OFFICE OF ENVIRONMENT
PRINCIPALITY OF LIECHTENSTEIN

# Liechtenstein's Greenhouse Gas Inventory 1990 - 2019

## National Inventory Report 2021

Submission of 15 April 2021
under the United Nations Framework Convention on Climate Change
and under the Kyoto Protocol

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## National Inventory Report 2021

Submission of April 2021 under the United Nations Framework Convention on Climate Change (UNFCCC) and the second commitment period (CP2) under the Kyoto Protocol


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# Glossary

| | |
|---|---|
| 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 |
| $CO_2$, ($CO_2$eq) | 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 | Global Warming Potential |
| 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 |
| NIR | National Inventory Report |
| 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 climate change, greenhouse gas inventories and supplementary information required under Art. 7.1. KP

### 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 in 2004, Liechtenstein ratified the Kyoto Protocol to the UNFCCC. A National Inventory System (NIS) according to Article 5.1 of the Kyoto Protocol has been implemented. 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.

In 1995, 1998, 2002, 2006, 2010, 2014 and 2017 Liechtenstein submitted its National Communication Reports to the secretariat of the UNFCCC as well as Biennial Reports in 2013, 2016, 2017 and 2019. Also, a first Greenhouse Gas Inventory (without National Inventory Report) was submitted in the Common Reporting Format (CRF) in 2005. In 2006, two submissions took place, the first on May 31, including the national greenhouse gas inventory for 1990 and 2004, as well as the National Inventory Report (NIR). The second submission on 22 December 2006 contained the national greenhouse gas inventory for the full-time period 1990–2004, National Inventory Report and the Initial Report under Article 7, paragraph 4 of the Kyoto Protocol (OEP 2006, 2006a, 2007a). In May 2007, the GHG inventory 1990–2005 was submitted together with the National Inventory Report (OEP 2007). In February 2008, in April 2009, 2010, 2011, 2012, 2013, 2014, 2016, in May 2016 and in April 2017, 2018, 2019, 2020, the further GHG inventories 1990–2006, 1990-2007, 1990-2008, 1990-2009, 1990-2010, 1990-2011, 1990-2012, 1990-2013, 1990-2014 and 1990-2015, 1990-2016, 1990-2017 and 1990-2018 were submitted together with the National Inventory Report (OEP 2008, 2009, 2010, 2011, 2012b, OE 2013, 2014, 2016a, 2016c, 2017, 2018, 2019, 2020). The present report is Liechtenstein's 16th National Inventory Report, NIR 2021, prepared under the UNFCCC and under the Kyoto Protocol. It includes, as a separate document, Liechtenstein's 1990–2019 Inventory in the CRF. Furthermore, the Standard Electronic Format application (SEF) is submitted along with the NIR 2021, providing an annual account of Kyoto units traded in the respective year.

From 11 to 15 June 2007 an individual review (in-country review) took place in Vaduz: The submission documents, the Initial Report and the GHG inventory 1990-2004 including CRF tables and National Inventory Report were objects of the review (FCCC/ARR 2007). Following the recommendations of the expert review team, some minor corrections were carried out in the emission modelling leading to recalculations and some methodological changes (revision of the definition of forests). Due to the recalculation, the time series of the national total of emissions did slightly change and therefore, Liechtenstein's assigned amount has been adjusted by -0.407%. After this correction, Liechtenstein's assigned amount corresponded to 1'055.623 kt $CO_2$ equivalents.

In September 2008, 2009, 2010, 2011 and 2012, centralized reviews of Liechtenstein's GHG inventories and NIRs of 2007/2008, 2009, 2010, 2011 and 2012 took place in Bonn, Germany. Again, a number of recommendations were addressed to Liechtenstein, which were accounted for in subsequent submissions (FCCC/ARR 2009, 2010, 2010a, 2011, 2012).

Between 2 and 6 September 2013 a second individual (in-country) review took place in Vaduz. The submission documents, GHG inventory 1990-2011 including CRF tables and the National Inventory Report were scrutinized during the review. Following the recommendations of the Expert Review Team (ERT), numerous improvements were implemented in the 2014 submission. Amongst others, this included methodological changes where data was delineated from the Swiss inventory (sectors Energy, Industrial Processes and Solvents) and complementation of text in the NIR for transparency reasons. The recommendations by the ERT are documented in the report of the individual review of the greenhouse gas inventory of Liechtenstein submitted in 2013 (FCCC/ARR 2013).

Further centralized reviews took place in 2014, 2016 and 2018 (FCC/ARR 2014, 2015, 2016, 2018) - in September 2016, the review concerned the two submissions of 2015 and

2016 simultaneously. The latest centralized review took place in September 2020. The review report was not available at the time the greenhouse gas inventory and the NIR were elaborated. The current IDP shows the status of implementation for the preliminary findings of the review in 2020 (see also Annex A8.3, Table A - 9). Note that for the 2017 and 2019 submission, no separate review was conducted due to lack of UNFCCC's resources for reviewing all national inventories.

