
Pre-Weaned Calves
Breeding Cattle 1st year
Breeding Cattle 2nd year
Breeding Cattle 3rd year
Fattening Cattle</td></tr>
<tr><td>Sheep</td><td colspan="2">Sheep</td><td colspan="2">Fattening Sheep
Milk Sheep</td></tr>
<tr><td>Swine</td><td colspan="2">Swine</td><td colspan="2">Piglets
Fattening Pig over 25 kg
Dry Sows
Nursing Sows
Boars</td></tr>
<tr><td>Goats</td><td colspan="2">Goats</td><td colspan="2">Goat places</td></tr>
<tr><td>Horses</td><td colspan="2">Horses < 3 years
Horses > 3 years</td><td colspan="2">Horses < 3 years
Horses > 3 years</td></tr>
<tr><td>Mules and Asses</td><td colspan="2">Mules an Asses</td><td colspan="2">Mules an Asses</td></tr>
<tr><td>Poultry</td><td colspan="2">Poultry</td><td colspan="2">Growers
Layers
Broilers
Turkey
Other Poultry (Geese, Ducks, Ostriches, Quails)</td></tr>
</table>

5.3.2.2 Emission factors CH_4

Calculation of CH_4 emissions from manure management is based on methods described in the 2006 IPCC Guidelines (IPCC 2006, equation 10.23):

$$EF_T = VS_T \cdot 365 \frac{days}{year} \cdot B_{0T} \cdot 0.67 \frac{kg}{m^3} \cdot \sum_S MCF_S \cdot MS_{T,S}$$

Where:

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/m³ = conversion factor of m³ 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)

Volatile solids excretion (VS) (compare FOEN 2019 page 293)

The daily excretions of volatile solids (VS) for all **cattle sub-categories** were estimated according to equation 10.24 in the 2006 IPCC Guidelines (IPCC 2006):

$$VS = \left[GE \cdot \left\{1 - \frac{DE\%}{100}\right\} + (UE \cdot GE)\right] \cdot \left[\frac{1 - ASH}{EDF}\right]$$

Where:

VS = volatile solids excretion per day on a dry-organic matter basis (kg/head/day)

GE = gross energy intake (MJ/head/day)

DE = digestibility of the feed (%)

(UE • GE) = urinary energy expressed as fraction of GE (MJ/head/day)

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)

Gross energy intake was calculated according to the method described in chp. 5.2.2.1. For **mature dairy cattle**, data on energy density and ash content of feed as well as data on feed digestibility was adopted from Switzerland. To derive these parameters, the Swiss inventory system uses the same feeding model that is also used for the estimation of GE (Agroscope 2014c). The digestibility of feed is of crucial importance for the calculation of volatile solids. The modelled values for dairy cows are somewhat higher than the IPCC default 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 the high feeding level that is 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 2.5 percentage 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 urinary energy expressed as fraction of gross energy the default value of 0.04 was adopted (IPCC 2006).

IPCC default values of 65% respectively 60% were taken for the feed digestibility of **calves and other growing cattle.** For the urinary energy expressed as fraction of gross energy and for the energy density of the feed (EDF) the IPCC default values, i.e. 0.04 and 18.45 MJ/kg were adopted. Furthermore, an ash content of 8.0% was used for all these categories.

For VS excretion of the livestock categories **sheep, swine, goats, mules and asses** and **poultry** default values from IPCC were taken (IPCC 2006, Tables 10A-7, 10A-8, 10A-9).

Considering the gross energy intake of **horses**, the VS-excretion in the revised 1996 IPCC Guidelines (1.72 kg/head/day) is clearly more appropriate and was thus adopted instead of the default value of the 2006 Guidelines (i.e. 2.13 kg/head/day), similar as in the Swiss GHG inventory (FOEN 2019). The default IPCC 2006 values were used for feed digestibility of horses (70%) and for ash content of manure (4.0%).

Maximum CH_4 producing capacity (B_0)

For the methane producing capacity (B_o), default values were used (IPCC 2006).

Methane conversion factor (MCF) (compare FOEN 2019, page 294)

For estimating CH_4 emissions from source category 3B manure management, five different manure management systems are distinguished. Liechtenstein has an average annual temperature below 15°C (MeteoSwiss 2022) and was therefore allocated to the cool climate region without any differentiation.

In the case of **solid manure** and **pasture range and paddock** the default MCF values from table 10.17 of the 2006 IPCC Guidelines were used (see Table 5-11).

Liquid/slurry systems are usually responsible for the major part of methane emissions from Manure management. Accordingly, the Swiss inventory system uses a more detailed model based on Mangino et al. (2001) to determine the respective MCF. As the manure management and temperature regimes do not differ substantially between Switzerland and Liechtenstein, the model results were also used in inventory of Liechtenstein. The respective MCF-values for liquid/slurry systems decrease slightly from 14.3% in 1990 to 13.5% in 2021. The variation of the MCF is due to the increasing share of manure application on pasture, range and paddock which can be observed in Switzerland as well as in Liechtenstein. The higher the share of manure applied 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 decreases when summer grazing time increases. Note that in Liechtenstein's inventory the MCF is kept constant since submission 2020 (i.e. 13.5%) until the agriculture model is updated (5-yearly).

Fattening calves, sheep 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 (IPCC 2006). The choice of a MCF of 10% for deep litter is supported by the specific feeding and manure management regime in Liechtenstein (especially cold winter temperatures) and confirmed by a number of studies that are representative for the country-specific manure 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, Sommer et al. 2007 and Zeitz et al. 2012). Note that the use of the relatively high MCF of 10% (justified by the literature mentioned) leads to a clearly higher methane emission factor for sheep in Liechtenstein compared to other European countries.

For all poultry categories, a MCF value of 1.5% was used according to the default value for **poultry manure systems** in the 2006 IPCC Guidelines.

Table 5-11 Manure management systems and methane conversion factors (MCFs) for 2021. Note that the encoding items 3B6a, 3B6b, 3B6e are an auxiliary convention in Switzerland's EMIS database, which is also used in Liechtenstein's emission model.

Manure management system				**Description**	**MCF (%)**
3B6a	Direct emissions	Liquid systems		Combined storage of dung and urine under animal confinements for longer than 1 month.	13.5
3B6b		Solid storage and dry lot		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
3B / 3D		Pasture, range and paddock		Manure is allowed to lie as it is, and is not managed (distributed, etc.).	1.0
3B6e		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

Manure management system distribution (MS) (compare FOEN 2019, page 297)

In Switzerland, 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 (see Table 5-12). Since agricultural structures and practices are basically identical in Liechtenstein, these values were also adopted for Liechtenstein. The fractions are determined by the livestock husbandry system (e.g. tie stall or loose housing system) as defined in Richner et al. (2017). The estimation is conducted within the framework of the Swiss nitrogen flow model AGRAMMON (Kupper et al. 2018). Values for 1990 and 1995 are based on expert judgement and values from literature, while values for 2002, 2007, 2010 and 2015 are based on extensive farm surveys in Switzerland. The data clearly reproduces 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 21st century (see Liechtenstein's strategy for agriculture/Landwirtschaftliches Leitbild, Government 2004, and OE 2013c).

For cattle, the distribution of animal excreta to the various manure management systems (MS) is different with regard to estimating N_2O emissions from 3B Manure management (for further information refer to chp. 5.3.2.4) compared to estimating CH_4 emissions from 3B Manure management. This is because cattle stables usually 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 further information regarding the estimation of the distribution of nitrogen and volatile solids to manure management systems for cattle, please refer to Switzerland's greenhouse gas inventory (FOEN 2023, Annex A5.3).

Table 5-12 Manure management system (MS) distribution for Liechtenstein for selected years.

MS Distribution	1990				1995				2002			
	%				%				%			
	Liquid / Slurry	Solid storage	Pasture range and paddock	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Other (Deep litter, Poultry manure)
Mature Dairy Cattle	64.0	27.7	8.3	0.0	66.0	24.5	9.5	0.0	65.6	16.4	18.0	0.0
Other Mature Cattle	41.5	32.2	26.3	0.0	39.5	34.2	26.2	0.0	40.2	20.7	39.1	0.0
Growing Cattle (weighted average)	34.8	46.5	16.7	2.1	35.4	45.9	16.0	2.8	31.0	40.4	26.3	2.2
Fattening Calves	*14.8*	*0.0*	*0.0*	*85.2*	*15.2*	*0.0*	*0.0*	*84.8*	*22.0*	*0.0*	*0.3*	*77.7*
Pre-Weaned Calves	*41.5*	*32.2*	*26.3*	*0.0*	*39.5*	*34.2*	*26.2*	*0.0*	*41.6*	*21.1*	*37.3*	*0.0*
Breeding Cattle 1st Year	*37.2*	*48.7*	*14.1*	*0.0*	*38.2*	*47.6*	*14.2*	*0.0*	*34.1*	*38.9*	*27.0*	*0.0*
Breeding Cattle 2nd Year	*45.6*	*29.0*	*25.4*	*0.0*	*47.5*	*26.8*	*25.6*	*0.0*	*38.2*	*23.5*	*38.4*	*0.0*
Breeding Cattle 3rd Year	*50.8*	*29.2*	*20.0*	*0.0*	*51.7*	*28.0*	*20.3*	*0.0*	*42.6*	*22.6*	*34.8*	*0.0*
Fattening Cattle	*70.4*	*24.2*	*0.0*	*5.5*	*66.7*	*27.7*	*0.0*	*5.6*	*67.7*	*26.9*	*2.2*	*3.2*
Sheep (weighted average)	0.0	0.0	30.7	69.3	0.0	0.0	30.7	69.3	0.0	0.0	33.5	66.5
Swine (weighted average)	100.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	99.5	0.3	0.1	0.0
Goats	0.0	0.0	13.6	86.4	0.0	0.0	13.6	86.4	0.0	0.0	12.2	87.8
Horses (weighted average)	0.0	93.2	6.8	0.0	0.0	93.2	6.8	0.0	0.0	78.9	21.1	0.0
Mules and Asses (weighted average)	0.0	93.2	6.8	0.0	0.0	93.2	6.8	0.0	0.0	76.9	23.1	0.0
Poultry (weighted average)	0.0	0.0	0.0	100.0	0.0	0.0	0.6	99.4	0.0	0.0	5.0	95.0

MS Distribution	2007				2010				2015			
	%				%				%			
	Liquid / Slurry	Solid storage	Pasture range and paddock	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Other (Deep litter, Poultry manure)	Liquid / Slurry	Solid storage	Pasture range and paddock	Other (Deep litter, Poultry manure)
Mature Dairy Cattle	68.4	13.9	17.7	0.0	68.4	14.8	16.9	0.0	72.3	11.7	15.9	0.0
Other Mature Cattle	50.6	20.5	29.0	0.0	49.3	18.3	32.4	0.0	53.5	15.1	31.5	0.0
Growing Cattle (weighted average)	31.7	42.1	23.5	2.6	31.0	43.2	23.7	2.1	34.8	39.9	23.5	1.8
Fattening Calves	*22.8*	*0.0*	*0.2*	*77.0*	*18.2*	*0.0*	*0.2*	*81.6*	*26.1*	*0.0*	*1.7*	*72.2*
Pre-Weaned Calves	*51.0*	*18.8*	*30.1*	*0.0*	*46.0*	*33.2*	*20.9*	*0.0*	*37.8*	*30.2*	*32.0*	*0.0*
Breeding Cattle 1st Year	*42.0*	*34.8*	*23.3*	*0.0*	*44.7*	*33.8*	*21.5*	*0.0*	*47.0*	*32.1*	*20.9*	*0.0*
Breeding Cattle 2nd Year	*42.4*	*21.1*	*36.5*	*0.0*	*44.5*	*21.2*	*34.3*	*0.0*	*44.8*	*20.4*	*34.8*	*0.0*
Breeding Cattle 3rd Year	*46.6*	*21.6*	*31.8*	*0.0*	*47.6*	*21.8*	*30.6*	*0.0*	*56.3*	*18.1*	*25.6*	*0.0*
Fattening Cattle	*63.3*	*29.2*	*4.3*	*3.2*	*59.0*	*33.1*	*4.0*	*3.9*	*65.3*	*26.5*	*4.9*	*3.4*
Sheep (weighted average)	0.0	0.0	40.2	59.8	0.0	0.0	34.5	65.5	0.0	0.0	36.7	63.3
Swine (weighted average)	98.6	0.1	1.3	0.0	99.4	0.5	0.1	0.0	100.0	0.0	0.0	0.0
Goats	0.0	0.0	7.1	92.9	0.0	0.0	10.0	90.0	0.0	0.0	11.6	88.4
Horses (weighted average)	0.0	79.9	20.1	0.0	0.0	74.8	25.2	0.0	0.0	78.6	21.4	0.0
Mules and Asses (weighted average)	0.0	75.2	24.8	0.0	0.0	79.3	20.7	0.0	0.0	77.6	22.4	0.0
Poultry (weighted average)	0.0	0.0	6.9	93.1	0.0	0.0	5.8	94.2	0.0	0.0	6.7	93.3

5.3.2.3 Activity data CH_4

The activity data was obtained from Liechtenstein's Office for Food-control and Veterinary (Amt für Lebensmittelkontrolle und Veterinärwesen) in cooperation with the Division of Agriculture. Annual data for the livestock categories mature dairy cattle, sheep, goats and swine are available for the full time series. For all the other livestock categories, data are available for the years 1990 and 2000 as well as for 2002 onward. Data in between was interpolated. Table 5-7 (see chp. 5.2.2.2) shows the time series of livestock data.

Any deviation from FAO figures is due to the fact that Liechtenstein is not a FAO member and has no obligation to report livestock numbers to FAO. Consequently, FAO makes its own estimates regarding Liechtenstein's livestock numbers.

5.3.2.4 Emission factors N_2O

Estimation of direct N_2O emissions from Manure management relies basically on the same manure management systems as the estimation of CH_4 emissions (see Table 5-9). All emission factors are based on default values given in table 10.21 of the 2006 IPCC Guidelines (see Table 5-13). For liquid/slurry systems an emission factor (EF3) of 0.002% as suggested for "Pit storage below animal confinements" was considered appropriate.

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 and Liechtenstein, where agricultural land use alternates with natural and semi-natural ecosystems over short distances, the average share of volatilised nitrogen that is re-deposited in (semi-)natural habitats is 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 here. 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 2006) and the indirect emission factor for (semi-)natural land (as provided in Bühlmann 2014). 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 2.6%. Note that in Liechtenstein's inventory the emission factor for indirect emissions is kept constant from submission 2020 onwards (i.e. 0.026 kg N_2O-N / kg N) until the agriculture model is updated (5-yearly).

Table 5-13 N_2O emission factor for manure management systems in Liechtenstein (2021).

Animal waste management system	**Emission factor**
	kg N_2O-N / kg N
Liquid/Slurry: with natural crust cover	0.002
Liquid/Slurry: without natural crust cover	0.002
Solid storage	0.005
Cattle and swine deep bedding: no mixing	0.010
Poultry manure	0.001
Indirect emissions due to volatilisation	0.026

Note that the emission factors used above are used in the Swiss GHG inventory. A Swiss expert for the agricultural sector from Agroscope has evaluated the application of these emission factors for Liechtenstein's inventory and considers them suitable (Bretscher 2020).

5.3.2.5 Activity data N_2O

Activity data for N_2O emissions from source category 3B Manure management was estimated according to equation 10.25 of the 2006 IPCC Guidelines:

$$N_2O_{D(mm)} = \left[\sum_S \left\{\sum_T \left(N_T \cdot Nex_T \cdot MS_{T,S}\right)\right\} \cdot EF_{3(S)}\right] \cdot \frac{44}{28}$$

Where:

$N_2O_{D(mm)}$ = 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 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

Livestock population

The activity data was obtained from Liechtenstein's Office for Food-control and Veterinary (Amt für Lebensmittelkontrolle und Veterinärwesen) in cooperation with the Division of Agriculture. Annual data for the livestock categories mature dairy cattle, sheep, goats and swine are available for the whole time-series. For all the other livestock categories data are available for the years 1990 and 2000 as well as for 2002 onward. Data in between was interpolated. Underlying data is given below.

Table 5-14 Sizes of Liechtenstein’s animal populations.

Population sizes Liechtenstein	1990	1995	2000	2005	2010	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	1990 - 2021 (%)
Fattening Calves	50	81	112	83	81	82	79	79	77	75	75	76	78	77	75	50%
Pre-Weaned Calves	15	35	11	266	281	395	341	330	342	304	318	331	359	356	364	2327%
Breeding Cattle 1st Year	1’136	1’057	649	601	814	792	789	877	828	982	785	801	828	948	935	-18%
Breeding Cattle 2nd Year	903	699	544	676	808	786	782	871	822	974	778	794	822	940	927	3%
Breeding Cattle 3rd Year	631	575	343	348	459	446	444	494	466	553	442	451	467	534	526	-17%
Fattening Cattle	723	725	774	743	743	792	748	745	732	700	709	720	747	740	721	0%
Growing Cattle	3’458	3’172	2’433	2’717	3’186	3’293	3’183	3’396	3’267	3’588	3’107	3’173	3’301	3’595	3’548	3%
Mature Dairy Cattle	2’850	2’643	2’440	2’489	2’425	2’456	2’363	2’367	2’299	2’232	2’246	2’271	2’332	2’311	2’231	-22%
Other Mature Cattle	20	47	74	362	382	538	464	449	465	413	432	450	489	484	495	2375%
Total Cattle	**6’328**	**5’862**	**4’947**	**5’568**	**5’993**	**6’287**	**6’010**	**6’212**	**6’031**	**6’233**	**5’785**	**5’894**	**6’122**	**6’390**	**6’274**	**-1%**
Fattening Sheep	1’636	1’079	1’522	2’005	2’061	2’154	2’077	2’105	2’094	2’087	2’168	2’165	2’225	1’992	2’176	33%
Milksheep	0	0	0	41	0	0	0	0	1	0	0	0	0	0	0	-
Total Sheep	**2’781**	**2’632**	**2’983**	**3’063**	**3’656**	**3’800**	**3’522**	**3’581**	**3’892**	**4’050**	**4’123**	**3’989**	**3’884**	**3’829**	**4’228**	**52%**
Goat Places	111	100	96	171	253	217	187	169	182	217	242	293	267	297	350	215%
Total Goats	**171**	**145**	**164**	**324**	**434**	**388**	**269**	**283**	**285**	**330**	**361**	**431**	**431**	**511**	**544**	**218%**
Horses <3 years Agr.	33	27	20	28	31	46	29	27	29	17	12	11	16	14	12	-64%
Horses >3 years Agr.	133	135	136	237	304	283	271	282	272	249	243	233	236	221	214	61%
Total Horses Agr.	**166**	**162**	**156**	**265**	**335**	**329**	**300**	**309**	**301**	**266**	**255**	**244**	**252**	**235**	**226**	**36%**
Total Mules and Asses Agr.	**73**	**133**	**223**	**144**	**154**	**177**	**166**	**178**	**163**	**172**	**157**	**230**	**218**	**230**	**227**	**211%**
Piglets	506	452	398	222	301	234	242	114	285	226	197	183	172	291	214	-58%
Fattening Pig over 25 kg	1’006	1’091	1’229	1’162	1’058	1’053	1’112	1’180	1’206	1’153	1’309	1’149	1’131	901	1’106	10%
Dry Sows	207	191	91	96	101	76	94	72	87	77	70	68	73	80	80	-61%
Nursing Sows	66	62	22	21	18	28	14	26	12	25	25	27	25	13	16	-76%
Boars	5	5	4	3	3	4	4	2	10	2	2	2	2	3	2	-60%
Total Swine	**3’251**	**2’429**	**1’992**	**1’703**	**1’690**	**1’739**	**1’655**	**1’712**	**1’747**	**1’789**	**1’875**	**1’772**	**1’724**	**1’465**	**1’632**	**-50%**
Growers	105	53	0	0	61	15	17	12	246	141	131	95	100	104	162	54%
Layers	4’145	5’506	6’866	10’112	12’175	12’216	12’544	12’509	12’056	12’438	12’141	12’371	14’322	15’143	20’337	391%
Broilers	0	500	1’000	250	390	112	250	5	0	100	0	300	400	60	51	-
Turkey	22	55	87	52	103	0	25	31	43	44	46	13	37	0	0	-
Other Poultry	163	134	106	39	191	182	189	123	153	104	137	137	151	129	90	-45%
Total Poultry	**4’435**	**6’248**	**8’059**	**10’453**	**12’920**	**12’525**	**13’025**	**12’680**	**12’498**	**12’827**	**12’455**	**12’916**	**15’010**	**15’436**	**20’640**	**365%**

Nitrogen excretion (N_{ex}) (compare FOEN 2019 page 300)

Data on nitrogen excretion per animal category (kg N/head/year) is country-specific and is the same as in the Swiss inventory (Kupper et al. 2018), see Figure 5-6 below. These values are based on the “Principles of Fertilisation in Arable and Forage Crop Production” (Richner et al. 2017). Unlike to the method in the IPCC Guidelines, the age structure of the animals and the different use of the animals (e.g. fattening and breeding) are considered. Standard nitrogen excretion rates are modified within the Swiss AGRAMMON model (nitrogen flow 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. 2018). This more disaggregated approach leads to considerably lower calculated nitrogen excretion rates compared to IPCC, 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) and including excretions from corresponding offspring and other associated animals (sheep, goats, swine) (see ART/SHL 2012).

In Liechtenstein, nitrogen excretion of **mature dairy cattle** is not directly adopted from the Swiss AGRAMMON model. In order to simulate the effect of milk production and feed properties on nitrogen excretion, an approach based on the results from the Swiss feeding model was chosen (Agroscope 2014c, see also chp. 5.2.2.1). As no separate model runs were performed for Liechtenstein, the respective effects were reproduced by using linear regressions displays the increase in nitrogen excretion with increasing milk yield. Equations for milk yields ≤ 6’030 kg*year-1 and > 6’030 kg*year-1 are:

- milk production per head and year ≤ 6'030 kg:
  NexDC = 0.00457 kg N / kg * Milk + 77.93381 kg N/head/year
- milk production per head and year > 6'030 kg:
  NexDC = 0.00445 kg N / kg * Milk + 80.46846 kg N/head/year

Where:

NexDC = annual average N excretion per mature dairy cattle (kg N/head/year)

Milk = amount of milk produced (kg/head/year)

To achieve high milk yields, cows have to be fed with an increasing share of feed concentrates. Due to the energy dense feed concentrates, the ratio between net energy content and protein content increases. For milk yields above 6'030 kg/year the increase in nitrogen excretion rate is thus lower than for lower milk yields. Data on milk yield is contained in Table 5-4.

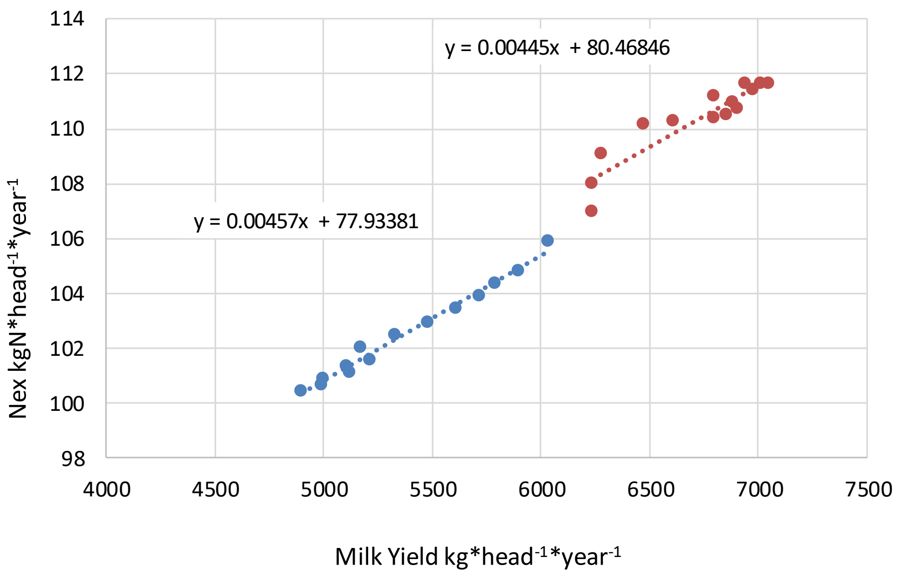


Figure 5-6 Linear regression relating nitrogen excretion (NexDC) of mature dairy cattle to milk yield (based on FOEN 2019).

Table 5-15 Nitrogen excretion rates of Liechtenstein's livestock.

Nitrogen Excretion	1990	1995	2000	2005	2010	2012	2013	2014
	kg N/head/year							
Cattle (weighted average)	66.9	66.9	71.8	71.8	68.7	68.9	68.7	67.7
Mature Dairy Cattle	104.4	104.7	108.6	110.7	110.1	110.9	110.6	110.5
Other Mature Cattle	85.0	85.0	85.0	85.0	85.0	85.0	85.0	85.0
Growing Cattle (weighted average)	35.9	35.2	34.6	34.5	35.2	34.9	35.2	35.5
Fattening Calves	*13.0*	*13.0*	*13.0*	*14.2*	*16.0*	*16.8*	*17.2*	*17.6*
Pre-Weaned Calves	*22.0*	*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*	*25.0*
Breeding Cattle 2nd Year	*40.0*	*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*	*55.0*
Fattening Cattle	*33.0*	*33.0*	*33.0*	*34.2*	*36.0*	*36.8*	*37.2*	*37.6*
Sheep (weighted average)	8.8	6.1	7.7	10.1	8.5	8.5	8.8	8.8
Swine (weighted average)	8.8	11.9	11.5	11.0	10.3	9.5	10.3	10.0
Goats	11.0	11.7	10.0	9.0	9.9	9.5	11.8	10.2
Horses (weighted average)	43.6	43.7	43.7	43.8	43.8	43.7	43.8	43.8
Mules and Asses	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Poultry (weighted average)	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8

Nitrogen Excretion	2015	2016	2017	2018	2019	2020	2021
	kg N/head/year						
Cattle (weighted average)	68.2	66.3	68.9	68.9	69.2	67.4	66.9
Mature Dairy Cattle	111.3	111.8	111.9	112.4	113.8	113.2	112.7
Other Mature Cattle	85.0	85.0	85.0	85.0	85.0	85.0	85.0
Growing Cattle (weighted average)	35.5	35.8	35.5	35.5	35.4	35.6	35.6
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)	8.1	7.7	7.9	8.1	8.6	7.8	7.7
Swine (weighted average)	10.2	9.6	10.0	9.5	9.6	9.6	10.0
Goats	10.9	11.2	11.4	11.6	10.5	9.9	10.9
Horses (weighted average)	43.8	43.9	43.9	43.9	43.9	43.9	43.9
Mules and Asses	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Poultry (weighted average)	0.8	0.8	0.8	0.8	0.8	0.8	0.8

Note that for sheep, N_{ex} rates for the entire time period were evaluated as a weighted-average based population number of fattening sheep and milksheep. The inter-annual fluctuations in the values of N_{ex} rates (especially in the period of 1994–1996) are due to changes in population structure of sheep.

Manure management system distribution (MS) (compare FOEN 2019, page 302)

The split of nitrogen flows into the different animal waste management systems and its temporal dynamics are based on the respective analysis of the Swiss AGRAMMON model (Kupper et al. 2018) and on data provided in Richner et al. (2017).

For cattle, the distribution of animal excreta to the various manure management systems (MS) is different with regard to estimating CH_4 emissions from 3B Manure management (for further information refer to chp. 5.3.2.2) compared to estimating N_2O emissions from 3B Manure management. This is because cattle stables usually 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 5-12 refers to the distribution of nitrogen while data provided in CRF Table3.B(a)s2 refer to the distribution of VS. A detailed table of the distribution of VS is contained in Annex A5.2. For further information regarding the estimation of the distribution of nitrogen and volatile solids to manure management systems for cattle, please refer to Switzerland's greenhouse gas inventory (FOEN 2023, Annex A5.3).

Note that for all other animal categories, the distribution of animal excreta to the various manure management systems is similar when estimating CH_4 emissions compared to N_2O emissions from 3B Manure management. Any differences between the distribution of excreta to manure management systems for superordinate animal categories solely occur due to different weighting of sub-animal categories.

Volatilisation of NH_3 and NO_x from manure management systems (compare FOEN 2019 page 302)

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 AGRAMMON model (Kupper et al. 2018). It is assumed that the same underlying assumptions on agricultural structures and practices in Switzerland are also valid for Liechtenstein. 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 nitrogen 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 around 14% to 20%.

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.

5.3.3 Uncertainties and time-series consistency

Uncertainties of emission factors and activity data are taken from ART (2008). These uncertainties were determined for the Swiss GHG inventory. Since the same model is applied for Liechtenstein's GHG inventory, the uncertainties are adopted for

Liechtenstein, too. ART (2008) was updated with current activity and emission data of the Swiss inventory and completed with default uncertainties from the 2006 IPCC Guidelines (IPCC 2006). The arithmetic mean of the lower and upper bound was used for activity data and for emission factors in the Approach 1 analysis (only for key categories, see Table 3-16).

Table 5-16 Uncertainties for source category 3B Manure management 2021. AD: Activity data; EF: Emission factor; comb.: Combined.

Uncertainty 3B		Approach 1		
		AD	EF	comb.
		%		
CH_4		6.5	54.0	54.4

The time series 1990–2021 is consistent. 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 in chp. 5.3.2.2
- Input data from the AGRAMMON model is available for the years 1990 and 1995 (expert judgement and literature) as well as for 2002, 2007, 2010 and 2018 (extensive surveys on approximatively 3’000 farms). Values in-between the assessment years were interpolated linearly, whereas values beyond 2018 are kept constant and will be updated as new survey results become available in parallel with an update of the whole agriculture model.
- Since Liechtenstein has only small animal populations the proportion of the sub-animal categories to each other are highly variable. For that reason, the weighted N-excretions also fluctuate from year to year (e.g. swine and goat). The fluctuation can be fully explained with the underlying data structure in the model for Liechtenstein.
- 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 Bühlmann (2014).

5.3.4 Category-specific QA/QC and verification

The category-specific QA/QC activities were carried out as mentioned in section 1.5 including triple checks of Liechtenstein’s reporting tables (CRF tables). The triple check includes a detailed comparison of current and previous submission data for the base year 1990 and the year 2020 as well as an analysis of the increase or decrease of emissions between 2020 and 2021 in the current submission.

In addition to the overall triple check a separate internal technical documentation of Liechtenstein’s model is available (Bretscher 2019, in German only). The manual also ensures transparency and retraceability of the calculation methods and data sources. Supplementary, a quality control was done by Acontec and INFRAS by a countercheck of the calculation sheets.

Further QA/QC activities are also documented in the Swiss NIR (see FOEN 2019). The respective conclusions are equally valid for Liechtenstein since the methods used are an adaptation of the Swiss model version. Bottom-up inventory estimates in Switzerland agree well with several atmospherically CH_4 measurements, thus verifying the respective methodological approach applied in the inventory.

The sectoral expert, the NIC and the NID author report their QC activities in a checklist (see Annex 4).

5.3.5 Category-specific recalculations

There were no category-specific recalculations.

5.3.6 Category-specific planned improvements

- It is planned that Liechtenstein's agriculture model will be updated every 5 years with latest Swiss values and data. The effort updating the model annually is not feasible for a small country such as Liechtenstein. The latest update has been done for the submission 2020.

5.4 Rice cultivation (3C)

Rice cultivation does not occur in Liechtenstein.

5.5 Agricultural soils (3D)

5.5.1 Category description: Agricultural soils (3D)

Key category information 3D

Direct N_2O emissions from agricultural soils (3D1) are a key category by level and trend (KCA excluding LULUCF categories).

The source category 3D includes direct and indirect N_2O emissions from managed soils with a subdivision given in Table 5-17.

The most significant N_2O emission sources in 2021 were animal manure applied to soils (25.4%), nitrogen input from atmospheric deposition (16.8%), urine and dung deposition by grazing animals (14.7%), inorganic nitrogen fertilisers (13.6%) and nitrogen in crop residues returned to soils (9.7%).

Furthermore, NO_x emissions from managed soils as well as NMVOC emissions are estimated.

Table 5-17 Specification of source category 3D Agricultural soils. AD: Activity data; EF: Emission factors.

3D	Source	Specification
3Da	Direct N_2O emissions from managed soils	1. Inorganic N fertilisers 2. Organic N fertilisers (animal manure applied to soils, sewage sludge applied to soils, other organic fertilisers applied to soils) 3. Urine and dung deposited by grazing animals 4. Crop residues (inc. residues from meadows and pasture) 5. Mineralisation/immobilisation associated with loss/gain of soil organic matter 6. Cultivation of organic soils (i.e. histosols) 7. Other (Domestic synthetic fertiliser)
3Db	Indirect N_2O emissions from managed soils	1. Atmospheric deposition 2. Nitrogen leaching and run-off

Direct and indirect N_2O emissions have decreased by 6.9% and 25.0% in 2021 compared to 1990 levels, respectively. The lowest N_2O emission level was in the year 2000. Since then, total emissions are slightly increasing, reflecting a similar increase of cattle numbers (see Figure 5-5).

5.5.2 Methodological issues: Agricultural soils (3D)

5.5.2.1 Methodology

As done for previous submission, Liechtenstein adopted the methodology of Switzerland (for further information see chp. 5.1) in order to calculate emissions originating from source category 3D Agricultural soils. The calculation is based on methods described in the 2006 IPCC Guidelines.

For the calculation of most N_2O emissions from source category 3D Agricultural soils a Tier 1 method used in the Swiss inventory and based on the IULIA model from Schmid et al. (2000) was applied. IULIA is an IPCC-derived method for the calculation of N_2O emissions from agriculture that basically uses the same emission factors but adjusts the activity data to the particular situation of Switzerland. IULIA is continuously updated. New values for nitrogen excretion rates, manure management system distribution and ammonium emission factors from the Swiss AGRAMMON model were adopted (Kupper et al. 2018). Furthermore, the updated version of the "Principles of Fertilisation in Arable and Forage Crop Production" (GRUD; Richner et al. 2017) was used. Most 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 IPCC 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 2019) and is consistent with source category 3B N_2O

emissions from manure management. The model structure is displayed in Figure 5-7 and the corresponding amounts of nitrogen are given in Table 5-18.

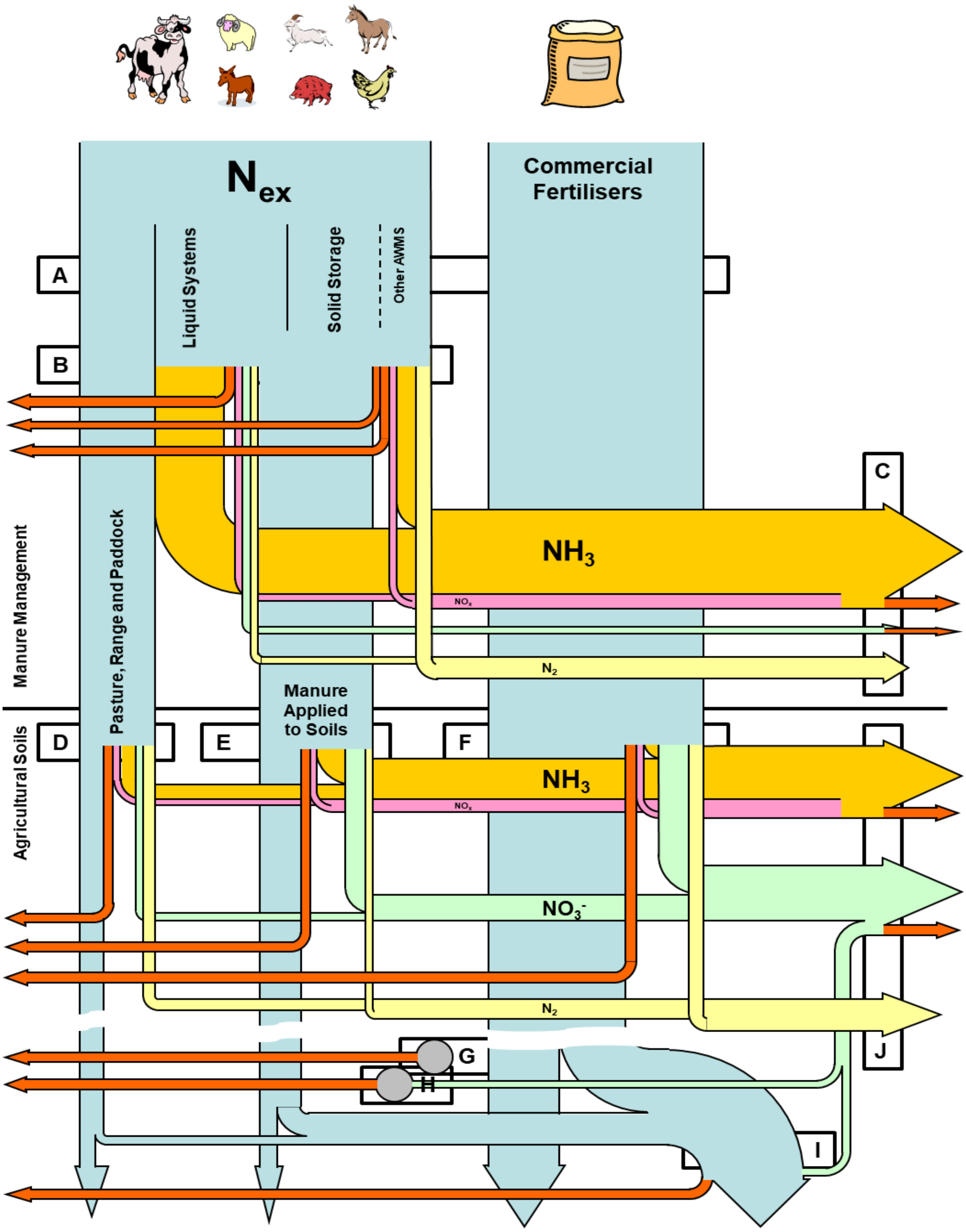


Figure 5-7 Diagram depicting the methodology of the approach to calculate the N_2O emissions in agriculture (red arrows). Black frames and the respective letters refer to the nitrogen flows in Table 5-18. Note that the figure shows explicitly the methodology of the approach and not necessarily the physical 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 5-18 Nitrogen flows of the N-flow model for Liechtenstein's agriculture. Letters refer to the letters in Figure 5-7. Processes refer to the nitrogen flows in the black frames in Figure 5-7 from left to right or from top to bottom.

	Process	Amount of N			CRF table
		1990	0		
		tN		equals	
A	1 Pasture, range and paddock	53.58	99.10	= B	3.Da3
	2 Liquid/slurry systems	281.62	285.81		3.B(b)
	3 Solid storage	131.11	76.44		3.B(b)
	4 Other AWMS	23.60	43.09		3.B(b)
	5 Commercial fertiliser	278.07	176.11	= F	3.Da1,2,7
B	1 Pasture, range and paddock	53.58	99.10	= A1-A4	3.Da3
	2 NH_3 volatilisation housing	28.57	50.65		3.B(b)5
	3 N_2O emission liquid/slurry	0.56	0.57		3.B(b)
	4 NO_x volatilisation liquid/slurry and digester	0.56	0.57		3.B(b)5
	5 Leaching manure management	0.00	0.00		3.B(b)5
	6 N2 volatilization liquid/slurry and digester	5.63	5.72		
	7 Manure applied to soils	364.49	315.61		3.Da2
	8 N2O emission solid storage	0.66	0.38		3.B(b)
	9 N2O emission other AWMS	0.21	0.29		3.B(b)
	10 NOx volatilisation solid storage and deep litter	0.86	0.68		3.B(b)5
	11 NH3 volatilisation storage	30.41	27.18		3.B(b)5
	12 N2 volatilization solid storage and deep litter	4.38	3.68		
C	1 NH_3 deposition manure management	58.98	77.83	= B2+B10	3.B(b)5
	2 NO_x deposition manure management	1.43	1.25	= B4+B9	
	3 Leaching manure management	0.00	0.00	= B5	
D	1 Available N PR&P	38.75	74.03	= B1	
	2 N_2O emission PR&P	0.99	1.83		3.Da3
	3 NO_x volatilisation PR&P	0.29	0.55		
	4 NH_3 volatilisation PR&P	2.51	5.02		
	5 Leaching and run-off PR&P	11.04	17.68		
E	1 Available N animal manure	193.89	191.38	= B6	
	2 N_2O emission application animal manure	3.64	3.16		3.Da2
	3 NO_x volatilisation application animal manure	2.00	1.74		
	4 NH_3 volatilisation application animal manure	89.83	63.04		
	5 Leaching and run-off application animal manure	75.11	56.30		
F	1 Available N com. fertiliser	199.77	134.29	= A5	
	2 N_2O emission application com. fertiliser	2.78	1.76		3.Da1,2,7
	3 NO_x volatilisation application com. fertiliser	1.53	0.97		
	4 NH_3 volatilisation application com. fertiliser	16.68	7.67		
	5 Leaching and run-off application com. fertiliser	57.31	31.42		
G	1 Cultivation of organic soils (ha)	*191.50*	*180.50*		3.Da6
H	1 Mineralisation/immobilisation soil organic matter	0.00	0.00		3.Da5
I	1 N in crop residues pasture, range and paddock	79.59	89.30		3.Da4
	2 N in crop residues arable crops	34.11	30.94		
J	1 NH_3 deposition fertiliser appl. and PR&P	109.02	75.73	= D4+E4+F4	3.Db1
	2 NO_x deposition fertiliser appl. and PR&P	3.83	3.25	= D3+E3+F3	
	3 Leaching and run-off fertiliser appl. and PR&P	143.46	105.40	= D5+E5+F5	3.Db2
	4 Leaching and run-off mineralisation SOM	0.00	0.00		
	5 Leaching and run-off crop residues	23.43	21.45		

5.5.2.2 Direct N_2O emissions from managed soils (3Da)

Calculation of Direct N_2O emissions from managed soils is based on IPCC 2006 equation 11.2 including six terms for activity data and three different emission factors:

$$N_2O_{Direct} - N = (F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \bullet EF_1 + F_{OS} \bullet EF_2 + F_{PRP} \bullet EF_3$$

Where:

N_2O_{Direct} = annual direct N_2O 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/year)

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)

Emission factors for direct N_2O emissions

Emission factors for calculating 3Da Direct N_2O emissions from managed soils are based on default values as provided in the 2006 IPCC Guidelines (see Table 5-19). Due to the lack of data, no fertiliser specific emission factors were applied for EF_1. 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 ($EF_{3PRP,CPP}$ = 0.02) and the emission factor for sheep and "other animals" ($EF_{3PRP,SO}$ = 0.01) according to the shares of nitrogen excreted on pasture, range and paddock by the respective animals.

Table 5-19 Emission factors for calculating direct N_2O emissions from managed soils (IPCC 2006).

Emission Source	Emission factor
EF_1 Inorganic N fertilisers (kg N_2O-N/kg)	0.0100
EF_1 Organic N fertilisers (kg N_2O-N/kg)	0.0100
EF_1 Crop residue (kg N_2O-N/kg)	0.0100
EF_1 Mineralisation/immobilisation soil organic matter (kg N_2O-N/kg)	0.0100
EF_1 Other (domestic synthetic fertilisers) (kg N2O-N/kg)	0.0100
EF_2 Cultivation of organic soils (kg N_2O-N/ha)	8.0000
EF_3 Urine and dung deposited by grazing animals (kg N_2O-N/kg)	0.0184

Activity data for direct N_2O emissions

Activity data for calculation of direct soil emissions includes 1. Inorganic N fertilisers, 2. Organic N fertilisers, 3. Urine and dung deposited by grazing animals, 4. Crop residues, 6. Cultivation of organic soils (i.e. histosols) and 7. Other (i.e. domestic inorganic fertilisers). 5. Nitrogen from mineralisation/immobilisation associated with loss/gain of soil organic matter is not occurring in Liechtenstein.

Emissions from **inorganic nitrogen fertilisers** include urea and other mineral fertilisers (mainly ammonium-nitrate). Data on the application of synthetic fertilisers in Liechtenstein is not available. Consequently, N input was estimated multiplying average inorganic N input per ha in Switzerland (FOEN 2019) with the area fertilized in Liechtenstein which is provided by the Division of Agriculture (OE 2015a). The split of mineral fertilisers in urea and other mineral fertiliser is based on the mean value of the respective time series 1990-2017 in the Swiss inventory (see internal technical documentation in Bretscher (2019). Accordingly, a share of 15% was allocated to urea and 85% to other synthetic fertilisers. 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. 2018). These fertilisers are used in public green areas, sports grounds and home gardens. In the CRF-tables they are reported under 3Da7 Other (Domestic synthetic fertilisers) while emission calculation is conducted together with 3Da1. In certain occasions, as for instance for the estimation of indirect N_2O emissions from managed soils, the sum of urea, other mineral fertilisers, sewage sludge (1990-2003 only), other organic fertilisers and domestic fertilisers is referred to as “commercial fertilisers” (see also Figure 5-7 and Table 5-18).

Organic nitrogen fertilisers include animal manure 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 chapter 10.5.4. and equation 10.34 of the 2006 IPCC Guidelines (IPCC 2006), 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 N-volatilisation see chp. 5.3.2.5, compare also Figure 5-7 and Table 5-21). $Frac_{GASM}$ in reporting table 3.D represents the amount of nitrogen volatilised as NH_3, NO_x and N_2O from housing and manure storage divided by the manure excreted in the stable (liquid/slurry, solid storage, deep litter and poultry manure). The nitrogen input from manure applied to soils under 3Da2a in reporting table 3.D can thus be calculated with the numbers given in reporting table 3.B(b) and 3.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 is provided by the annual report “Rechenschaftsbericht” (CG 2021). Since 2003, the use of sewage sludge as fertiliser is prohibited in Liechtenstein (see Annex0). From then on, the entire sewage sludge is treated in one centralized Municipal Wastewater Treatment Plant (MWWTP) in Bendern. After the anaerobic digestion, the digested sewage sludge is dewatered and dried. Pellets are transported and incinerated in Switzerland in the cement plant Untervaz (AZV 2022).

Other organic fertilisers contain compost. Compost data are provided by the Office of Environment. It is assumed that 15% of the total amount of Liechtenstein’s compost is used as agricultural fertiliser. The rest of the compost amount is reported under sector 5 Waste, categories 5B and 5C.

Calculation of emissions from **urine and dung deposited by grazing animals** is based on equation 11.5 of the 2006 IPCC Guidelines (IPCC 2006). Estimation of total livestock nitrogen excretion is described under 5.3.2.5. The share of manure nitrogen excreted on pasture, range and paddock is the same as in the Swiss AGRAMMON model (Kupper et al. 2018). 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. The 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).

N_2O emissions from **crop residues** are based on the amount of nitrogen in crop residues returned to soil. For **arable crops** data were calculated based on standard values for nitrogen in crop residues per hectare from GRUD (Richner et al. 2017) and the corresponding cropland of Liechtenstein (OE 2015a):

$$F_{CR,AC} = \sum_{T} (N_T \cdot A_T)$$

Where:

$F_{CR,AC}$ = amount of nitrogen in crop residues from arable crops returned to soils (t N)

N_T = standard nitrogen amount in crop residues per hectare for crop T (t N / ha)

A_T = cropland in hectare for crop T (ha)

Standard values for fresh matter crop yields and nitrogen contained in crop residues are given in the "Principles of Fertilisation in Arable and Forage Crop Production" (FAL/RAC 2001 and Richner et al. 2017). For sugar beet and fodder beet it is assumed that 10% of the crop residues are removed from the fields for animal fodder. For silage corn it is assumed that 5% of the biomass harvested is left as crop residues.

Crop residues from **meadows and pastures** were also assessed. The main part of the agricultural land use consists of grassland which underscores the importance of this source for Liechtenstein.

$$F_{CR,MP} = \sum_{P} \left(A_P \bullet \frac{SY_{DM,P}}{10} \bullet N_{DM,P} \div 1000 \bullet R_P \right)$$

Where:

$F_{CR,MP}$ = amount of nitrogen in crop residues from meadows and pastures returned to soils (t N)

A_P = area of meadow and pasture of type P (ha)

$SY_{DM,P}$ = standard dry matter yield per area of meadow and pasture of type P (dt/ha)

$N_{DM,P}$ = dry matter nitrogen content of meadow and pasture of type P (kg/t)

R_P = ratio of residues to harvested yield for meadows and pasture of type P (kg/kg)

Input data on the managed area of meadows and pastures are taken from the Office of the Environment, Division of Agriculture (OE 2015a). Note that this input data shows an increase of the area of natural meadows for the year 2011, which leads to the increase of PR&P residues visible in Table 5-20 in the year 2011. Standard dry matter yields per area, nitrogen content of dry matter as well as percentage of yield losses were based on the original IULIA model (Schmid et al. 2000) and on Richner et al. (2017).

N_2O emissions from **N-mineralization** are zero (not occurring NO) in Liechtenstein since net carbon stock changes for mineral soils under cropland remaining cropland are zero (NO) (compare chp. 6.5.2).

Estimates of N_2O emissions from **cultivated organic soils** are based on the area of cultivated organic soils and the IPCC default emission factor for N_2O emissions from cultivated organic soils (IPCC 2006). The area of cultivated organic soils corresponds to the total area of organic soils under cropland and grassland as reported in the reporting tables 4.B and 4.C (see also chp. 6).

The relevant activity data for calculating N_2O emissions from managed soils are displayed in Table 5-20. Additional information is given in Annex A5.2.

Table 5-20 Activity data for calculating direct N_2O emissions from managed soils.

Activity Data		1990	1995	2000	2005	2010	2012	2013	2014
		t N/yr							
1. Inorganic N fertilisers	Urea	37	31	29	29	27	28	27	26
	Other mineral fertilisers	200	169	155	158	147	151	147	142
2. Organic N fertilisers	a. Animal manure	364	333	279	297	308	321	307	312
	b. Sewage sludge	30.4	31.3	10.8	0.0	0.0	0.0	0.0	0.0
	c. Other organic fertilisers	0.3	0.3	0.4	0.5	0.4	0.5	0.5	0.5
3. Urine and dung deposited by grazing animals		54	51	71	98	97	102	96	98
4. Crop residues	Arable crops	34	44	32	30	27	27	27	31
	Residues PR&P	80	84	86	93	86	87	85	85
5. Min./imm. associated with loss/gain of SOM		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6. Cultivation of organic soils (ha)		192	189	187	184	182	183	184	184
7. Other (domestic inorganic fertilisers)		9.9	8.4	7.6	7.8	7.3	7.5	7.2	7.0

Activity Data		2015	2016	2017	2018	2019	2020	2021	1990 -2021
		t N/yr							%
1. Inorganic N fertilisers	Urea	30	27	28	31	29	26	26	-29%
	Other mineral fertilisers	162	145	152	166	155	138	142	-29%
2. Organic N fertilisers	a. Animal manure	307	307	300	305	317	317	316	-13%
	b. Sewage sludge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
	c. Other organic fertilisers	0.4	0.5	0.5	0.4	0.5	0.5	0.5	84%
3. Urine and dung deposited by grazing animals		95	96	92	94	98	99	99	85%
4. Crop residues	Arable crops	30	30	32	32	33	35	31	-9%
	Residues PR&P	85	85	86	86	86	98	89	12%
5. Min./imm. associated with loss/gain of SOM		0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
6. Cultivation of organic soils (ha)		183	183	182	182	181	181	181	-6%
7. Other (domestic inorganic fertilisers)		8.0	7.2	7.5	8.2	7.7	6.8	7.0	-29%

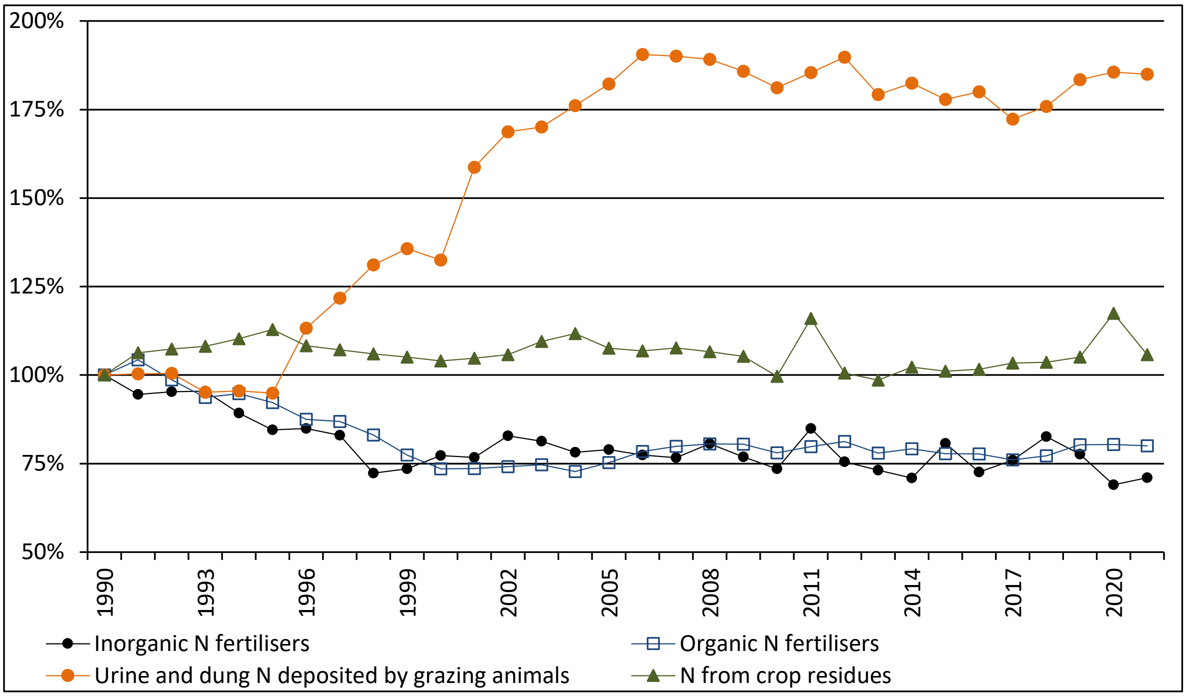


Figure 5-8 Relative development of the most important activity data for source category 3Da direct N_2O emissions from managed soils

Figure 5-8 depicts the development of the most important activity data for direct N_2O emissions from managed soils. The use of inorganic N-fertiliser declined mainly during the 1990s due to structural changes: Between 1996 and 2011, the number of farms certified by the production labels “BIO” (organic production) and “IP” (integrated production) grew from 80 to 115 (OS 2014d). Simultaneously, nitrogen input from animal manure declined due to smaller livestock populations (mainly cattle) and an increasing share of nitrogen deposited on pasture, range and paddock. 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). N inputs from crop residues remained more or less constant during the inventory time period due to more or less stable crop production rates.

5.5.2.3 Indirect N_2O emissions from atmospheric deposition of N volatilised from managed soils (3Db1)

N_2O emissions from atmospheric deposition of N volatilised from managed soil were estimated based on equations 11.9 and 11.11 of the 2006 IPCC Guidelines (IPCC 2006), which were adapted to the more detailed approach applied in Switzerland as follows:

$$N_2O_{(ATD)} - N = \left\{ \left[\sum_i \left(F_{CN_i} * Frac_{GASF_i} \right) + \sum_T \left(F_{AM_T} * Frac_{GASM_T} \right) + \sum_T \left(F_{PRP_T} * Frac_{GASP_T} \right) \right] + \left[(F_{CN} + F_{AM}) * Frac_{NOXA} + F_{PRP} * Frac_{NOXP} \right] \right\} * EF_4$$

Where:

$N_2O_{(ATD)}$-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 N)

F_{CN} = total amount of commercial fertiliser N applied to soils (kg N/year)

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 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)

Emission factors for indirect N_2O emissions from atmospheric deposition

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 2.6%. For further information, see chp. 5.3.2.4.

Activity data for indirect N_2O emissions from atmospheric deposition (compare FOEN 2019 page 317)

The estimation of volatilisation of ammonia and NO_x was harmonized with the Swiss AGRAMMON model using the same emission factors and basic parameters (see Table 5-21). Losses of commercial fertiliser nitrogen, animal manure N applied to soils, urine and dung N deposited on pasture, range and paddock by grazing animals as well as ammonia losses from agricultural soils due to processes in the vegetation cover were considered. For the calculation of NH_3 emissions, changes of agricultural structures (e.g. 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 urea and other synthetic fertilisers, sewage sludge (1990-2003), and other organic fertilisers (compost). Ammonia volatilisation of nitrogen in synthetic fertilisers was assessed separately for individual fertiliser types based on (EMEP/EEA 2016). The weighted mean value for synthetic fertilisers excluding urea is 2.8% (mean 1990–2017). 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. 2018) and is NO from 2004 onwards. Other organic fertilisers include compost as well as liquid and solid digestates. Ammonia emission factors are 3.4% for compost.

Total $Frac_{GASF}$ as reported in reporting table 3.D declined considerably from 6.0% in 1990 to 4.4% in 2021 due to a change in the shares of the different commercial fertilisers: the use of urea and sewage sludge (sewage sludge only 1990-2003), which both have high NH_3 emission factors, has declined since 1990.

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. 2018). Overall weighted $Frac_{GASMT}$ for animal manure applied to soils slightly decreased from 24.6% in 1990 to 20.0% in 2021.

Ammonia volatilisation from **urine and dung N deposited on pasture, range and paddock by grazing animals** was also assessed individually for each livestock category. Weighted mean loss rates ($Frac_{GASPT}$) range between 4.7% and 5.1%.

Nitrogen pools and flows for calculating 3Db Indirect N_2O emissions from managed soils are displayed in Table 5-22. Additional information is given in AnnexA5.2.

Table 5-21 Overview of NH_3 and NO_x emission factors used for the assessment of emissions from source category 3Db1 Indirect N_2O emissions from atmospheric deposition.

Emission Factors Volatilisation	1990	1995	2000	2005	2010	2012	2013	2014
	%							
NH_3 from commercial fertiliser N ($Frac_{GASFi}$)	6.00	6.84	5.27	4.31	4.57	4.61	4.62	4.55
Urea	13.11	13.11	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	3.11	3.12	3.04
Recycling Fertilisers (weighted average)	19.84	23.74	25.21	3.43	3.43	3.43	3.43	3.43
Sewage Sludge	20.00	23.94	26.07	NO	NO	NO	NO	NO
Compost	3.43	3.43	3.43	3.43	3.43	3.43	3.43	3.43
NH_3 from application of animal manure N ($Frac_{GASMT}$)	24.65	24.76	22.96	22.61	21.24	20.81	20.58	20.35
Mature Dairy Cattle	26.69	26.78	25.38	25.30	23.76	23.12	22.81	22.50
Other Mature Cattle	24.16	23.68	21.76	22.65	22.45	22.11	21.94	21.77
Growing Cattle (weighted average)	24.84	24.75	22.72	22.86	21.99	21.57	21.42	21.28
Sheep (weighted average)	3.72	4.38	4.14	5.23	5.50	5.27	5.16	5.04
Swine (weighted average)	21.52	21.02	19.79	20.02	18.82	18.52	18.38	18.21
Other Livestock (weighted average)	5.73	7.32	7.32	7.70	8.26	8.34	8.63	8.58
NH_3 from urine and dung N deposited on PR&P ($Frac_{GASPT}$)	4.68	4.68	4.78	4.86	4.88	4.88	4.90	4.90
Mature Dairy Cattle	4.67	4.65	4.65	4.61	4.59	4.59	4.59	4.59
Other Mature Cattle	4.57	4.57	4.57	4.57	4.57	4.56	4.56	4.56
Growing Cattle (weighted average)	4.57	4.57	4.57	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	5.00	5.00
Swine (weighted average)	NA	NA	14.00	14.00	14.00	14.00	14.00	14.00
Other Livestock (weighted average)	5.00	6.01	8.11	9.96	9.22	9.56	10.33	10.42
NH_3 from Agricultural Soils (kg/ha/year)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NO_x from applied fertilisers ($Frac_{NOXA}$)	0.55	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	0.55

Emission Factors Volatilisation	2015	2016	2017	2018	2019	2020	2021	1990 -2021
	%							%
NH_3 from commercial fertiliser N ($Frac_{GASFi}$)	4.83	4.36	4.36	4.36	4.36	4.36	4.36	-27%
Urea	13.11	13.10	13.10	13.10	13.10	13.10	13.10	0%
Other Mineral Fertilisers	3.37	2.82	2.82	2.82	2.82	2.82	2.82	3%
Recycling Fertilisers (weighted average)	3.43	3.43	3.43	3.43	3.43	3.43	3.43	-83%
Sewage Sludge	NO	NO	NO	NO	NO	NO	NO	-
Compost	3.43	3.43	3.43	3.43	3.43	3.43	3.43	0%
NH_3 from application of animal manure N ($Frac_{GASMT}$)	20.10	20.11	20.05	20.04	20.07	20.16	19.97	-19%
Mature Dairy Cattle	22.19	22.19	22.19	22.19	22.19	22.19	22.19	-17%
Other Mature Cattle	21.61	21.61	21.61	21.61	21.61	21.61	21.61	-11%
Growing Cattle (weighted average)	21.07	21.12	21.07	21.07	21.07	21.10	21.10	-15%
Sheep (weighted average)	4.92	4.92	4.92	4.92	4.92	4.92	4.92	32%
Swine (weighted average)	18.05	18.04	18.05	18.03	18.03	18.05	18.04	-16%
Other Livestock (weighted average)	8.59	8.74	8.73	8.60	8.94	9.04	9.64	68%
NH_3 from urine and dung N deposited on PR&P ($Frac_{GASPT}$)	4.91	4.91	4.92	4.92	4.95	4.95	5.07	8%
Mature Dairy Cattle	4.59	4.59	4.59	4.59	4.59	4.59	4.59	-2%
Other Mature Cattle	4.57	4.57	4.57	4.57	4.57	4.57	4.57	0%
Growing Cattle (weighted average)	4.57	4.57	4.57	4.57	4.57	4.57	4.57	0%
Sheep (weighted average)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	0%
Swine (weighted average)	14.00	14.00	14.00	14.00	14.00	14.00	14.00	-
Other Livestock (weighted average)	10.58	11.10	11.17	10.88	11.65	12.03	13.85	177%
NH_3 from Agricultural Soils (kg/ha/year)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
NO_x from applied fertilisers ($Frac_{NOXA}$)	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0%
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	0%

Note: The notation key of emission factors for sewage sludge is automatically set “NO” by the CRF reporter.

Table 5-22 Overview of N pools and flows for calculating indirect N_2O emissions from managed soils.

Nitrogen Pools and Flows		1990	1995	2000	2005	2010	2012	2013	2014
		t N/yr							
	Animals manure N applied to soils	364	333.0	279.2	296.8	307.8	320.6	307.4	312.5
	Commercial fertiliser	278.1	240.7	202.4	195.7	182.3	187.3	181.4	175.9
	Area of agricultural soils (ha)	5'278	5'377	5'476	5'476	5'476	5'476	5'476	5'476
Deposition	Sum volatised N (NH_3 and NO_x)	112.8	104.7	81.2	83.5	81.7	83.6	79.6	79.6
	NH_3 emissions from commercial fertilisers	16.7	16.5	10.7	8.4	8.3	8.6	8.4	8.0
	NH_3 emissions from applied animal manure	89.8	82.4	64.1	67.1	65.4	66.7	63.3	63.6
	NH_3 emissions from pasture, range and paddock	2.51	2.38	3.39	4.75	4.73	4.96	4.71	4.79
	NH_3 emissions from agricultural soils	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NO_x emissions from commercial fertilisers	1.53	1.32	1.11	1.08	1.00	1.03	1.00	0.97
	NO_x emissions from applied animal manure	2.00	1.83	1.54	1.63	1.69	1.76	1.69	1.72
	NO_x emissions from PR&P	0.29	0.28	0.39	0.54	0.53	0.56	0.53	0.54
Leaching and run-off	Sum leaching and run-off	166.9	155.1	132.0	133.7	124.9	129.1	124.3	125.3
	Leaching and run-off from commercial fertilisers	57.3	49.6	39.8	36.7	32.5	33.4	32.4	31.4
	Leaching and run-off from applied animal manure	75.1	68.6	55.0	55.7	54.9	57.2	54.8	55.7
	Leaching and run-off from pasture, range and paddock	11.0	10.5	14.0	18.3	17.3	18.1	17.1	17.4
	Leaching and run-off from crop residues	23.4	26.4	23.3	22.9	20.2	20.4	20.0	20.7
	Leaching and run-off from mineralisation of SOM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Nitrogen Pools and Flows		2015	2016	2017	2018	2019	2020	2021	1990 -2021
		t N/yr							%
	Animals manure N applied to soils	307	307	300.0	304.6	316.8	317.0	315.6	-13%
	Commercial fertiliser	200.0	180.0	188.4	204.7	192.4	171.2	176.1	-37%
	Area of agricultural soils (ha)	5'476	5'476	5'476	5'476	5'476	5'476	5'476	4%
Deposition	Sum volatised N (NH_3 and NO_x)	79.4	77.4	76.1	77.9	80.2	79.5	79.0	-30%
	NH_3 emissions from commercial fertilisers	9.7	7.8	8.2	8.9	8.4	7.5	7.7	-54%
	NH_3 emissions from applied animal manure	61.7	61.7	60.1	61.0	63.6	63.9	63.0	-30%
	NH_3 emissions from pasture, range and paddock	4.68	4.73	4.54	4.63	4.86	4.93	5.02	100%
	NH_3 emissions from agricultural soils	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
	NO_x emissions from commercial fertilisers	1.10	0.99	1.04	1.13	1.06	0.94	0.97	-37%
	NO_x emissions from applied animal manure	1.69	1.69	1.65	1.68	1.74	1.74	1.74	-13%
	NO_x emissions from PR&P	0.52	0.53	0.51	0.52	0.54	0.55	0.55	85%
Leaching and run-off	Sum leaching and run-off	128.0	124.6	124.6	128.7	129.7	128.7	126.8	-24%
	Leaching and run-off from commercial fertilisers	35.7	32.1	33.6	36.5	34.3	30.5	31.4	-45%
	Leaching and run-off from applied animal manure	54.8	54.7	53.5	54.3	56.5	56.6	56.3	-25%
	Leaching and run-off from pasture, range and paddock	17.0	17.2	16.5	16.8	17.5	17.7	17.7	60%
	Leaching and run-off from crop residues	20.5	20.6	21.0	21.0	21.3	23.8	21.4	-8%
	Leaching and run-off from mineralisation of SOM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-

Figure 5-9 depicts the development of the most important activity data for indirect N_2O emissions from managed soils. Ammonia emissions from application of commercial fertilisers declined mainly due to reduced fertiliser use and due to the decreasing share of fertilisers with high ammonia emission rates (i.e. urea and sewage sludge) (see chapter 5.5.2.2). 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.

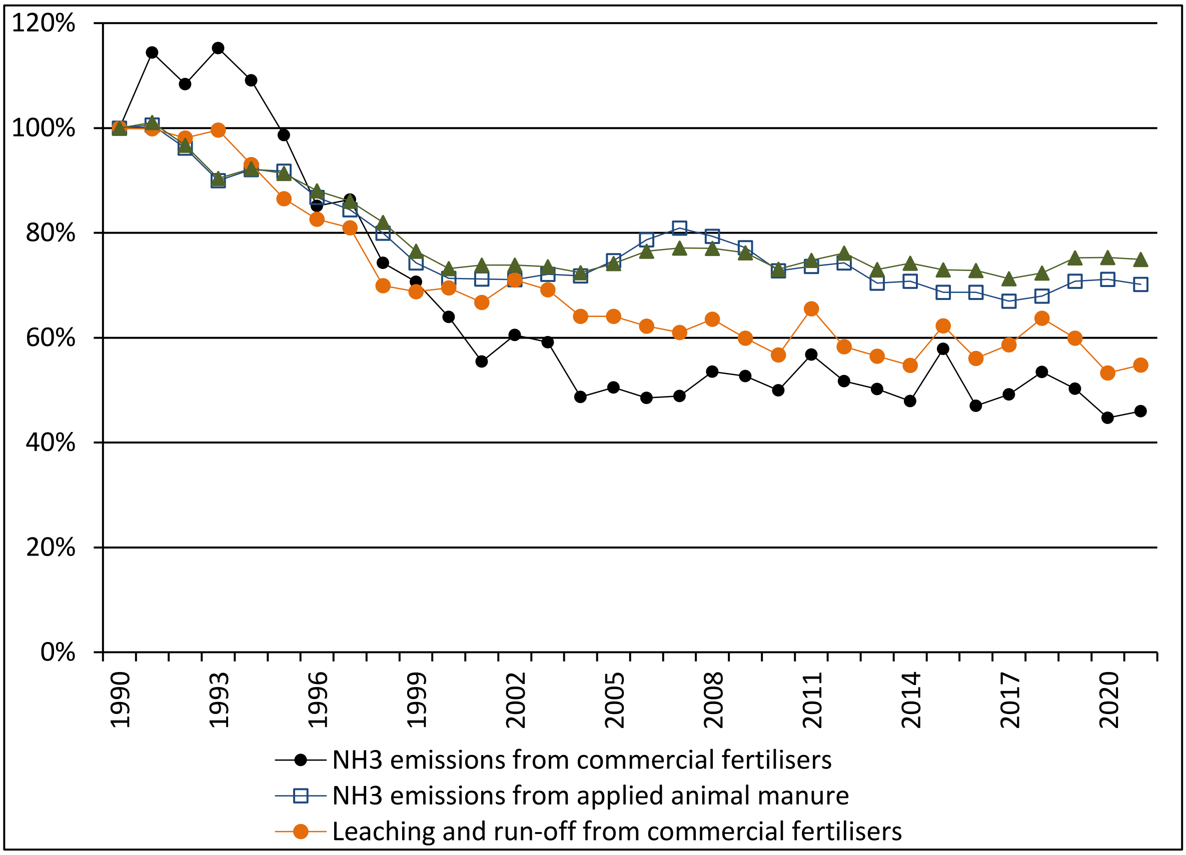


Figure 5-9 Relative development of the most important activity data for source category 3Db indirect N_2O emissions from managed soils.

5.5.2.4 Indirect N_2O emissions from leaching and run-off from managed soils (3Db2)

N_2O emissions from leaching and run-off from managed soils were estimated based on equation 11.10 of the 2006 IPCC Guidelines (IPCC 2006):

$$N_2O_{(L)} - N = \left(F_{CN} + F_{AM} + F_{PRP} + F_{CR} + F_{SOM}\right) \bullet Frac_{LEACH-(H)} \bullet EF_5$$

Where:

$N_2O_{(L)}$–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)

Emission factor for indirect N_2O emissions from nitrogen leaching and run-off

The emission factor for indirect N_2O emissions from leaching and run-off from managed soils is 0.0075 kg N_2O–N/kg N according to the 2006 IPCC guidelines (IPCC 2006).

Activity data for indirect N_2O emissions from nitrogen leaching and run-off (compare FOEN 2019 page 322)

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 and compost), managed animal manure N applied to soils (F_{AM}), urine and dung N deposited by grazing animals (F_{PRP}) and N in crop residues returned to soils (F_{CR}) were accounted for. It is assumed that no nitrogen is mineralised in agricultural soils of Liechtenstein. The method for the assessment of the respective amounts of nitrogen is described in chp. 5.5.2.2 and numbers are shown in Table 5-20.

$Frac_{LEACH}$ was taken from the Swiss GHG inventory. It 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. According to Spiess and Prasuhn (2006), it can be assumed that loss rates were somewhat higher in the early 1990s and then declined due to 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. The resulting amount of nitrogen that is lost through leaching and run-off is given in Table 5-22.

Figure 5-9 depicts the development of the most important activity data for 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 ($Frac_{LEACH}$).

5.5.3 Uncertainties and time-series consistency

Uncertainties of emission factors and activity data are taken from ART (2008). These uncertainties were determined for the Swiss GHG inventory. Since the same model is applied for Liechtenstein's GHG inventory, the uncertainties are adopted for

Liechtenstein, too. ART (2008) was updated with current activity and emission data of the Swiss inventory and completed with default uncertainties from the 2006 IPCC Guidelines (IPCC 2006). The arithmetic mean of the lower and upper bound uncertainty was used for the uncertainty of activity data and emission factors, resulting in combined Approach 1 uncertainties as shown in Table 5-23. For 3Da (Direct N_2O emissions – Fertilisers) the sub-positions 3Da 1, 2, 4, and 7 were combined according to Approach 1 error propagation.

Since there are two aggregate categories 3D direct/N_2O and 3D indirect/N_2O, the uncertainties of fertilisers, organic soils, urine and dung deposited on pasture range and paddock are aggregated (via error propagation) and similar for 3D indirect/N_2O atmospheric deposition and leaching /runoff. The results of the aggregations are given in Table 5-23 and are used in chp. 1.6.

Table 5-23 Approach 1 uncertainties for 3D Agricultural soils in 2021. AD: Activity data; EF: Emission factor; CO: Combined.

Uncertainty 3D		**Approach 1**		
		AD	**EF**	**comb.**
		%		
3D1 Direct soil emissions	Fertilisers	13.6	135.0	135.7
	Organic soils	32.2	137.5	141.2
	Urine and dung deposited on PR&P	67.7	132.5	148.8
	3D1 aggregate	16.9	94.1	95.6
3D2 Indirect soil emissions	Atmospheric deposition	41.8	240.0	243.6
	Leaching and run-off	22.2	163.3	164.8
	3D2 aggregate	29.6	173.3	175.8

For further uncertainty results also consult chp. 1.6.

The time series 1990–2021 are consistent. The following issues should be considered:

- Input data from the AGRAMMON model is available for the years 1990 and 1995 (expert judgement and literature) as well as for 2002, 2007, 2010 and 2015 (extensive surveys on approximatively 3000 farms). Values in-between the assessment years were interpolated linearly, whereas values beyond 2015 are kept constant and will be updated as new survey results become available.
- The emission factor for indirect N_2O emissions following volatilization of NH_3 and NO_x varies according to varying land use as described in chp. 5.3.2.4.
- Considerable fluctuations within the small animal populations due to establishment or cessation of farms or agricultural activities can lead to fluctuations in activity data and emissions (e.g. for animal manure applied to agricultural soils).
- For more details on time-series consistency see chp. 5.2.3 and 5.3.3.

5.5.4 Category-specific QA/QC and verification

The category-specific QA/QC activities was carried out as mentioned in section 1.5 including triple checks of Liechtenstein's reporting tables (CRF tables). The triple check includes a detailed comparison of current and previous submission data for the base year 1990 and the year 2020 as well as an analysis of the increase or decrease of emissions between 2020 and 2021 in the current submission.

In addition to the overall triple check a separate internal technical documentation of Liechtenstein's model is available (Bretscher 2019). The manual also ensures transparency and retraceability of the calculation methods and data sources. Supplementary, a quality control was done by Acontec and INFRAS by a countercheck of the calculation sheets.

Further QA/QC activities are also documented in the Swiss NIR (see FOEN 2019). The respective conclusions are equally valid for Liechtenstein since the methods used are an adaptation of the Swiss model.

The SE, the NIC and the NID author report their QC activities in a checklist (see Annex).

5.5.5 Category-specific recalculations

There were no category-specific recalculations.

5.5.6 Category-specific planned improvements

It is planned that Liechtenstein's agriculture model will be updated every 5 years with latest Swiss values and data. The effort updating the model annually is not feasible for a small country such as Liechtenstein. The latest update has been done for the submission 2020.

5.6 Prescribed burning of savannas (3E)

Burning of savannas does not occur (NO) as this is not an agricultural practice in Liechtenstein.

5.7 Field burning of agricultural residues (3F)

Field burning of agricultural residues is not occurring (NO) in Liechtenstein.

5.8 Liming (3G)

According to a research of the OE, liming is not occurring (NO) in Liechtenstein (OE 2015b).

5.9 Urea application (3H)

5.9.1 Category description: Urea application (3H)

Key category information 3H
There are no key categories under source category 3H Urea application.

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 Liechtenstein have decreased between 1990 and 2021, ranging from 0.06 to 0.04 kt CO_2.

5.9.2 Methodological issues: Urea application (3H)

Methodology

A simple Tier 1 approach was adopted using estimated amounts of urea applied and IPCC default emission factors.

Emission factors

No country-specific emission factors are available. Consequently, the IPCC default emission factor of 0.20 t of C per t of urea was applied.

Activity data

The amount of urea applied to Liechtenstein's soils is not known. Based on Swiss fertiliser use data it is assumed that urea holds a share of 15% of all synthetic fertilisers. Further information regarding the methods for estimating commercial fertilisers see chp. 5.2.2.2. Note that the amount of urea ammonium nitrate (UAN) is not quantified. It is estimated to be <1% in Switzerland (Agricura 2016) and therefore negligible in Liechtenstein.

5.9.3 Uncertainties and time-series consistency

For the current submission, a simplified uncertainty analysis has been carried out as described in chp. 1.6. Uncertainties were accounted individually only for the key categories, whereas the rest of the sources was aggregated by gas and treated as four "rest" categories (CO_2, CH_4, N_2O, F-gases) with mean uncertainties according to Table 1-7. Since 3H is not a key category its uncertainties are accounted in the "rest" categories with mean uncertainty.

Consistency: Time series for source category 3H Urea application are all considered consistent.

5.9.4 Category-specific QA/QC and verification

General QA/QC measures are described in NID chp. 1.5. No further category-specific quality assurance activities were conducted.

5.9.5 Category-specific recalculations

No category-specific recalculations were carried out.

5.9.6 Category-specific planned improvements

It is planned that Liechtenstein's agriculture model will be updated every 5 years with latest Swiss values and data. The effort updating the model annually is not feasible for a small country such as Liechtenstein. The latest update has been done for the submission 2020.

5.10 Other carbon-containing fertilisers (3I)

The use of other carbon-containing fertilisers was not estimated (NE) for Liechtenstein. Urea ammonium nitrate (UAN) is used in Switzerland. On average, the share of UAN applied in Switzerland is <1% of total urea (Agricura 2016). The share of UAN used in Liechtenstein cannot be determined. However, it is very likely <1% as well. Accordingly, the emissions from UAN application are very likely <0.005 kt CO_2 in the year 2021 (1% of emissions of source category 3H Urea application), which means that it accounts for less than 0.001% of total GHG emissions (excl. LULUCF). Accordingly, the application of UAN contributes less than 0.05% of the national total GHG emissions and does not exceed 500 kt CO_2 eq. It is considered below the threshold of significance pursuant to decision 24/CP.19, annex I, paragraph 37(b).

6. Land Use, Land-Use Change and Forestry (LULUCF) (CRT sector 4)

6.1 Overview of sector

6.1.1 Methodology

Chapter 6 presents estimates of greenhouse gas emissions by sources and removals by sinks from land use, land-use change and forestry (LULUCF). The sector LULUCF also includes emissions and removals from the carbon pool in harvested wood products (HWP). Data acquisition and calculations are based on the Guidelines for National Greenhouse Gas Inventories (IPCC 2006), Volume 4 "Agriculture, Forestry and Other Land Use" (AFOLU). In several sub-categories, country-specific emission factors are used.