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. It 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 as well as of the revised supplementary methods and good practice guidance arising from the Kyoto Protocol (IPCC 2014). 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 Report** follows in its structure the default chapters of the "UNFCCC reporting guidelines on annual greenhouse gas inventories" (UNFCCC 2014).

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 38'749 inhabitants (2019) 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.1.3 Background information on supplementary information required under Article 7.1. of the Kyoto Protocol (KP)

Chapter 11 of this NIR and Liechtenstein's Second Initial Report under the Kyoto Protocol (Government 2016) provide information on KP-LULUCF.

Liechtenstein only accounts for the mandatory activity Forest Management under Article 3, paragraph 4 of the Kyoto Protocol. In accordance with Annex I to Decision 2/CMP.7 (Annex I, Para 13), credits from Forest Management are capped in the second commitment period. Thus, for Liechtenstein the cap amounts to 3.5% of the 1990 emissions (excluding LULUCF).

Liechtenstein has chosen to account over the entire commitment period for emissions and removals from activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol. In addition to the mandatory submission of the inventory years 2013, 2014, 2015, 2016, 2017, 2018 and 2019, data for the years 2008-2012 are available and shown in Liechtenstein's NIR.

# ES.2 Summary of national emission and removal-related trends as well as emissions and removals from KP-LULUCF activities

## ES.2.1 GHG inventory

**National total emissions**

Liechtenstein's greenhouse gas emissions in the year 2019 amount to 187.1 kt $CO_2$ equivalent ($CO_2$eq) excluding LULUCF sources or sinks (including LULUCF: 198.9 kt $CO_2$eq). This refers to 4.95 t $CO_2$eq per capita.

Total emissions in 2019 (excl. LULUCF) have declined by 18.1% compared to 1990. Compared to 2018, they increased by 3.6%. When including LULUCF categories, total emissions decreased by 1.8% between 2018-2019 and by 15.5% between 1990-2019.

**Key category analysis (KCA)**

For 2019, 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 96.4% of the national total emissions. The three major sources, all from the energy sector, sum up to a contribution of 64.5% 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, 20 among 223 categories are key. Six of the key categories are from the LULUCF sector.

**Uncertainties**

Uncertainty analyses with Approach 1 are carried out and presented in chp. 1.6.1.3.

- Uncertainty of national total $CO_2$eq emissions **excluding LULUCF:**
  The Approach 1 level uncertainty for the year 2019 is estimated to be 5.43%, trend uncertainty (1990-2019) is 5.14% (see Table 1-8). The level uncertainty for the year 1990 amounts 7.11% (see Table 1-9).
- Uncertainty of national total $CO_2$eq emissions **including LULUCF**:
  The Approach 1 level uncertainty for the year 2019 is estimated to be 5.27%, trend uncertainty (1990-2019) is 4.94% (see Table 1-10). The level uncertainty for the year 1990 amounts 7.02% (see Table 1-11).

**Recalculations**

Some emissions have been recalculated due to updates in respective sectors. The results are discussed in Chapter 10. For the base year 1990, the recalculations carried out in submission 2020 lead to an increase of 0.053% in the national total emissions (excluding LULUCF categories). The national total emissions of the year 2018 decreased by 0.21% due to the recalculations (excluding LULUCF categories).

## ES.2.2 KP-LULUCF activities

Liechtenstein reports LULUCF activities afforestation and reforestation, deforestation, forest management including the forest management reference level (FMRL) and harvested wood products (HWP) from forest management. ES Table 1 shows the result for the KP-LULUCF Inventory in year 2019. The net $CO_2$eq emissions add up to 5.04 kt. The corrected forest management reference level 2013-2020 is 0.36 kt $CO_2$eq. The level uncertainty (Approach 1) is estimated at ± 2.66 kt $CO_2$eq.

ES Table 1 Summary table afforestation and reforestation, deforestation, forest management and HWP. FMRL: Forest Management Reference Level, incl. technical corrections.