Many of the country-specific methods were adopted from Switzerland. In general, carbon stocks and stock changes based on studies and surveys carried out in Switzerland are compatible with the activity data collected in Liechtenstein (AREA, see chp. 6.2), because (1) the land-use categories are defined in the same way and the same nomenclature (SFSO 2006a) and (2) the topographic, climatic and geological conditions in Liechtenstein are very similar to the Region 3 (Pre-Alps) of the Swiss NFI (Thürig et al. 2004). Region 3 is situated adjacently along the Western border of Liechtenstein.

The land areas in the period 1990-2021 are represented by geographically explicit land-use data with a resolution of one hectare (following approach 3 for representing land areas; IPCC 2006). Direct and repeated assessment of land use with full spatial coverage also enables to calculate spatially explicit land-use change matrices. Land-use statistics for Liechtenstein are available for the years 1984, 1996, 2002, 2008 and 2014. They are based on the same methodology as the Swiss land-use statistics (SFSO 2006a).

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 categories were divided in 18 sub-divisions of land use. A further spatial stratification reflects the criteria “altitude” (3 zones) and “soil type” (mineral, organic).

Country-specific emission factors and carbon stocks for Forest Land were derived from Liechtenstein's National Forest Inventory (LWI 2012), which had been recorded in 2010. The inventory comprehended ca. 400 terrestrial sampling plots, where biomass stock, growth, harvesting and mortality had been measured.

For cropland and grassland, partially country-specific emission factors and carbon stock values were applied. For other land use categories, IPCC default values or expert estimates from Switzerland are used.

6.1.2 Emissions and removals

Table 6-1 and Figure 6-1 summarize the CO_2 equivalent emissions and removals in consequence of carbon losses and gains for the years 1990-2021. The total net emissions of CO_2 equivalent vary between -8.10 kt (1991) and 25.32 kt (2008). Three components of the CO_2 balance are shown separately:

- Gain of living biomass on forest land: this is the growth of biomass on forest land remaining forest land; it is the largest sink of carbon.
- Loss of living biomass on forest land: decrease of carbon in living biomass (by harvest and mortality) on forest land remaining forest land; it is the largest source of carbon.
- Land-use change, soil and HWP: this is all the rest including carbon removals/emissions due to land-use changes and use of soils, especially of organic soils, as well as the carbon stock changes in harvested wood products (HWP). It also includes the N_2O emissions due to N mineralization in soils (up to 0.38 CO_2 eq) associated with land-conversions (CRF-table 4(III)) and nitrogen leaching and run-off on non-agricultural soils (indirect N_2O emissions; CRF-table 4(IV)).

Table 6-1 CO_2 equivalent emissions/removals [kt] of the source category LULUCF. Positive values refer to emissions; negative values refer to removals from the atmosphere. A GWP of 265 was used for N_2O.

LULUCF	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
	kt CO2 eq									
Gain of living biomass in forest	-49.78	-49.85	-49.92	-49.98	-50.05	-50.12	-50.19	-50.27	-50.35	-50.43
Loss of living biomass in forest	49.53	33.78	44.49	41.12	60.13	46.70	38.35	49.21	41.07	39.49
Land-use change, soil and HWP	7.79	7.98	8.17	8.35	8.54	8.71	8.89	9.46	10.01	10.57
Sector 4 LULUCF (total)	**7.53**	**-8.10**	**2.74**	**-0.51**	**18.61**	**5.30**	**-2.95**	**8.40**	**0.73**	**-0.36**

LULUCF	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
	kt CO2 eq									
Gain of living biomass in forest	-50.50	-50.58	-50.66	-50.73	-50.80	-50.87	-50.94	-51.01	-51.08	-51.24
Loss of living biomass in forest	64.49	41.17	41.70	45.49	47.47	47.33	51.92	60.79	62.72	59.79
Land-use change, soil and HWP	11.12	11.61	12.09	12.36	12.62	12.89	13.16	13.42	13.68	13.84
Sector 4 LULUCF (total)	**25.10**	**2.19**	**3.12**	**7.12**	**9.29**	**9.35**	**14.14**	**23.20**	**25.32**	**22.38**

LULUCF	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
	kt CO2 eq									
Gain of living biomass in forest	-51.40	-51.56	-51.72	-51.89	-52.05	-52.17	-52.27	-52.26	-52.25	-52.25
Loss of living biomass in forest	58.38	62.20	62.57	55.22	55.25	50.05	48.32	49.94	60.95	51.29
Land-use change, soil and HWP	13.99	14.05	14.11	14.17	14.23	14.28	14.33	13.99	13.65	13.31
Sector 4 LULUCF (total)	**20.96**	**24.69**	**24.96**	**17.51**	**17.44**	**12.16**	**10.38**	**11.67**	**22.34**	**12.35**

LULUCF	**2020**	**2021**	**Mean**							
	kt CO2 eq									
Gain of living biomass in forest	-52.24	-52.17	-51.05							
Loss of living biomass in forest	44.06	39.80	50.15							
Land-use change, soil and HWP	12.97	12.65	11.91							
Sector 4 LULUCF (total)	**4.79**	**0.29**	**11.00**							

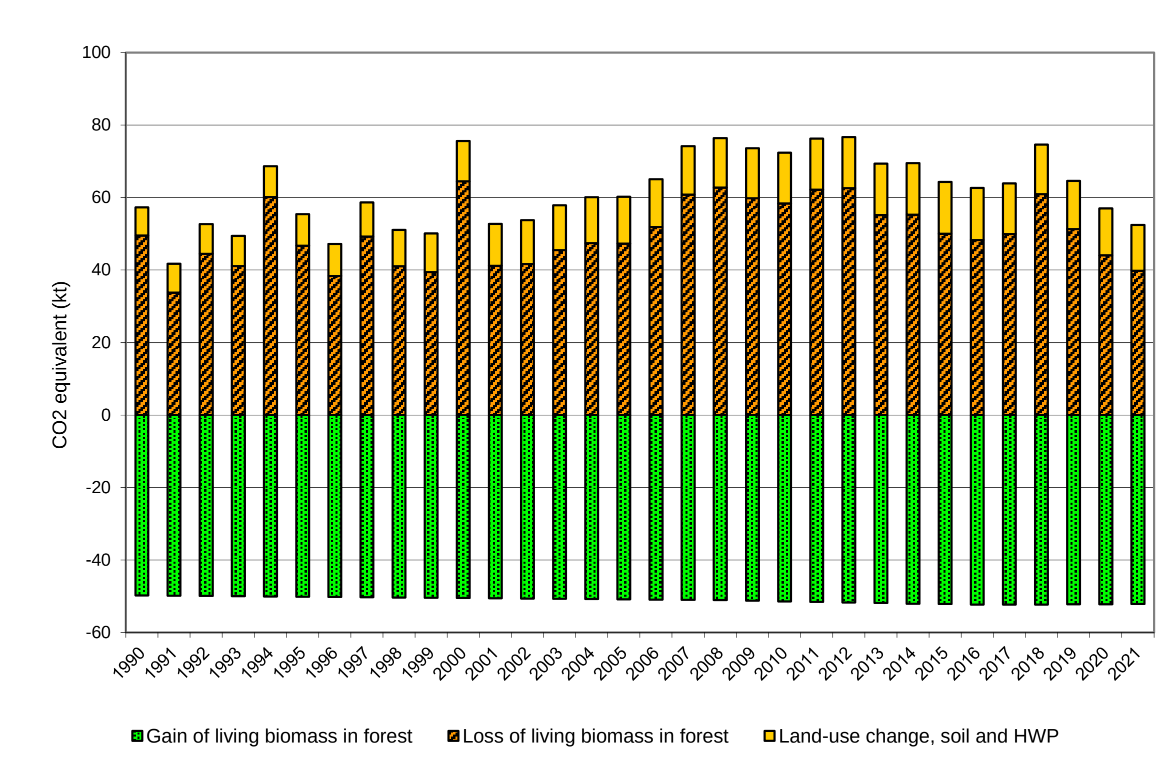


Figure 6-1 Liechtenstein's CO_2 removals due to the increase (growth) of living biomass on forest land, the CO_2 emissions due to the decrease (harvest and mortality) of living biomass on forest land and the net CO_2 equivalent emissions due to land-use changes and from use of soils.

Gain and loss of living biomass in forests are the dominant categories when looking at the CO_2 emissions and removals. There is a considerable annual variation of loss of living biomass in forests dependent on the wood harvesting rate. In 1994 and 2000 as well as 2006-2014 and 2018 the loss of living biomass in forests was larger than the gain (Table 6-1). The resulting CO_2 emissions are also visible in the total emissions/removals of the LULUCF sector (see Figure 6-2). Further explanatory notes on variations and trends can be found in chp. 2.2.2 "Sector 4 LULUCF".

Compared to these biomass changes in forests, the net CO_2 equivalent emissions arising from land-use changes, from soils and HWP are relatively small (see Figure 6-1). It can be observed that land-use conversions to grassland increase significantly between 1997 and 2013: higher conversion rates from forest land to grassland leads to increased CO_2 emissions (see Table 6-2). However, the application of a conversion period of 20 years smoothens and delays the effect in time. The net carbon stock change in the HWP pool varies from one year to the other mainly following the production rate of sawnwood.

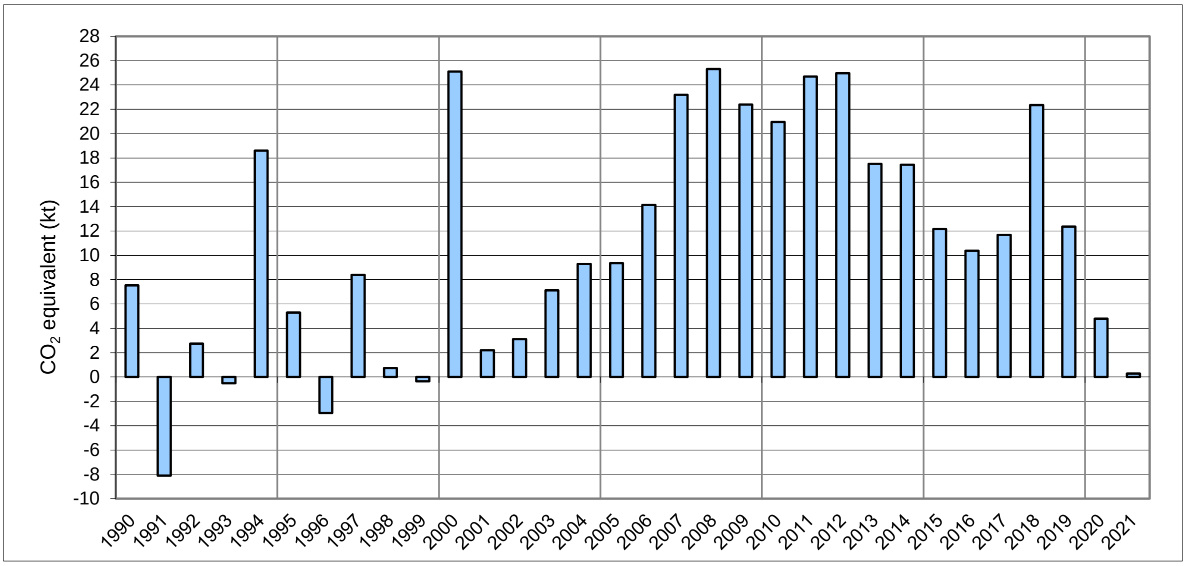


Figure 6-2 Liechtenstein's CO2 emissions/removals of sector 4 LULUCF.

Table 6-2 Net CO_2 removals and emissions per land-use category in kt CO_2 equivalent.

Net CO_2 emissions/removals	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Total Land-Use Categories	**7.27**	**-8.36**	**2.47**	**-0.77**	**18.35**	**5.04**	**-3.21**	**8.12**	**0.45**	**-0.66**
A. Forest Land	**-0.14**	**-15.96**	**-5.32**	**-8.75**	**10.19**	**-3.30**	**-11.72**	**-0.94**	**-9.15**	**-10.80**
1. Forest Land remaining Forest Land	0.11	-15.71	-5.07	-8.50	10.44	-3.05	-11.47	-0.69	-8.91	-10.57
2. Land converted to Forest Land	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.25	-0.24	-0.24	-0.23
B. Cropland	**4.49**	**4.48**	**4.47**	**4.46**	**4.45**	**4.44**	**4.44**	**4.43**	**4.43**	**4.43**
1. Cropland remaining Cropland	4.18	4.17	4.17	4.16	4.15	4.14	4.13	4.13	4.12	4.11
2. Land converted to Cropland	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.32
C. Grassland	**1.97**	**1.96**	**1.96**	**1.95**	**1.94**	**1.93**	**1.92**	**2.15**	**2.37**	**2.59**
1. Grassland remaining Grassland	1.53	1.52	1.51	1.50	1.49	1.48	1.48	1.47	1.47	1.46
2. Land converted to Grassland	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.67	0.90	1.13
D. Wetlands	**0.16**	**0.16**	**0.16**	**0.16**	**0.16**	**0.16**	**0.16**	**0.18**	**0.20**	**0.22**
1. Wetlands remaining Wetlands	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2. Land converted to Wetlands	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.18	0.20	0.22
E. Settlements	**3.06**	**3.06**	**3.06**	**3.06**	**3.06**	**3.06**	**3.06**	**3.09**	**3.13**	**3.17**
1. Settlements remaining Settlements	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.24	0.26	0.27
2. Land converted to Settlements	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.85	2.87	2.90
F. Land converted to Other Land	**0.42**	**0.42**	**0.42**	**0.42**	**0.42**	**0.42**	**0.42**	**0.50**	**0.58**	**0.67**
G. Harvested wood products	**-2.69**	**-2.48**	**-2.27**	**-2.07**	**-1.87**	**-1.67**	**-1.48**	**-1.29**	**-1.11**	**-0.93**

Net CO_2- emissions/removals	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Total Land-Use Categories	**24.80**	**1.88**	**2.79**	**6.78**	**8.95**	**9.00**	**13.78**	**22.84**	**24.95**	**22.02**
A. Forest Land	**14.12**	**-9.27**	**-8.82**	**-5.08**	**-3.16**	**-3.36**	**1.17**	**9.98**	**11.86**	**8.78**
1. Forest Land remaining Forest Land	14.35	-9.04	-8.60	-4.87	-2.96	-3.17	1.35	10.15	12.01	8.92
2. Land converted to Forest Land	-0.23	-0.23	-0.22	-0.21	-0.20	-0.19	-0.18	-0.17	-0.16	-0.14
B. Cropland	**4.43**	**4.43**	**4.43**	**4.41**	**4.38**	**4.36**	**4.34**	**4.32**	**4.30**	**4.30**
1. Cropland remaining Cropland	4.11	4.10	4.10	4.08	4.07	4.06	4.05	4.04	4.03	4.03
2. Land converted to Cropland	0.32	0.33	0.33	0.32	0.31	0.30	0.29	0.28	0.27	0.27
C. Grassland	**2.81**	**3.04**	**3.25**	**3.38**	**3.51**	**3.63**	**3.76**	**3.88**	**4.01**	**4.04**
1. Grassland remaining Grassland	1.46	1.46	1.45	1.43	1.40	1.37	1.34	1.32	1.29	1.28
2. Land converted to Grassland	1.35	1.58	1.80	1.96	2.11	2.26	2.41	2.57	2.72	2.76
D. Wetlands	**0.24**	**0.26**	**0.28**	**0.29**	**0.29**	**0.30**	**0.30**	**0.31**	**0.31**	**0.33**
1. Wetlands remaining Wetlands	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2. Land converted to Wetlands	0.24	0.26	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.33
E. Settlements	**3.20**	**3.24**	**3.28**	**3.29**	**3.29**	**3.30**	**3.31**	**3.32**	**3.32**	**3.32**
1. Settlements remaining Settlements	0.28	0.29	0.30	0.31	0.31	0.32	0.33	0.34	0.34	0.36
2. Land converted to Settlements	2.93	2.95	2.98	2.98	2.98	2.98	2.98	2.98	2.98	2.96
F. Land converted to Other Land	**0.75**	**0.83**	**0.91**	**0.94**	**0.98**	**1.02**	**1.05**	**1.09**	**1.12**	**1.12**
G. Harvested wood products	**-0.75**	**-0.65**	**-0.54**	**-0.44**	**-0.34**	**-0.25**	**-0.15**	**-0.06**	**0.04**	**0.13**

Net CO_2- emissions/removals	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total Land-Use Categories	**20.59**	**24.31**	**24.59**	**17.14**	**17.06**	**11.78**	**10.00**	**11.30**	**21.98**	**12.00**
A. Forest Land	**7.22**	**10.89**	**11.13**	**3.63**	**3.51**	**-1.80**	**-3.62**	**-1.98**	**9.04**	**-0.60**
1. Forest Land remaining Forest Land	7.35	11.01	11.23	3.72	3.58	-1.74	-3.57	-1.93	9.08	-0.57
2. Land converted to Forest Land	-0.13	-0.12	-0.10	-0.09	-0.08	-0.06	-0.05	-0.04	-0.03	-0.03
B. Cropland	**4.30**	**4.30**	**4.31**	**4.31**	**4.31**	**4.30**	**4.29**	**4.27**	**4.26**	**4.24**
1. Cropland remaining Cropland	4.03	4.03	4.03	4.03	4.03	4.01	4.00	3.98	3.97	3.96
2. Land converted to Cropland	0.27	0.28	0.28	0.28	0.28	0.29	0.29	0.29	0.29	0.28
C. Grassland	**4.08**	**4.11**	**4.14**	**4.18**	**4.21**	**4.25**	**4.28**	**4.09**	**3.90**	**3.71**
1. Grassland remaining Grassland	1.27	1.26	1.24	1.23	1.22	1.21	1.20	1.19	1.18	1.17
2. Land converted to Grassland	2.81	2.86	2.90	2.95	2.99	3.04	3.08	2.90	2.72	2.54
D. Wetlands	**0.34**	**0.36**	**0.38**	**0.39**	**0.41**	**0.42**	**0.44**	**0.43**	**0.42**	**0.42**
1. Wetlands remaining Wetlands	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2. Land converted to Wetlands	0.34	0.36	0.38	0.39	0.41	0.42	0.44	0.43	0.42	0.42
E. Settlements	**3.32**	**3.31**	**3.31**	**3.30**	**3.30**	**3.30**	**3.29**	**3.25**	**3.21**	**3.17**
1. Settlements remaining Settlements	0.37	0.38	0.39	0.40	0.41	0.42	0.43	0.43	0.44	0.44
2. Land converted to Settlements	2.95	2.93	2.92	2.90	2.89	2.87	2.86	2.82	2.78	2.73
F. Land converted to Other Land	**1.12**	**1.12**	**1.12**	**1.12**	**1.12**	**1.12**	**1.12**	**1.04**	**0.96**	**0.88**
G. Harvested wood products	**0.21**	**0.21**	**0.21**	**0.20**	**0.20**	**0.19**	**0.19**	**0.19**	**0.18**	**0.18**

Net CO_2- emissions/removals	2020	2021
Total Land-Use Categories	**4.45**	**-0.05**
A. Forest Land	**-7.81**	**-11.98**
1. Forest Land remaining Forest Land	-7.79	-11.98
2. Land converted to Forest Land	-0.02	-0.01
B. Cropland	**4.22**	**4.22**
1. Cropland remaining Cropland	3.94	3.94
2. Land converted to Cropland	0.28	0.28
C. Grassland	**3.51**	**3.32**
1. Grassland remaining Grassland	1.16	1.15
2. Land converted to Grassland	2.35	2.17
D. Wetlands	**0.41**	**0.41**
1. Wetlands remaining Wetlands	NO	NO
2. Land converted to Wetlands	0.41	0.41
E. Settlements	**3.13**	**3.09**
1. Settlements remaining Settlements	0.44	0.44
2. Land converted to Settlements	2.69	2.65
F. Land converted to Other Land	**0.80**	**0.72**
G. Harvested wood products	**0.18**	**0.17**

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 is similar to the approaches used in Switzerland (FOEN 2022). It corresponds to a Tier 2 approach as described in IPCC (2006); Volume 4, chp. 3 and can be summarised as follows:

- Land use categories and sub-divisions with respect to available land-use data (see Table 6-3) were defined. For these carbon emissions and removals estimations so-called combination categories (CC) were defined on the basis of the land-use and land-cover categories of Liechtenstein's land-use statistics, which uses the same nomenclature as the Swiss land-use statistics (AREA survey, SFSO 2006a).
- Criteria for the spatial stratification of the land-use categories (altitude and soil type) were taken from Switzerland. Based on these criteria data for the spatial stratification of the land-use categories were collected in Liechtenstein.
- Carbon stocks, gains and losses in living biomass of managed forests were derived from results of Liechtenstein's forest inventory (LWI 2012). For other categories, carbon stocks and carbon stock changes were taken from Swiss data based on measurements and estimations.
- The land use and the land-use change matrix were calculated in each spatial stratum.
- Carbon stock changes in living biomass ($deltaC_l$), in dead organic matter ($deltaC_d$) and in soil ($deltaC_s$) were calculated for all cells of the land-use change matrix.
- Finally, the results were aggregated by summarising the carbon stock changes over land-use categories and strata according to the level of disaggregation displayed in the CRF tables.

The procedure of calculating emissions and removals in LULUCF and the different institutions involved are displayed schematically in Figure 6-3.

The distinction between managed and unmanaged land (Table 6-3) is done as follows:

- Forest land is by definition managed land as all forests in Liechtenstein are subject to forest management.
- Land categories which can’t be cultivated, are classified as unmanaged. This holds for stony grassland (CC36), unproductive grassland (CC37), surface waters (CC41), unproductive wetland (CC42) and other land (rocks, sand, glaciers; CC61).

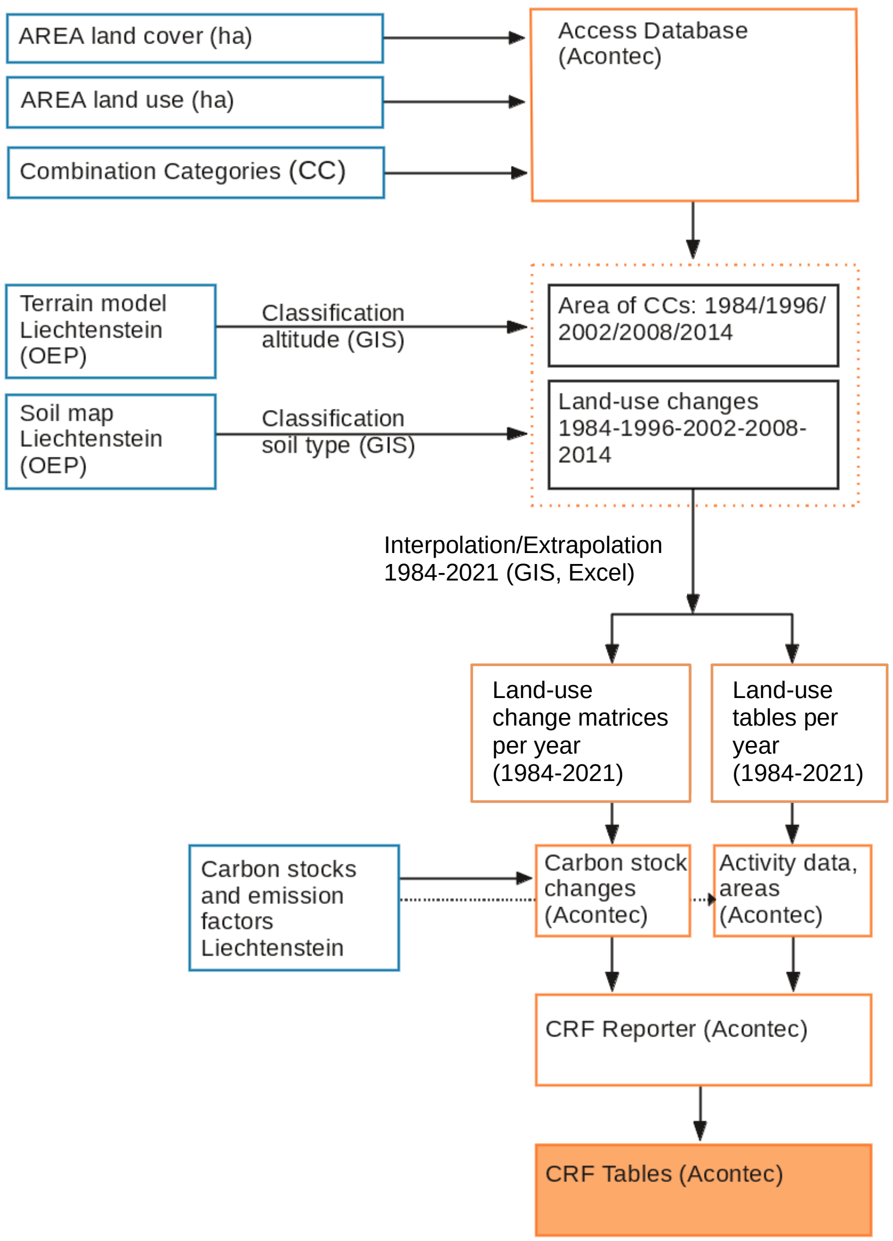


Figure 6-3 Procedure of calculating emissions and removals from LULUCF in Liechtenstein.

Table 6-3 Land-use categories used in this report (so-called combination categories CC): 6 main land-use categories and the 18 sub-divisions. Additionally, descriptive remarks, abbreviations used in the CRF tables, and CC codes are given. For a detailed definition of the CC categories see chp. 6.2.1.

CC Main category	CC Sub-division	Remarks	Managed or unmanaged	*CC code*
A. Forest Land	Afforestations	areas converted to forest by active measures, e.g. planting	managed	*11*
	Managed Forest	dense and open forest meeting the criteria of forest land	managed	*12*
	Unproductive Forest	brush forest and inaccessible forest meeting the criteria of forest land	managed	*13*
B. Cropland		arable and tillage land (annual crops and leys in arable rotations)	managed	*21*
C. Grassland	Permanent Grassland	meadows, pastures (low-land and alpine)	managed	*31*
	Shrub Vegetation	agricultural and unproductive areas predominantly covered by shrubs	managed	*32*
	Vineyards, Low-Stem Orchards, Tree Nurseries	perennial agricultural plants with woody biomass (no trees)	managed	*33*
	Copse	agricultural and unproductive areas covered by perennial woody biomass including trees	managed	*34*
	Orchards	permanent grassland with fruit trees	managed	*35*
	Stony Grassland	grass, herbs and shrubs on stony surfaces	unmanaged	*36*
	Unproductive Grassland	unmanaged grass vegetation	unmanaged	*37*
D. Wetlands	Surface Waters	lakes and rivers	unmanaged	*41*
	Unproductive Wetland	reed, unmanaged wetland	unmanaged	*42*
E. Settlements	Buildings and Constructions	areas without vegetation such as houses, roads, construction sites, dumps	managed	*51*
	Herbaceous Biomass in Settlements	areas with low vegetation, e.g. lawns	managed	*52*
	Shrubs in Settlements	areas with perennial woody biomass (no trees)	managed	*53*
	Trees in Settlements	areas with perennial woody biomass including trees	managed	*54*
F. Other Land		areas without soil and vegetation: rocks, sand, screes, glaciers	unmanaged	*61*

6.1.3.2 Calculating carbon stock changes

The method is based largely on the Swiss procedure according to FOEN (2022).

For calculating carbon stock changes, the following input parameters (mean values per hectare) must be quantified for all land-use categories (CC) and spatial strata (i):

$stockC_{l,i,CC}$: carbon stock in living biomass

$stockC_{d,i,CC}$: carbon stock in dead organic matter (sum of dead wood and litter)

$stockC_{s,i,CC}$: carbon stock in soil

$increaseC_{l,i,CC}$: annual gain (growth) of carbon in living biomass

$decreaseC_{l,i,CC}$: annual loss (cut & mortality) of carbon in living biomass

$changeC_{d,i,CC}$: annual net carbon stock change in dead organic matter (sum of dead wood and litter)

$changeC_{s,i,CC}$: annual net carbon stock change in soil

On this basis, the carbon stock changes in living biomass ($deltaC_l$), in dead organic matter ($deltaC_d$) and in soil ($deltaC_s$) are calculated for all cells of the land-use change matrix. 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). Equations 6.1-6.3 show the general approach of calculating C-removals/emissions taking into account the net carbon stock changes in living biomass, dead organic matter and soils as well as the stock changes due to conversion of land use (difference of the stocks before and after the conversion):

$$deltaC_{l,i,ba} = [\ increaseC_{l,i,a} - decreaseC_{l,i,a} + W_l * (stockC_{l,i,a} - stockC_{l,i,b}) / CT\ ] * A_{i,ba} \quad (6.1)$$

$$deltaC_{d,i,ba} = [\ changeC_{d,i,a} + W_d * (stockC_{d,i,a} - stockC_{d,i,b}) / CT\ ] * A_{i,ba} \quad (6.2)$$

$$deltaC_{s,i,ba} = [\ changeC_{s,i,a} + W_s * (stockC_{s,i,a} - stockC_{s,i,b}) / CT\ ] * Ai,ba \quad (6.3)$$

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

$A_{i,ba}$: area of land converted from b to a in the spatial stratum I, activity data from the land-use change matrix (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)

W_l, W_d, W_s: weighting factors for living biomass, dead organic matter and soil, respectively.

CT: conversion time (yr)

The following values for W were chosen:

$W_l = W_d = W_s = 0$ if land use after the conversion is 'Forest Land' (a = {11,12,13})

or if a and b are unmanaged categories {36,37,41,42,61}; this

corresponds to the gain-loss approach.

$W_s = 0.5$ if a or b is 'Buildings and Constructions' (a = 51 or b = 51)

$W_l = W_d = W_s = 1$ otherwise; this corresponds to the stock difference approach.

The difference of the stocks before and after the conversion are weighted with a factor (W_l, W_d, W_s) accounting for the effectiveness of the land-use change in some special cases. For example, the succession from grassland to forest land is quite frequent in mountainous regions (see Table 6-8). Immediately after the conversion young forests have lower carbon stocks than the mean carbon stock values determined for 'managed forest'. Therefore, the weighting factors for the conversion 'to forest land' was set to zero in order to avoid an overestimation of C-sinks. In the case of land-use changes involving ‘buildings and constructions’ it is assumed that only 50% of the soil carbon is emitted as the humus layer is re-used on construction sites.

The weighting factors W were set to zero in case of changes between unmanaged categories in order to prevent reporting of emissions or sinks on unmanaged land.

For calculating annual carbon stock changes in soils due to land-use conversion, IPCC (2006) suggests a default delay time (CT) of 20 years. In Liechtenstein, a conversion time of 20 years has been applied to all carbon stock changes in soil and biomass. Accordingly, the CRF tables 4A2, 4B2 and 4C2, 4D2, 4E2 and 4F2 contain the cumulative area remaining in the respective category in the reporting year.

There is no consistent data on land-use changes before 1984, but it is known (Broggi 1987, ARE/SAEFL 2001 in Switzerland) that the main trends of the land-use dynamics (e.g. increase of settlements, decrease of cropland) did arise before 1970. 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 has been possible to produce the land-use data required for the consideration of the conversion time in that period.

6.1.4 Carbon emission factors and stocks at a glance

Table 6-4 lists all values of carbon stocks, increases, decreases and net changes of carbon specified for land-use category (CC) and associated spatial strata. These values remain constant during the period 1990-2021 except for the loss in living biomass of productive forest (CC12) where annual values are used (see chp. 6.4.2).

Table 6-4 Carbon stocks and changes in biomass, dead organic matter and soils for the combination categories (CC), stratified for altitude and soil type. These values are valid for the whole period 1990-2021, except the cells highlighted in orange (see main text). There are no recalculated values in Submission 2023.

land-use code CC	altitude zone z	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)	gain of living biomass (gainCl,i)	loss of 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 organic soil (changeCs,i)
	Strata	Stocks (t C ha-1)					Changes (t C ha-1 yr-1)					
11 Afforestations	1	10.00	0	0	66.10	NO	2.39	-0.21	0	0	0	NO
	2	10.00	0	0	75.91	NO	2.39	-0.21	0	0	0	NO
	3	7.50	0	0	95.78	NO	1.35	-0.1	0	0	0	NO
12 Productive forest	1	125.25	7.77	7.51	66.10	NO	3.12	-3.19	0.0473	-0.049	0	NO
	2	121.94	8.96	16.29	75.91	NO	2.77	-2.83	0.0473	-0.049	0	NO
	3	122.18	11.01	26.21	95.78	NO	2.27	-2.32	0.0069	-0.053	0	NO
13 Unproductive forest	1	20.45	0	7.51	66.10	NO	0	0	0	0	0	NO
	2	47.53	0	16.29	75.91	NO	0	0	0	0	0	NO
	3	42.36	0	26.21	95.78	NO	0	0	0	0	0	NO
21 Cropland	all	6.82	0	0	50.65	155.00	0	0	0	0	0	-9.52
31 Permanent Grassland	1	5.61	0	0	58.65	155.00	0	0	0	0	0	-9.52
	2	5.26	0	0	63.89	155.00	0	0	0	0	0	-9.52
	3	3.30	0	0	63.88	155.00	0	0	0	0	0	-9.52
32 Shrub Vegetation	1	20.45	0	0	58.65	NO	0	0	0	0	0	NO
	2	20.45	0	0	63.89	NO	0	0	0	0	0	NO
	3	20.45	0	0	63.88	NO	0	0	0	0	0	NO
33 Vineyards et al.	all	5.58	0	0	50.58	155.00	0	0	0	0	0	-9.52
34 Copse	1	20.45	0	0	58.65	NO	0	0	0	0	0	NO
	2	20.45	0	0	63.89	NO	0	0	0	0	0	NO
	3	20.45	0	0	63.88	NO	0	0	0	0	0	NO
35 Orchards	all	23.32	0	0	59.70	155.00	0	0	0	0	0	-9.52
36 Stony Grassland	all	7.16	0	0	22.35	NO	0	0	0	0	0	NO
37 Unproductive Grassland	all	3.45	0	0	63.65	NO	0	0	0	0	0	NO
41 Surface Waters	all	0	0	0	0	NO	0	0	0	0	0	NO
42 Unproductive Wetland	all	6.50	0	0	62.80	NO	0	0	0	0	0	NO
51 Buildings, Constructions	all	0	0	0	0	NO	0	0	0	0	0	NO
52 Herbaceous Biomass in S.	all	9.54	0	0	50.38	NO	0	0	0	0	0	NO
53 Shrubs in Settlements	all	15.43	0	0	50.38	NO	0	0	0	0	0	NO
54 Trees in Settlements	all	20.72	0	0	50.43	NO	0	0	0	0	0	NO
61 Other Land	all	0	0	0	0	NO	0	0	0	0	0	NO

Legend

altitude zones:

1	< 600 m
2	601 - 1200 m
3	> 1200 m

NO: land-use type does not occur on organic soil

On organic soils, a value of 155 t C ha^{-1} for stock Cs was assumed for all land-use categories that occur on organic soils (based on Oechslin et al. 2021). Thus, when calculating carbon changes in organic soils as a consequence of land-use changes, the difference of carbon stocks is always zero.

For productive forests (CC12), stocks, gains and losses are based on Liechtenstein's NFI (LWI 2012). The cells highlighted in orange in Table 6-4 include annual losses of biomass based on harvesting statistics. The data for afforestations, unproductive forests, agriculture, grassland and settlements are based on experiments, field studies, literature and expert estimates from Switzerland. For wetlands and other land, expert estimates or default values are available. The deduction of the individual values is explained in the sector sub-chapters 6.x.2.

6.1.5 Uncertainty estimates, overview

Table 6-5 gives an overview of uncertainty estimates of activity data (AD) and of emission factors (EF). The uncertainty of AD often depends on the uncertainty of the AREA survey data (see chp. 6.3.1.3); in the Table 6-5 these values are highlighted in orange. For categories 4B, 4(III), 4(IV) and 4G other data sources are relevant; they are presented in detail in the respective chp. (6.x.3) of the LULUCF categories, along with the uncertainty estimates of EF.

Table 6-5 Uncertainty estimates in the LULUCF sector, expressed as half of the 95% confidence intervals. Highlighted values: see main text.

IPCC category		Gas	Activity data uncertainty	Emission factor uncertainty	Combined uncertainty	Key category
			%	%	%	
4A1	Forest Land remaining Forest Land	CO_2	2.7	46.7	46.8	yes
4A2	Land converted to Forest Land	CO_2	17.2	46.7	49.8	
4B1	Cropland remaining Cropland	CO_2	30.8	23.0	38.4	yes
4B2	Land converted to Cropland	CO_2	26.9	34.0	43.4	
4C1	Grassland remaining Grassland	CO_2	6.0	51.2	51.6	
4C2	Land converted to Grassland	CO_2	13.6	51.0	52.8	yes
4D1	Wetlands remaining Wetlands	CO_2	10.5	50.0	51.1	
4D2	Land converted to Wetlands	CO_2	40.9	32.1	52.0	
4E1	Settlements remaining Settlements	CO_2	6.4	34.8	35.3	
4E2	Land converted to Settlements	CO_2	19.4	33.7	38.9	yes
4F1	Other Land remaining Other Land	CO_2	NA	NA	NA	
4F2	Land converted to Other Land	CO_2	40.9	34.0	53.2	
4III	N Mineralization	N_2O	85.6	100.0	131.6	
4IV2	Indirect emissions Leaching	N_2O	87.9	100.0	133.1	
4G	Harvested Wood Products	CO_2	50.0	54.8	74.2	yes

6.2 Land-use definitions and classification systems

6.2.1 Combination Categories (CC) as derived from AREA land-use statistics

The nomenclature of the Swiss Land Use Statistics (AREA) evaluated by the Swiss Federal Statistical Office (SFSO 2006a) is the basis for the land-use categories and subcategories used for land area representation in Liechtenstein. In the course of the AREA surveys (see chp. 6.1.3) every hectare of Liechtenstein's territory was assigned to a land-use category (NOLU04) and to a land-cover category (NOLC04) according to the "nomenclature 2004".

The 46 land-use categories and 27 land-cover categories of the land-use statistics were aggregated to 18 combination categories (CC) implementing the main categories proposed by IPCC as well as by country-specific sub-divisions (see Table 6-6). The first digit of the CC-code represents the main category, whereas the second digit stands for the respective sub-division.

The sub-divisions were defined with respect to possible differentiation of biomass densities, carbon turnover, and soil carbon contents. They 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 Swiss Federal Statistical Office and Agroscope as well as private consultants. The evaluation process resulted in the elaboration of Table 6-6. CC definition was strongly influenced by the land cover and land use (NOLC04/NOLU04) classification and "nomenclature 2004" of AREA (SFSO 2006a). Most criteria and thresholds as defined therein were adopted.

For Forest Land, e.g., the criteria correspond to the NFI thresholds with respect to minimum area, width, crown cover, and tree height.

For LC 31 (land cover shrub), e.g., the criteria include: vegetation height <3 m, degree of coverage >80%, dominated by shrubs, dwarf-shrubs, and bushes.

For LC32 (land cover brush meadows), e.g., the criteria include vegetation height <3 m, degree of coverage 50-80%, dominated by shrubs, dwarf-shrubs, and bushes.

With regard to carbon content in biomass, there is a strong relation to the vegetation type (i.e. land cover in most cases). This is exemplarily reflected by the mainly horizontal arrangement of the individual CCs in Table 6-6. With regard to carbon turnover and soil organic carbon the CC definition was driven by the consideration that most vegetation units are subject to a similar management that leads to comparable C fluxes in biomass and soil.