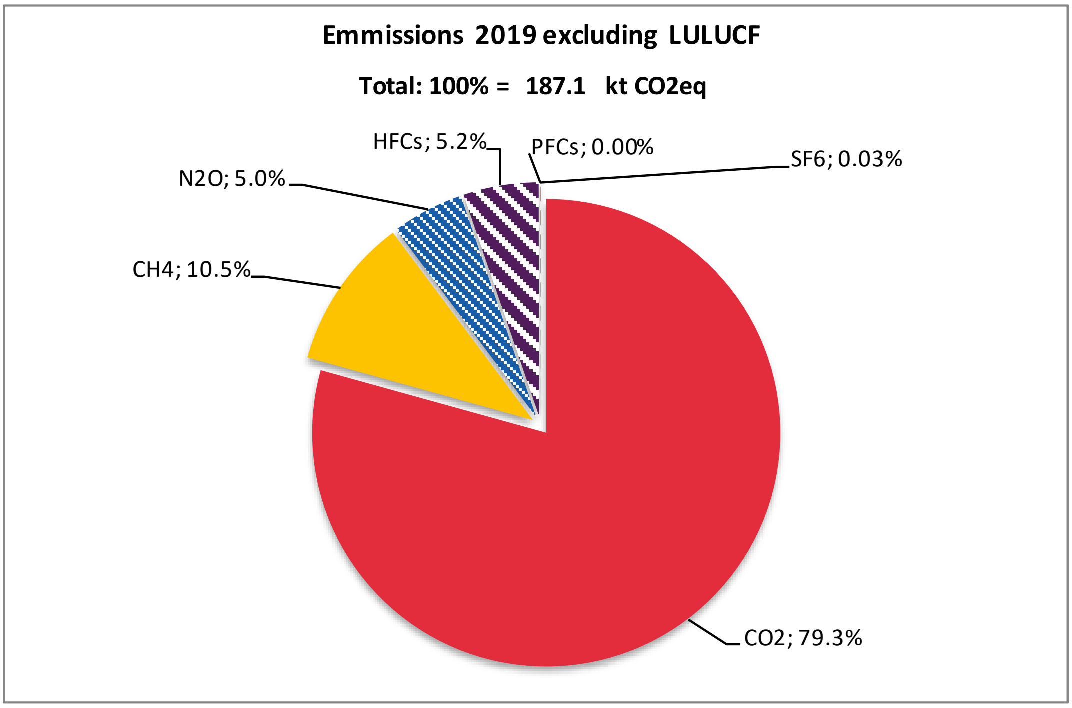
| **Activity, year 2019** | **Area** kha | **Net $CO_2$ emission/removal** kt $CO_2$ | **$N_2O$ emission** kt $N_2O$ | **Net $CO_2$ eq emission/removal** kt $CO_2$ eq |
|---|---|---|---|---|
| A.1 Afforestation | 0.036 | -0.35 | NO | -0.35 |
| A.2 Deforestation | 0.248 | 4.39 | 0.00024 | 4.46 |
| B.1 Forest managment (FM) | 6.223 | 0.75 | NO | 0.75 |
| 4.C HWP from FM | --- | 0.18 | NO | 0.18 |
| Total emission/removal | | 4.97 | 0.00024 | 5.04 |
| B.1.1 FMRL 2013-2020 | --- | | | 0.36 |

*FMRL: Forest Management Reference Level, incl. Technical corrections*

# ES.3. Overview of source and sink category emission estimates and trends including KP-LULUCF activities

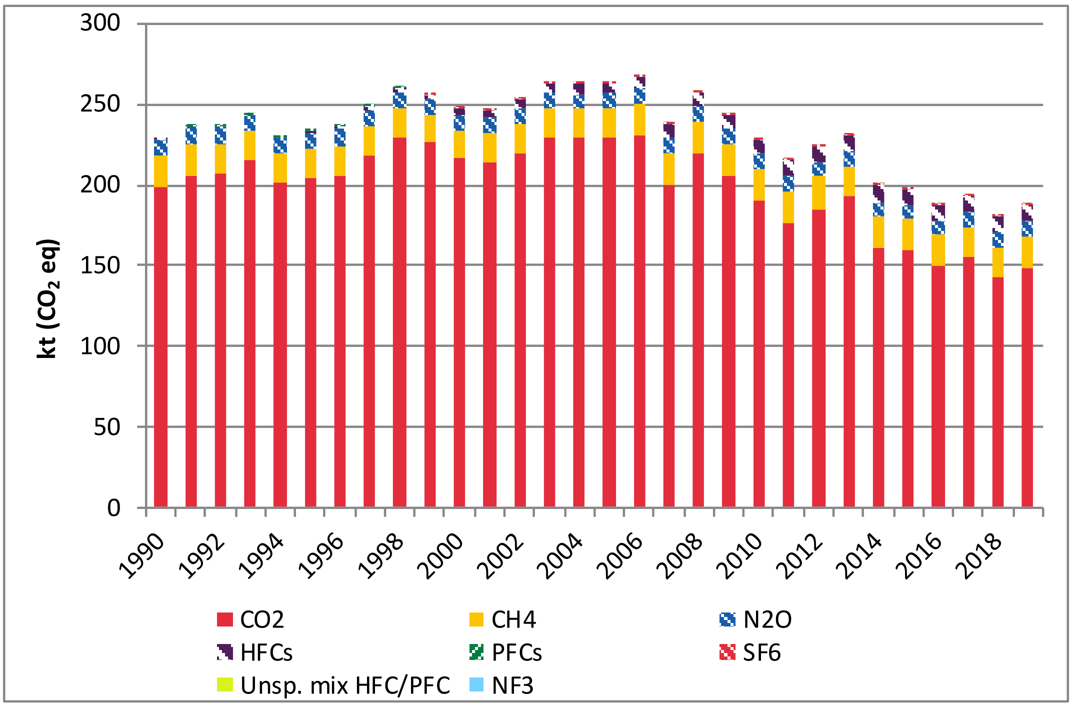
## ES.3.1 GHG inventory

ES Figure 1 shows the emissions in 2019 by GHG. The main GHG is $CO_2$ with a share of 79.3%. $CH_4$ and $N_2O$ contribute with 10.4% and 5.0%, F-gases with about 5.2%, 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. After increasing emissions between 1990 and 1998, the emissions fluctuate between 1998 and 2006 without any significant trend. After 2006, emissions show a decreasing trend while still showing fluctuations driven by the varying temperatures of winter seasons and fuel prices. In 2019, emissions have slightly increased compared to the previous year 2018 (when 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.

Over the period 1990-2019, the share of $CO_2$ (excl. LULUCF) decreased between 1990 (87.1%) and 2019 (79.3%). The share of $CH_4$ increased from 8.4% in 1990 to 10.5% in 2019. Simultaneously, the share of $N_2O$ slightly increased from 4.5% (1990) to 5.0% (2019) and the share of F-gases clearly increased from 0.0% (1990) to 5.2% (2019). See ES Table 2 for further information.

ES Table 3 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 2019. Emissions caused within the energy sector decreased by 25.0% over the period 1990-2019. The emissions from sector 2 Industrial processes and product use increased by a factor of about 15 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 are 1.6% below the level of 1990. Emissions and removals in the sector 4 LULUCF form a net source in 2019 and show an increase of 68.9% compared to 1990. The emissions from sector 5 Waste have decreased 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 2 Summary of Liechtenstein's GHG emissions in $CO_2$eq (kt) by gas. The last column shows the percentage change in emissions in 2019 as compared to the base year 1990. HFC emissions have increased by about a factor of 100'000 in 2019 compared to 1990.

| **Greenhouse Gas Emissions** | **1990** | **1995** | **2000** | **2005** | **2010** |
|---|---|---|---|---|---|
| | **$CO_2$ equivalent (kt)** | | | | |
| $CO_2$ emissions incl. net $CO_2$ from LULUCF | 205.6 | 208.6 | 241.0 | 237.3 | 210.7 |
| $CO_2$ emissions excl. net $CO_2$ from LULUCF | 199.0 | 204.2 | 216.8 | 229.0 | 190.8 |
| $CH_4$ emissions incl. $CH_4$ from LULUCF | 19.2 | 18.0 | 16.7 | 18.6 | 19.1 |
| $CH_4$ emissions excl. $CH_4$ from LULUCF | 19.2 | 18.0 | 16.7 | 18.6 | 19.1 |
| $N_2O$ emissions incl. $N_2O$ from LULUCF | 10.6 | 10.5 | 9.8 | 9.5 | 9.7 |
| $N_2O$ emissions excl. $N_2O$ from LULUCF | 10.3 | 10.2 | 9.5 | 9.1 | 9.3 |
| HFCs | 0.0 | 1.2 | 3.9 | 6.7 | 9.0 |
| 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)** | 235.5 | 238.3 | 271.6 | 272.4 | 248.5 |
| **Total (excluding LULUCF)** | 228.5 | 233.6 | 247.0 | 263.7 | 228.2 |

| **Greenhouse Gas Emissions** | **2011** | **2012** | **2013** | **2014** | **2015** |
|---|---|---|---|---|---|
| | **$CO_2$ equivalent (kt)** | | | | |
| $CO_2$ emissions incl. net $CO_2$ from LULUCF | 200.4 | 209.2 | 209.0 | 177.6 | 170.8 |
| $CO_2$ emissions excl. net $CO_2$ from LULUCF | 176.7 | 185.3 | 192.5 | 161.2 | 159.6 |
| $CH_4$ emissions incl. $CH_4$ from LULUCF | 19.4 | 19.8 | 19.0 | 19.2 | 19.1 |
| $CH_4$ emissions excl. $CH_4$ from LULUCF | 19.4 | 19.8 | 19.0 | 19.2 | 19.1 |
| $N_2O$ emissions incl. $N_2O$ from LULUCF | 10.1 | 10.0 | 9.7 | 9.6 | 9.6 |
| $N_2O$ emissions excl. $N_2O$ from LULUCF | 9.7 | 9.5 | 9.2 | 9.1 | 9.2 |
| HFCs | 9.4 | 9.8 | 9.8 | 10.0 | 10.1 |
| PFCs | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| $SF_6$ | 0.0 | 0.0 | 0.2 | 0.1 | 0.0 |
| Unspecified mix of HFCs and PFCs | NO | NO | NO | NO | NO |
| $NF_3$ | NO | NO | NO | NO | NO |
| **Total (including LULUCF)** | **239.4** | **248.9** | **247.6** | **216.5** | **209.6** |
| **Total (excluding LULUCF)** | **215.3** | **224.5** | **230.7** | **199.7** | **198.0** |