For individual CCs (especially Forest Land, i.e. CC11, CC12, CC13) further spatial stratifications were introduced (cf. following chp. 6.2.2) with intent to approximate the real/natural differences in carbon stock, carbon turnover and soil conditions as good as possible.

The underlying criteria to include land-use sub-categories such as Shrub vegetation, Vineyards, Low-stem Orchards, Tree Nurseries, Copse and Orchards (CC32-CC37) 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 permanent grass understory. Also, low-stem orchards and tree nurseries (CC33) and copse (CC34) typically have a permanent grass layer – even in vineyards it is good practice in the country to maintain complete grass cover in order to prevent erosion. Therefore, these categories represent soil management, carbon stocks and carbon dynamics of grassland better than those of cropland. Cropland (CC21) is ploughed on a regular basis.

Regarding the applicability of the combined categories (CC) for Liechtenstein, we can conclude that the basic land-use and land-cover categories (NOLC04/NOLU04 as shown in Table 6-6) are an integrated part of the AREA methodology and it was important to adopt them for Liechtenstein's AREA surveys. However, the CC derived from NOLC04/NOLU04 are not always essential in Liechtenstein: for example, CC35 occurs very sparely (see Table 6-7).

Table 6-6 Relation between the land-use (NOLU04) and land-cover (NOLC04) categories of the AREA survey and the derived 18 combination categories (CC).

18 Combination Categories (CC)

Land Use (NOLU04) acc. to AREA – Settlement and urban areas (Building areas: 101–108; Transport surfaces: 121–125; Special urban areas: 141–147; Recreational areas and cemeteries: 161–166)

Land Cover (NOLC04) acc. to AREA	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 Use (NOLU04) acc. to AREA – Agricultural areas (Orchards, vineyards, horticulture: 201–203; Arable and grassland: 221–223; Alpine grazing areas: 241–243), Forest areas (Forest (not used for agriculture): 301–304), Unproductive areas (Lakes and rivers: 401–403; Unproductive land: 421–424)

Land Cover (NOLC04) acc. to AREA	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		11	12	12	37	37	37	37	37	37	31
30 Brush vegetation																				
31 Shrub		32	32								11	12	12	32	32	32	32	32	32	32
32 Brush meadows		32	32		32	32	32	32			11	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	11					12		12		
42 Forest edges	35									12	11	12	12			12		12		
43 Forest strips	35									12	11					12		12		
44 Open forest	35				12	12	12	12	13	12	11	12	12			12		12	12	12
45 Brush forest										13						13		13		
46 Linear woods	34	34	34	34	34	34	34	34	34		11	12	12	34	34	34	34	34	34	34
47 Clusters of trees	34	34	34	34	34	34	34	13	34		11	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			11	13	13	36	36	36	36	36	36	36
60 Watery areas																				
61 Water														41	41	41				41
62 Glacier, perpetual snow																	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):

- 11 Afforestations
- 12 Productive forest
- 13 Unproductive forest
- 21 Cropland
- 31 Permanent grassland
- 32 Shrub vegetation
- 33 Vineyards, Low-stem Orchards, Tree nurseries
- 34 Copse
- 35 Orchards
- 36 Stony grassland
- 37 Unproductive grassland
- 41 Surface waters
- 42 Unproductive wetland
- 51 Buildings and construction
- 52 Herbaceous biomass in settlements
- 53 Shrubs in settlements
- 54 Trees in settlements
- 61 Other land

6.2.2 Spatial stratification

In order to quantify carbon stocks and increases/decreases, a further spatial stratification of the territory turned out to be useful. For forests and grassland three different altitudinal belts were differentiated. The whole territory of Liechtenstein is considered to be part of the pre-alpine region, which is one of the five main regions used in the Swiss National Forest Inventory (Thürig et al. 2004).

Altitude data were available on a hectare-grid from the Office of Environmental Protection (OEP 2006d) and classified in belts ≤ 600 m a.s.l. (metres above sea level), 601-1200 m a.s.l., and >1200 m a.s.l. (Figure 6-4). For cropland and grassland, two soil types (organic and mineral soils) were additionally differentiated. The organic soils had been mapped in digital form for Liechtenstein's concept of environmental and agricultural development (Büchel et al. 2006). That map contains the following groups and categories:

- Organic soils ('Moorböden, Alluvial überschüttetes Moor');
- Mineral soils (*'Fahlgley, Fahlgley mit z.T. Torfunterlage, Buntgley, Buntgley mit z.T. Torfunterlage, Braunerde, Fluvisol'*);
- Other (recultivated areas).

The first group (organic soils) was selected for defining the respective stratum as shown in Figure 6-4. Organic soils only occur on the ground of the Rhine valley. In the regions where organic soils occur, only agricultural areas can be found; there is no forest on organic soils.

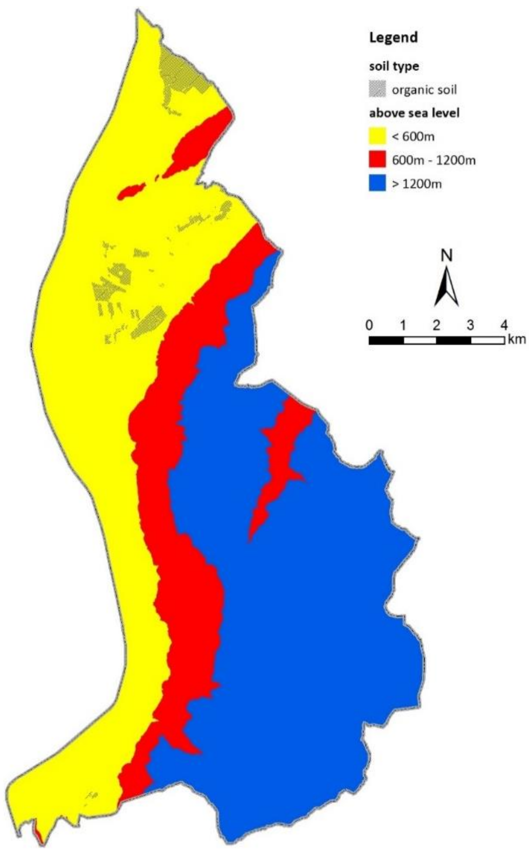


Figure 6-4 Map of Liechtenstein showing the altitude classes and soil types. Reference: OEP 2006d.

6.2.3 The land-use tables and change matrices (activity data)

Table 6-7 shows the trend of land-use changes at the level of the disaggregated land-use categories (CC). The data results from interpolation and extrapolation in time and from spatial stratification (altitude classes and soil types). For example, areas of afforestation (CC11) decrease in all altitude classes between 82% and 100% from 1990 to 2021, while the area of managed forests (CC12) increases by 10% since 1990 at altitudes over 1200 m. The most significant land-use changes in absolute terms since 1990 can be observed in the categories cropland CC21 (decrease by 328 ha, mineral and organic soils), grassland CC31-CC37 (decrease by 452 ha) and settlements CC51-CC54 (increase by 554 ha).

Table 6-7 Statistics of land use (CC = combination categories) for the period 1990-2021 (in ha) and change between 1990 and 2021. (n.s. = no stratification)

CC	altitude	soil type	1990	2000	2010	2015	2016	2017	2018	2019	2020	2021	Change 1990-2021 (ha)	Change 1990-2021 (%)
11	≤ 600	n.s.	9	7	1	2	2	2	1	1	1	1	-7	-87%
	601-1200	n.s.	7	2	1	0	0	0	0	0	0	0	-7	-100%
	> 1200	n.s.	29	19	11	9	8	8	7	6	5	5	-24	-82%
12	≤ 600	n.s.	966	967	958	948	948	947	946	946	945	945	-21	-2%
	601-1200	n.s.	1970	1967	1961	1962	1962	1961	1960	1960	1959	1958	-11	-1%
	> 1200	n.s.	2171	2220	2269	2336	2346	2355	2365	2375	2385	2385	214	10%
13	≤ 600	n.s.	1	0	0	0	0	0	0	0	0	0	-1	-100%
	601-1200	n.s.	9	10	8	3	3	2	2	2	2	2	-7	-82%
	> 1200	n.s.	877	916	943	957	962	968	973	978	983	983	107	12%
21	n.s.	mineral	1826	1771	1634	1574	1560	1547	1534	1520	1507	1507	-319	-17%
	n.s.	organic	127	124	120	120	119	119	118	118	118	118	-9	-7%
31	≤ 600	mineral	1131	1076	1118	1136	1134	1132	1130	1129	1127	1127	-4	0%
	≤ 600	organic	64	61	64	63	63	63	63	63	62	62	-1	-2%
	601-1200	mineral	364	347	342	336	334	332	331	329	327	327	-37	-10%
	601-1200	organic	0	0	0	0	0	0	0	0	0	0	0	0%
	> 1200	mineral	1668	1647	1629	1621	1618	1614	1611	1608	1605	1605	-63	-4%
	> 1200	organic	0	0	0	0	0	0	0	0	0	0	0	0%
32	≤ 600	n.s.	20	23	27	28	29	29	30	30	31	31	11	53%
	601-1200	n.s.	10	9	12	13	13	13	13	14	14	14	4	43%
	> 1200	n.s.	563	514	500	458	451	444	437	430	423	423	-140	-25%
33	n.s.	mineral	31	33	34	36	37	37	37	38	38	39	8	27%
	n.s.	organic	0	0	0	0	0	0	0	0	0	0	0	0%
34	≤ 600	n.s.	382	347	302	284	279	274	268	263	258	258	-123	-32%
	601-1200	n.s.	81	74	75	76	75	75	75	74	74	74	-7	-8%
	> 1200	n.s.	255	252	237	225	223	222	220	219	218	218	-37	-15%
35	n.s.	mineral	1	0	0	0	0	0	0	0	0	0	-1	-100%
	n.s.	organic	0	0	0	0	0	0	0	0	0	0	0	0%
36	n.s.	n.s.	347	345	337	331	330	329	328	327	326	326	-21	-6%
37	n.s.	n.s.	399	382	368	367	365	363	361	359	357	357	-42	-10%
41	n.s.	n.s.	203	208	207	206	206	205	204	203	203	203	0	0%
42	n.s.	n.s.	160	162	164	168	169	169	170	170	171	171	11	7%
51	n.s.	n.s.	904	1044	1185	1254	1275	1295	1316	1336	1357	1357	453	50%
52	n.s.	n.s.	305	327	374	385	390	394	399	403	407	407	103	34%
53	n.s.	n.s.	15	16	19	16	16	16	15	15	15	15	0	1%
54	n.s.	n.s.	144	158	139	139	139	140	140	141	142	142	-2	-1%
61	n.s.	n.s.	1027	1026	1016	1001	1000	1000	999	999	998	998	-28	-3%
Sum			16054	16054	16054	16054	16054	16054	16054	16054	16054	16054	0	0%

The annual rates of change in the whole country (change-matrix) are achieved by adding up the annual change rates of all hectares per combination category (CC). Table 6-8 shows an overview of the mean annual changes of all CC in 2010 as an example. The totals of the columns equal the total increase of one specific category. The totals of the rows equal the total decrease of one specific category. The sum of increases and decreases is identical.

For calculating the carbon stock changes, fully stratified land-use change matrices are used for each year (see chp.6.1.3). More aggregated change-matrices are reported in CRF-table 4.1 for each year 1990-2021.

Table 6-8 Land-use change in 2010 (change matrix). Units: ha/year.

			To																		
	main category		Forest Land			Cropl.	Grassland							Wetlands		Settlement				Other L.	
		CC	11	12	13	21	31	32	33	34	35	36	37	41	42	51	52	53	54	61	Decrease
From	Forest Land	11		1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
		12	0.0		1.0	0.0	1.2	0.7	0.0	1.0	0.0	0.0	0.3	0.0	0.7	1.3	0.3	0.0	0.0	0.3	6.8
		13	0.0	7.0		0.0	1.3	0.8	0.0	0.3	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	9.8
	Cropland	21	0.0	0.0	0.0		16.3	0.0	0.5	0.3	0.0	0.0	0.0	0.2	0.0	2.8	1.0	0.0	0.0	0.0	21.2
	Grassland	31	0.0	0.7	2.2	8.3		2.5	0.0	2.5	0.0	1.0	0.2	0.0	0.5	6.3	3.0	0.2	0.2	0.2	27.7
		32	0.2	4.8	7.2	0.0	1.7		0.0	2.2	0.0	0.5	0.3	0.0	0.0	0.2	0.0	0.0	0.0	0.0	17.0
		33	0.0	0.0	0.0	0.0	0.2	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.3
		34	0.0	5.2	0.2	0.0	4.3	0.5	0.3		0.0	0.3	0.5	0.3	0.0	0.7	1.0	0.0	0.3	0.0	13.7
		35	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
		36	0.2	0.3	0.3	0.2	2.0	1.5	0.0	0.3	0.0		0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.5	6.0
		37	0.0	0.0	0.0	0.0	0.2	1.5	0.0	0.2	0.0	0.3		0.2	0.0	0.0	0.0	0.0	0.0	0.2	2.5
	Wetlands	41	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.2	0.0	0.0	0.0	2.5	2.7
		42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2		0.2	0.0	0.0	0.0	0.0	0.3
	Settlement	51	0.0	0.0	0.0	0.5	2.2	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.0		1.5	0.2	0.2	0.0	4.8
		52	0.0	0.0	0.0	0.2	0.7	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	3.7		0.5	2.5	0.0	7.8
		53	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.3		0.0	0.0	1.5
		54	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.8	2.5	0.0		0.0	3.5
	Other Land	61	0.0	0.2	0.0	0.0	0.7	1.0	0.0	0.5	0.0	2.7	0.5	1.8	0.2	0.2	0.0	0.0	0.0		7.7
		Increase	0.5	19.5	10.8	9.2	30.7	8.7	0.8	7.8	0.0	4.8	2.8	2.7	1.3	17.2	9.7	0.8	3.2	3.8	134.3

In accordance with the Guidelines (IPCC 2006, Volume 4, Chapter 3.2) land-use changes between two categories of unmanaged land (e.g. CC36-CC37, stony and unproductive grassland) are not considered for calculating emissions/removals. However, the area of unmanaged land is quantified and tracked over time, so that consistency in area accounting is maintained as land-use change occurs.

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 Liechtenstein's land-use statistics (AREA)

Land-use data for Liechtenstein are collected according to the same method as in Switzerland. This so-called AREA survey is based on sampling points covering the whole territory on a 100x100 m^2 grid ('hectare raster'). Every sampling point was assigned to one of 46 land-use categories and to one of 27 land-cover categories (NOLU04/NOLC04, see chp. 6.2.1) by means of stereographic interpretation of aerial photos (EDI/BFS 2009).

For the reconstruction of the land use conditions in Liechtenstein for the period 1990-2021 five data sets are used:

- Land-Use Statistics 1984
- Land-Use Statistics 1996
- Land-Use Statistics 2002

- Land-Use Statistics 2008
- Land-Use Statistics 2014

Land-use statistics from the years 1984 and 1996 were originally evaluated according to a set of different land-use categories. For this purpose, they were being re-evaluated according to the newly designed land-use and land-cover categories (SFSO 2006a). For the interpretation of the 2002, 2008 and 2014 data the new land-use and land-cover categories were used directly (EDI/BFS 2009).

6.3.1.2 Interpolation and extrapolation of the status for each year

The exact dates of aerial photo shootings for AREA are known. However, the exact year of the land-use change on a specific hectare is unknown. The actual change could have taken place in any year between the two land-use surveys. It is assumed that the probability of a land-use change from 1984 to 1996, 1996 to 2002, 2002 to the 2008 and from 2008 to 2014 is uniformly distributed over the respective interim period between two surveys. Therefore, the land-use change of each hectare has to be equally distributed over its specific interim period (e.g. when a specific area increased by three hectares between 1996 and 2002, it was assumed that the annual increase was 0.5 hectares).

Thus, the land-use status for the years between two data collection dates can be calculated by linear interpolation. The status after 2014 is estimated by linear extrapolation, assuming that the average trend observed between 2008-2014 goes on.

Figure 6-5 shows an example: A certain area was assigned to the land-use category “Cropland” (CC 21) in 1984. A partial land-use change to “Shrubs in Settlements” (CC 53) was discovered in 1996. And another partial change to “Buildings and construction” (CC 51) was discovered in 2002.

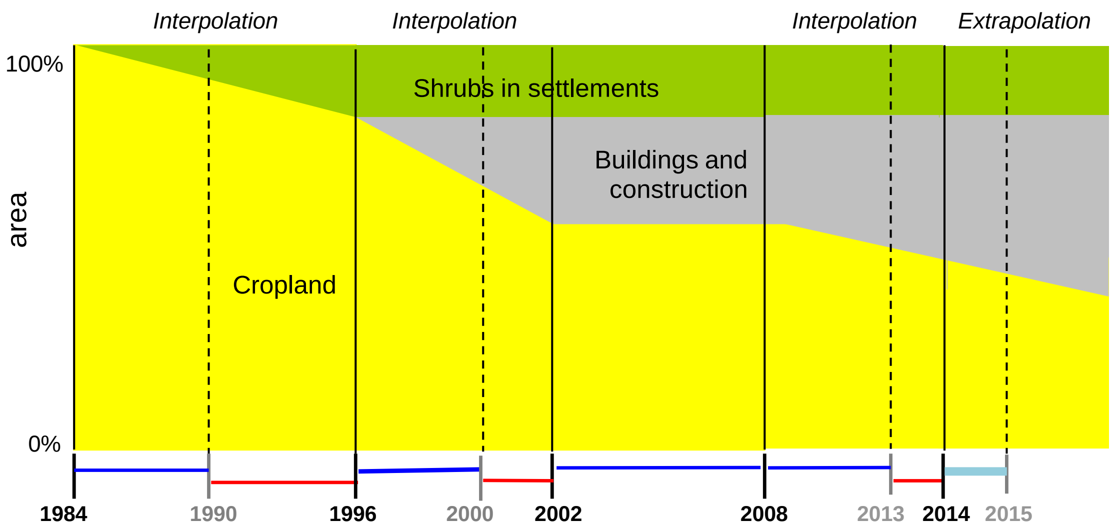


Figure 6-5 Hypothetical linear development of land-use changes between the five Land-use surveys (1984, 1996, 2002, 2008, 2014) with the example of areas changing 1984-1996 from “cropland” to “shrubs in settlements” and then 1996-2002 and again 2008-2014 to “buildings and constructions". The dotted lines show how the share of the different land use categories is determined in years between land use statistics and extrapolated after 2014.

The ‘status 1990’ is determined by calculating the fractions of the two land-use categories for the year 1990. A linear development from “cropland” to “shrubs in settlements” during the whole interim period is assumed. The same procedure can be applied for two survey dates between 1996 and 2002 (see year 2000 in Figure 6-5 as example). Extrapolation after 2014 is done by taking the average trend of the time period 2008 to 2014. The ‘status’ for each individual year in the period 1990-2021 for the whole territory of Liechtenstein results from the summation of the fractions of all hectares per combination category CC (considering the spatial strata where appropriate; see Table 6-7).

6.3.1.3 Uncertainties and time-series consistency of activity data

An overview of uncertainty estimates for activity data (AD) and emission factors (or biomass parameters) is shown in Table 6-5. Details related to uncertainties of AREA data are presented in this chapter, while uncertainties of other AD (such as consumption of harvested wood products) and emission factors are presented in the respective chapters (6.x.3) of the LULUCF categories.

Uncertainties of the AREA-based activity data are presented in Table 6-9. They have two main sources that were quantified as follows:

1) Interpretation error: 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 supplied by SFSO and used as the uncertainty of the interpretation. This uncertainty 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 more accurate information is available.

2) Statistical sampling error: In the AREA survey, the land-use types are interpreted on points situated on a regular 100x100 m grid. Thus, the uncertainty of the surface area covered by a certain land-use type or land-use change decreases with increasing numbers of sampling points. 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 in AREA 2014 lies between 23 (for 4F2) and 6'074 (for 4A1) leading to values of $U_{samplin}$g between 40.9% and 2.5%.

The overall uncertainty is between 2.7% and 40.9%. It was calculated as:

$$U_{overall} = (U_{interpret}^2 + U_{sampling}^2)^{0.5}$$

Table 6-9 Sources of AD uncertainty and overall uncertainties in the area calculations, expressed as half of the 95% confidence intervals. Calculations are based on AREA data from 2014.

Category	Description	Interpretation uncertainty	Sampling uncertainty	Overall uncertainty
4A1	Forest Land remaining Forest Land	1.1	2.5	**2.7**
4A2	Land converted to Forest Land	1.1	17.1	**17.2**
4B1	Cropland remaining Cropland	4.9	4.8	**6.9**
4B2	Land converted to Cropland	4.9	26.4	**26.9**
4C1	Grassland remaining Grassland	5.2	2.8	**6.0**
4C2	Land converted to Grassland	5.2	12.6	**13.6**
4D1	Wetlands remaining Wetlands	0.9	10.4	**10.5**
4D2	Land converted to Wetlands	0.9	40.9	**40.9**
4E1	Settlements remaining Settlements	4.4	4.8	**6.5**
4E2	Land converted to Settlements	4.4	18.9	**19.4**
4F1	Other Land remaining Other Land	1.4	6.3	**6.4**
4F2	Land converted to Other Land	1.4	40.9	**40.9**

Consistency: Time series for activity data are all considered consistent; they are 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.

The AREA survey is a well-defined and controlled, long-term process in the responsibility of the Swiss Federal Statistical Office (SFSO 2006a). It was assured that the total country area remained constant over the inventory period.

6.3.1.5 Recalculations of activity data

There were no recalculations of AREA data.

6.3.1.6 Planned improvements for activity data

An update of the AREA survey is planned. Due to technical modifications at the Swiss Federal Statistical Office the results are delayed: they are expected to be available in 2023 (Banzer 2021) and should be ready for the Submission 2024 (IDP ARR 2018, ID#L.12).

6.3.2 Information on approaches used for natural disturbances

Presently, Liechtenstein intends to apply, in the case of significant magnitude events, the provision of natural disturbances for units of Forest land. Natural disturbances were not mentioned in the Intended Nationally Determined Contribution (Government 2015a). It is planned to include them in future contributions.

For non-Forest land, no provisions for natural disturbances will be applied.

6.3.3 Information on approaches used for harvested wood products

For accounting harvested wood products (HWP), the approach B (production approach) as described in chp. 12, Volume 4 of IPCC (2006) is applied. The wood products pool contains only products made from wood harvested in Liechtenstein. The wood products pool possibly includes products made from domestic harvest that are exported to other countries. More details and results are presented in chp. 6.11.

6.4 Forest Land (4A)

6.4.1 Description

Key category information 4A

The CO_2 emission from 4A1 Forest Land remaining Forest Land is key source by level and trend. 4A2 Land Converted to Forest Land is not a key source.

39.1% of the total area of Liechtenstein is forest land. The total forest area increased by 4.0% between 1990 and 2021. The annual net CO_2 emissions/removals are in the range -15.96 kt CO_2 (1991) to 14.12 kt CO_2 (2000). The source category 4A1 "Forest Land remaining Forest Land" is in some years a net source and in some years a net sink depending on the harvesting amount of the year. The source category 4A2 "Land converted to Forest Land" is a net sink in all years.

All of the forest land is temperate forest. The definition of forest land is originally based on the Swiss definition and was revised after the in-country reviews carried out in Switzerland and Liechtenstein 2007. Forest land is now defined as follows (Government 2016):

- Minimum area of land: 0.0625 hectares with a minimum width of 25 m
- Minimum crown cover: 20%
- Minimum height of the dominant trees: 3 m (dominant trees must have the potential to reach 3 m at maturity in situ)

For calculating emissions and removals, forest land was subdivided into afforestation (CC 11), managed forest (CC 12) and unproductive forest (CC 13) based on the land use and land cover categories (see Table 6-3; SFSO 2006a).

6.4.2 Methodological issues

The activity data collection follows the methods described in chp. 6.3.1. Carbon stocks and carbon stock changes are taken partly from Switzerland and partly from Liechtenstein's NFI as well as from Liechtenstein's wood harvesting statistics. Details are described in the following paragraphs.

6.4.2.1 National Forest Inventory (NFI) data for productive forest (CC12)

For productive forest (CC12), data for carbon stocks in living biomass and dead wood, as well for gain (growth) and loss of living biomass (cut and mortality) was derived from Liechtenstein's National Forest Inventory. The NFI is based on 403 terrestrial sampling points situated in accessible forest stands (without brush forest) representing a mesh of 354 x 354 m^2. It was conducted between 1998 and 2010 (LWI 2012). Thus, the carbon fluxes induced by growth, cut and mortality are an average of that 12-year period. Table 6-10 shows important results of the LWI (2012). The average annual rates were 7.9 m^3 ha^{-1} for growth, 5.7 m^3 ha^{-1} for cut and 2.7 m^3 ha^{-1} for mortality. Overall, the growing stock decreased during this period.

In order to simplify the calculation of annual gains and growing stocks, it is assumed that gross growth and stocks are constant over the whole time period, i.e. the average rates 1998-2010 are applied for all years between 1990 and 2021.

For calculating cut and mortality annual values of biomass loss by harvesting are used (see chp. 6.4.2.3).

Table 6-10 Results of Liechtenstein's forest inventory 2010 (LWI 2012).

	Growth [m^3 ha^{-1} yr^{-1}], 1998-2010		
	elevation ≤ 1000 m	elevation > 1000 m	Liechtenstein
Coniferous	4.9	6.4	5.8
Deciduous	4.3	0.7	2.1
Total	9.2	7.1	7.9
	Stocks 2010 [m^3 ha^{-1}]		
	elevation ≤ 1000 m	elevation > 1000 m	Liechtenstein
Growing stock	374	383	379
Dead wood	24	34	30

As in Switzerland, forests in Liechtenstein reveal a high heterogeneity in terms of elevation, growth conditions and tree species composition. To find explanatory variables that significantly reduce the variance of gross growth and biomass expansion factors (BEFs) an analysis of variance was done in Switzerland (Thürig and Schmid 2008). The considered explanatory variables are (see also chp.6.2.2):

- altitude (≤ 600 m, 601-1200 m, > 1200 m)
- tree species (coniferous and deciduous species).

The NFI-report (LWI 2012) presents results separately for coniferous and deciduous trees. The carbon values for CC12 were calculated as volume-weighted averages as AREA cannot distinguish coniferous and deciduous forests. Furthermore, the NFI report presents results for the altitudinal belts ≤1'000 m and >1'000 m a.s.l. These results were transformed to the three altitudinal belts used for LULUCF calculations (≤ 600 m, 601-1'200 m, > 1'200 m) by weighting with the forest areas measured in the different elevation ranges. With this procedure, the values for CC12 shown in Table 6-4 were produced.

6.4.2.2 Biomass Conversion and Expansion Factors (BCEF)

BCEFs for Liechtenstein were derived from results of the 4th National Forest Inventory (NFI4, 2017) of Switzerland. As shown by Thürig et al. (2004), Liechtenstein's forest has similar growing conditions as the forest area in the Swiss NFI region 3 (Pre-Alps). Therefore, published data on stocks and biomass from the NFI region 3 were used to calculate BCEFs for Liechtenstein as shown in Table 6-11. The necessary NFI result-tables were downloaded from www.lfi.ch/resultate (Abegg et al. 2020). In the Swiss NFI as well as in Liechtenstein's NFI, growing stock, gross growth, cut (harvesting) and mortality are expressed as round wood over bark.

In previous Swiss NIRs (FOEN 2008) Round wood over bark was expanded to total biomass as done in Thürig et al. (2005) by applying allometry single-tree functions to all trees measured at the second Swiss NFI and other functions for twigs, branches, bark, coarse roots and foliages; BCEFs were then calculated for each spatial stratum as the ratio between round wood over bark (m^3 ha^{-1}) and the total above- and belowground biomass (t ha^{-1}) (as documented by Thürig and Schmid 2008). For comparison, Table 6-12 shows the new and the previously used BCEFs for coniferous and deciduous species stratified for altitude.

The new BCEFs for living biomass derived from NFI4 were initially not stratified for altitude (Table 6-11). Stratified values for the three altitude zones were calculated in accordance with the previous values, maintaining the overall area-weighted average (see Table 6-12). The new values are 2-4% lower than the previous version. They lie in the default range given by IPCC 2006. The BCEF for dead wood was not stratified.

Table 6-11 BCEFs to convert growing stock (round-wood over bark, m^3 ha^{-1}) to total biomass (t ha^{-1}) for conifers and deciduous species as well as BCEF for dead wood, derived from results of the Swiss NFI4, region 3 (Abegg et al. 2020).

Swiss NFI 4 (2017)	Units	Region 3 (Pre-Alps) Coniferous	Deciduous	Total
Living biomass:				
Growing stock	m^3/ha	331.7	106.8	438.5
Biomass of living trees	t/ha	200.4	85.9	286.3
BCEF living biomass	t/m^3	**0.60**	**0.80**	**0.65**
default BCEF	t/m^3	0.7 (0.4-1.0)	0.8 (0.55-1.1)	
Dead wood:				
Stock of dead wood	m^3/ha			31.2
Biomass of dead wood	t/ha			20.2
BCEF dead wood	t/m^3			**0.65**

Table 6-12 BCEFs from NFI4 stratified for altitude according to previous BCEFs from NFI2 (FOEN 2008).

BCEFs		New values (NFI4 2009/2017)		Previous values 2008	
Living biomass	Units	Coniferous	Deciduous	Coniferous	Deciduous
Altitude:					
< 601 m	t/m^3	0.59	0.78	*0.59*	*0.82*
601 - 1200 m	t/m^3	0.59	0.78	*0.59*	*0.82*
> 1200 m	t/m^3	0.62	0.82	*0.64*	*0.86*
weighted mean	t/m^3	**0.60**	**0.80**	***0.61***	***0.83***

In the Swiss GHG inventories after 2012, single-tree allometric functions were used instead of BCEFs. Therefore, BCEFs are no longer published in the Swiss NIDs.

The IPCC default carbon content of solid wood of 50% was applied (IPCC 2006 Table 4.3: mean value from Lamlom and Savidge (2003) for conifers and broadleaved trees in temperate forests).

BCEFs and carbon contents were used to calculate carbon stocks and fluxes from the volumes measured in Liechtenstein's NFI (LWI 2012).

6.4.2.3 Gain and loss of living biomass for productive forest (CC12)

Carbon stock changes in living biomass for productive forests (CC12) are calculated with the gain-loss approach. The values for gain (gross growth) were derived from Liechtenstein's National Forest Inventory (NFI, LWI 2012); they represent the average of the period 1998-2010 (see Table 6-4 and Table 6-14).

For calculating the loss, annual harvesting statistics (Table 6-13) are used in addition to the NFI results as follows:

- The relative harvesting rates are calculated as the ratio of the yearly harvesting to the average harvesting of the NFI period 1998-2010 (see Table 6-13).
- According to the NFI (period 1999-2010), the average cut is 5.65 m^3 ha^{-1} yr^{-1} and the average mortality is 2.70 m^3 ha^{-1} yr^{-1}. The total loss is 8.35 m^3 ha^{-1} yr^{-1}. With this information the carbon stock losses were calculated and split in the two parts cut and mortality as shown in Table 6-14.
- The annual losses per altitude zone were calculated assuming that the annual cut is proportional to the relative harvesting factor (see Table 6-13) and that mortality does not depend on the harvesting rate:
  annual loss = (relative harvesting) * (average cut) + (average mortality)

The resulting annual loss is shown in Table 6-14.

Table 6-13 Wood harvesting statistics for Liechtenstein's forest 1986-2021 and the annual harvesting relative to the reference period of the NFI (1999-2010). Source: OE 2022b.

Year	Harvesting m^3	Relative harvesting
1986	18'143	0.876
1987	13'194	0.637
1988	13'843	0.668
1989	13'479	0.651
1990	20'024	0.967
1991	10'333	0.499
1992	16'853	0.814
1993	14'759	0.713
1994	26'315	1.270
1995	18'087	0.873
1996	12'970	0.626
1997	19'527	0.943
1998	14'537	0.702
1999	13'538	0.654
2000	28'683	1.385
2001	14'477	0.699
2002	14'755	0.712
2003	17'016	0.821
2004	18'169	0.877
2005	18'038	0.871
2006	20'776	1.003
2007	26'099	1.260
2008	27'217	1.314
2009	25'364	1.224
2010	24'436	1.180
2011	26'664	1.287
2012	26'813	1.294
2013	22'316	1.077
2014	22'259	1.075
2015	19'089	0.922
2016	18'012	0.870
2017	18'986	0.917
2018	25'573	1.235
2019	19'790	0.955
2020	15'468	0.747
2021	12'958	0.626
Mean 1999-2010	20'714	1.000

Table 6-14 (a) Splitting total carbon stock loss of living biomass (NFI, mean 1999-2010) into cut and mortality and (b) calculated annual losses 1990-2021 for the three altitude zones (≤ 600 m, 601-1200 m, > 1200 m). Units: t C ha^{-1} yr^{-1}

(a) Average 1999-2010:

Altitude	Gain	Total loss	Mortality	Cut
zone 1	3.12	-3.27	-1.06	-2.21
zone 2	2.77	-2.90	-0.94	-1.96
zone 3	2.27	-2.38	-0.77	-1.61

(b) Annual loss:

Altitude	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
zone 1	-3.19	-2.16	-2.85	-2.63	-3.86	-2.99	-2.44	-3.14	-2.61	-2.50
zone 2	-2.83	-1.91	-2.53	-2.33	-3.43	-2.65	-2.16	-2.78	-2.31	-2.22
zone 3	-2.32	-1.57	-2.08	-1.91	-2.81	-2.17	-1.78	-2.28	-1.90	-1.82

Altitude	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
zone 1	-4.12	-2.60	-2.63	-2.87	-3.00	-2.98	-3.27	-3.84	-3.96	-3.76
zone 2	-3.65	-2.31	-2.33	-2.55	-2.66	-2.64	-2.90	-3.41	-3.51	-3.34
zone 3	-2.99	-1.89	-1.91	-2.09	-2.18	-2.17	-2.38	-2.79	-2.88	-2.74

Altitude	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
zone 1	-3.66	-3.90	-3.92	-3.44	-3.43	-3.09	-2.98	-3.08	-3.79	-3.17
zone 2	-3.25	-3.46	-3.47	-3.05	-3.04	-2.74	-2.64	-2.73	-3.36	-2.81
zone 3	-2.67	-2.84	-2.85	-2.50	-2.50	-2.25	-2.17	-2.24	-2.75	-2.30

Altitude	2020	2021
zone 1	-2.71	-2.44
zone 2	-2.40	-2.16
zone 3	-1.97	-1.77

6.4.2.4 Growing stocks in Unproductive Forests (CC13)

The unproductive forest in Liechtenstein mainly consists of brush forest and inaccessible forest. In unproductive forests, there is no harvesting for economic reasons. Only in special cases (e.g. maintenance of hiking trails) there can be interventions where the log is moved, but not removed from the stand. Therefore, this type of forest is still categorized as managed forest and for transparency reason productive and unproductive forest areas are reported separately.

There is no information on carbon for unproductive forest in the NFIs of Liechtenstein. Therefore, the same carbon stocks per hectare as in Switzerland are assumed (see Table 6-4).

The carbon content of unproductive forest was calculated as a weighted average of brush forest, inaccessible stands and other unproductive forest not covered by NFI per spatial stratum (FOEN 2022, Chapter 6.4.2.7), see Table 6-15. For Liechtenstein, the values of the Swiss NFI-region 3 (Pre-alps) were chosen as that region corresponds to the topographic and climatic conditions in Liechtenstein.

As described in FOEN (2022) 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). Following the NFI definition, brush forests are dominated by more than two thirds by shrubs. For brush forests, no NFI data are available to derive their growing stock since only a limited number of attributes are measured on these plots. Düggelin and Abegg (2011) analysed the carbon stock of total living biomass in Swiss brush forests and found an average value of 20.45 t C ha^{-1}."

Inaccessible stands are considered similar to 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 (land use codes 403 and 422 in Table 6-6).

"Unproductive forests not covered by NFI are mainly associated with extensively pastured land where sparse tree vegetation (land cover 44 and 47 in 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} is assumed. Multiplied by the mean BCEF of 0.69 (see Thürig and Herold 2013), an average biomass for these forests of 102.75 t ha^{-1} was estimated, which translates to 51.38 t C ha^{-1} (using the IPCC default carbon content of 50%)."

Table 6-15 Areal fractions of brush forest, inaccessible forest and forest not covered by NFI, and the resulting weighted carbon content in t C ha^{-1} of unproductive forests (CC13) specified for spatial strata in NFI-region 3 (from FOEN 2022).

Altitude [m]	Fraction of brush and inaccessible forest	Fraction of forest not covered by NFI	Weighted carbon stock in living biomass [t C ha^{-1}]
≤ 600	1.00	0.00	20.45
601-1200	0.12	0.88	47.53
> 1200	0.29	0.71	42.36

6.4.2.5 Dead wood and litter

Stock data from Liechtenstein's NFI (see Table 6-10) and the BCEF derived from the Swiss NFI4 (Table 6-11) were used to calculate carbon contents in dead wood for productive forest (CC12) per spatial stratum (see Table 6-4).

For unproductive forests (CC13) there is no information available on dead wood and therefore, the Swiss value of 0 t C ha^{-1} (FOEN 2022) is used.

As there are no data on forest soils in Liechtenstein, data from Switzerland are used for carbon contents in litter. As described in FOEN (2019), Nussbaum et al. (2012, 2014) provided updated data for carbon stocks of litter (organic soil horizons L - litter, F - fermentation and H - humus) and soil organic carbon in Swiss forests. "1’033 sites of a database stored at WSL distributed among different forest types throughout Switzerland were chosen for this study." Further information on the carbon content of L horizons was taken from Moeri (2007). The data for litter and soil carbon stocks are stratified by the five NFI production regions and three elevation levels.

For Liechtenstein, the carbon stocks in litter of the Swiss NFI-region 3 (Pre-Alps) are used as shown in Table 6-4 for productive forest (CC12) and unproductive forest (CC13). For afforestations (CC11), the amount of carbon in the organic LFH-horizons was conservatively assumed to be zero as most of the afforestations took place on previous grassland or settlements, where no or only very small organic soil layers are expected.

Applying a Tier 2 approach, changes in carbon contents in deadwood and litter were derived from results of the model Yasso07 applied in Switzerland. Figure 6-6 shows the results of the model Yasso07 applied in Switzerland (FOEN 2022) in NFI-region 3 for productive forests.

- A clear carbon increase is visible in deadwood (1990-2019); this is also confirmed Liechtenstein's NFI where the average stock of deadwood increased from 20 to 30 m^3/ha between 1998 and 2010. In 2020, deadwood has become a minor net source on the average.
- Carbon stock changes in litter have a higher inter-annual variability than changes in deadwood. Until 2011, there was a carbon gain in litter in most years. After 2011, litter has become a net source on the average.