| **Greenhouse Gas Emissions** | **2016** | **2017** | **2018** | **2019** | **1990-2019** |
|---|---|---|---|---|---|
| | **$CO_2$ equivalent (kt)** | | | | **%** |
| $CO_2$ emissions incl. net $CO_2$ from LULUCF | 158.9 | 165.9 | 163.6 | 159.8 | -22% |
| $CO_2$ emissions excl. net $CO_2$ from LULUCF | 149.5 | 155.3 | 142.3 | 148.4 | -25% |
| $CH_4$ emissions incl. $CH_4$ from LULUCF | 19.2 | 18.7 | 18.9 | 19.6 | 2% |
| $CH_4$ emissions excl. $CH_4$ from LULUCF | 19.2 | 18.7 | 18.9 | 19.6 | 2% |
| $N_2O$ emissions incl. $N_2O$ from LULUCF | 9.5 | 9.4 | 9.6 | 9.7 | -8% |
| $N_2O$ emissions excl. $N_2O$ from LULUCF | 9.0 | 9.0 | 9.2 | 9.3 | -10% |
| HFCs | 9.8 | 10.0 | 10.2 | 9.7 | see caption |
| PFCs | 0.0 | 0.0 | 0.0 | 0.0 | - |
| $SF_6$ | 0.0 | 0.0 | 0.1 | 0.0 | - |
| Unspecified mix of HFCs and PFCs | NO | NO | NO | NO | - |
| $NF_3$ | NO | NO | NO | NO | - |
| **Total (including LULUCF)** | **197.3** | **204.1** | **202.4** | **198.9** | **-16%** |
| **Total (excluding LULUCF)** | **187.5** | **193.0** | **180.7** | **187.1** | **-18%** |

ES Table 3 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 2019 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** | **217.9** | **203.9** | **207.1** | **208.9** | **221.5** | **232.4** | **229.7** |
| 1A1 Energy industries | 0.2 | 0.9 | 1.9 | 2.0 | 1.8 | 2.1 | 2.6 | 2.5 | 2.9 | 2.9 |
| 1A2 Manufacturing industries & constr. | 36.3 | 36.0 | 36.4 | 37.6 | 35.7 | 35.7 | 35.8 | 37.6 | 40.4 | 39.9 |
| 1A3 Transport | 76.9 | 90.2 | 89.6 | 87.5 | 80.1 | 82.1 | 83.4 | 87.0 | 86.6 | 90.8 |
| 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 | 0.4 | 0.5 | 0.5 | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 | 0.8 |
| **2 IPPU** | **0.7** | **0.6** | **0.7** | **0.8** | **1.0** | **1.8** | **2.1** | **2.4** | **3.0** | **3.6** |
| **3 Agriculture** | **24.9** | **24.9** | **24.2** | **23.1** | **23.3** | **23.1** | **23.3** | **22.9** | **22.5** | **21.5** |
| **5 Waste** | **1.7** | **1.6** | **1.7** | **1.6** | **1.6** | **1.6** | **1.6** | **1.6** | **1.6** | **1.6** |
| ***Total (excluding LULUCF)*** | ***228.5*** | ***236.1*** | ***236.3*** | ***243.4*** | ***229.8*** | ***233.6*** | ***235.9*** | ***248.5*** | ***259.4*** | ***256.4*** |
| **4 LULUCF** | **7.0** | **-8.7** | **2.2** | **-1.1** | **18.0** | **4.7** | **-3.5** | **7.8** | **0.2** | **-0.9** |
| ***Total (including LULUCF)*** | ***235.5*** | ***227.4*** | ***238.4*** | ***242.3*** | ***247.8*** | ***238.3*** | ***232.4*** | ***256.3*** | ***259.6*** | ***255.5*** |

| Source and Sink Categories | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | | | | | | |
| **1 Energy** | **220.1** | **217.8** | **223.0** | **232.3** | **231.9** | **231.5** | **233.6** | **203.3** | **222.1** | **208.0** |
| 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 industries & constr. | 36.5 | 36.4 | 37.9 | 41.2 | 39.9 | 39.2 | 40.6 | 33.9 | 36.4 | 27.6 |
| 1A3 Transport | 91.6 | 88.2 | 84.1 | 83.8 | 82.2 | 81.8 | 79.2 | 83.3 | 87.8 | 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 | 0.8 | 0.9 | 0.9 | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 | 1.2 | 1.1 |
| **2 IPPU** | **4.4** | **5.2** | **5.9** | **6.6** | **7.3** | **7.5** | **7.9** | **8.8** | **9.4** | **9.0** |
| **3 Agriculture** | **20.9** | **21.9** | **22.3** | **22.5** | **22.5** | **23.1** | **24.1** | **24.4** | **24.7** | **24.5** |
| **5 Waste** | **1.6** | **1.7** | **1.7** | **1.7** | **1.7** | **1.7** | **1.6** | **1.6** | **1.6** | **1.6** |
| ***Total (excluding LULUCF)*** | ***247.0*** | ***246.6*** | ***252.9*** | ***263.1*** | ***263.3*** | ***263.7*** | ***267.3*** | ***238.1*** | ***257.9*** | ***243.1*** |
| **4 LULUCF** | **24.5** | **1.6** | **2.5** | **6.5** | **8.7** | **8.8** | **13.5** | **22.6** | **24.7** | **21.8** |
| ***Total (including LULUCF)*** | ***271.6*** | ***248.2*** | ***255.5*** | ***269.6*** | ***272.0*** | ***272.4*** | ***280.8*** | ***260.7*** | ***282.6*** | ***264.9*** |

| Source and Sink Categories | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 1990-2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | | | | | | | % |
| **1 Energy** | **193.4** | **179.3** | **187.9** | **195.1** | **163.6** | **162.1** | **152.0** | **157.8** | **144.8** | **150.9** | **-25.0%** |
| 1A1 Energy industries | 3.3 | 3.1 | 2.8 | 3.0 | 2.5 | 2.0 | 2.2 | 2.1 | 2.2 | 3.4 | 1844.0% |
| 1A2 Manufacturing industries & constr. | 26.1 | 23.6 | 25.7 | 26.4 | 27.4 | 27.6 | 26.0 | 27.7 | 24.6 | 24.1 | -33.7% |
| 1A3 Transport | 77.7 | 76.9 | 79.9 | 79.6 | 73.7 | 61.7 | 60.2 | 60.4 | 58.3 | 56.8 | -26.1% |
| 1A4 Other sectors | 85.2 | 74.7 | 78.3 | 84.9 | 58.9 | 69.5 | 62.5 | 66.4 | 58.6 | 65.4 | -25.3% |
| 1A5 Other | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | - |
| 1B Fugitive emissions from fuels | 1.1 | 1.1 | 1.1 | 1.2 | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 225.6% |
| **2 IPPU** | **9.4** | **9.9** | **10.2** | **10.3** | **10.5** | **10.5** | **10.1** | **10.4** | **10.5** | **10.0** | **1432.3%** |
| **3 Agriculture** | **23.7** | **24.5** | **24.8** | **23.6** | **24.0** | **23.9** | **23.9** | **23.3** | **23.7** | **24.5** | **-1.6%** |
| **5 Waste** | **1.6** | **1.7** | **1.6** | **1.7** | **1.6** | **1.6** | **1.6** | **1.6** | **1.6** | **1.6** | **-2.4%** |
| ***Total (excluding LULUCF)*** | ***228.2*** | ***215.3*** | ***224.5*** | ***230.7*** | ***199.7*** | ***198.0*** | ***187.5*** | ***193.0*** | ***180.7*** | ***187.1*** | ***-18.1%*** |
| **4 LULUCF** | **20.4** | **24.1** | **24.4** | **16.9** | **16.8** | **11.6** | **9.8** | **11.1** | **21.7** | **11.8** | **68.9%** |
| ***Total (including LULUCF)*** | ***248.5*** | ***239.4*** | ***248.9*** | ***247.6*** | ***216.5*** | ***209.6*** | ***197.3*** | ***204.1*** | ***202.4*** | ***198.9*** | ***-15.5%*** |