Based on these results (Figure 6-6), the carbon stock changes in deadwood and litter for Liechtenstein were calculated as the average in the period 2013-2020:

- Deadwood: 0.047 t C $ha^{-1}yr^{-1}$ below 1200 m altitude, 0.007 t C $ha^{-1}yr^{-1}$ above 1200 m altitude
- Litter: -0.049 t C $ha^{-1}yr^{-1}$ below 1200 m altitude, -0.053 t C $ha^{-1}yr^{-1}$ above 1200 m altitude

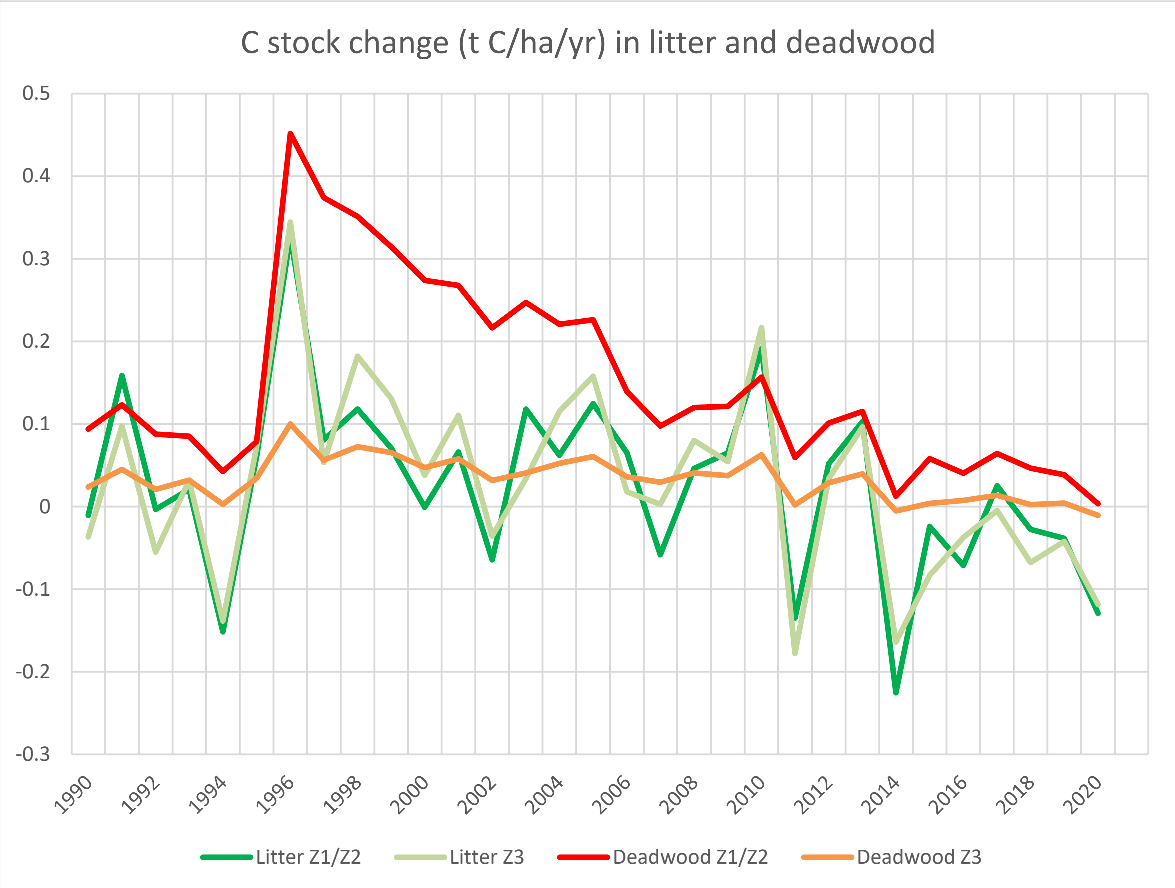


Figure 6-6 Carbon stock changes in deadwood and litter modelled with Yasso for different elevation zones (Z1/Z2: ≤1'200m, 3: >1'200 m) in the NFI-region 3. Data source: FOEN 2022.

6.4.2.6 Human-induced conversion to Forest Land (Afforestations)

For the afforestation areas (CC11), the Swiss growing stocks, gains and losses of living biomass per altitude level are applied in Liechtenstein (see Table 6-4). The following paragraph explains the Swiss calculation of carbon stock changes in living biomass (excerpt from FOEN 2021):

"Thürig and Traub (2015: Table 6) estimated the average carbon stock and gains and losses in living biomass of afforestations and young stands….

In Switzerland, land-use change from non-forest to forest is usually not caused by plantation but by abandonment of agricultural land-use (Rutherford et al. 2008…). These newly forested areas are often characterized by continuously growing trees with a large diversity in diameter at breast height (DBH) and tree age. Afforested stands established by plantation or even-aged young forest stands, however, are generally characterized by a large number of trees in small DBH classes and few trees in large DBH classes. Thürig and Traub (2015) selected NFI plots to represent both types of afforestation. Young stands were defined as stands that changed from non-forest to forest between two consecutive NFIs with at least 85% of the trees with a DBH smaller or equal to 20 cm. As there is almost no land-use change from non-forest to forest below 600 m above sea level, results were stratified for below 1200 m above sea level and above 1200 m. As a consequence of the plot selection, small losses caused by natural mortality or cut of single trees occur."

6.4.2.7 Land converted to Forest Land, not human-induced

According to the land use statistic the areas switching to forest land (CC12 or CC13) are mainly abandoned areas of grassland with woody biomass (CC32 and CC34), see Table 6-8.

The carbon fluxes of living biomass in case of land-use change comprising forest land are specified as follows:

According to the stock-difference approach, the growing stock of e.g. shrub vegetation (CC32; living biomass and soil carbon) should be subtracted and the average growing stock of forests should be added. However, these forests are supposed to have a growing stock smaller than the growing stock of an average forest and adding the average growing stock of forest areas would possibly overestimate the carbon increase. In terms of IPCC good practice, a conservative assumption was met, and the gain-loss approach was applied (see also chp. 6.1.3.2): I.e., the annual increase of biomass (carbon flux) on these areas was approximated by the annual gross growth rate of the respective forest type (CC11, 12 or 13). The change of soil carbon was not considered in source category 4A2 and was set to zero.

The annual area of forest changing to other land use categories was derived by the AREA land use statistics. In these cases, the stock-difference approach was applied (see also chp. 6.1.3.2).

6.4.2.8 Soil carbon in all forest categories (CC11, CC12, CC13)

As there are no data on forest soils in Liechtenstein, data from Switzerland are used for soil carbon contents. As described in FOEN (2021), Nussbaum et al. (2012, 2014) provided updated data for carbon stocks of litter (organic soil horizons L - litter, F - fermentation and H - humus) and soil organic carbon in Swiss forests. The data for soil carbon stocks are stratified by the five NFI production regions and three elevation levels.

For Liechtenstein, the carbon stocks in mineral soils of the Swiss NFI-region 3 (Pre-Alps) are used as shown in Table 6-4 for afforestations (CC11), productive forest (CC12) and unproductive forest (CC13). Applying a Tier 1 approach, constant carbon contents are used.

Due to following reasons, it is assumed that in the years 1990 to 2021 mineral forest soils in Liechtenstein were no carbon source:

- Within the last decades, no drastic changes of management practices in forests have taken place due to restrictive forest laws.
- Fertilization of forests is prohibited in Liechtenstein. Drainage of forests is no common practice in Liechtenstein.
- As shown in the study by Thürig et al. (2005), wind-throw may have a slightly increasing effect on soil carbon. However, this study neglected the effect of soil disturbances which could equalize those effects.
- The results of the model Yasso07 applied in Switzerland (FOEN 2021) in NFI-region 3 show only very small carbon stock changes in mineral soils for CC12 (average +0.001 t C $ha^{-1}yr^{-1}$).
- In the case of land converted to forest land, the stock of soil organic carbon (SOC) is always larger on forest land than on non-forest land (see Table 6-4) and therefore a loss of SOC is improbable. This is also the case for human-induced conversions, as the process of afforestation consists of planting small trees on grasslands; therefore, the conversion itself hardly disturbs the soil structure. In fact, an increase of SOC could be expected. However, in category 4A2 those sinks are not reported (see chp. 6.1.3.2, factor W_S is set to zero).

6.4.2.9 N_2O emissions from N fertilization and drainage of soils

Fertilization of forests is prohibited by law in Liechtenstein. Therefore, no emissions are reported in CRF Table 4(I).

Drainage of forests is no common practice in Liechtenstein. As a first guess drainage activity was set to zero, and no emissions are reported for forest land in CRF Table 4(II).

6.4.2.10 Emissions from wildfires

Controlled burning of forests is not allowed in Liechtenstein. Wildfires affecting forest did not occur in Liechtenstein since 1990 as confirmed by Nägele (2022). Therefore, no emissions are reported for forest land in CRF Table 4(V).

6.4.3 Uncertainties and time-series consistency

An overview of uncertainties in the LULUCF sector is shown in Table 6-5. The uncertainty of the AD (areas) for categories 4A1 and 4A2 are presented in chp. 6.3.1.3.

The EF uncertainty for categories 4A1 and 4A2 was estimated to 46.7%. This value was adopted from Switzerland (FOEN 2022) as the methods of the national forest inventories of the two countries are similar). This value includes the uncertainties of all processes. Gain and loss in living biomass are by far the dominant processes for 4A1 and 4A2 as shown in CRF Table 4.A.

Time series are consistent.

6.4.4 Category-specific QA/QC and verification

The category-specific QA/QC activities have been carried out as mentioned in section 1.5 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2020 and for the changing rates 2020/2021).

The LULUCF expert, the NIC and the NID author report their QC activities in a checklist (see Annex 4).

6.4.5 Category-specific recalculations

There were no recalculations in 4A.

6.4.6 Category-specific planned improvements

It is planned to update the carbon stocks in mineral soils of 4A according to the Swiss method (FOEN 2022).

6.5 Cropland (4B)

6.5.1 Description

Key category information 4B
CO_2 emissions from 4B1 Cropland remaining Cropland is a key source by level and trend. 4B2 Land Converted to Cropland is not a key source.

10.1% of Liechtenstein's total surface is cropland. Land use changes to cropland or from cropland are not very common. The most important changes are from grassland to cropland on the one hand and from cropland to grassland and to settlements on the other hand. The total area of cropland decreased between 1990 and 2021 by 16.8%.

Croplands in Liechtenstein belong to the cold temperate wet climatic zone. Carbon stocks in above ground living biomass and carbon stocks in mineral and organic soils are considered. Croplands (CC 21) cover the arable land (annual crops and leys in arable rotations).

6.5.2 Methodological issues

6.5.2.1 Cropland remaining Cropland (4B1)

The activity data collection follows the methods described in chapter 6.3.1.

a) Carbon in living biomass

The carbon stock value given in Table 6-4 (6.82 t C ha^{-1}) represents the average 1990-2020 of Swiss crops. It is based on area-weighted means of standing stocks at harvest (including root biomass) for the 19 most important annual crops (see FOEN 2022, Chapter 6.5.2.1).

b) Carbon in soils

The Swiss mean carbon stocks for cropland on mineral soils in altitude zone 1 (50.65t C ha^{-1}) was applied. It represents the average 1990-2020 of Swiss crops calculated with the model RothC (FOEN 2022, Wüst-Galley et al. 2019).

For cultivated, drained organic soils 155 t C ha^{-1} (0–30 cm) were applied in Liechtenstein. This value is based on measurements in the Ruggeller Riet, the most important area with fens in Liechtenstein, by Oechslin et al. 2021. A mean total carbon content of 312 t C ha^{-1} was measured, which corresponds to 155 t C ha^{-1} in the upper 30 cm of the soil.

c) Changes in carbon stocks

The annual net carbon stock change in organic soils was estimated to -9.52 t C ha^{-1} with an uncertainty of 23% according to measurements in Europe including Switzerland as compiled by Leifeld et al. (2003, 2005) and rechecked by ART (2009b).

Changes of carbon stocks in mineral soils and in living biomass of crops are assumed to be zero for cropland if there is no land-use change (Tier 1 approach).

6.5.2.2 Land converted to Cropland (4B2)

The activity data collection follows the methods described in chapter 6.3.1.

a) Carbon in living biomass

When a conversion of a land to cropland occurs, the stock-difference approach is applied for living biomass according to equation 6.1 in chp. 6.1.3.2, with W_l=1 and CT=20 years.

b) Carbon in soils and dead organic matter (DOM)

When a conversion of a land to cropland occurs, the stock-difference approach is applied for soil and DOM carbon according to equations 6.2 and 6.3 in chp. 6.1.3.2, with W_d=1, W_s=1 and CT=20 years.

c) N_2O Emissions from cropland

N_2O emissions from drainage of organic soils on cropland are reported in the agriculture sector.

The calculation of emissions for categories 4III and 4IV (N_2O from Nitrogen Mineralization in mineral soils) is described in chp. 6.10.

6.5.3 Uncertainties and time-series consistency

The dominant process determining the uncertainty of categories 4B1 is the carbon loss on organic soils, for 4B2 also the carbon stock change in mineral soils is relevant (see Annex A2.2for more information).

The uncertainty of the area of organic soils (AD) is determined by the uncertainty of the AREA survey (4B1 6.9%, 4B2 26.9% from Table 6-9) combined with the uncertainty of the soil map used to identify organic soils (chp. 6.2.2), which is assumed to be 30%. The uncertainty of 30% is an expert judgement by Eberle (2018) and the NID authors considering the scale and quality of the soil map produced by Büchel et al. (2006). As shown in Table 6-5 and Annex A2.2, the resulting AD uncertainties are 30.8% for 4B1 and 26.9% for 4B2.

The uncertainty of the emission factor on organic soils is 23% according to Leifeld et al. (2003). It can be used directly for 4B1.

For 4B2 the carbon stock changes in mineral soils are assumed to have a mean uncertainty of 50.0% which results in a combined EF-uncertainty of 34.0% for the sum of the pools in organic and mineral soils (Annex A2.2).

For the current submission, a simplified uncertainty analysis has been carried out as described in chp. 1.6.2. Uncertainties were accounted individually only for the key categories, whereas the rest of the sources was aggregated by gas and treated as four “rest” categories (CO_2, CH_4, N_2O, F-gases) with mean uncertainties according to Table 1-7. Emissions and sinks of the category 4B2 are no key category and are therefore part of the "rest" categories with mean uncertainty.

The time-series are consistent.

6.5.4 Category-specific QA/QC and verification

The category-specific QA/QC activities have been carried out as mentioned in section 1.5 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2020 and for the changing rates 2020/2021).

The LULUCF expert, the NIC and the NID author report their QC activities in a checklist (see Annex 4). No additional category-specific QA/QC activities have been carried out.

6.5.5 Category-specific recalculations

There were no recalculations in 4B.

6.5.6 Category-specific planned improvements

No category-specific improvements are planned.

6.6 Grassland (4C)

6.6.1 Description

Key category information 4C
4C1 Grassland remaining Grassland is not a key source. CO_2 emissions from 4C2 Land converted to Grassland are a key category concerning level and trend.

30.3% of Liechtenstein’s total surface is grassland, whereof 86% is managed and 14% is unmanaged grassland. Conversion to grassland occurs mainly from cropland to grassland and from forest to grassland. These changes are however less important than the reverse conversion from grassland to forest and from grassland to cropland. The total area of grassland decreased by 8.5% in 2021 compared to 1990.

Liechtenstein’s grasslands belong to the cold temperate wet climatic zone. Carbon stocks in living biomass and carbon stocks in soils are considered. Grasslands include permanent grassland (CC31), shrub vegetation (CC32), vineyards, low-stem orchards (‘Niederstamm-obst’) and tree nurseries (CC33), copse (CC34), orchards (‘Hochstammobst’; CC35), stony grassland (CC36), and unproductive grassland (CC37). The combination categories CC31-35 are considered as managed and CC36-37 as unmanaged grasslands.

As there are no data available from Liechtenstein related to carbon pools in Grassland, data based on experiments, field studies, literature and expert estimates from Switzerland are used (see chp. 6.6.2). The applicability of those data is justified by the facts that

- the land-use categories used in Liechtenstein are defined in the same way and the same nomenclature (SFSO 2006a) and
- the topographic, climatic and geological conditions in Liechtenstein are very similar to the Region 3 (Pre-Alps) of the Swiss NFI. Region 3 is situated adjacently along the Western border of Liechtenstein, i.e. it extends to the same valley where the main part of Liechtenstein's territory is situated. Further, the management practices of the

different grassland types are very similar in Switzerland and Liechtenstein, e.g. related to vineyards, orchards or alpine farming at higher altitudes.

6.6.2 Methodological issues

6.6.2.1 Grassland remaining Grassland (4C1)

The activity data collection follows the methods described in chp.6.3.1. Carbon stocks are based on data from Switzerland (FOEN 2022) as shown in Table 6-4. Details are described in the following paragraphs.

a) Carbon in living biomass

Permanent Grassland (CC31)

Permanent grasslands range in altitude from 400 m to 2’500 m above sea level. Because both biomass productivity and soil carbon rely on the prevailing climatic and pedogenic conditions, grassland stocks were calculated separately for three altitude zones (see chp. 6.2.2).

Swiss values for carbon stock in living biomass of permanent grassland are applied. They were calculated as the annual cumulative yield of six differentially managed grasslands for three altitude zones (FOEN 2022). Root biomass was estimated based on allometric function as described in Wüst-Galley et al. (2020).

Shrub Vegetation (CC32) and Copse (CC34)

Swiss values for living biomass in shrub vegetation and copse were applied (FOEN 2022). Due to a lack of more precise data, the living biomass of shrub vegetation and copse was assumed to correspond with brush forest described in chp. 6.4.2.4. Brush forest is assumed to contain 20.45 t C ha^{-1}.

Vineyards, Low-stem Orchards and Tree Nurseries (CC33)

Swiss values for standing carbon stock of living biomass (Cl) for CC33 were applied (FOEN 2022). Cl of vineyards is 5.43 t C ha^{-1}, Cl of low-stem orchards is 15.06 t C ha^{-1}. For tree nurseries no stand densities are available. The weighted mean carbon stock of this combination category is 5.58 t C ha^{-1}.

Orchards (CC35)

Orchards are loosely planted larger fruit trees (‘Hochstammobst’) with grass understory. Swiss values for the biomass stock of orchards were applied (FOEN 2022). The total biomass stock of this combination category is 23.32 t C ha^{-1} including woody biomass (17.78 t C ha^{-1}) and the grass layer (5.54 t C ha^{-1}).

Stony Grassland (CC36)

Stony grassland is categorized as unmanaged grassland. Swiss values for carbon stock of stony grassland were applied (FOEN 2022). Approximately 35% of the surface of CC36 (herbs and shrubs on stony surfaces) is covered by vegetation. No accurate data were available for this category. Therefore, the carbon content of brush forest (20.45 t C ha^{-1}; Düggelin and Abegg 2011) was multiplied by 0.35 to account for the 35% vegetation coverage. This results in a carbon content of 7.16 t C ha^{-1}.

Unproductive Grassland (CC37)

Unproductive grassland is categorized as unmanaged grassland. The category includes grass and herbaceous plants at watersides of lakes and rivers including dams and other flood protection structures, constructions to protect against avalanches and rockslides, and alpine infrastructure. These areas are not used as grassland and are therefore categorised as unmanaged land.

For none of these land-use types, biomass data are currently available. Therefore, the area-weighted mean of permanent grasslands in the three altitude zones, 3.45 t C ha^{-1} (cf. Table 6-4), was assumed to be representative for the biomass on unproductive grassland CC37 (FOEN 2022).

b) Carbon in soils

Permanent Grassland (CC31)

Carbon stocks in grassland soil refer to a depth of 0-30 cm.

The Swiss mean values for carbon stocks in mineral and organic soils are applied (FOEN 2022). They represent the average 1990-2020 of Swiss permanent grassland calculated with the model RothC (FOEN 2022, Wüst-Galley et al. 2020). Six differently managed permanent grassland types were considered. Plant carbon inputs into the soil from grasslands were assumed to be constant. The initial values for the model are based on Leifeld et al. (2003) and Leifeld et al. (2005). The resulting carbon stock values for mineral soils on CC31 are displayed in Table 6-4.

The mean soil organic carbon stock (0-30 cm) for organic soils is 155 t C ha^{-1} (0–30 cm). This value is based on measurements in the Ruggeller Riet, the most important area with fens in Liechtenstein, by Oechslin et al. 2021. A mean total carbon content of 312 t C ha^{-1} was measured, which corresponds to 155 t C ha^{-1} in the upper 30 cm of the soil.

Shrub Vegetation (CC32) and Copse (CC34)

Due to lack of data, the values of carbon stocks under permanent grassland on mineral soils (CC31) were used (see Table 6-4).

Vineyards, Low-stem Orchards and Tree Nurseries (CC33)

As no specific value for mineral soils under CC33 was available the mean soil organic carbon stock of cropland (CC21) (area-weighted mean across the three elevation zones 1990–2020) was taken: 50.58 t C ha^{-1} (0–30 cm) (see FOEN 2022).

The mean soil organic carbon stock (0–30 cm) for organic soils is 155 t C ha^{-1} (see CC31).

Orchards (CC35)

No specific value for mineral soils under orchards was available. As most orchard areas have grass understorey the average soil carbon content of permanent grassland (CC31) for the period 1990–2020 was taken, weighted with the area of CC35 per elevation zone: 59.70 t C ha^{-1} (0–30 cm).

The mean soil organic carbon stock (0-30 cm) for organic soils is 155 t C ha^{-1} (see CC31).

Stony Grassland (CC36)

Soil organic carbon stocks under herbs and shrubs on stony surfaces were calculated according to the procedure used for biomass, i.e. it is 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. These grasslands are mainly located at altitudes > 1200m a.s.l. Thus, using the respective value of CC31, the carbon stock Cs of CC36 is calculated as:

$$Cs(CC36) = 0.35 * Cs(\text{permanent grassland} > 1200\text{ m}) = 22.35\text{ t C ha}^{-1}$$

Unproductive Grassland (CC37)

The category CC37, unproductive grasslands' includes grass and herbaceous plants at watersides of lakes and rivers including dams and other flood protection structures, constructions to protect against avalanches and rockslides, and alpine infrastructure. For none of these land-use types, Cs data are currently available. Therefore, the carbon stock of mineral soils was calculated as average soil carbon content of permanent grassland (CC31) for the period 1990–2020, weighted with the area of CC37 per elevation zone: 63.65 t C ha^{-1} (0–30 cm).

c) Changes in carbon stocks

The annual net carbon stock change in organic soils on managed grassland (CC31-CC35) 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 rechecked by ART (2009b).

Applying a Tier 1 approach, changes of carbon stocks in mineral soils and in biomass are assumed to be zero if there is no land-use change.

6.6.2.2 Land converted to Grassland (4C2)

The activity data collection follows the methods described in chp. 6.3.1.

a) Carbon in biomass

When a conversion of a land to grassland occurs, the stock-difference approach is applied for living and dead biomass according to equations 6.1 and 6.2 in chp. 6.1.3.2, with W_l=1, W_d=1 and CT=20 years.

The carbon stocks in living biomass and in soil are reported in detail under "Grassland remaining grassland" (chp. 6.6.2.1) and are summarized in Table 6-4.

b) Carbon in soils

When a conversion of a land to grassland occurs, the stock-difference approach is applied for soil carbon according to equation 6.3 in chp. 6.1.3.2, with W_s=1 and CT=20 years.

c) N_2O emissions from Grassland

N_2O emissions from drainage of organic soils on grassland are reported in the agriculture sector.

The calculation of emissions for categories 4III and 4IV (N_2O from Nitrogen Mineralization in mineral soils) is described in chp. 6.10.

6.6.3 Uncertainties and time-series consistency

For category 4C1, the dominant processes determining the uncertainty are the carbon stock change on organic and mineral soils. For 4C2 also the carbon stock change in living biomass is relevant (see Annex A2.2 for more information).

The uncertainty of the area of organic soils (AD) is determined by the uncertainty of the AREA survey (4C1 6.0%, and 4C2 13.6% from Table 6-9) combined with the uncertainty of the soil map used to identify organic soils (chp. 6.2.2), which is assumed to be 30%. The uncertainty of 30% is an expert judgement by Eberle (2018) and the NID authors considering the scale and quality of the soil map produced by Büchel et al. (2006). As shown in Annex A2.2, the resulting AD uncertainty on organic soils is 30.6% for 4C1 and 32.9% for 4C2.

The uncertainty of the emission factor on organic soils is 23% according to Leifeld et al. (2003).

The carbon stock changes in mineral soils are assumed to have a mean uncertainty of 50.0% which results in a combined EF-uncertainty of 51.2% for the sum of the pools in organic and mineral soils of category 4C1 (Annex A2.2).

For category 4C2, land converted to grassland, the relevant emissions from living biomass, mineral soils and organic soils were considered:

- Living biomass: the dominant process is the carbon loss in (living) biomass calculated by the stock-difference approach for conversions from forest land to grassland (4C2.1). Therefore, the uncertainty of the carbon stock of forest was used as EF-uncertainty

(40.3%, see below). The resulting absolute uncertainty in living biomass is 0.315 t C ha^{-1} yr^{-1}.

- Mineral soils: Carbon stock change in mineral soils is assumed to have a mean uncertainty of 50.0%. Thus, the absolute uncertainty for 4C2 is 0.125 t C ha^{-1} yr^{-1}.
- Organic soils: The uncertainty of the carbon stock change (emission factor) in organic soils is 23% as reported by Leifeld et al. (2003: 56) and the uncertainty of the activity data (area of organic soil form soil map by Büchel et al., 2006) is 30% (see above), resulting in a combined uncertainty of 32.9%. Thus, the absolute uncertainty of the total organic soil emissions in 2021 is 0.056 t C ha^{-1} yr^{-1} (related to the total area of 4C2) as shown in Annex A2.2.

The root sum squares of those three absolute uncertainties are 0.343 t C ha^{-1} yr^{-1} for 4C2. This absolute uncertainty was used to calculate a relative emission factor uncertainty for 4C2 by dividing with the mean net carbon stock change per hectare of 4C2. In 2021, the mean net carbon stock changes were -0.67 t C ha^{-1} for 4C2 (calculated from CRF Table4.C). The resulting relative EF-uncertainty is 51.0% for 4C2 (see Table 6-5).

The AD uncertainty (13.6%) for 4C2 comes from the AREA survey as shown in Table 6-9.

The uncertainty of the carbon stock of forest was used as EF-uncertainty for living biomass in 4C2 (40.3%, see above). It was calculated by error propagation combining the following uncertainties of input data:

- Growing stock: 26.0%. This value was derived from the Swiss NFI online-results for the Canton Glarus (GL), which is comparable with the geographic extent and the topographic situation in Liechtenstein (http://www.lfi.ch/resultate/anleitung-en.php?lang=en).
- Carbon content: 2% (FOEN 2022, Chapter 6.4.3)
- Biomass expansion functions: 21.2% (see FOEN 2022, Chapter 6.4.3)
- Sampling uncertainty: 22.2% (FOEN 2022, Chapter 6.4.3)

The time-series are consistent.

6.6.4 Category-specific QA/QC and verification

The category-specific QA/QC activities have been carried out as mentioned in section 1.5 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2020 and for the changing rates 2020/2021).

The LULUCF expert, the NIC and the NID author report their QC activities in a checklist (see Annex 4). No additional category-specific QA/QC activities have been carried out.

6.6.5 Category-specific recalculations

There were no recalculations in 4C.

6.6.6 Category-specific planned improvements

The possible inconsistency related to organic soils in sector 4C (IDP Internal decision, planned improvement for 2024) will be checked in Submission 2024, when the updated AREA survey will be available, and a new data processing model will be implemented.

6.7 Wetlands (4D)

6.7.1 Description

Key category information 4D
Source categories 4D1 Wetlands remaining Wetlands and 4D2 Land converted to Wetlands are not key categories.

3.0% of the total surface of Liechtenstein are wetlands. Land-use changes from and to wetlands are not very common and occur mainly from forest land to wetlands (e.g. in case of rivers with flood water). Wetlands consist of surface waters (CC41) and unproductive wet areas such as shore vegetation and fens (CC42) (Table 6-3). Both types of wetland are categorized as unmanaged.

6.7.2 Methodological issues

6.7.2.1 Wetlands remaining Wetlands (4D1)

The activity data collection follows the methods described in chp. 6.3.1. Carbon stocks are taken from Switzerland (FOEN 2022). Details are described in the following paragraphs.

a) Carbon in living biomass

Surface Waters (CC41)

Surface waters have no carbon stocks by definition.

Unproductive Wetland (CC42)

CC42 consists of unmanaged or weakly managed grassland, bushes or tree groups. The pool of living biomass was estimated to 6.50 t C ha^{-1} (Mathys and Thürig 2010).

b) Carbon in soils

The soil carbon stock for surface waters (CC41) is zero.

Land cover in CC42 includes bogs and fens as well as reed. Currently, no specific soil data are available for CC42. As a first approximation, it was assumed that the soil carbon stock of unproductive wetlands is similar to permanent grassland (CC31). Therefore, the averages 1990–2020 of CC31 (see chp. 6.6.2.3) were calculated and weighted with the area per altitude zone of CC42: 62.80 t C ha^{-1} (0–30 cm) as proposed in FOEN 2022.

c) Changes in carbon stocks

Applying a Tier 1 approach, changes of carbon stocks in soils and in biomass are assumed to be zero if there is no land-use change.

d) N_2O emissions from drainage of soils

Drainage of intact wetlands is very unlikely. Therefore, no N_2O emissions are reported in CRF Table 4(II).

6.7.2.2 Land converted to Wetlands (4D2)

The activity data collection follows the methods described in chapter 6.3. In the case of land-use change, the net changes in biomass and soil of both surface waters (CC41) and unproductive wetland (CC42) are calculated by the stock-difference approach according to equations 6.1, 6.2 and 6.3 in chp. 6.1.3.2, with W_l=W_d=W_s=1 and CT=20 years.

The calculation of emissions for categories 4III and 4IV (N_2O from Nitrogen Mineralization in mineral soils) is described in chp. 6.10.

6.7.3 Uncertainties and time-series consistency

Category 4D1 does not have any sinks or emissions. For completeness, Table 6-5 shows the AD uncertainty of the AREA survey (10.5%) and a generic EF uncertainty of 50%.

For category 4D2, land converted to wetlands, the dominant processes determining the EF uncertainty are the carbon loss in (living) biomass and in mineral soils calculated by the stock-difference approach for conversions from forest land to wetlands. Therefore, the uncertainty of the carbon stock of forest was used (40.3%, see chp. 6.6.3) for living biomass, and the carbon stock changes in mineral soils are assumed to have a mean uncertainty of 50.0% (see Annex A2.2). The resulting relative EF uncertainty for 4D2 is 32.1% (see Table 6-5).

The AD uncertainty (40.9%) for 4D2 comes from the AREA survey as shown in Table 6-9.

For the current submission, a simplified uncertainty analysis has been carried out as described in chp. 1.6.2. Uncertainties were accounted individually only for the key categories, whereas the rest of the sources was aggregated by gas and treated as four “rest” categories (CO_2, CH_4, N_2O, F-gases) with mean uncertainties according to Table 1-7. Emissions and sinks of the category 4D2 are no key category and are therefore part of the "rest" categories with mean uncertainty.

Time series for Wetlands are all considered consistent; they are calculated based on consistent methods and homogenous databases.

6.7.4 Category-specific QA/QC and verification

The category-specific QA/QC activities have been carried out as mentioned in section 1.5 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2020 and for the changing rates 2020/2021).

The LULUCF expert, the NIC and the NID author report their QC activities in a checklist (see Annex 4). No additional category-specific QA/QC activities have been carried out.

6.7.5 Category-specific recalculations

There were no recalculations in 4D.

6.7.6 Category-specific planned improvements

No category-specific improvements are planned.

6.8 Settlements (4E)

6.8.1 Description

Key category information 4E
CO_2 emissions from 4E2 Land converted to Settlements are a key category by level. Category 4E1 Settlements remaining Settlements is not a key category.

12.0% of Liechtenstein's total surface are settlements. Between 1990 and 2021, 554 net hectares were converted to settlements, which is an increase of 40.6%. Settlements consist of buildings/constructions (CC51), herbaceous biomass in settlements (CC52), shrubs in settlements (CC53) and trees in settlements (CC54) as shown in Table 6-3.

6.8.2 Methodological issues

6.8.2.1 Settlements remaining Settlements (4E1)

The activity data collection follows the methods described in chapter 6.3.1. Carbon stocks are taken from Switzerland. As structure and density of Liechtenstein's settlements are very similar to the settlements in Switzerland (FOEN 2022), Liechtenstein adopted the Swiss data on vegetation in settlements for CC52, 53 and 54. Details are described in the following paragraphs.

a) Carbon in living biomass

Buildings and Constructions (CC51): Buildings/constructions contain no carbon by default.

Herbaceous Biomass, Shrubs and Trees in Settlements (CC 52, 53, 54): 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).

b) Carbon in soils

The carbon stock in soil for the combination category "Buildings and Construction" (CC51) was set to zero. However, a weighting factor of 0.5 (Leifeld et. al. 2003) was applied to soil carbon changes due to land-use changes involving CC51 (see Chapter 6.1.3). The reason for this is that in general the soil organic matter on construction sites is stored temporarily and later used for replanting the surroundings, or it is used to vegetate dumps, for example. The oxidative carbon loss due to the disturbance of the soil structure may reach 50%.

The carbon stocks in soil for CC 52, 53 and 54 are 50.38, 50.38 and 50.43 t C ha^{-1} (0-30 cm), respectively. These values correspond to soil carbon stocks in mineral soils under cropland and were calculated as the area-weighted (across the three altitude zones) mean for 1990–2020 of Swiss crops calculated with the model RothC (FOEN 2022, Wüst-Galley et al. 2019).

c) Changes in carbon stocks

Applying a Tier 1 approach, changes of carbon stocks in soils and in biomass are assumed to be zero if there is no land-use change.

6.8.2.2 Land converted to Settlements (4E2)

The activity data collection follows the methods described in chapter 6.3.1.

When a conversion of a land to settlements occurs, the stock-difference approach is applied for living biomass, dead biomass and soil carbon as described in chp. 6.1.3, equations 6.1, 6.2 and 6.3, with specific W-factors for CC51 and with CT=20 years. Carbon stocks are summarized in Table 6-4.

The calculation of emissions for categories 4III and 4IV (N_2O from Nitrogen Mineralization in mineral soils) is described in chp. 6.10.

6.8.3 Uncertainties and time-series consistency

The dominant processes determining the uncertainty of categories 4E1 and 4E2 are the carbon loss on mineral soils and in living biomass (see Annex A2.2).

Thus, the uncertainty of the area (AD) is determined by the uncertainty of the AREA survey (4E1 6.4%, 4E2 19.4% from Table 6-9).

In accordance with the Swiss National Inventory Report (FOEN 2022) the EF uncertainty for carbon stock changes in mineral soils are 50%.

For category 4E2, the dominant process determining the EF uncertainty in living biomass is the stock-difference in conversions from forest land to settlements. Therefore, the uncertainty of the carbon stock of forest was used (40.3%, see chp. 6.6.3) for living biomass. The same value is used for 4E1.

The resulting relative EF uncertainty for 4E1 and 4E2 are 34.8% and 33.7%, respectively (see Table 6-5 and Annex A2.2).

For the current submission, a simplified uncertainty analysis has been carried out as described in chp. 1.6.2. Uncertainties were accounted individually only for the key categories, whereas the rest of the sources was aggregated by gas and treated as four “rest” categories (CO_2, CH_4, N_2O, F-gases) with mean uncertainties according to Table 1-7. Since 4E1 is not a key category, its emissions are accounted in the “rest” category CO_2 with mean uncertainty.

The time series are consistent.

6.8.4 Category-specific QA/QC and verification

The category-specific QA/QC activities have been carried out as mentioned in section 1.5 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2020 and for the changing rates 2020/2021).

The LULUCF expert, the NIC and the NID author report their QC activities in a checklist (see Annex 4). No additional category-specific QA/QC activities have been carried out.

6.8.5 Category-specific recalculations

There were no recalculations in 4E.

6.8.6 Category-specific planned improvements

No category-specific improvements are planned.

6.9 Other Land (4F)

6.9.1 Description

Key category information 4F2
Category 4F2 Land converted to Other Land CO_2 is not a key category.

6.2% of Liechtenstein’s total surface are summarized in “Other Land”. Between 1990 and 2021 the area of “Other Land” has declined by 2.7%. As shown in Table 6-3 other land (CC61) covers non-vegetated areas such as glaciers, rocks and shores. For category 4F1 “Other Land remaining Other Land” only areas are reported (no emissions or sinks).

6.9.2 Methodological issues

By definition, other land has no carbon stocks. In the case of land-use change (4F2), the net changes in biomass and soil are calculated by the stock-difference approach according to equations 6.1, 6.2 and 6.3 in chp. 6.1.3.2, with W_l=W_d=W_s=1 and CT=20 years.

6.9.3 Uncertainties and time-series consistency

For category 4F2, land converted to other land, the dominant processes determining the EF uncertainty are the carbon loss in (living) biomass and in mineral soils calculated by the stock-difference approach for conversions from forest land or grassland to other land. As a best guess, the uncertainty of the carbon stock of forest was used (40.3%, see chp. 6.6.3) for living biomass, and the carbon stock changes in mineral soils are assumed to have a mean uncertainty of 50.0%. The resulting relative EF uncertainty for 4F2 is 34.0% (see Annex A2.2).

The AD uncertainty (40.9%) for 4F2 comes from the AREA survey as shown in Table 6-9.

The time series are consistent.

6.9.4 Category-specific QA/QC and verification

The category-specific QA/QC activities have been carried out as mentioned in sections 1.5 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2020 and for the changing rates 2020/2021).

The LULUCF expert, the NIC and the NID author report their QC activities in a checklist (see Annex 4). No additional category-specific QA/QC activities have been carried out.

6.9.5 Category-specific recalculations

There were no category-specific recalculations.

6.9.6 Category-specific planned improvements

No category-specific improvements are planned.

6.10 N_2O from nitrogen mineralization (Categories 4(III), 4(IV))

6.10.1 Description

This chapter presents the methods for calculating direct and indirect N_2O emissions from nitrogen (N) mineralization in mineral soils. The source of nitrogen is N mineralization associated with loss of soil organic matter resulting from land-use change. These N_2O emissions are not key categories.

- In category 4(III), direct N_2O emissions on land converted to forest land, cropland, grassland, wetlands, settlements or other land are reported.
- In category 4(IV2), indirect emissions of N_2O due to nitrogen leaching and run-off are reported.

The following N_2O emissions were included in the agriculture sector and not in the LULUCF sector:

- N_2O emissions associated with inputs from N fertilisers (CRF table 4(I)).
- N_2O emissions on cropland remaining cropland and on grassland remaining grassland (CRF table 4(III)). In Liechtenstein, managed grassland also belongs to the agricultural area.
- Indirect N_2O emissions due to atmospheric deposition (CRF table 4(IV1)).

6.10.2 Methodological issues

Direct N_2O emissions (4(III)) as a result of the disturbance of mineral soils associated with land-use change are calculated according to IPCC (2006, Chapter 4_11):

Emission(N_2O) = – deltaCs * 1 / (C:N) * EF1 * 44 / 28, if deltaCs < 0 [kt N_2O]

where:

deltaCs: soil carbon change induced by land-use change [kt C]

C:N: C to N ratio of the soil before the land-use change

EF1: default emission factor = 0.01 kg N_2O-N (kg N)$^{-1}$, IPCC 2006 (Table 4_11.1)

deltaCs is calculated according to the methodology described in chp. 6.1.3.2. If deltaCs is zero or positive (carbon gain) there are no N_2O emissions provoked by a land-use change.

The value of the C:N ratio is related to the land-use category before the change. For cropland and grassland, the ratio is 9.8 according to Leifeld et al. (2007). This value was also used for the mineral soils in wetlands (CC42) and unsealed settlement areas (CC 52, 53, 54). For forest land, the default value of C:N = 15 was used (IPCC 2006, Equation 4_11.8).