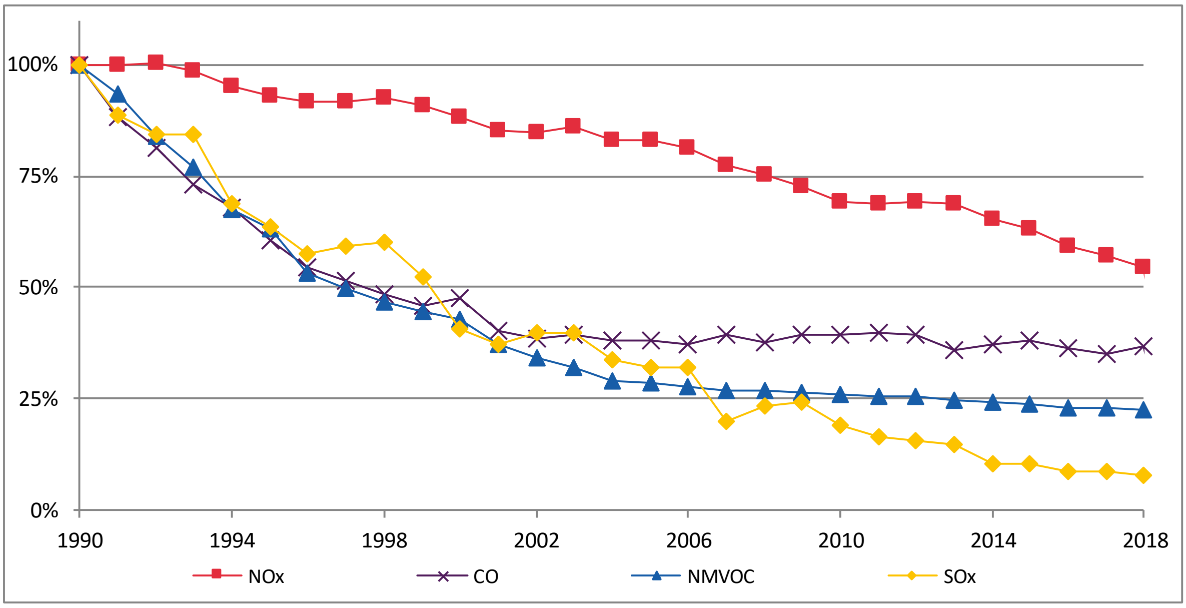
## ES.3.2 KP-LULUCF activities

See ES 2.2 for KP-LULUCF overview.

## 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 2021 will take place at the end of April 2021, and **the overview and results provided below stem from the submission to CLRTAP in 2020** (OE 2020f). Therefore, results for 2019 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 2020). 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 2020 (OE 2020f).

# 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 NIR.

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), Swiss Helicopter AG, Swiss Federal Office of Civil Aviation (FOCA), Swiss Federal Office for the Environment (FOEN), the sectoral experts and the NIR authors. Their effort made it possible to finalise the inventory and the NIR 2021.

# PART 1: Annual inventory submission under the UNFCCC

# 1. Introduction

## 1.1 Background information on Liechtenstein's greenhouse gas inventory, climate change and supplementary information of the Kyoto Protocol (KP)

### 1.1.1 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, "Climate Scenarios for Switzerland" (NCCS 2018) were published. They are more detailed as compared to previous studies. They are especially much more differentiated regionally.

The development so far 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 CH2014-Impacts 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, 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). 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.

#### 1.1.1.1 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) currently is 10.1°C (MeteoSwiss 2015a) for the reference period 1981-2010. The mean annual temperature increased by 0.7°C compared to the reference period 1961-1990 (MeteoSwiss 2015b). Figure 1-1 shows a time series of deviation from mean temperature in Liechtenstein between 1901 and 2019. The symbols are maps of Liechtenstein (details see Figure 1-5) for each year.