The indirect N_2O emissions (4(IV)) as a result of N leaching and run-off are calculated as follows using default emission factors (IPCC 2006, Table 4_11.3):

Emission(N_2O) = – deltaCs * Frac / (C:N) * EF5 * 44 / 28, if deltaCs < 0 [kt N_2O]

where:

Frac: fraction of mineralized N lost by leaching or run-off, Frac=30%

EF5: default emission factor = 0.0075 kg N_2O-N (kg N)$^{-1}$, IPCC 2006 (Table 4_11.3)

If deltaCs is zero or positive (carbon gain) there are no N_2O emissions provoked by a land-use change. As the approach applied is not tier 3, no N_2O immobilization is reported.

For calculating deltaCs, all land-use changes and conversions between land-use subcategories were taken into account. Cropland remaining cropland is reported in the agriculture sector as prescribed in CRF table 4(III) in footnote 1. For Liechtenstein, also the N_2O emissions for grassland remaining grassland are reported in the agriculture sector as grassland is part of the agricultural land.

6.10.3 Uncertainties and time-series consistency

The uncertainty of the activity data for category 4(III) corresponds to the uncertainty of the amount of mineralized N. It was calculated as the combined uncertainty of:

- Uncertainty of the carbon stock losses in mineral soils: Land converted to settlements (4E2) is the main source in category 4(III). Therefore, the uncertainty of the area converted to settlements (19.4%; Table 6-9) and the uncertainty of the CO_2 emission factor (50.0%) were combined to estimate the uncertainty of the carbon stock loss: 53.6%.
- Uncertainty of the C:N ratio: The uncertainty of the C:N ratio for Forest land is used here. With a value of 15 and a 95%-range between 10 and 30 (IPCC 2006, Volume 4, equation 11.8) the mean uncertainty results in 66.7%.

The resulting uncertainty for AD of category 4(III) is 85.6%, calculated as $(53.6^2 + 66.7^2)^{0.5}$.

The uncertainty of the activity data for category 4(IV)2 is 87.9%. It is the combined uncertainty of the amount of leached N, which is calculated from the amount of mineralized N (uncertainty 85.6%, see category 4(III)) and $Frac_{LEACH}$ (uncertainty 20%, adopted from ART 2008).

A relative uncertainty for the emission factors of 4(III) and 4(IV2) was estimated as the mean of the upper and the lower limit of the uncertainty ranges listed in IPCC (2006), Vol 4, Tables 11.1 and 11.3.:

Uncertainty (EF1): 135%
Uncertainty (EF5): 162%

According to IPCC (2006, Vol 3, p. 3.32) the final value for EF uncertainty was set to 100% (see Table 6-5) as the EF is a non-negative quantity.

For the current submission, a simplified uncertainty analysis has been carried out as described in chp. 1.6.2. Uncertainties were accounted individually only for the key categories, whereas the rest of the sources was aggregated by gas and treated as four “rest” categories (CO_2, CH_4, N_2O, F-gases) with mean uncertainties according to Table 1-7. Since 4(III) and 4(IV) are no key categories their uncertainties are accounted in the “rest” categories with mean uncertainty of N_2O.

Consistency: Time series for Nitrogen Mineralization are all considered consistent; they are calculated based on consistent methods and homogenous databases.

6.10.4 Category-specific QA/QC and verification

The general QA/QC measures are described in Chapter 1.5.

No category-specific QA/QC activities have been carried out.

6.10.5 Category-specific recalculations

There were no category-specific recalculations.

6.10.6 Category-specific planned improvements

No category-specific improvements are planned.

6.11 Harvested Wood Products (HWP) (4G)

6.11.1 Description

Key category information 4G
Category 4G Harvested Wood Products (HWP) CO_2 is a key category by trend.

The data presented in this chapter are estimates of net emissions and removals from HWP due to changes in the HWP carbon pool. The applied approach to HWP accounting is a production approach (see chp. 6.3.3). The estimate uses the product categories, half-lives, and methodologies as described in IPCC (2006) and IPCC (2014).

6.11.2 Methodological issues

For the estimation of carbon stocks and carbon stock change, the equations described in IPCC (2014) and IPCC Guidelines 2006 were used.

In Liechtenstein, the enterprise register does not show any enterprises producing paper/paperboard (NOGA code 171200, see https://www.kubb-tool.bfs.admin.ch/en) or wood-based panels (NOGA code 162100). Thus, there is no domestic production of paper or wood panels. For the product category 'sawnwood' a Tier 2 approach (first order decay) was applied according to equation 2.8.5 in IPCC (2014) as follows:

- The starting year used to estimate the delayed emissions from the existing pool is 1900.
- The feedstock from domestic harvest is calculated on the basis of the feedstock for Switzerland (FOEN 2022) and of data resulting from a brief survey in Liechtenstein and data related to the development of the population (see below).

- The change in carbon stocks was estimated only for HWPs originating from Forest land, as there is practically no harvest in afforestations in Liechtenstein.
- Instantaneous oxidation was assumed to wood originating from deforestations. This wood is regarded unsuitable for sawnwood production as it originates mostly from natural hazards (such as avalanches and floodings) and from management of forest edges at higher altitudes.

Liechtenstein's sawnwood production between 1900 and 1960 was calculated with the default Tier 1 method provided in Equation 12.6 of the 2006 IPCC Guidelines using the annual rate of increase for Europe (0.0151) from Table 12.3. Equation 12.6 requires the sawnwood production in 1961 (V_{1961}) as an input. For Liechtenstein, there are no country-specific statistical data available for calculating the feedstock from domestic harvest. Therefore, feedstock data from Switzerland related to sawnwood for the year 1961 ($V_{swiss,1961}$) was adopted for Liechtenstein. Those Swiss data (FOEN 2022) were calculated with equation 2.8.1 and 2.8.4 in IPCC (2014) on the basis of national statistics, FAO-data. The conversion factors correspond to the default values given by IPCC (2014; table 2.8.1): density 0.5 t/m^3, carbon fraction 0.5. Emission factors were calculated with the default half-live of 35 years for sawn wood.

The Swiss feedstock data were adapted to Liechtenstein using the population ratio as follows:

$$V_{1961} = V_{swiss,1961} * Population_{1961} / Population_{swiss,1961} = 3'671\ m^3$$

where:

$V_{swiss,1961}$ = 1'181'000 m^3 (FOEN 2022)

$Population_{1961}$ = 16'894 in Liechtenstein (https://databank.worldbank.org/source/population-estimates-and-projections)

$Population_{swiss,1961}$ = 5'434'294 in Switzerland.

Liechtenstein's sawnwood production between 1962 and 1990 was calculated based on the assumption that the development is proportional to the development of the population in Liechtenstein (increase from 17'298 inhabitants in 1962 to 28'745 inhabitants in 1990). This results in a sawnwood production of 6'247 m^3 in 1990 (see Figure 6-7).

In 2017, a brief survey was made in Liechtenstein in order to estimate the sawnwood production after 1990 (Rihm 2017). The main results were:

- Since 2017, two enterprises produce totally 3'500 m^3 of sawnwood per year.
- Their products are mainly produced for own demand on construction sites. It can be assumed that there is no export of HWP.
- Around the year 2000 a relevant sawmill was shut down. It is estimated that the total production before 2000 was approximately twice as much as today's production. This is in line with the calculated amount for 1990 (6'247 m^3).

With this information the time-series of sawnwood production in Liechtenstein was constructed as follows: 1990–2000 decline from 6'247 m^3 to 4'500 m^3, 2001–2010 decline from 4'500 m^3 to today's value (3'500 m^3), since 2011 a constant value of 3'500 m^3.

Production, gains and losses from sawnwood are listed in Table 6-16 and Figure 6-7 shows the resulting sawnwood production, net emissions and removals.

Table 6-16 Emissions (positive sign) and removals (negative sign) from HWP (sawnwood) between 2000 and 2021, in kt CO_2. Wood panels and paper/paperboard are not produced in Liechtenstein.

Harvested wood products	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Sawnwood production, m^3	4'500	4'400	4'300	4'200	4'100	4'000	3'900	3'800	3'700	3'600
Gains sawnwood, kt C	1.13	1.10	1.08	1.05	1.03	1.00	0.98	0.95	0.93	0.90
Losses sawnwood, kt C	-0.92	-0.92	-0.93	-0.93	-0.93	-0.93	-0.93	-0.93	-0.93	-0.93
Net emissions/removals, kt CO_2	**-0.75**	**-0.65**	**-0.54**	**-0.44**	**-0.34**	**-0.25**	**-0.15**	**-0.06**	**0.04**	**0.13**

Harvested wood products	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Sawnwood production, m^3	3'500	3'500	3'500	3'500	3'500	3'500	3'500	3'500	3'500	3'500
Gains sawnwood, kt C	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Losses sawnwood, kt C	-0.93	-0.93	-0.93	-0.93	-0.93	-0.93	-0.93	-0.93	-0.92	-0.92
Net emissions/removals, kt CO_2	**0.21**	**0.21**	**0.21**	**0.20**	**0.20**	**0.19**	**0.19**	**0.19**	**0.18**	**0.18**

Harvested wood products	**2020**	**2021**								
Sawnwood production, m^3	3'500	3'500								
Gains sawnwood, kt C	0.88	0.88								
Losses sawnwood, kt C	-0.92	-0.92								
Net emissions/removals, kt CO_2	**0.18**	**0.17**								

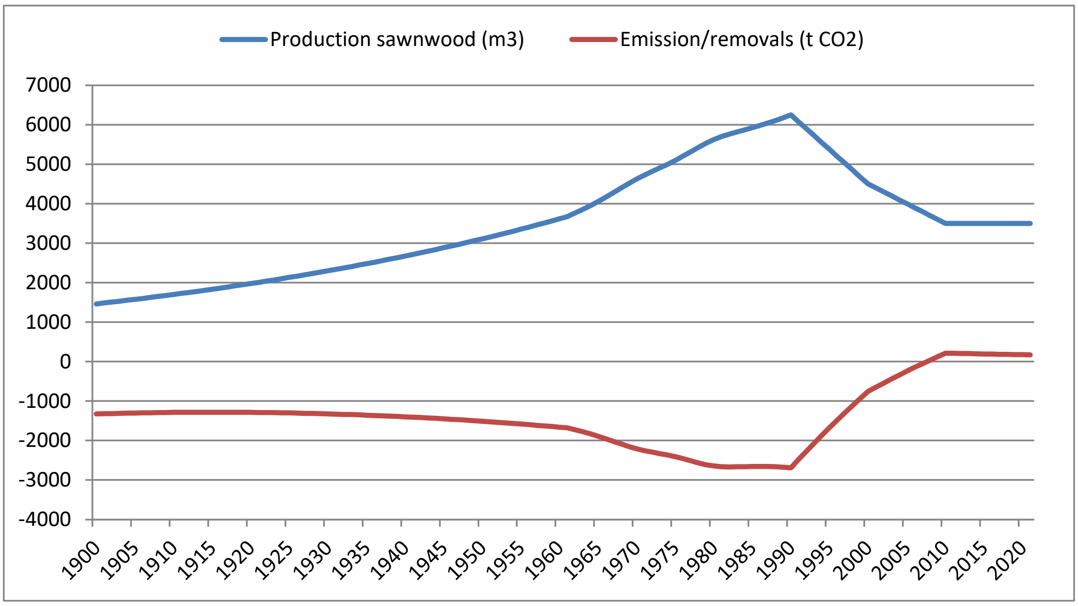


Figure 6-7 Liechtenstein's sawnwood production (m^3) and net emissions (positive sign) and removals (negative sign) of CO_2 (tons) from Harvested Wood Products between 1900 and 2021.

Import and export of sawnwood from 1990 to 2021 are reported in CRF Table4.Gs2. They were estimated on the basis of Swiss import and export data published in the Swiss NID (FOEN 2023) as Liechtenstein lacks own customs statistics (Customs Union with

Switzerland, see chp. 1.1.1). Imports were calculated as a fraction of 0.0045 (ratio of Liechtenstein's and Switzerland's population in 2016) of Swiss sawnwood imports.

Exports of sawnwood were calculated as fraction of 0.0045 of Swiss exports until the year 2000. Between 2001 and 2009 a linear decline of the exports was assumed, concurrently with the drop of domestic sawnwood production. After 2009, the exports of sawnwood are zero according to the survey by Rihm (2017). Import and Export in 2021 are provisional: The same values as in 2020 were used because the FAO-database (https://www.fao.org/faostat/en/#data/FO) had not been updated on time.

6.11.3 Uncertainties and time-series consistency

For category 4G HWP, the following information on relative uncertainty was used.

- Activity data:
  - Sawnwood production: 50%
    (Switzerland has 3% for activity data since 1990, but the adaptation to Liechtenstein using the number of inhabitants induces additional uncertainty which is estimated by expert judgement.)
- Emission factor, including conversion factors:
  - Wood density: 20% (Swiss expert judgement, see FOEN 2022);
  - Carbon contents in wood products: 10% (Lamlom and Savidge 2003);
  - Emission factors (half-life estimates): 50% (default from IPCC 2006).

The total relative uncertainty of the EF for carbon losses and gains in HWP can be calculated as:

$$U_{HWP}EmissionFactor = \sqrt{20\%^2 + 10\%^2 + 50\%^2} = 54.8\%$$

Consistency: Time series for HWP are considered consistent.

6.11.4 Category-specific QA/QC and verification

The category-specific QA/QC activities have been carried out as mentioned in section 1.5 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2020 and for the changing rates 2020/2021).

No category-specific QA/QC activities have been carried out.

6.11.5 Category-specific recalculations

There were no recalculations of CO_2 sinks or emissions.

6.11.6 Category-specific planned improvements

No category-specific improvements are planned.

7. Waste (CRT sector 5)

7.1 Overview of sector

Within the waste sector, emissions from four categories are considered:

- 5A Solid waste disposal
- 5B Biological treatment of solid waste
- 5C Incineration and open burning of waste
- 5D Wastewater treatment and discharge

Category 5E Other is not occurring in Liechtenstein.

Figure 7-1 depicts Liechtenstein's greenhouse gas emissions in sector 5 Waste between 1990 and 2021 according to the four categories 5A - 5D. Additionally, Table 7-1 lists the GHG emissions of this sector by gas in CO_2 equivalent (kt) for the years 1990 - 2021.

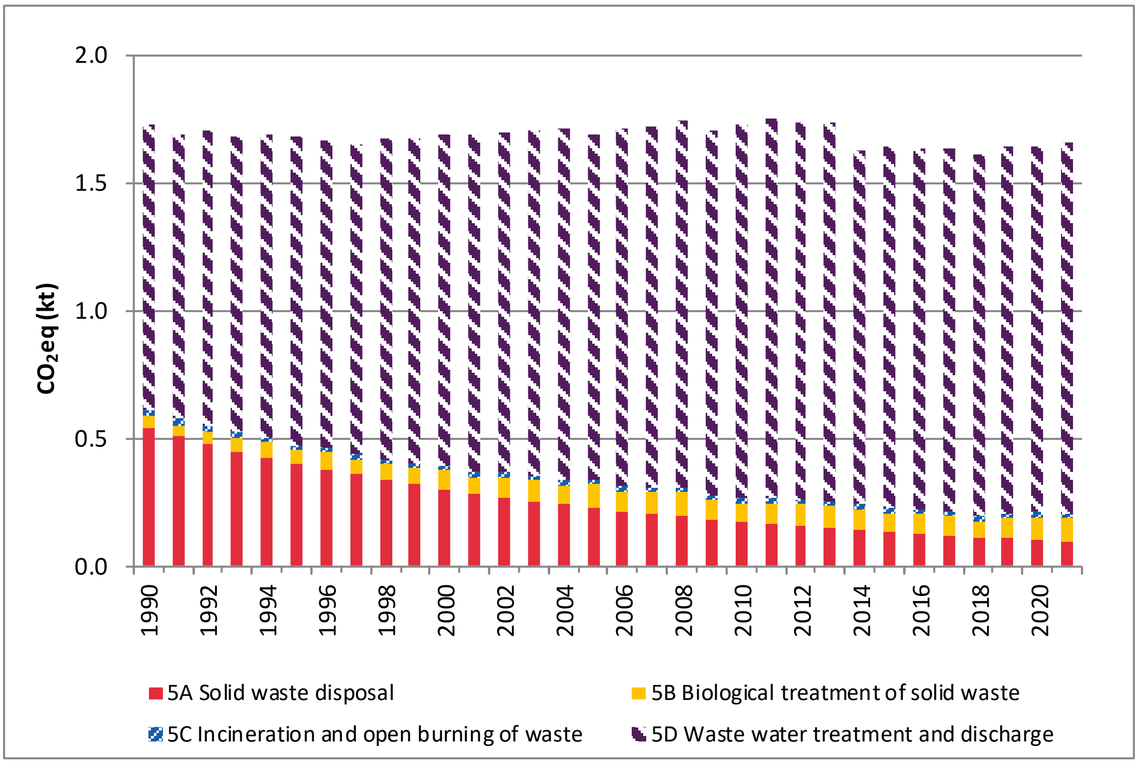


Figure 7-1 Liechtenstein's GHG emissions of sector 5 Waste. Note that there are no emissions in category 5E Other.

Table 7-1 GHG emissions of sector 5 Waste by gas in CO_2 equivalent (kt), and the relative change (last column bottom right).

Gas	1990	1995	2000	2005	2010
	CO2 equivalent (kt)				
CO_2	0.01	0.01	0.01	0.01	0.01
CH_4	1.24	1.17	1.17	1.17	1.13
N_2O	0.48	0.50	0.51	0.51	0.58
Sum	**1.73**	**1.68**	**1.69**	**1.69**	**1.73**

Gas	2012	2013	2014	2015	2016
	CO2 equivalent (kt)				
CO_2	0.01	0.01	0.01	0.01	0.01
CH_4	1.14	1.14	1.04	1.03	1.04
N_2O	0.59	0.59	0.57	0.60	0.58
Sum	**1.74**	**1.74**	**1.63**	**1.65**	**1.63**

Gas	2017	2018	2019	2020	2021	1990-2021
	CO2 equivalent (kt)					%
CO_2	0.01	0.01	0.01	0.01	0.01	-28%
CH_4	1.04	1.03	1.04	1.05	1.06	-15%
N_2O	0.58	0.57	0.59	0.58	0.59	24%
Sum	**1.63**	**1.61**	**1.64**	**1.64**	**1.66**	**-4%**

In sector 5 Waste a total of 1.66 kt CO_2 equivalents of greenhouse gases were emitted in 2021. 5.9% of the total emissions origin from 5A Solid waste disposal, 5.2% from 5B Biological treatment of solid waste, 1.1% from 5C Incineration and open burning of waste and 87.8% from source category 5D Wastewater treatment and discharge. Emissions from 5E Other are not occurring in Liechtenstein.

The total greenhouse gas emissions show a slight decrease from 1990 to 2021 by -3.9%. The development of the greenhouse gas emissions is determined by category 5D Wastewater treatment and discharge and to a lesser and decreasing extend by category 5A Solid waste disposal. In category 5D Wastewater treatment and discharge since 2014 sewage gas is not used any more as fuel for boilers or co-generation, all sewage gas is up-graded and supplied to the gas grid. In category 5A Solid waste disposal a steady decrease of greenhouse gas emissions can be observed, due to cease landfilling in 1974.

General methodological remark for sector 5 Waste: As living standards, infrastructure as well as regulatory frameworks, technical standards and legal principles in the waste sector of Liechtenstein correspond to Swiss standards, Switzerland’s country-specific methodology and/or emission factors are usually adopted. Wherever available country-specific data have been used, e.g. activity data for unmanaged waste disposal sites or for the estimation of CH_4 from wastewater treatment.

Waste management in Switzerland and Liechtenstein is governed by the same legal regulations and principles, e.g. waste avoidance, waste recycling and sound treatment of the remaining waste are guiding principles. As an example, both countries introduced the polluter-pays-principle at the beginning of the 1990ies. The very same effect in both countries could be observed, that the amount of MSW incinerated dropped significantly due to a better segregation with a slight increase of incinerated quantities afterwards.

As examples for the same regulatory framework in Liechtenstein (left) and Switzerland (right) may serve environmental law and clean air law (see Table 7-2).

Table 7-2 Environmental Law (Government 2008a) and Clean Air Law (Government 2008b) in Liechtenstein and Switzerland.

Liechtenstein	Switzerland
814.01 2008.199 Umweltschutzgesetz (USG) vom 29. Mai 2008 (Fassung vom 1. Februar 2022)	814.01 Bundesgesetz über den Umweltschutz (Umweltschutzgesetz, USG) vom 7. Oktober 1983 (Stand am 1. Januar 2022)
814.301.1 2008.245 Luftreinhalteverordnung (LRV) vom 30. September 2008 (Fassung vom 13. Januar 2023)	814.318.142.1 Luftreinhalte-Verordnung (LRV) vom 16. Dezember 1985 (Stand am 1. Januar 2023)

Furthermore, in 1960 Vaduz was one of the three communities which established ‘Verein für Abfallentsorgung’, a cooperation to jointly organize and finance the sound solid waste management in Switzerland and Liechtenstein in this region. Since 1974 every community in Liechtenstein is member and participating in this joint effort between Switzerland and Liechtenstein.

7.2 Solid waste disposal (5A)

7.2.1 Category Description: Solid waste disposal (5A)

Key category information 5A

Category 5A Solid waste disposal is not a key category.

Category 5A Solid waste disposal comprises all emissions from handling of solid waste on landfill sites.

5A1 Managed waste disposal sites

There are no managed waste disposal sites in Liechtenstein. There are three landfills which are managed (e.g. sealing, control of water quality), but they operate exclusively for inert materials and do therefore not cause any greenhouse gas emissions. Thus, emissions from category 5A1 Managed waste disposal sites are not occurring.

5A2 Unmanaged waste disposal sites

100% of the collected municipal solid waste (and the combustible industrial waste) is being exported to Switzerland for incineration to a Swiss municipal solid waste incinerator nearby (MSWIP Buchs). Incineration plants in Switzerland co-generate heat and electricity in a highly efficient manner. Heat is generally fed in a district heating system, which allows replacing large amounts of fossils fuels such as oil and gas. The heat imported by Liechtenstein from the MSWIP Buchs is reported in section Energy.

The transition from “landfilling in the country” to “exporting MSW and industrial waste” to Switzerland for incineration started during the 1960ies and was concluded in 1974, when the last municipality in the country stopped landfilling. Before 1974, some waste (municipal and others) were landfilled along the river Rhine in sandy soils which were not suitable for agriculture. In the year 1998, those sites were recorded in a 'contaminated site register'. About 20 of all registered contaminated sites are from waste dumping. They are not managed (they are not really “landfills” but rather “contaminated sites”). No landfill gas was collected for flaring or energy recovery. The emissions from these 20 sites are reported under 5A2 Unmanaged waste disposal sites.

The landfills in Liechtenstein were unmanaged (in the definition of IPCC GPG), because municipal solid waste was disposed off on the landfills by users directly (only on 3 landfill sites a temporary control by landfill staff was executed). No mechanical compacting or levelling of waste has been carried out. No collection or treatment of leachate took place which caused environmental pollution. Landfills are all less than 5 m deep (OEP 2007g).

5A3 Uncategorized waste disposal sites

Category 5A3 “Uncategorized waste disposal sites” does not occur in Liechtenstein.

Table 7-3 Specification of category 5A Solid waste disposal.

5A	Source	Specification
5A1	Managed Waste Disposal on Land	Not occurring in Liechtenstein
5A2	Unmanaged Waste Disposal Sites	Emissions from handling of solid waste on unmanaged landfill sites
5A3	Uncategorized waste disposal sites	Not occurring in Liechtenstein

7.2.2 Methodological issues: Solid waste disposal (5A)

Emissions from solid waste disposal are exclusively occurring from category 5A2 Unmanaged waste disposal sites (Table 7-3).

7.2.2.1 Solid waste disposal on unmanaged waste disposal sites (5A2)

Methodology

The CH_4 emissions from solid waste disposal are estimated according to the 2006 IPCC Guideline.

Emissions are calculated by a Tier 2 method based on the decision tree in Fig. 3.1 of chapter 3. Solid waste disposal in 2006 IPCC Guideline. The spreadsheet for the First Order Decay (FOD) model provided by IPCC 2006 has been applied and parametrised for Liechtenstein's conditions.

The following equation is applied to calculate the CH_4 generation in the year t:

CH_4 generated in the year t [kt/year] = ∑x [A • k • M(x) • L0(x) • e-k(t-x)] • (1-OX)

where

t =	current year
x =	the year of waste input, x ≤ t
A =	(1-k)/k, norm factor (fraction)
k =	methane generation rate [1/yr]
M(x) =	the amount of waste disposed in year x
L0(x) =	methane generation potential (MCF(x) • DOC(x) • DOCF • F • 16/12) [kt CH_4 / kt waste]
MCF(x) =	methane correction factor (fraction)
DOC(x) =	degradable organic carbon [kt C/ kt waste]
DOC_F =	fraction of DOC, that is converted to landfill gas (fraction)
F =	fraction of CH_4 in landfill gas (fraction)
16/12 =	factor to convert C to CH_4.
OX =	oxidation factor (fraction)

The general parameters are set as follows (all 2006 IPCC default values):

- k (methane generation rate) = 0.09/year
- DOC_F (fraction of DOC dissimilated) = 0.5
- Delay time (months) = 6
- Fraction of methane (F) in developed landfill gas = 0.5
- Conversion factor, C to CH_4 = 1.33
- Oxidation factor (OX) = 0

The values for the parameter degradable organic carbon (DOC) are provided for each waste fraction. For all waste types, the 2006 IPCC default values are used, except for industrial waste. For industrial waste, the default value for wood and straw is applied, as most of the industrial waste deposited in Liechtenstein is assumed to be wood waste.

The methane generation rate [1/yr] is chosen according to wet temperate conditions. For all waste types, the 2006 IPCC default values are used, except for industrial waste. For industrial waste, the default value for wood and straw is applied, again based on the fact that most of it is assumed to be wood waste.

Composition of landfilled municipal solid waste is estimated to be similar as the one in Switzerland. Therefore, the same values have been applied (see Table 7-4).

Table 7-4 Composition of MSW going to solid waste disposal sites (BUS 1978).

Fraction	Share
Food	24%
Garden	4%
Paper	36%
Wood	4%
Textile	4%
Nappies	0%
Plastics, other inert	28%

Emission Factors

The emissions are directly calculated in the FOD-model as described above. No country-specific emission factor was used.

Activity data

Activity data for unmanaged MSW Disposal on Land (5A2) have been estimated by OEP (OEP 2007c). The estimates are based on internal (unpublished) research done at OEP from 1985 - 1990 that analysed the development of waste quantities in the last century for the elaboration of a national waste strategy.

Based on this work, the MSW quantities are assumed to have been landfilled from 1930 until the closure of the last landfill in 1974 (see Table 7-5).

Table 7-5 Amount of municipal solid waste (MSW) landfilled in Liechtenstein (OEP 2007c).

Year	MSW/cap [kg/a]	Inhabitants (average)	MSW [t/a]
1930-1939	150	10500	1575
1940-1949	100	12300	1230
1950-1959	200	15200	3040
1960-1969	300	18500	5550
1970-1975	MSW declines linearly to zero		

Because the transition from landfilling in the country to exporting MSW to Switzerland for incineration took place gradually, it is assumed that the amount of MSW landfilled declines linearly after 1970 to zero tons in 1975.

7.2.3 Uncertainties and Time-Series Consistency: Solid Waste Disposal (5A)

For the current submission a simplified uncertainty analysis has been carried out as described in chapter 1.6. Uncertainties were accounted individually only for the key categories, whereas the rest of the sources was aggregated by gas and treated as four "rest" categories (CO_2, CH_4, N_2O, F-gases) with mean uncertainties according to Table 1-7. Since 5A is not a key category, its emissions are part of the "rest" categories with mean uncertainty of CH_4. The combined uncertainty for CH_4 is estimated 30% (see Table 1-7).

The time series are consistent.

7.2.4 Category-specific QA/QC and Verification: Solid Waste Disposal (5A)

The category-specific QA/QC activities have been carried out as mentioned in sections 1.5 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2020 and for the changing rates 2020/2021).

7.2.5 Category-specific recalculations: Solid Waste Disposal (5A)

No category-specific recalculations have been carried out.

7.2.6 Category-specific planned improvements: Solid Waste Disposal (5A)

Switzerland has recalculated its waste composition landfilled (FOEN 2020). The shares of kitchen waste and garden waste within the deposited amounts of organic waste on solid waste disposal sites from 1950–1979 have been recalculated according to BUS 1978.

Lichtenstein is planning to align its activity data at the time when the FOD model is going to be updated.

7.3 Biological treatment of solid waste (5B)

7.3.1 Category description: Biological treatment of solid waste (5B)

Key category information 5B
Category 5B Biological treatment of solid waste is not a key category.

Category 5B Biological treatment of solid waste comprises the GHG emissions from composting of organic waste. Composting covers the GHG emissions from larger, centralized composting plants as well as from backyard composting. Yard waste is mainly composed of residues from tree pruning and hedge trimming as well as of garden waste. Backyard composting is carried out on-site. The composition of composted waste is considered to be similar to the one in Switzerland.

Separately door-to-door collected organic waste from households (generally food waste) is taken to a composting plant in Switzerland.

Emissions from the application of compost to agricultural land are reported under sector Agriculture.

Table 7-6 Specification of category 5B Biological treatment of solid waste.

5B	Source	Specification
	Composting	Emissions from composting of organic waste - centralized composting plants - backyard composting

7.3.2 Methodological issues: Biological Treatment of Solid Waste (5B)

Methodology

Emissions are calculated by a Tier 2 method based on chapter 4.1.1 Biological treatment of solid waste in IPCC 2006.

Activity data and emission factors for centralized and backyard composting in Switzerland have been thoroughly reassessed in 2017 (Schleiss 2017). New data were gained and EMIS 2022/5B1 Kompostierung, which serves as basis for greenhouse gas emission estimates, has been revised accordingly. Liechtenstein’s greenhouse gas emission estimates are based on these latest results from Switzerland.

CH_4 and N_2O emissions from centralized composting plants are calculated by multiplying the quantity of composted waste fractions by the emission factors.

CH_4 and N_2O emissions from backyard composting are calculated by multiplying the quantity of composted waste per inhabitant by the population and the emission factors.

N_2O emissions from the product of composting that arise after their application in agriculture are reported under source category 3Da2c.

Emission Factors

Emission factors for composting have been adopted from the Swiss NIR (FOEN 2022): 1.0 kg CH_4/t of composted waste and 0.05 kg N_2O/t of composted waste. They are based on measurements and expert estimates, documented in the Swiss EMIS database (EMIS 2022/5B1 Kompostierung).

For all years the same constant country-specific emission factors have been applied.

Activity data

The Office of Environment provides data on the amount of waste treated in centralized composting plants (OE 2022c).

Activity data for backyard composting were reassessed in Switzerland in 2017 (Schleiss 2017). Amounts of organic waste composted in backyards are based on expert assessments as well as on data from a small number of cities and villages. The experts took into account different parameters affecting the waste amounts composted in backyards over the time, i.e. urban, rural situation, communication and incentive programs, and services for separate door-to-door collection of organic wastes. Liechtenstein takes these latest data and specific information into account.

A gradually increase of organic waste treated in centralized composting plants can be observed, starting from 1993. This is most probable directly linked to the introduction of the polluter-pays-principle for mixed municipal solid waste management. However, a peak has been reached in 2008 and a slight decreasing development can be noticed since.

Table 7-7 Activity data of 5B Biological treatment of solid waste composted centrally (kilotons as dry matter).

Waste composting		1990	1995	2000	2005	2010
Composted centrally	kt dm/a	1.07	1.12	1.56	1.98	1.55

Waste composting		2012	2013	2014	2015	2016
Composted centrally	kt dm/a	1.93	1.94	1.81	1.60	1.67

Waste composting		2017	2018	2019	2020	2021
Composted centrally	kt dm/a	1.67	1.35	1.76	1.96	1.97

In 2008, there was a significant increase of composted waste quantities. The peak can be related to the clearing of a forest area in the community of Eschen for environmental restoration. Already in 2009, the total amount of composted material falls back to similar levels as previous years. The peak is also the reason for the sudden decrease in CH_4 and N_2O emission in 2009 compared to 2008.

Table 7-8 Activity data of 5B Biological treatment of solid waste backyard composting (kilotons as dry matter).

Waste composting		1990	1995	2000	2005	2010
organic waste	kg wet/inhabitant	16.2	21.9	25.0	22.7	15.2
Population	inhabitants	29'032	30'923	32'863	34'905	36'149
Composted backyard	kt dm/a	0.14	0.20	0.25	0.24	0.17

Waste composting		2012	2013	2014	2015	2016
Backyard composting	kg wet/inhabitant	12.5	12.4	12.2	12.1	11.9
Population	inhabitants	36'838	37'129	37'366	37'623	37'810
Composted backyard	kt dm/a	0.14	0.14	0.14	0.14	0.14

Waste composting		2017	2018	2019	2020	2021
Backyard composting	kg wet/inhabitant	11.9	11.9	11.9	11.9	11.9
Population	inhabitants	38'114	38'380	38'749	39'055	39'315
Composted backyard	kt dm/a	0.14	0.14	0.14	0.14	0.14

7.3.3 Uncertainties and Time-Series Consistency: Biological treatment of solid waste (5B)

For the current submission a simplified uncertainty analysis has been carried out as described in chapter 1.6. Uncertainties were accounted for individually only for the key categories, whereas the rest of the sources was aggregated by gas and treated as four “rest” categories (CO_2, CH_4, N_2O, F-gases) with mean uncertainties according to Table 1-7. 5B is not a key category and therefore its uncertainties are part of the “rest” categories with mean uncertainty for CH_4 and N_2O. The combined uncertainty for CH_4 is estimated 30% and for N_2O 80% (see Table 1-7).

The time series are consistent.

7.3.4 Category-specific QA/QC and Verification: Biological treatment of solid waste (5B)

The category-specific QA/QC activities have been carried out as mentioned in sections 1.5 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2020 and for the changing rates 2020/2021).

7.3.5 Category-specific recalculations: Biological treatment of solid waste (5B)

No category-specific recalculations have been carried out.

7.3.6 Category-specific Planned Improvements: Biological treatment of solid waste (5B)

No category-specific improvements are planned.

7.4 Incineration and open burning of waste (5C)

7.4.1 Category Description: Incineration and open burning of waste (5C)

Key category information 5C
Category 5C Incineration and open burning of waste is not a key source.

There are no waste incineration plants operating in Liechtenstein. Since the beginning of 1975 all municipal solid waste from Liechtenstein is exported to Switzerland for incineration. However, there are emissions from some illegal waste burning of household wastes and of wastes on construction sites. They are reported under 5C2 Open burning of waste.

Table 7-9 Specification of category 5C Incineration and open burning of waste.

5C	Source	Specification
5C2	Open burning of waste	Emissions from illegal incineration of municipal solid wastes at home. Emissions from waste incineration at construction sites (open burning)

7.4.2 Methodological issues: Incineration and open burning of waste (5C)

Methodology

For the calculation of the greenhouse gas emissions from illegal incineration of waste, a country-specific Tier 2 method is used, based on CORINAIR, adapted from the Swiss NIR (FOEN 2022).

GHG emissions are calculated by multiplying the estimated amount of illegally incinerated waste by emission factors.

Emission Factors

Country-specific emission factors for CO_2, N_2O and CH_4 are adopted from the Swiss NIR (FOEN 2022, EMIS 2022/5C1 Abfallverbrennung illegal). The CO_2 emission factor in municipal solid waste fluctuates over the reporting period because of gradual changes in the net calorific values of the waste.

The following tables present the emission factors used in source category 5C2. Emission factors are referring to kg wet matter.

Table 7-10 Emission Factors CH_4 and N_2O for 5C Incineration and open burning of waste (FOEN 2022).

5C Waste Incineration		
Source	CH_4 (kg/t)	N_2O (kg/t)
Illegal waste incineration	6.0	0.150

Table 7-11 Emission Factor CO_2 for 5C Incineration and open burning of waste (FOEN 2022).

5C Open burning of waste	unit	**1990**	**1995**	**2000**	**2005**	**2010**
EF CO_2 fossil	kg/t waste	525.79	552.94	578.49	560.55	523.14

5C Open burning of waste	unit	**2012**	**2013**	**2014**	**2015**	**2016**
EF CO_2 fossil	kg/t waste	508.95	506.37	512.49	515.28	520.35

5C Open burning of waste	unit	**2017**	**2018**	**2019**	**2020**	**2021**
EF CO_2 fossil	kg/t waste	522.22	522.59	523.51	523.31	519.87

Activity Data

The activity data for waste incineration is the fossil share of waste quantities incinerated illegally. This amount is calculated from the total amount of municipal solid waste generated in Liechtenstein by assuming that waste incinerated illegally represents 0.5% of waste generated (OE 2018d) and taking into account its fossil share.

The MSW generated (t wet matter/a) represents the amount of incinerated municipal solid waste which is exported for the purpose of incineration to Switzerland. The recycled fraction and the composted fraction are not included (OS 2022c).

The fossil fraction of waste incinerated is assumed to be the same as in Switzerland. Data used are based on a study conducted in year 2014 (Rytec 2014, FOEN 2022).

Table 7-12 Activity data for category 5C Incineration and open burning of waste (OS 2022c, OE 2018d, FOEN 2022).

5C Open burning of waste	unit	**1990**	**1995**	**2000**	**2005**	**2010**
MSW generated	kt	10.64	6.73	7.79	8.04	8.66
Fraction incinerated illegally		0.5%	0.5%	0.5%	0.5%	0.5%
Waste incinerated illegally	kt	0.053	0.034	0.039	0.040	0.043
Fossil share of MSW		49.7%	51.3%	50.5%	50.5%	48.6%
fossil waste incinerated illegaly	kt	0.03	0.02	0.02	0.02	0.02

5C Open burning of waste	unit	**2012**	**2013**	**2014**	**2015**	**2016**
MSW generated	kt	8.78	8.67	8.58	8.50	8.27
Fraction incinerated illegally		0.5%	0.5%	0.5%	0.5%	0.5%
Waste incinerated illegally	kt	0.044	0.043	0.043	0.043	0.041
Fossil share of MSW		47.8%	47.8%	47.8%	47.8%	47.8%
fossil waste incinerated illegaly	kt	0.02	0.02	0.02	0.02	0.02

5C Open burning of waste	unit	**2017**	**2018**	**2019**	**2020**	**2021**
MSW generated	kt	8.32	8.26	7.98	8.20	8.11
Fraction incinerated illegally		0.5%	0.5%	0.5%	0.5%	0.5%
Waste incinerated illegally	kt	0.042	0.041	0.040	0.041	0.041
Fossil share of MSW		47.8%	47.8%	47.8%	47.8%	47.8%
Fossil waste incinerated illegaly	kt	0.02	0.02	0.02	0.02	0.02

7.4.3 Uncertainties and time-series consistency: Incineration and open burning of waste (5C)

For the current submission a simplified uncertainty analysis has been carried out as described in chapter 1.6. Uncertainties were accounted individually only for the key categories, whereas the rest of the sources was aggregated by gas and treated as four "rest" categories (CO_2, CH_4, N_2O, F-gases) with mean uncertainties according to Table 1-7. 5C is not a key category and therefore its uncertainties are part of the "rest" categories with mean uncertainty for CO_2, CH_4 and N_2O. The combined uncertainty for CO_2 is estimated 10%, for CH_4 30%, and for N_2O 80% (see Table 1-7).

The time series are consistent.

7.4.4 Category-specific QA/QC and Verification: Incineration and Open Burning of Waste (5C)

The category-specific QA/QC activities have been carried out as mentioned in sections 1.5 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2020 and for the changing rates 2020/2021).

7.4.5 Category-specific recalculations: Incineration and open burning of waste (5C)

No category-specific recalculations have been carried out.

7.4.6 Category-specific planned improvements: Incineration and open burning of waste (5C)

No category-specific improvements are planned.

7.5 Wastewater treatment and discharge (5D)

7.5.1 Category Description: Wastewater treatment and discharge (5D)

Key category information 5D
Category 5D Wastewater treatment and discharge is not a key source.

Category 5D1 Domestic wastewater comprises all emissions from handling of liquid wastes and sludge from housing and commercial sources (including grey water and night soil).

Source 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 also reported in 5D, since the energy is used on site for the wastewater treatment process.

Wastewater deriving from public sewer systems is treated in the Municipal Waste Water Treatment Plant (MWWTP) in Bendern. Wastewater is treated in three steps: 1. mechanical treatment, 2. biological treatment, and 3. chemical treatment. The treated water is discharged into the river Rhine. The sludge is stabilized in a digester where sewage gas is generated. Until 2013 the biogas was used in a co-generation unit to produce heat and power on-site. Since 2014 biogas is upgraded and fed into the natural gas network. The digested sewage sludge is dewatered and dried. Dried sludge is transported to Switzerland and used as alternative fuel in a cement plant (AZV 2022).

Source category 5D2 Industrial wastewater comprises all emissions from handling liquid wastes and sludge from industrial processes such as food processing and metal processing industry. In order to reduce the load of organically polluted wastewater (and to meet the regulatory standards as well as to reduce discharge fee) the effluent is pre-treated on-site. Two metal processing companies have polluted wastewater which is pre-treated on-site by a mechanical and a chemical process. These effluents are then further processed in the MWWTP in Bendern as well. Toxic wastewater from pre-treatment activities is disposed of in Switzerland.

As all industrial wastewater is processed in the MWWTP in Bendern after a pre-treatment, emissions from source category 5D2 Industrial wastewater are included in 5D1 Domestic wastewater.

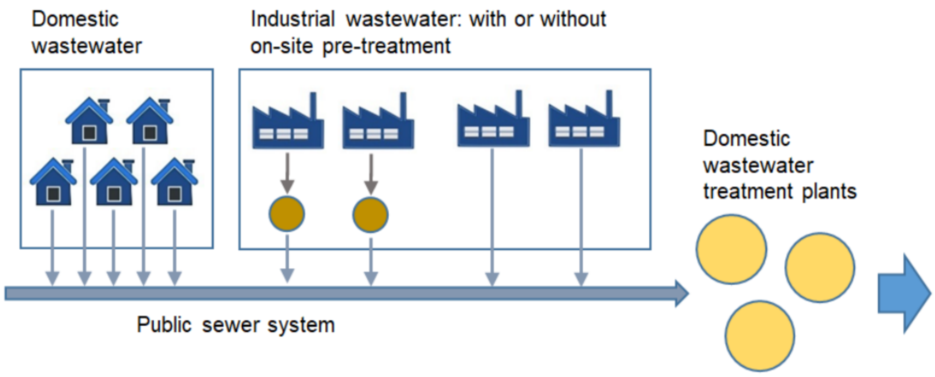


Figure 7-2 Graphical representation of domestic and industrial wastewater streams and treatment.

Table 7-13 Specification of category 5D Wastewater treatment and discharge.

5D	Source	Specification
5D1	Domestic wastewater	Emissions from handling of liquid wastes and sludge from housing and commercial sources
5D2	Industrial wastewater	Emissions from handling of liquid wastes and sludge from industrial processes (included in 5D1)
5D3	Other	Not occurring in Liechtenstein

7.5.2 Methodological issues: Wastewater treatment and discharge (5D)

7.5.2.1 CH_4 Emissions

Methodology

Emissions are calculated by a Tier 3 method based on the decision tree in Fig. 6.2 and Fig. 6.3 in chapter 6. Wastewater treatment and discharge in IPCC 2006.

The amount of sewage gas produced is measured as well as the amounts recovered in boilers, co-generation plants, flared and upgraded.

Subsequent general parameters have been applied (default values according to IPCC 2006):

- BOD (BOD5), biochemical oxygen demand = 60 g/inhabitant/day
- I, correction factor for additional industrial BOD = 1.25
- B0, maximum CH_4 producing potential = 0.60 kg CH_4/kg BOD
- MCF, methane correction factor = 0.05

Emission Factors

The emission factors are adopted from Switzerland. It is assumed that similar conditions prevail in Liechtenstein. The data are based on measurements (EMIS 2022/5D1 Wastewater treatment plants).

Table 7-14 CH_4 emission factors of category 5D Wastewater treatment and discharge.

5D Waste Water Treatment	
Source	kg CH4/TJ
Boiler	6.0
CHP generation	25.0
Torches	6.0

Emissions from sewage gas upgrading are estimated separately. Based on a SVGW analysis (SVGW 2016) CH_4 emissions are estimated as a constant share of 0.062%-Vol. of CO_2 stripped.

Activity Data

Activity data for CH_4 emissions from sewage gas treatment are the amount of gas treated, from losses and leakage from upgrading. In 1990 three wastewater treatment plants had been operational. In 2004, two plants remained, and since 2005 all wastewater of the principality is treated in the MWWTP in Bendern.

Sewage gas is used in boilers, in co-generation plants, flared and up-graded (AZV 2022). These sewage gas amounts are measured.

It is assumed that 0.75% of sewage gas amount (volume) used in boilers and co-generation plants is leaked (SFOE 2002).

The losses from sewage gas upgrading were measured (SVGW 2016).

Table 7-15 Activity data for CH_4 emission calculation from sewage gas treatment in 5D Wastewater treatment and discharge (AZV 2022, SFOE 2002, SVGW 2016).

Sewage gas treatment		**1990**	**1995**	**2000**	**2005**	**2010**
Sewage gas for boilers	TJ	5.82	6.34	8.10	0.59	9.79
Sewage gas for CHP generation	TJ	6.27	7.72	11.00	18.85	10.97
Sewage gas flared	TJ	2.46	1.79	1.15	0.02	0.04
Sewage gas losses	t CH4	1.81	2.10	2.86	2.91	3.11
Sewage gas for upgrading	t CH4	0	0	0	0	0

Sewage gas treatment		**2012**	**2013**	**2014**	**2015**	**2016**
Sewage gas for boilers	TJ	8.46	8.57	0.33	0.06	0.53
Sewage gas for CHP generation	TJ	12.82	11.68	0.64	0.39	1.11
Sewage gas flared	TJ	0.02	0.07	0.00	0.02	0.03
Sewage gas losses	t CH4	3.03	0.15	0.07	0.24	0.34
Sewage gas for upgrading	t CH4	0	0	448	457	418

Sewage gas treatment		**2017**	**2018**	**2019**	**2020**	**2021**
Sewage gas for boilers	TJ	0.74	0.32	0.52	0.10	0.19
Sewage gas for CHP generation	TJ	1.56	1.35	0.78	0.38	0.64
Sewage gas flared	TJ	0.03	0.02	0.01	0.01	0.01
Sewage gas losses	t CH4	0.34	0.25	0.19	0.07	0.12
Sewage gas for upgrading	t CH4	462	482	508	548	533

7.5.2.2 N_2O Emissions

Methodology

N_2O emissions from centralized WWT plants are calculated with a Tier 3 method in accordance with the 2006 IPCC Guidelines (IPCC 2006).

Subsequent general parameters have been applied (default values according to IPCC 2006):

- $F_{IND\text{-}COM}$ (correction for commercial/industrial N) = 1.25
- EF_{PLANT} = 3.2 g N_2O/inhabitant/yr
- $EF_{EFFLUENT}$ = 0.005 kg N_2O-N/kgN
- F_{NPR}, fraction of nitrogen in protein = 0.16 kg N/kg protein

Activity Data

The time-dependent data on population, degree of utilization and annual per capita protein consumption are summarized in Table 7-16.

Specific numbers for yearly protein consumption are adopted from Switzerland. It is assumed that similar conditions prevail in Liechtenstein. Total protein consumption in Liechtenstein fluctuates around 37 kg/inhabitant and year. The values 1990 - 2021 are taken from Switzerland (FOEN 2022).

Table 7-16 Activity data for N_2O emission calculation in 5D Wastewater treatment and discharge (OS 2022d, FOEN 2022).

5D Wastewater treatment and discharge		1990	1995	2000	2005	2010
Population	inhabitants	29'032	30'923	32'863	34'905	36'149
Degree of Utilization	%	90.0	93.5	95.4	96.8	97.0
Protein Consumption	kg/capita/a	38.1	37.1	37.2	36.3	38.0

5D Wastewater treatment and discharge		2012	2013	2014	2015	2016
Population	inhabitants	36'838	37'129	37'366	37'623	37'810
Degree of Utilization	%	97.0	97.0	97.0	97.0	97.0
Protein Consumption	kg/capita/yr	36.8	37.1	36.6	37.3	35.8

5D Wastewater treatment and discharge		2017	2018	2019	2020	2021
Population	inhabitants	38'114	38'380	38'749	39'055	39'315
Degree of Utilization	%	97.0	97.0	97.0	97.0	97.0
Protein Consumption	kg/capita/yr	35.8	35.4	35.4	35.4	35.4

7.5.3 Uncertainties and Time-Series Consistency: Wastewater treatment and discharge (5D)

For the current submission a simplified uncertainty analysis has been carried out as described in chapter 1.6. Uncertainties were accounted for individually only for the key categories, whereas the rest of the sources was aggregated by gas and treated as four "rest" categories (CO_2, CH_4, N_2O, F-gases) with mean uncertainties according to Table 1-7. 5B is not a key category and therefore its uncertainties are part of the "rest" categories with mean uncertainty for CH_4 and N_2O. The combined uncertainty for CH_4 is estimated 30%, and for N_2O 80% (see Table 1-7).

The time series are consistent.

7.5.4 Category-specific QA/QC and Verification: Wastewater treatment and discharge (5D)

The category-specific QA/QC activities have been carried out as mentioned in sections 1.5 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2020 and for the changing rates 2020/2021).

7.5.5 Category-specific recalculations: Wastewater treatment and discharge (5D)

The activity data for sewage gas losses are calculated as percentage of 0.75% from the total amount sewage gas used in combined heat and power units and in boilers. The calculation starting from the year 2005 was wrong and was corrected in the present submission. I.e. the formula calculating the activity data had a wrong cell reference starting from 2005. The time series from 2005 to 2020 is affected.

7.5.6 Category-specific planned improvements: Wastewater treatment and discharge (5D)

There is a slight inconsistency between the sewage gas generated and the total of sewage gas used in boilers, co-generation plants, flared and up graded. The origin of the mistake will be assessed and the activity data will be corrected in the next submission 2024.

7.6 Other (5E)

No emissions are occurring in Liechtenstein under this category.

8. Other

No other sources or sinks are occurring in Liechtenstein.

9. Indirect CO_2 and N_2O emissions

Based on the UNFCCC reporting guidelines (UNFCCC 2014) it is not mandatory to take into account indirect CO_2 emissions. Liechtenstein decided not to report indirect CO_2 and nitrous oxide emissions. The emissions are therefore not estimated – NE. For that reason, precursor substances such as NMVOC are only reported under 2D3 Other (Solvent use, road paving and asphalt roofing).

10. Recalculations and improvements

10.1 Explanations and justifications for recalculations, including in response to the review

The quantitative impact of recalculations on emissions, i.e. the absolute difference that results from the recalculations between the previous and the latest submission, is documented for all key categories (values are taken from CRF Table8.s1, 8s2, 8s3 and 8s4).

In addition to the recalculations described below, the current greenhouse gas inventory of Liechtenstein 1990-2021 (NID and CRF reporting tables) uses the 100-year time-horizon global warming potentials (GWP_{100}) from the Fifth Assessment Report (AR5) of the IPCC (Myhre et al. 2013). In the previous submissions GWP values from the Fourth Assessment Report (AR4) were used. This leads to changes in CH_4, N_2O, and F-gas emissions.

1 Energy

Recalculation in the Reference Approach

- For gasoline and diesel, emission factors of CH_4 and N_2O were updated based on Switzerland's Handbook of emission factors version 4.2 for the entire time series (INFRAS 2022, INFRAS 2022a). This leads to a recalculation of CH_4 and N_2O emissions.

Recalculation in 1A1

There were no category-specific recalculations.

Recalculation in 1A2

There were no category-specific recalculations.

Recalculation in 1A3

The following recalculation leads to minor changes in CH_4 and N_2O emissions:

- 1A3b: In this submission the latest version of the Handbook Emission Factors for Road Transport (HBEFA 4.2) is used (INFRAS 2022a). Hence, CH_4 and N_2O emission factors for gasoline, diesel and natural gas were updated for the complete time series.

Recalculation in 1A4

There were no category-specific recalculations.

Recalculation in 1B2

There were no category-specific recalculations.

2 IPPU

Recalculation in 2D

The following recalculation was implemented:

- 2D1: The emission factor for lubricants use was updated for the years 2019 and 2020, since updated data on CO_2 emissions from lubricant use in Switzerland was available (FOEN 2022b).

Recalculation in 2F

Switzerland’s GHG inventory 2023 was not yet available for Liechtenstein’s submission 2023. For Switzerland, the following recalculations have been carried out in submission 2022, which also influence Liechtenstein’s emission time series reported in Submission 2023:

- 2F2: A correction of roundings was made, using two decimal places as applied for other emission factors.

In addition, the following recalculations lead to minor changes in HFC and PFC emissions:

- 2F1 Refrigeration and air conditioning: An error was corrected in the calculation of the conversion factor (activity data) in 2F1 commercial refrigeration, leading to changes in the activity data in the complete time series.
- 2F1 Refrigeration and air conditioning: Since a new household statistic is available for Switzerland (SFSO 2022e) the activity data (number of households) has changed from 2012-2020.
- 2F1 Refrigeration and air conditioning: Since the number of employees in industrial and service sector in Switzerland was updated based on newest available data (SFSO 2022b) the activity data (number of employees) has changed from 2010-2020.
- 2F1 Refrigeration and air conditioning: Since the number of registered passenger cars in Switzerland was updated based on newest available data (SFSO 2022c) the activity data (number of registered PC) has changed from 1995-2004.

Recalculation in 2G

The following recalculation leads to minor changes in N_2O emissions:

- 2G3 N_2O from product use: An error was corrected in the calculation of the emission factor in 2G3, leading to minor changes in N_2O emissions in the complete time series.

3 Agriculture

General: It is planned that Liechtenstein's agriculture model will be updated every 5 years with latest Swiss values and data. The effort updating the model annually is not feasible for a small country such as Liechtenstein. The latest update has been done for the submission 2020.

- 3A: There were no category-specific recalculations.
- 3B: There were no category-specific recalculations.
- 3D: There were no category-specific recalculations.
- 3H: There were no category-specific recalculations.

4 LULUCF

There were no recalculations in sector 4 LULUCF.

5 Waste

- 5A: There were no category-specific recalculations.
- 5B: There were no category-specific recalculations.
- 5C: There were no category-specific recalculations.
- 5D: The Activity Data for sewage gas losses are calculated as percentage of 0.75% from the total amount sewage gas used in combined heat and power units and in boilers. The calculation starting from the year 2005 was wrong and was corrected in the present submission. I.e. the formula calculating the Activity Data related to a wrong row applying wrong percentage values. The time series from 2005 to 2020 is affected.

10.2 Implications for emission and removal levels 1990 and 2020

Table 10-1 shows the recalculation results for the base year 1990. The recalculations have the following effect on the emissions in 1990 in comparison with the submitted emissions of the previous year:

- The difference in national total emissions 1990 amounts to a total increase of 1.17 kt CO_2eq (0.51%) without emissions/removals from LULUCF.
- Including LULUCF, the difference in national total emissions 1990 amounts to a total increase of 1.14 kt CO_2eq (0.48%).

The main reason for differences in emissions in 1990 between the current submission and the previous submission is the adoption of the GWPs according to AR5 in the current submission.

Table 10-1 Overview of implications of recalculations on 1990 data. Emissions are shown before the recalculation according to the previous submission in 2022 "Prev." (Submission of November 2022, OE 2022g) and after the recalculation according to the present submission 2022 "Latest". The differences "Differ." are defined as latest minus previous submission. Where there is no difference between the two submissions (i.e. no recalculations), this is indicated with a dash.

Recalculation	**CO_2**			**CH_4**			**N_2O**			**Sum (CO_2, CH_4 and N_2O)**		
Emissions for 1990	Prev.	Latest	Differ.	Prev.	Latest	Differ.	Prev.	Latest	Differ.	Prev.	Latest	Differ.
Source and sink categories	CO_2 equivalent (kt)									CO_2 equivalent (kt)		
1 Energy	198.7	198.7	-	1.3	1.4	*0.15*	1.3	1.1	*-0.13*	201.3	201.3	*0.02*
2 IPPU (without F-gases)	0.2	0.2	-	NO	NO	*NO*	0.5	0.4	*-0.06*	0.7	0.6	*-0.06*
3 Agriculture	0.1	0.1	-	16.9	18.9	*2.02*	8.0	7.1	*-0.88*	24.9	26.0	*1.14*
4 LULUCF	7.3	7.3	-	NO	NO	*NO*	0.3	0.3	*-0.03*	7.6	7.5	*-0.03*
5 Waste	0.0	0.0	-	1.1	1.2	*0.13*	0.5	0.5	*-0.06*	1.7	1.7	*0.07*
Sum (without F-gases)	206.2	206.2	-	19.2	21.5	*2.31*	10.6	9.4	*-1.17*	236.0	237.2	*1.14*

Recalculation	**HFC**			**PFC**			**SF_6**			**Sum (F-gases)**		
Emissions for 1990	Prev.	Latest	Differ.	Prev.	Latest	Differ.	Prev.	Latest	Differ.	Prev.	Latest	Differ.
Source and sink categories	CO_2 equivalent (kt)									CO_2 equivalent (kt)		
2 IPPU (F-gases only)	0.0	0.0	*-0.00*	NO	NO	*NO*	NO	NO	*NO*	0.0	0.0	*-0.00*

Recalculation	**Sum (all gases)**		
Emissions for 1990	Prev.	Latest	Differ.
Source and sink categories	CO_2 equivalent (kt)		
Total CO_2 eq Em. with LULUCF	**236.0**	**237.2**	***1.14***
	100.0%	100.5%	*0.48%*
Total CO_2 eq Em. without LULUCF	**228.5**	**229.6**	***1.17***
	100.0%	100.5%	*0.51%*

The analogous recalculation results for 2020 are shown in Table 10-2 and have the following effects on emissions:

- The difference in national total emissions 2020 amounts to a total increase of 0.86 kt CO_2eq (0.48%) without emissions/removals from LULUCF.
- Including LULUCF, the difference in national total emissions 2020 amounts to an increase of 0.82 kt CO_2eq (0.44%).

The main reason for differences in emissions in 2020 between the current submission and the previous submission is the adoption of the GWPs according to AR5 in the current submission.

Table 10-2 Overview of implications of recalculations on 2020 data. Emissions are shown before the recalculation according to the previous submission in 2022 "Prev." (OE 2022g) and after the recalculation according to the present submission 2023 "Latest". The differences "Differ." are defined as latest minus previous submission. Where there is no difference between the two submissions (i.e. no recalculations), this is indicated with a dash.

Recalculation	**CO_2**			**CH_4**			**N_2O**			**Sum (CO_2, CH_4 and N_2O)**		
Emissions for 2020	Prev.	Latest	Differ.	Prev.	Latest	Differ.	Prev.	Latest	Differ.	Prev.	Latest	Differ.
Source and sink categories	CO_2 equivalent (kt)									CO_2 equivalent (kt)		
1 Energy	141.8	141.8	-	1.6	1.8	*0.19*	0.9	0.8	*-0.09*	144.3	144.4	*0.10*
2 IPPU (without F-gases)	0.1	0.1	*-0.02*	NO	NO	*NO*	0.1	0.1	*-0.02*	0.3	0.2	*-0.03*
3 Agriculture	0.0	0.0	-	17.2	19.2	*2.06*	7.4	6.6	*-0.82*	24.7	25.9	*1.24*
4 LULUCF	4.4	4.4	-	NO	NO	*NO*	0.4	0.3	*-0.04*	4.8	4.8	*-0.04*
5 Waste	0.0	0.0	-	0.9	1.0	*0.11*	0.7	0.6	*-0.07*	1.6	1.6	*0.04*
Sum (without F-gases)	146.4	146.4	*-0.02*	19.7	22.1	*2.37*	9.6	8.5	*-1.05*	175.7	177.0	*1.30*

Recalculation	**HFC**			**PFC**			**SF_6**			**Sum (F-gases)**		
Emissions for 2020	Prev.	Latest	Differ.	Prev.	Latest	Differ.	Prev.	Latest	Differ.	Prev.	Latest	Differ.
Source and sink categories	CO_2 equivalent (kt)									CO_2 equivalent (kt)		
2 IPPU (F-gases only)	9.1	8.6	*-0.48*	0	0	*0.00*	0.1	0.1	*0.00*	9.2	8.7	*-0.48*

Recalculation	**Sum (all gases)**		
Emissions for 2020	Prev.	Latest	Differ.
Source and sink categories	CO_2 equivalent (kt)		
Total CO_2 eq Em. with LULUCF	**184.8**	**185.7**	***0.82***
	100.0%	100.4%	*0.44%*
Total CO_2 eq Em. without LULUCF	**180.0**	**180.9**	***0.86***
	100.0%	100.5%	*0.48%*

10.3 Implications for emission and removal trends, including time series consistency

Due to recalculations, the emission trend 1990–2020 reported in submission 2022 has changed. The emission trend showed a decrease by 21.21% before the recalculations (previous submission, national total without emissions/removals from LULUCF). After the recalculations in the latest submission 2023, the decreasing trend is slightly higher (-21.24%).

Table 10-3 Change of the emission trend 1990–2020 due to recalculations carried out in the latest submission 2023. "Previous" refers to the values from submission 2022 (OE 2022g)

Recalculation	**1990**		**2020**		**change 1990/2020**	
Submission	previous	latest	previous	latest	previous	latest
	CO_2 eq (kt)				%	
Total excl. LULUCF	228.47	229.64	180.01	180.87	-21.21%	-21.24%

All time series in the present submission are consistent.

10.4 Recalculations in response to the review process and planned improvements

The Inventory Development Plan (IDP) is a tool within Liechtenstein's National Inventory System (NIS) to improve the Greenhouse Gas Inventory and the National Inventory Document (NID). The IDP summarises all issues detected from internal and external QA/QC activities. It is updated regularly based on the recommendations of the expert review teams of the UNFCCC (ERT).

The latest review of Liechtenstein's greenhouse gas inventory took place in September 2022. The findings of the ERT were published in February 2023 in the report of the individual review of the annual submission of Liechtenstein submitted in 2022 (FCCC/ARR 2023).

Liechtenstein prioritises the implementation of planned improvements based on the results of the key category analysis (see chp. 1.4) and the uncertainty analysis (see chp. 1.6). High priority is assigned to improvements that concern key categories and/or sectors with high uncertainty, such as:

- 1A3b Road transport: The emission factors are updated annually to the newest version of the handbook of emission factors (HBEFA).
- 3 Agriculture: The model is fully revised every 5 years. The last update was implemented in submission 2020.
- 4 LULUCF: A new computing framework for the LULUCF sector will be developed in the next years and its implementation is planned for submission 2023.

The IDP summarises the recommendations and planned improvements and illustrates the implementation status of those. Table 10-4 shows all planned improvements of the IDP that were implemented in the current submission, planned improvements for future submissions and improvements that will not be implemented.

A description of the IDP headers is provided here:

Reference (according to ARR)

This column in the IDP refers to the relevant paragraph in the report of the individual review of the greenhouse gas inventory of Liechtenstein of the corresponding year, e.g. ARR 2022/#G.1 refers to ID G.1 of the report on the inventory submitted in 2022, FCCC/ARR/2022/LIE.

Recommendations/Planned improvement

The recommendations of the ERT or planned improvements are described in detail in the second column.

Status

The status provides information about the state of development of each specific point (“implemented in submission 20XX” or “planned improvement for submission 20XX”).

Comment/Reason

The last column includes a short summary of the issue given or an explanation on what Liechtenstein’s has done related to this point.

Table 10-4 Inventory development plan for Liechtenstein’s greenhouse gas inventory 2023.

Reference	Identified Issues, e.g. recommendations or planned improvements	Status	Comment/Reason NID	Sector
ARR 2020, ID#G.10, ARR 2022 ID#G.5	Update CRF table 9 and annex 5 to the NIR to include information on where emissions from light- and heavy-duty trucks are accounted for and information justifying the assumption that emissions for category 3.I (other carbon-containing fertilizers) are insignificant in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines.	Implemented in submission 2023	Liechtenstein included a documentation of the notation key used in CRF table 1.A.(a)s3 in the NIR of submission 2021 (see chp. 3.2.7.2 - Methodology - Road transportation). Liechtenstein populated Table 9 and added information regarding category 3.I in chapter 1.7. of the NID in submission 2023.	0 General
Review 2013	Conduct internal review complemented with systematic external review.	Ongoing implementation	As the emissions of Liechtenstein are relatively low and partially based on Swiss data that is quality assured and reviewed, we assume that the data is sufficiently assured. The party is continuously trying to improve internal review procedures.	0 General
ARR 2013 / 21;81;87;89; Table 3; ARR 2016, ID#G.6	Review and strengthen its QC procedures to eliminate errors and improve the accuracy of its emission estimates.	Ongoing implementation	The party will check how systematic additional quality control procedures can be implemented for future submissions and is continuously improving existing QC procedures.	0 General
ARR 2013 / 16c;21;24;35; Table 3, ARR 2018, ID#G.6, PMF 2020, ID#G.5	Implement additional QC procedures to avoid mistakes or discrepancies between the CRF tables and the NIR.	Ongoing implementation	The party will check how systematic additional quality control procedures can be implemented for future submissions and is continuously improving existing QC procedures.	0 General
ARR 2022 ID#G.6	In several of the CRF tables submitted by the Party, some cells were left blank. Blank cells were found for several categories of many sectors across the time series in CRF tables 1.A(a), 2(I)A–H, 3.A, 3.B(a–b), 4(I–III), 4.G, 6, 8 (sheet 4) and 4(KP-II)2–4.. The ERT confirms that no underestimation related with the incorrect use of the notation key was done. The ERT recommends that the Party fill any blank cells in the CRF tables with values or appropriate notation keys.	Ongoing implementation	The party will include the missing notation keys in the CRF reporter application where this is possible.	0 General

Reference	Identified Issues, e.g. recommendations or planned improvements	Status	Comment/Reason NID	Sector
ARR 2013 / 21	Implement additional QC procedures to avoid mistakes or discrepancies between the CRF tables and the NIR.	Ongoing implementation	The party will check how systematic additional quality control procedures can be implemented for future submissions and is continuously improving existing QC procedures.	1 Energy
ARR 2020, ID#E.10, ARR 2022 ID#E.2	1.A.3.b Road transportation - Gasoline, Diesel oil, Gaseous fuels, Biomass - CO2, CH4, N2O: The ERT recommends that the Party provide emission estimates in the sub categories 1A3bii, 1A3biii, 1A3biv in the next CRF and NIR, or provide information on the notation key "IE". The ERT notes that the Party could consider applying approximate data and drivers (e.g. number of vehicles, information from the Swiss inventory, etc) and / or expert judgement to allocate the AD and corresponding emissions. Make efforts to disaggregate AD and report emission estimates for gasoline, diesel oil, gaseous fuels and biomass under categories 1.A.3.b.ii (light-duty trucks), 1.A.3.b.iii (heavy-duty trucks and buses) and 1.A.3.b.iv (motorcycles); where this is not possible, provide information on the use of the notation key "IE" in CRF table 9.	Planned improvement for 2024	A more detailed explanation was added in the NIR of submission 2021 on how the data is aggregated under source category 1A3bi – Cars and that vehicle categories except passenger cars are therefore IE (see chp. 3.2.7.2 - Methodology - Road transportation). Unfortunately, Liechtenstein does not have sufficiently detailed activity data (e.g. distances travelled and fuel consumption per vehicle category), which would allow to disaggregate the emission data for the different vehicle categories under 1A3b. Liechtenstein is of the opinion that the effort needed to implement this improvement is not justified. Liechtenstein will however examine simplified methods to further disaggregate the emission data for the different vehicle categories under source category 1A3b for the next submission. Information on the use of the notation key "IE" is provided in NID submission 2023 chapter 1.7.	1 Energy
ARR 2022 ID#E.7	1.A.3.b Road transportation – biodiesel – CO2 Estimate and report CO2 emissions associated with the fossil part of the carbon content of biofuels or, if these emissions are considered insignificant, report them as "NE" and provide a quantitative estimate of the likely level of the emissions in accordance with paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines.	Planned improvement for 2024	The party will examine how to report the emissions as "NE" and provide an estimate of the likely level.	1 Energy
Internal decision	Update of CO2 emissions from lubricant use (2D1) based on updated data from Switzerland's GHG inventory.	Implemented in submission 2023	At the time of the inventory preparation in submission 2022, CO2 emissions from lubricant use for 2020 were not yet available from Switzerland's GHG inventory. Therefore, in submission 2022 Liechtenstein derived the emissions factor per capita based on Switzerland's emissions reported for 2019. In the next submission, emissions from 2D1 in 2020 were updated based on the updated emissions from Switzerland's GHG inventory.	2 IPPU

Reference	Identified Issues, e.g. recommendations or planned improvements	Status	Comment/Reason NID	Sector
ARR 2022 ID#I.2	2.F.4 Aerosols -HFCs The Party reported in CRF Table2(II)B-Hs2 emissions of HFC134a from stocks of metered dose inhalers for the time series of 1997-2019. For inventory year 2020, emissions were reported as "NO". During the review, the Party clarified that due to an error in the data preparation, the emissions of HFC134a for inventory year 2020 were not included in the CRF tables. Include the emissions of HFC134a associated with metered dose inhalers for 2020 in the next inventory submission.	Implemented in submission 2023	Liechtenstein included the emissions of HFC134a for 2020 in the submission 2023.	2 IPPU
ARR 2022 ID#A.6	3B: The Party reported in its NIR (p.176) that the EFs applied to estimate N2O emissions from liquid/slurry manure management systems were updated and adjusted in the 2020 submission in accordance with the information presented in the Netherlands' GHG inventory (van Bruggen et al., 2014). Namely, Liechtenstein applied N2O EFs of 0.002 kg N2O-N (kg N excreted)-1 for a liquid/slurry system with a natural crust cover and a liquid/slurry system without a natural crust cover (versus the default EFs of 0.005 and 0.00 N2O-N (kg N excreted)-1, respectively, in table 10.21 of the 2006 IPCC Guidelines). The ERT noted that the implementation of the updated N2O EFs has resulted in a significant increase in N2O emissions from liquid/slurry manure management systems (e.g. from 0.0003 kt N2O in 2017, as reported in the 2019 submission, to 8.34 kt N2O in 2017, as reported in the 2020 submission). The ERT recommends that the Party provide the information in its NIR to justify the applicability of the N2O EF values it uses, which were developed by researchers of the Netherlands, to the national circumstances of Liechtenstein for the entire reporting period and, if a justification is not possible, consider using the default values of the N2O EFs reported in table 10.21 of the 2006 IPCC Guidelines (vol. 4, chap. 10) to calculate N2O emissions from liquid/slurry manure management systems.	Implemented in submission 2023	The party is in the view that "downgrading" to a tier 1 method would be a clear step back and would harm the overall consistency of the agriculture model. Furthermore, the party wants to state that it cannot be in the spirit of the UNFCCC to push parties towards using a tier 1 approach instead of a tier 2 approach. The party explained in its NID that this emission factor is used in the Swiss inventory as well, and has been evaluated by a Swiss expert for its application for Liechtenstein. Furthermore, as suggested by the ERT in the ARR 2022, the party documented in its NID an unpublished source (Bretscher 2020) confirming the conclusion of the Swiss inventory expert.	3 Agriculture

Reference	Identified Issues, e.g. recommendations or planned improvements	Status	Comment/Reason NID	Sector
ARR 2022 ID#A.3	3A2: The Party reported in its NIR (section 5.2.5, p.161) that a weighted-average value of Ym was used to estimate CH4 emissions from enteric fermentation of sheep (e.g. 5.68 per cent for 1990 and 5.94 per cent for 2018). However, the ERT noted that CRF table 3.As1 provides a constant GE of 22.52 MJ/head/day for sheep for the entire time series. As GE is a function of Ym, according to equation 10.21 of the 2006 IPCC Guideline (vol. 4), it cannot be constant, as Ym is not constant. Therefore, it was not clear to the ERT how EF for the two subcategory of sheep (lambs <1 year old and mature sheep) were developed. The ERT recommends that the Party evaluate the CH4 enteric fermentation EF for each subcategory of sheep (i.e. for lambs <1 year old and mature sheep), taking into account the GEI and Ym values that are relevant for each subcategory, and use the country-specific data on sheep population by subcategory for the entire reporting period.	Will not be implemented	The Party believes that this recommendation imposes a disproportionate effort compared to the improvement in the estimation of the EF. Furthermore, in the ARR 2022, the ERT notes that the issue does not lead to a potential underestimation of emissions.	3 Agriculture
ARR 2022 ID#L.4	The ERT recommends that the Party improve in the NIR the methodological description for the LULUCF sector by including specific information, such as tier level, carbon stocks and calculation formula, for each carbon pool and land-use category; for example, in NIR sections 6.5.2.2 and 6.6.2.2, under (a) and (b), the calculation formula, including conversion time and carbon stocks, could be described.	Implemented in submission 2023	The party improved the description of the methods in chapters 6.5.2, 6.6.2, 6.7.2, 6.8.2 and 6.9.2.	4 LULUCF
ARR 2022 ID#L.8	The Party did not include in CRF table 4.Gs2 data for sawnwood production, import and export for the entire time series – values for 1960 to 1989 are missing. The ERT recommends that the Party fill any blank cells in the CRF tables with values or appropriate notation keys.	Implemented in submission 2023	Date for the years 1961-1989 were filled in. There are no import/export data for 1960 available.	4 LULUCF
Internal decision	In 4.C1, an inconsistency (approximately 5%) in the carbon stock change of organic soils was detected.	Planned improvement for 2024	With the new calculation model the problem will be solved.	4 LULUCF
ARR 2022 ID#L.6	The ERT recommends that the Party change the methodology it uses for estimating carbon stock changes in living biomass by instead applying equations 2.15 and 2.16 from the 2006 IPCC Guidelines (vol. 4, chap. 2) so that carbon stocks are accounted for completely in the year of the conversion and explain the new methodology transparently in the NIR.	Planned improvement for 2024	The party will implement a new calculation model for LULUCF in 2024 where different conversion times will be implemented for soil and biomass.	4 LULUCF

Reference	Identified Issues, e.g. recommendations or planned improvements	Status	Comment/Reason NID	Sector
ARR 2018, ID#L.12	Deforestation: The ERT recommends that the Party takes efforts to use the results of the 2020 AREA survey for improving the estimate of the area of forest that has temporary lost covers.	Planned improvement for 2024	New AREA survey data will probably be available in summer 2023. See NID chp. 6.3.1.6	4 LULUCF
ARR 2022 ID#L.5	The ERT recommends that the Party (1) review the consistency of land representation between inventory years to ensure that the final areas of one year are equal to the initial areas of the next year in CRF table 4.1 and (2) report the final areas for the current inventory year in CRF tables 4.A–F.	Planned improvement for 2025	The party will implement a new calculation model for emissions and removals of sector LULUCF in 2024 and subsequently improve table 4.1	4 LULUCF
ARR 2022 ID#L.7	The ERT, noting that use of the Wetlands Supplement is not mandatory, recommends that if the Party chooses not to estimate CH4 and indirect DOC-CO2 emissions from drained organic soils on cropland and grassland, it report these emissions as "NE" in CRF table 4(II), provide a related explanation in CRF table 9 and report the areas identical to those reported as organic soils in CRF tables 4.B and 4.C. Furthermore, the ERT encourages Liechtenstein to use the Wetlands Supplement in preparing its inventory for future annual submissions and report estimated CH4 and indirect DOC-CO2 emissions from drained organic soils on cropland and grassland.	Planned improvement for 2025	The party will improve table 4(II) as recommended.	4 LULUCF
ARR 2022 ID#L.9	The ERT encourages the Party to report in CRF table 4.Gs2 the additional information items of factors used to convert from product units to carbon for HWP.	Planned improvement for 2025	The party will improve table 4Gs2 accordingly.	4 LULUCF
Internal decision, ARR 2022, IDW.11	5.D Wastewater treatment and discharge - CH4: The ERT recommends that the Party correct the error in the calculation of the AD for sewage gas losses for 2006 – 2020 and related CH4 emissions from wastewater treatment and discharge and report the revised estimates in the next annual submission.	Implemented in submission 2023	There was a wrong cell reference in calculation AD for sewage gas losses, starting from the year 2005. The mistake was corrected in Submission 2023	5 Waste
ARR 2022, ID#W.10	5.A Solid waste disposal on land - CH4: The ERT recommends that the Party correct the value of DOCf in CRF table 5.A so that it is consistent with the value reported in the NIR (0.5), which is the correct value.	Implemented in submission 2023	In Submission 2022 the DOCf value = 15.40 in CRF table 5.A was wrong. However, the correct value for DOCf = 0.5 value was applied in estimating the CH4 emissions. Mistake was corrected in Submission 2023.	5 Waste
ARR 2018, ID#W.2	Provide quantitative uncertainty estimates for all waste categories and discuss the reasons for the uncertainty estimates in the appropriate section of the waste chapter of the NIR, following the outline for the NIR in the UNFCCC	Ongoing implementation	All waste categories aren't key sources. Therefore, a simplified uncertainty analysis has been carried out. However, NIR submission 2020 CH4 emissions from 5D1 Wastewater Treatment and discharge was a key category.	5 Waste

Reference	Identified Issues, e.g. recommendations or planned improvements	Status	Comment/Reason NID	Sector
	Annex I inventory reporting guidelines.			
internal decision	5A: Switzerland has recalculated its waste composition landfilled. No category-specific improvements are planned. The shares of kitchen waste and garden waste within the deposited amounts of organic waste on solid waste disposal sites from 1950–1979 have been recalculated according to BUS 1978. Lichtenstein is planning to align its activity data at the time when the FOD model is going to be up-dated.	Ongoing implementation	This planned improvement will be implemented during the next update of the FOD-model of Liechtenstein.	5 Waste

Annexes to the National Inventory Document

Annex 1 Key categories

All relevant information regarding the key category analysis is given in chp. 1.4.

Annex 2 Uncertainty assessment

A2.1 Aggregation of categories for application of uncertainty analyses to key categories

In the automatic KCA of the CRF Reporter, the aggregation level of the categories is not identical to the data available for Liechtenstein. That means that uncertainties need to be aggregated to be applied to key categories. This paragraph shows how the aggregation has been carried out. Technically, the Gaussian error propagation is applied for the aggregation used in following analytical form in order aggregate uncertainties of EF and AD:

$$U_{\%,EF} = \sqrt{\sum_i (Em_{\%,i} * U_{\%,EF,i})^2} \quad (1)$$ error propagation for emission factors

$$U_{\%,AD} = \sqrt{\sum_i (Em_{\%,i} * U_{\%,AD,i})^2} \quad (2)$$ error propagation for activity data

Where:

$U_{\%,EF}$	aggregated relative uncertainty in emission factors
$U_{\%,AD}$	aggregated total relative uncertainty in activity data
$Em_{\%,i}$	disaggregated relative emissions of source i compared to total emissions
$U_{\%,EF,i}$	disaggregated relative uncertainty in emission factor of source i
$U_{\%,AD,i}$	disaggregated relative uncertainty in activity data of source i.

The results of the aggregation process are displayed in Table A - 1.

Table A - 1 Aggregation with Gaussian error propagation for the three relevant key categories.

1A3b CO_2	(Sub)Categories		**Aggr. Uncertainties**
	gasoline	*diesel*	*total/implied*
$U_{\%}$ Emissions	10.0%	15.0%	**9.5%**
$U_{\%}$ Activity Data	10.0%	15.0%	**9.5%**
$U_{\%}$ Emission Factor	0.1%	0.1%	**0.1%**
1A4 Liquid fuels CO_2	(Sub)Categories		**Aggr. Uncertainties**
	1A4a	*1A4b*	*total/implied*
$U_{\%}$ Emissions	20.0%	20.0%	**15.8%**
$U_{\%}$ Activity Data	20.0%	20.0%	**15.8%**
$U_{\%}$ Emission Factor	0.1%	0.1%	**0.1%**
1A4 Gaseous fuels CO_2	(Sub)Categories		**Aggr. Uncertainties**
	1A4a	*1A4b*	*total/implied*
$U_{\%}$ Emissions	5.0%	5.0%	**4.0%**
$U_{\%}$ Activity Data	5.0%	5.0%	**4.0%**
$U_{\%}$ Emission Factor	0.4%	0.4%	**0.3%**

A2.2 Aggregation of carbon pools in the sector LULUCF

The following table shows the relevant carbon pools that were considered in the uncertainty analysis as well their share in the total carbon stock change (CSC) per main category. "AD_Unc combined" is the uncertainty arising from the AREA survey combined with the uncertainty of the share of organic soils taken from the soil map (30%). If more than one pool was considered the calculation of the uncertainty of the sum of the pools using absolute uncertainties (EF_absUnc) is documented.

Table A - 2 Derivation of EF uncertainties from the relevant processes/pools in sector 4.

Category	Process, pool	CSC	Process share	AD_Unc AREA survey	AD_Unc organic soil	AD_Unc combined	EF_Unc	EF_absUnc
		t C/ha (1)		%	%	%	%	t C/ha
4A1	total	0.55	1.00	2.7			46.7	
4A2	total	0.01	1.00	17.2			46.7	
4B1	organic soil	-0.73	1.00	6.9	30.0	30.8	23.0	
	total	-0.73	1.00	6.9			23.0	
4B2	organic soil	-0.30	0.54	26.9	30.0	40.3	23.0	0.141
	mineral soil	-0.24	0.42	26.9			50.0	0.119
	total	-0.54	0.96	26.9			34.0	0.185
4C1	organic soil	-0.10	0.80	6.0	30.0	30.6	23.0	0.037
	mineral soil	0.02	0.18	6.0			50.0	0.011
	total	-0.08	0.98	6.0			51.2	0.039
4C2	organic soil	-0.14	0.12	13.6	30.0	32.9	23.0	0.056
	mineral soil	0.25	0.21	13.6			50.0	0.125
	living biom.	-0.78	0.67	13.6			40.3	0.315
	total	-0.67	0.88	13.6			51.0	0.343
4D1	total	0.00	1.00	10.5			50.0	
4D2	mineral soil	-0.38	0.26	40.9			50.0	0.192
	living biom.	-0.96	0.65	40.9			40.3	0.388
	total	-1.35	0.90	40.9			32.1	0.433
4E1	mineral soil	-0.05	0.63	6.4			50.0	0.024
	living biom.	-0.03	0.37	6.4			40.3	0.012
	total	-0.08	1.00	6.4			34.8	0.027
4E2	mineral soil	-1.08	0.59	19.4			50.0	0.542
	living biom.	-0.76	0.41	19.4			40.3	0.307
	total	-1.85	1.00	19.4			33.7	0.623
4F2	mineral soil	-1.07	0.41	40.9			50.0	0.535
	living biom.	-0.71	0.47	40.9			40.3	0.288
	total	-1.78	0.88	40.9			34.0	0.607
4G	total	-0.05	1.00	50.0			57.0	

(1) related to total area (sum of organic and mineral soils) in 2021.

Annex 3 Detailed description of reference approach

No supplementary information to the statements given in Chapter 3.2.1 Comparison of Sectoral Approach with Reference Approach.

Annex 4 QA/QC plan

A4.1 QA/QC plan

A.4.1.1 Quality assurance (QA) activities

According to IPCC (2006) quality assurance (QA) comprises activities outside of the actual inventory compilation. QA procedures include reviews and audits to assess the quality of the inventory, to determine the conformity of the procedures taken and to identify areas where improvements could be made. QA procedures are used in addition to the general and category-specific QC procedure. It is important to use QA reviewers that have not been involved in preparing the inventory (IPCC 2006).

Liechtenstein's NIS quality management system follows a Plan-Do-Check-Act-Cycle (PDCA-cycle), which is a generally accepted model for pursuing a systematic quality performance according to international standards. This approach is in accordance with procedures described in decision 19/CMP.1 and in the 2006 IPCC Guidelines (IPCC 2006).

Liechtenstein carries out the following QA activities:

- Internal review: The draft NID is passing an internal review. The project manager also being the NIC, the project manager assistant, specialised staff members of the climate unit and other staff member of the OE are proofreading the NID or parts of it (all personnel not directly involved in the preparation of a particular section of the inventory). They document their findings in checklists, which are sent back to the NID authors (see A4.3).
- The Swiss inventory management involves external experts for sectoral QA activities to review the Swiss GHG inventory. Since a number of Swiss methods and Swiss emission factors are used for the preparation of the Liechtenstein inventory as well, the results of the Swiss QA activities are checked and analysed by Liechtenstein's experts as well. Positive reviews may be interpreted as positive for Liechtenstein too, and problematic findings must not only be taken into account in Switzerland but also in Liechtenstein. The following sectors have already been reviewed:
    - A consulting group (not involved in the GHG emission modelling) was mandated to review the two sectors Energy and former Industrial Processes with respect to methods, activity data, emission factors, CRF tables and NID chapters (Eicher and Pauli 2006). The results were documented in a review report and communicated to Liechtenstein's Inventory Group. Regarding the topics, influencing GHG emissions, only minor issues were identified. The main issue of the Swiss inventory was the problem of insufficient transparency, which has been solved in recent years. Concerning Industrial Processes of Liechtenstein, emissions in 2F1 and 2F7 were

affected from the findings above. Other industrial processes are not occurring in Liechtenstein. The consequences for the main findings were evaluated for Liechtenstein's GHG inventory and for the NIR for submission December 2006.

- The Swiss Federal Institute of Technology (ETH) was mandated to review the methane emissions of agriculture with respect to methods, activity data and emission factors. The results were documented in two reports (Soliva 2006, 2006a) and communicated to Liechtenstein's Inventory Group. The consequences for the main findings have been evaluated for Liechtenstein's GHG inventory and for the NIR for submission December 2006.
- The waste sector of Switzerland was reviewed by a peer expert group in 2009. The reviewers concluded that waste related emissions are calculated in a plausible way and that results from the report are plausible. The emission factors as well as activity data are based on reliable and solid sources. For details see Rytec (2010). The share of fossil matter in municipal waste has been determined in an extended measuring campaign during 2011 (Mohn 2011). The consequences for the main findings had been evaluated for Liechtenstein's GHG inventory and had been accounted for in the submission April 2013.
- An expert peer review of the LULUCF sector of the Swiss GHG inventory took place in 2010. The reviewers concluded that "the LULUCF sector of the Swiss greenhouse gas inventory is proved to be of superior quality, good applicatory characteristics and scientifically sound applied definitions and methodology". For details see VTI (2011).
- Furthermore, in 2012 a Swiss national review of the former sector 2 Industrial Processes took place (CSD 2013). The final report has been evaluated and suggestions for improvement were implemented in the subsequent submissions of both, Switzerland's and Liechtenstein's, reports.
- For the Swiss NID, an annual internal review takes place shortly before the submission. Every chapter of the NID is being proofread by specialists not involved in the emission modelling or in the NID editing. The internal review is organised by the quality officer and the results are compiled by the same person that is also compiling Liechtenstein's NID (NID author F. Weber INFRAS). The results of the Swiss review are therefore communicated to Liechtenstein's Inventory Group. If methods and results are affected, which are relevant for Liechtenstein too, the consequences are taken into account accordingly. This procedure has been performed in the last and the current submissions (May and December 2006, May 2007, February 2008, April for the years 2009-2014 and April, May 2016 and April 2017, 2018, 2019,2020, 2021 and 2022). It will also be repeated for future submissions.

- The applicability of Swiss methodologies and emission factors to Liechtenstein's GHG inventory was reviewed as well: before Swiss methods were applied, they were discussed with the experts of Liechtenstein's administration. This process had taken place before the submission in December 2006 for the sectors energy, former industrial processes, former solvent and other product use, agriculture and waste, for the sector LULUCF before the submission in February 2008. Since then, the issue is a permanent point on the agenda of the annual kick-off meetings of the Inventory

Group. Potential modifications or updates of the Swiss emission factors are discussed and checked upon their applicability for Liechtenstein's GHG inventory.

- For the sector LULUCF a new external reviewer was mandated in 2012 (Meteotest 2012). The entire LULUCF sector was revised and brought in line with the IPCC methodology.

A.4.1.2 Quality control (QC) activities

General QC procedures include generic quality checks related to calculations, data processing, completeness, and documentation that are applicable to all inventory source and sink categories (IPCC 2006).

The following QC activities are carried out:

- The annual cycle for inventory preparation contains meetings of the inventory group and meetings of governmental and other data suppliers with the OE. In these meetings the activities, responsibilities and schedule for the inventory preparation process are being organised and determined.
- Regular meetings within the Office of Environment (OE) in particular between Karin Jehle (project manager) and Stefan Hassler Director of the Office of Environment/quality manager) take place. Beside technical issues also political topics are discussed. As needed, important information is referred to the department or ministry.

The project manager, also operating as the national inventory compiler (NIC), the sectoral experts, and the NID authors accomplish a number of QC activities:

- The NID authors check the emission results produced by the sectoral experts, for consistency of cross-cutting parameters, correctness of emissions aggregation, and completeness of the GHG inventory. They compare the methods used with 2006 IPCC Guidelines (IPCC 2006), check the correct compiling of the methods in the NID, the correct transcription of CRF data into NID data tables and figures, the consistency between data tables and text in the NID as well as the completeness of references in the NID. Furthermore, they are responsible for the correctness of the key source, the uncertainty analysis and the complete implementation of specific planned improvements of the inventory development plan.
- The sectoral experts check the description of methods, numbers and figures in the NID. They further incorporate recommendations by the ERT into respective text passages.
- The NIC checks the integrity of the database files, the consistency of time series, the correct and complete inputs into the CRF Reporter. A final data check is done by comparison of random data fields with the provided data modelling.
- Further staff members of the OE carry out a proof reading of single sectors.

- The project manager executes an overall checking function for the GHG inventory and the NID: monitoring of the GHG emission modelling and key category analysis. The project manager checks the NID for correctness, completeness, transparency and quality, checks for the complete archiving of documents and the completeness of the CRF submission documents.
- In order to provide an overview and to increase transparency, all authors, experts, and involved staff members of Liechtenstein's government are listed in a separate table together with specific descriptions about their responsibilities. This table is available for the entire reporting period and helps to improve the QC management in general.
- The CRF Reporting Tables for the current submission, exported from the CRF Reporter software, underwent an iterative quality control in a triple check:
    - The emissions of the year 2021 were compared with those of the year 2020 within the current Reporting Table Summary2.
    - The emissions of the year 2020 were compared between the current Reporting Table Summary2 of submission 2023 and the Reporting Table Summary2 of submission 2022.
    - The emissions of the base year 1990 were compared between the current Reporting Table Summary2 of submission 2023 and the Reporting Table Summary2 of the submission 2022.
- In the first step, the CRF Reporting Tables Summary2 are compared using Excel. For the comparable emissions and sinks the ratios in percent were calculated and the deviations from 100% were analysed. The findings due to this check were discussed among the core group members and the modelling specialists. In the second step, anomalies in data were investigated within more detailed CRF tables (e.g. Table1.A(a)s1) and explanations for those were sought. This procedure usually leads to the identification of errors in data, which are subsequently corrected before the submission.

The current NID passed several quality controls. Table 1-1 illustrates the official quality control procedure of Liechtenstein's NID. The first internal NID draft is cross-checked by the NID authors in terms of correctness, completeness, consistency and layout. The Office of environment (OE) and the emission modeller review the entire NID as external experts because experts of the OE and the emission modeller are not directly involved in updating the NID. They check the first draft of the NID in detail and provide a detailed feedback on data, interpretation, completeness, consistency, transparency and implementation of the issues given by Liechtenstein's inventory development plan. The review forms for the OE experts and the emission modeller are attached in Annex 4. Afterwards, the NID authors improve the NID considering the revisions made by the OE experts and prepare the second internal draft, which also undergoes an internal cross-check. This second NID draft again is reviewed by the OE and the emission modeller. Their inputs are implemented within the NID, too. The NID authors complete the final NID version including last internal cross-checks. The Office of Environment (OE) carries out a last check and then submits the official National Inventory Document (NID). This process guarantees the compliance of the QA/QC requirements according to the IPCC guidelines (IPCC 2006).

A.4.1.3 Switzerland's QC-plan with implications for Liechtenstein

In addition, Liechtenstein will also benefit from Switzerland's future QA activities and its QA plan. Because all important sectors were already reviewed by external experts, no future reviews are planned so far.

A4.2 Checklists for QC activities

- Checklist for project manager (PM), staff member climate unit (SC), sectoral experts (SE)
- Checklist for national inventory compiler (NIC)
- Checklist for NID authors (NA)

Table A - 3 Checklist for QC activities and for follow-up activities if necessary (table depicted on next page). The general activities are taken from IPCC 2006 Guidelines (IPCC 2006), table 6.1, the country-specific activities are ad-hoc activities. Abbr.: NA NID authors, NIC national inventory compiler, PM project manager, DFP designated focal point, SC staff member climate unit, SE sectoral experts. Member codes: ANE Anna Ehrler, BES Bettina Schäppi, BRI Beat Rihm, FEW Felix Weber, HE Hanspeter Eberle, JB Jürgen Beckbissinger, KJ Karin Jehle, MSM Markus Sommerhalder, SH Stefan Hassler.

Quality Control System for Climate Reporting Liechtenstein Submission 2022		**Respon-sible**	**Date**	**Visa**
Checklist for sectoral experts and NID authors				
Contact person:	Bettina Schäppi, INFRAS			
Telephone, e-mail:	+41 44 205 95 47, bettina.schaeppi@infras.ch			
QC general activities *(table 6.1 IPCC 2006 Guidelines)*	**Procedure *(description of checks that were carried out)***	**Respon-sible**	**Date**	**Visa**
1. Check that assumptions and criteria for the selection of activity data and emission factors are documented	Acontec-internal checks, comparison with methods chosen	SE/NIC	04.11.2022	JB, KJ
	INFRAS-internal checks, comparison with methods chosen	NA	09.11.2022	BES
2. Check for transcription errors in data input and reference	plausibility check of the basic input data for Solvent and Ind calculation	SE	11.11.2022	JB
	plausibility check of the basic input data from the LWA	SE	18.11.2022	JB
	check input Data for SF6 Emission calculation	SE	25.11.2022	JB
	check stationary Energy	NA	02.12.2022	BES
	check IPPU	NA	09.12.2022	BES
	check Waste	NA	05.12.2022	MSM
	Agriculture: Plausibility check of data in background tables Acontec. Issues identified and discussed with Acontec	SE	12.12.2022	FEW, JB
3. Check that emissions are calculated correctly	Ongoing checks of the calculated emissions in all sectors	SE	25.11.2022	JB
	Clarification of data/figures	PM	16.12.2022	BES
	INFRAS-internal control: Plausibility checks, "Delta-Analysis" combined with KCA, INFRAS-internal control of time series	NA	19.12.2022	BES, FEW

Quality Control System for Climate Reporting Liechtenstein Submission 2022		**Respon-sible**	**Date**	**Visa**
	INFRAS-internal checks during generation of tables/figure in Chapter. 2 Trends (independant control by second person BES)	SE	12.12.2022	FEW
4. Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used	check energy-activity-data (reference approach)	SE	04.11.2022	JB
	check energy-activity-data (reference approach)	NA	09.12.2022	BES
	check Energy	SE	04.11.2022	JB
	check Energy	NA	14.12.2022	BES
	check IPPU	SE	04.11.2022	JB
	check IPPU	NA	12.12.2022	BES
	check Agriculture	SE	04.11.2022	JB
	check Agriculture	NA	14.12.2022	FEW
	check LULUCF	SE	07.11.2022	JB
	check LULUCF	NA	24.11.2022	BRI
	check Waste	SE	07.11.2022	JB
	check Waste	NA	05.12.2022	MSM
5. Check the integrity of database files	integrity checked	SE	18.11.2022	JB
6. Check for consistency in data between source categories	check general data consistency	SE	18.11.2022	JB
	check Energy (stationary)	NA	09.12.2022	BES
	check Energy (mobile)	NA	12.12.2022	BES
	check IPPU	NA	12.12.2022	BES
	check Agriculture	NA	11.01.2023	FEW
	check LULUCF	NA	24.11.2022	BRI
	check Waste	NA	16.01.2023	MSM
7. Check that the movement of inventory data among processing steps is correct	Processing checked	NIC	12.12.2022	KJ
	Data transfer from the land-use statistics to the LULUCF tables and clarification of comprehensive questions with JB	SE	07.11.2022	KJ
	check Agriculture	SE	11.11.2022	JB
	plausibility check / control of overall emissions from agriculture in CO2 equivalents, in total and for the source categories for all years	SE	11.11.2022	JB
	check LULUCF	SE	12.12.2022	KJ
8. Check that uncertainties in emissions and removals are estimated or calculated correctly	check Energy	NA	11.01.2023	FEW
	check IPPU	NA	11.01.2023	FEW
	check Agriculture	NA	19.01.2023	FEW
	check Waste	NA	27.01.2023	MSM, FEW
9. Check time series consistency	check for temporal consistency in time series input data for each category.	NIC	20.01.2023	KJ
	check in the algorithm/method used for calculations throughout the time series.	NIC	20.01.2023	KJ
	check methodological and data changes resulting in recalculations.	NA	12.12.2022	BES
	check that the effects of mitigation activities have been appropriately reflected in time series calculations.	NIC	20.01.2023	KJ

Quality Control System for Climate Reporting Liechtenstein Submission 2022		Respon-sible	Date	Visa
10. Check completeness	Completeness check for all sectors	SE	25.11.2022	JB
	Completeness check for all sectors	NA	20.01.2023	BES
11. Trend checks	For each category, current inventory estimates should be compared to previous estimates, if available. If there are significant changes or departures from expected trends, re-check estimates and explain any differences. Significant changes in emissions or removals from previous years may indicate possible input or calculation errors.	NIC/SE/NA	14.12.2022	KJ, JB, FEW, BES, ANE, MSM, BRI
	Check value of implied emission factors across time series.	NIC	20.01.2023	KJ
	Check if there are any unusual and unexplained trends noticed for activity data or other parameters across the time series.	NIC/SE	12.12.2022	KJ, JB, FEW, BES, ANE, MSM, BRI
12. Review of internal documentation	Internal OE check of documentation; Clarification of open questions with SE	PM	13.12.2022	KJ
Further activities	**Procedure *(description of checks that were carried out)***	**Respon-sibles**	**Date**	**Visa**
13. Compare estimates for key categories to previous estimates	check of KCA previous/latest key categories	SE	13.12.2022	FEW, ANE
14. Compare CRF tables with previous year	check Energy	NA	02.12.2022	BES
	check IPPU	NA	05.12.2022	BES
	check Agriculture	NA	15.12.2022	FEW
	check Waste	NA	05.12.2022	MSM
	check LULUCF	NA	24.11.2022	BRI
15. Where LIE uses Swiss-specific methods: If a change in the Swiss inventory occurs, check whether the change has to be adopted for LIE or not	clarification of comprehensive questions	PM	7.11.2022	KJ
	check: Energy (stationary)	NA	05.12.2022	BES
	check: Solvents	NA	05.12.2022	BES
	Clarification of comprehensive questions in different sectors with SE	PM/NA	9.12.2022	KJ
	Two independent checks of Energy (mobile)	SE	05.12.2022	BES
	check waste	NA	16.01.2023	MSM
	check Agriculture	SE	15.12.2022	FEW
	check LULUCF	SE	13.10.2022	BRI
16. Where LIE uses Swiss-specific EF: Where changes in the Swiss EFoccur, check whether the changes are also adequate for LIE or not	Clarify the changes of emission factors in IPPU and Agriculture	SE	16.12.2022	BES
17. Check correctness of KCA, comparison with previous results	Plausibility checks of KCA	PM	09.01.2023	KJ
	cross-check within KCA with/without LULUCF 1990 and reporting year: Emissions correct, thresholds correct. Comparison with KCA of previous Submission. Plausibility checks of KCA	NA	05.12.2022	FEW, ANE
18. Check correctness of uncertainty analysis, comparison with previous results	internal plausibility checks for all sectors	NA	06.12.2022	FEW

Quality Control System for Climate Reporting Liechtenstein Submission 2022		**Respon-sible**	**Date**	**Visa**
19. Check of transcription errors CRF --> NID (numbers, tables, figures)	INFRAS internal plausibility checks	NA	10.01.2023	BES
	check waste	NA	20.01.2023	MSM
	INFRAS-internal control. Comparison of data in CRF tables and NID. For the transcription of emission data into chapters Exec. Summ., 2. Trends, X.1 Overview (in all sectors), Energy, Agriculture, a INFRAS collaborator generates figures and tables, copies them into NID and adjusts the text correspondingly. These working steps are afterwards checked by another collaborator of INFRAS.	NA	11.01.2023	BES, FEW
20. Check AD in NID and CRF and compare data with reference data sources	check waste	NA	20.01.2023	MSM
21. Check for complete and correct references in NID	INFRAS-internal checks	NA	23.01.2023	BES
22. Check for correctness, completeness, transparency and quality of NID	Proofread of complete draft NID	NA	23.01.2023	BES
	final proofread Executive Summary, feedback to KJ	NFP	3.04.2023	KJ
	final proofread inventory/NID, feedback and discussion with KJ	QM	4.04.2023	KJ
	final proofread inventory/NID, discussion with BES and JB	PM	1.04.2023	BES, KJ
	final proofread inventory/NID, feedback to KJ	SE	6.04.2023	HE
	Internal OE discussions on the inventory/NID draft with SH HE and KJ	PM	11.04.2023	KJ
	Feedback from OE internal discussions	PM	11.04.2023	KJ
	Final proofreading inventory/NID	PM	11.04.2023	KJ
23. Check for completeness of submission documents	Final check and Submission	PM/NIC NFP	14.04.2023	SH, KJ
24. Archiving activities	Archiving: INFRAS, Meteotest, save internally all data individually. NID in MS-DOC and PDF format are sent to OE. All tables in MS-EXCEL format are sent to OE for separate archiving. Compile all emails related to report and data.	NA	19.04.2023	BES, BRI
	Internal Review of documents submitted in April; all relevant documents archived	NIC	14.04.2023	KJ

A4.3 Checklists for QA activities (internal review)

Table A - 4 Checklists for QA activity internal review.

Liechtenstein's National Inventory Document
Review form for internal review of NID submission 2023

Reviewer	**Karin Jehle (KJ)**
Institution	Office of Environment
phone	+423 236 61 96
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Chapter(s) reviewed	all

NID authors	Bettina Schaeppi (BES)
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Reviewer's comments (yellow) and answers of authors (green)	
Consistency checks were made. Checks between CRF data and NID were made. Questions sent as comments.	
Comments in the text were addressed.	
Reviewers comments performed	
Date / Signum	31.03.2023 / KJ

Taken note of review	
Date / Signum	06.04.2023 / BES

If necessary: Additional comments of reviewer (yellow) and author's answers (green)

none	

Datum / Signum	13.04.2023 / KJ

Liechtenstein's National Inventory Document
Review form for internal review of NIDsubmission 2023

Reviewer	**Stefan Hassler (SH)**
Institution	Office of Environment
phone	+423 236 61 97
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Chapter(s) reviewed	ES, chp. 1

NID author	Bettina Schäppi
Institution	INFRAS
phone	+41 44 205 95 47
phone, e-mail	bettina.schaeppi@infras.ch

Reviewer's comments (yellow) and answers of authors (green)	
Double check consistency of CRF tables with data in the inventory report.	
Double check performed.	
Reviewers comments performed	
Date / Signum	31.03.2023 / SH

Taken note of review	
Date / Signum	06.04.2023 / BES

If necessary: Additional comments of reviewer (yellow) and author's answers (green)

none	

Datum / Signum	13.04.2023 / SH

Annex 5 Any additional information

A5.1 Road Transportation

Chapter 3.2.7.2 states that the of 1A3b Road transportation emissions are calculated with a Tier 2 method using Swiss implied emission factors. For CH_4 and N_2O, the country-specific implied emission factors of the Swiss GHG inventory are applied. Here some information concerning the modelling approach is provided:

The emission computation in the road transportation model is based on the following parameters (INFRAS 2017):

- 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 and vehicle stock (cold start, evaporative losses from gasoline passenger cars, light duty vehicles and motorcycles), fuel consumption per vehicle category.

Emission 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}, EF_{start}, $EF_{evap,i}$, $EF_{evap\text{-}RL}$: 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.
- Emission factors are differentiated for all fuel types: Gasoline (4-stroke), gasoline (2-stroke), diesel oil, LPG, bioethanol, biodiesel, gas (CNG), biogas.

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)), recently also complemented by measurements from RDE tests, as input. The method was developed in 1990–1995 and has been extended and updated in 2000, 2004, 2010, 2017, 2019 and latest in 2022. These emission factors are compiled in the “Handbook of Emission Factors for Road Transport” (HBEFA, see INFRAS 2022a). The latest version 4.2 – which was used for the update of the emissions in the current submission, resulting in a recalculation of the complete time series – is presented on the website (http://www.hbefa.net/) and documented in Notter et el. (2022), 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.

The export function for model results in the format required for climate reporting accounts for temporally varying fuel properties like CO_2 emission factors or heating values.

A5.2 Agriculture

Emissions of agricultural activities are estimated according to the model in the Swiss National Inventory (FOEN 2019). Detailed data for estimating emission factors are shown in the tables below.

A.5.2.1 Additional data for estimating CH_4 emissions from 3A Enteric fermentation

Table A - 5 Data for estimating enteric fermentation emission factors for cattle (for 2021).

Type	Age[a]	Weight[a]	Weight Gain[a]	Feeding Situation / Further Specification[a]	Milk[b]	Work	Pregnant[a]	Digestibility of feed	CH_4 Conversion[d]	Em. Factor
		kg	kg/day		kg/day	hrs/day	%	%[d]	%	kg/head/year[e]
Mature Dairy Cattle	0	0	0	0	18.9-24.5 c	0	305 days of lactation	72	7	139
Other Mature Cattle	319.3232256	307.202	289.13	0	8.2	0		60	7	107
Fattening Calves	229.2644652	199.83	198.43	0	0	0	0	65	0	0
Pre-Weaned Calves	5416.6	5436.4	5456.2	0	0	0	0	65	4	16
Breeding Cattle 1st Year	0	0	0	0	0	0	0	62	var	30
Breeding Cattle 2nd Year	96.69622078	90.7396	85.095	0	0	0	0	60	7	61
Breeding Cattle 3rd Year	14.40562432	12.3928	11.793	0	0	0	0	60	7	61
Fattening Cattle	75.82204611	71.8278	66.752	0	0	0	0	62	var	43

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 305 days (lactation period).
c data source: Swiss farmers union (SBV 2014).
d data source: IPCC 2006 and Zeitz et al. 2012.
e For better comparability emission factors of young cattle were converted to kg/head/year although the time span of most of the individual categories is less than 365 days.

A.5.2.2 Additional data for estimating CH4 emissions from 3B Manure management

Table A - 6 Data for estimating manure management CH_4 emission factors (for 2021).

Type	Weight kg [a]	Digestibility of Feed	Energy Intake MJ/day	Feed Intake kg/day	% Ash Dry Basis [b]	VS kg/head/day	B_0 m^3 CH_4/kg VS [b]
Mature Dairy Cattle	650	72	281 - 310	15.89 c	8.98 - 8.98	4.46 - 4.92	0.24
Other Mature Cattle	550	60	250.6	10.96 c	8	5.50	0.18
Fattening Calves	60 – 200	65	47.1	2.02 a	8	0.92	0.18
Pre-Weaned Calves	60 – 325	65	60.1	2.98 a	8	0.74	0.18
Breeding Cattle 1st Year	50 - 300	62	75.4	3.75 a	8	1.52	0.18
Breeding Cattle 2nd Year	300 - NA	60	143.6	7.78 a	8	3.15	0.18
Breeding Cattle 3rd Year	NA - 600	60	143.6	7.78 a	8	3.15	0.18
Fattening Cattle	70 - 550	62	103.7	5.64 a	8	2.19	0.18
Sheep	Not determined	60	22.5	0.90-1.47 c	8	0.40 b	0.19
Goats	Not determined	60	25.4	1.08-1.50 c	8	0.30 b	0.18
Horses	Not determined	70	108.6	7.78-7.93 c	4	1.90 b	0.33
Mules and Asses	Not determined	70	39.6	Not estimated	4	0.94 b	0.33
Swine	Not determined	75	22.5	Not estimated	2	0.31 b	0.45
Poultry	Not determined	Not estimated	1.3	Not estimated	Not estimated	0.02 b	0.39

a RAP 1999
b IPCC 1997c and IPCC 2006
c Flisch et al. 2009
d metabolizable energy (ME)

A.5.2.3 Additional data for estimating N_2O emissions from 3D Agricultural soils

Table A - 7 Data for estimating N_2O emissions from crop residues.

2021		Total crop production kg DM	Nitrogen incorporated with crop residues $F_{(CR)}$ t N	N_2O emissions from crop residues t N_2O
1. Cereals	Wheat	677’589	2.8	0.045
	Barley	259’794	1.3	0.021
	Maize	381’480	3.6	0.056
	Oats	2’758	0.02	0.00
	Rye	6’694	0.02825	0.0004439
	Other:	-	-	-
	Triticale	27’744	0.14	0.0021
	Spelt	30’830	0.28	0.0044
	Mix of Fodder Cereals	-	-	-
	Mix of Bread Cereals	2’248	0.01	0.00
	Millet	-	-	-
2. Pulse	Dry Beans	-	-	-
	Peas (Eiweisserbsen)	-	-	-
	Soybeans	-	-	-
	Leguminous Vegetables	17’393	1.8	0.028
	Lupines	-	-	-
3. Tuber and Root	Potatoes	732’007	2.7	0.042
	Other:	-	-	-
	Fodder Beet	58’450	0.42	0.007
	Sugar Beet	348’084	2.5	0.039
5. Other	Fruit	13’600	0.13	0.0020
	Grass	26’767’248	89	1.4
	Green Corn	-	-	-
	Non-Leguminous Vegetables	906’249	11	0.17
	Rape	30’461	0.52	0.008
	Renewable Energy Crops	-	-	-
	Silage Corn	6’001’030	3.5	0.056
	Sunflowers	8’441	0.179	0.00281
	Tobacco	-	-	-
	Vine	14’000	0.25	0.0039
	Oil Squash	-	-	-
	Oil Hemp	-	-	-
	Oil Flax	-	-	-
	Hops	-	-	-
	Medicinal Plants and Herbs	-	-	-
Total Non-leguminous		9’501’457	29.13	0.46
Total Leguminous		17’393	1.81	0.03
Total excluding grass		9’518’850	30.94	0.49
Total including grass		36’286’098	120.24	1.89

Table A - 8 Data for estimating N_2O emissions from crop residues (fractions).

2021		Residue/ Crop ratio kg/kg	Dry matter fraction of residue kg/kg	Nitrogen content of residues kg/kg
1. Cereals	Wheat	1.1	0.85	0.0037
	Barley	1.0	0.85	0.0051
	Maize	1.1	0.85	0.0086
	Oats	1.3	0.85	0.0049
	Rye	1.2	0.85	0.0036
	Other :	-	-	-
	Triticale	1.3	0.85	0.0039
	Spelt	1.6	0.85	0.0059
	Mix of Fodder Cereals	1.0	0.85	0.0051
	Mix of Bread Cereals	1.1	0.85	0.0037
	Millet	1.3	0.85	0.020
2. Pulse	Dry Beans	1.1	0.85	0.035
	Peas (Eiweisserbsen)	1.3	0.85	0.024
	Soybeans	1.0	0.85	0.041
	Leguminous Vegetables	3.9	0.16	0.033
	Lupines	1.0	0.85	0.041
3. Tuber and Root	Potatoes	0.47	0.13	0.013
	Other :	-	-	-
	Fodder Beet	0.37	0.15	0.023
	Sugar Beet	0.53	0.15	0.022
5. Other	Fruit	NA	0.17	0.0040
	Grass	0.32	NA	0.020
	Green Corn	0.053	0.32	0.019
	Non-Leguminous Vegetables	0.46	0.13	0.023
	Rape	2.6	0.85	0.0071
	Renewable Energy Crops	2.6	0.85	0.0071
	Silage Corn	0.053	0.32	0.012
	Sunflowers	2.0	0.60	0.015
	Tobacco	1.2	NA	0.022
	Vine	NA	0.20	0.0060
	Oil Squash	0.46	0.13	0.023
	Oil Hemp	4.6	0.85	0.011
	Oil Flax	1.3	0.85	0.0071
	Hops	NA	1.0	NA
	Medicinal Plants and Herbs	2.5	NA	0.033

A5.3 2F Product uses as ODS substitutes and 2G N_2O from Product use

Emissions of F-gases from source category 2F and N_2O emissions from source category 2G are calculated based on specific emission factors derived from emissions reported in Switzerland's GHG inventory 2022 (FOEN 2022) and conversion factors that are derived from proxy data, such as number of households, passenger cars, inhabitants and employees in the second and third sector (see Table 4-9 and Table 4-10). The conversion factors shown in Figure A - 1 correspond to the ratio of these proxy data between Liechtenstein and Switzerland. So, if the relative increase in Liechtenstein's and Switzerland's proxy data is identical, the conversion factor remains constant. If the increasing trend in Switzerland is stronger as compared to Liechtenstein (e.g. number of passenger cars 2005-2006), the conversion factor is reduced. Therefore, the resulting trend in emissions is not directly proportional to the trend in the emissions reported in the Swiss GHG inventory (FOEN 2022).

Therefore, the overall trend depends on both the evolution of these conversion factors as well as evolution of emissions of F-gases in Switzerland (FOEN 2022).

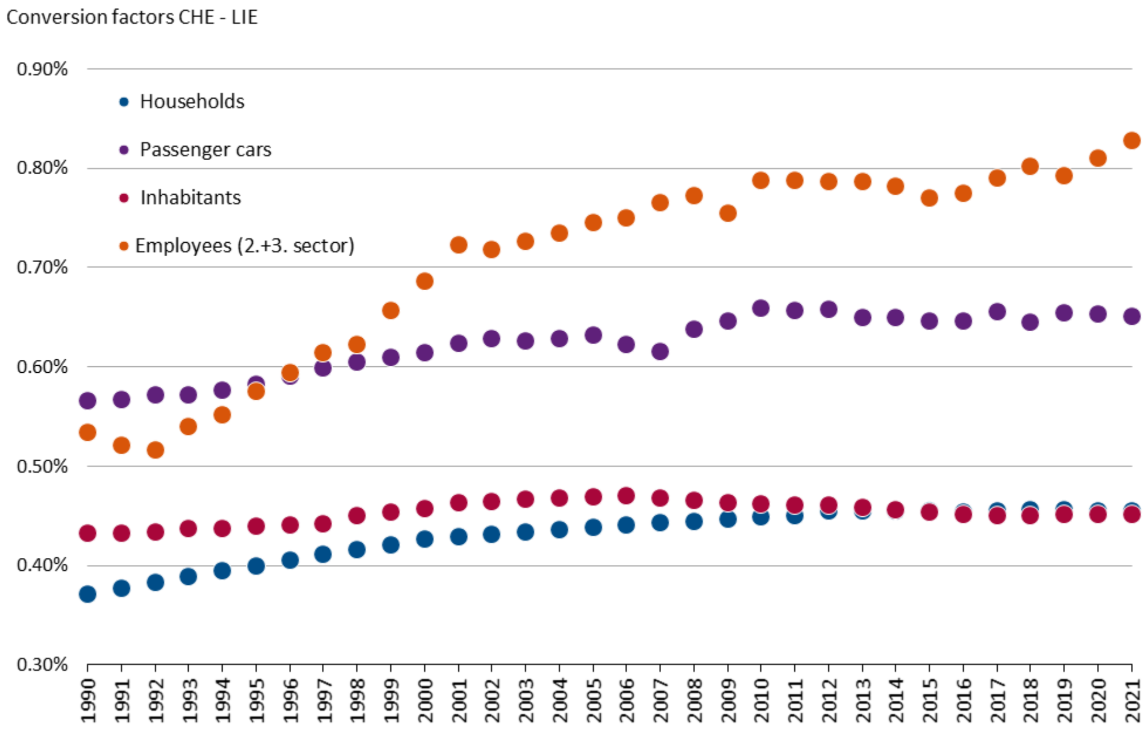

Figure A - 1 Conversion factors used to derive emissions in Liechtenstein from emissions reported in Switzerland's national GHG inventory 2022.

A5.4 Additional information on sewage sludge prohibition

As described in chapter 5.5 for source category 3D Agricultural soils, the use of sewage sludge as fertiliser is prohibited in Liechtenstein. The corresponding regulation (in German only) is given below:

814.201

Liechtensteinisches Landesgesetzblatt

Jahrgang 1997 Nr. 42 ausgegeben am 5. Februar 1997

Verordnung
vom 17. Dezember 1996
zum Gewässerschutzgesetz (GSchV)

Aufgrund von Art. 8 Abs. 1 und 2, Art. 16, 24 Abs. 3 und Art. 67 des Gewässerschutzgesetzes (GSchG) vom 15. Mai 2003, LGBl. 2003 Nr. 159[2], verordnet die Regierung:[3]

V. Klärschlamm[47]

Art. 35a[48]

Düngeverbot

Klärschlamm darf nicht als Dünger verwendet werden.

Art. 36

Klärschlamm-Entsorgungsplan

1) Die Inhaber von Abwasserreinigungsanlagen erstellen einen Klärschlamm-Entsorgungsplan und passen ihn in den fachlich gebotenen Zeitabständen den neuen Erfordernissen an.[49]

2) Der Klärschlamm-Entsorgungsplan legt mindestens fest:

a) wie der Klärschlamm der Abwasserreinigungsanlagen entsorgt werden soll;

b) welche Massnahmen, einschliesslich der Erstellung und Änderung von Anlagen, die der Entsorgung des Klärschlamms dienen, erforderlich sind und bis zu welchem Zeitpunkt diese umgesetzt werden.[50]

3) Der Klärschlamm-Entsorgungsplan ist dem Amt für Umwelt zur Genehmigung zu übermitteln.[51]

Annex 6 Common reporting tables

Reporting tables in the common reporting format (CRF) as created by the CRF Reporter v6.0.10_AR5 (released in January 2023) using GWP values from the Fifth Assessment Report (AR5) of the IPCC (Myhre et al. 2013) have been submitted for the years 1990–2021.

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