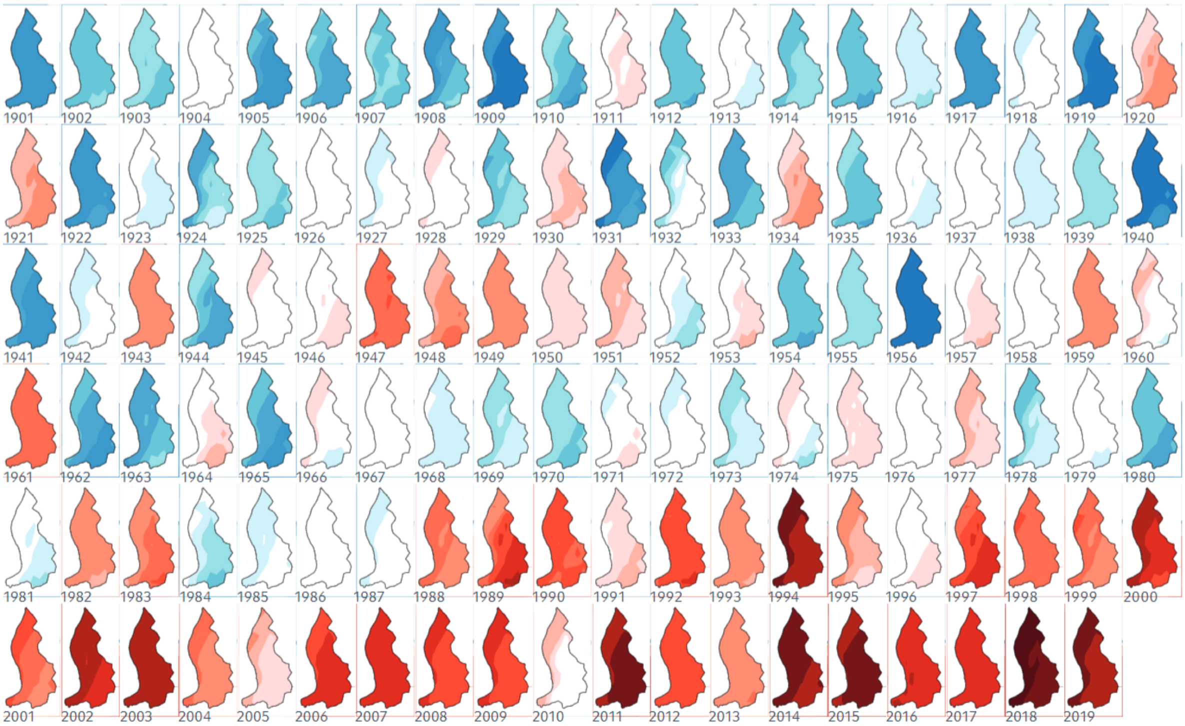



Figure 1-1 Deviation from mean annual temperature (mean of 1961-1990) in the principality of Liechtenstein between 1901 and 2019. Positive deviations are marked in red (max. +2.5°C), negative deviations in blue (min -2.5°C). Data: OE (2020h).

For the Principality of Liechtenstein there are actually no very long series of temperature measurements. However, there two stations in Switzerland close to the border to Liechenstein, Sargans (3 km up the Rhine valley from the border) and Bad Ragaz (5 km from the border). Since Liechtenstein has its own measuring station in Vaduz (1971), the temperature series are compared with those of Sargans and Bad Ragaz, and they all show high similarity. Since the beginning of the measurements in 1871, the temperature in Sargans and Bad Ragaz 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[1] reduced from

[1] Frosty day: Temperature falls below 0°C.

around 90 to around 80. These results hold with high probability also for Liechtenstein's valley regions. 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 increase and has been observed in the other Alpine countries as well. Associated with warming the zero-degree limit 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).

According to the Swiss Climate Change Scenarios CH2018 (NCCS 2018), the future climate of Liechtenstein is expected to change significantly from 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 1-3 illustrates the past and expected future changes in seasonal mean temperature over north-eastern Switzerland.

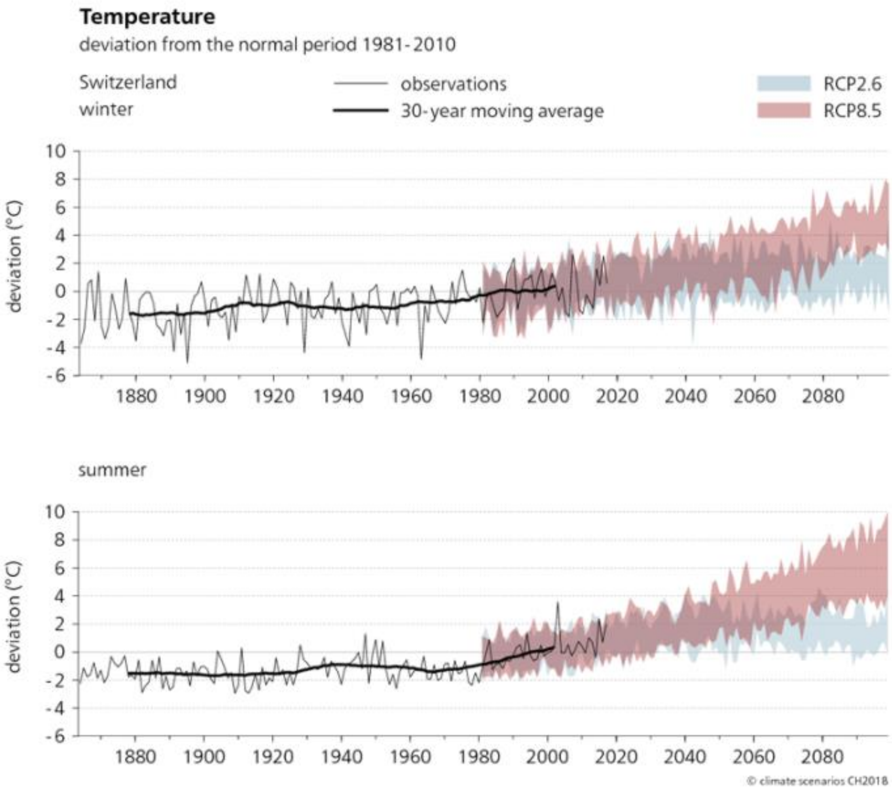



Figure 1-2 Past and expected future changes in seasonal temperature (°C) over north-eastern Switzerland for the scenario RCP2.6 (with mitigation measures) and RCP8.5 (without mitigation measures). The changes are depicted relative to the reference period 1981-2010 (from NCCS 2018).

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 1-3).

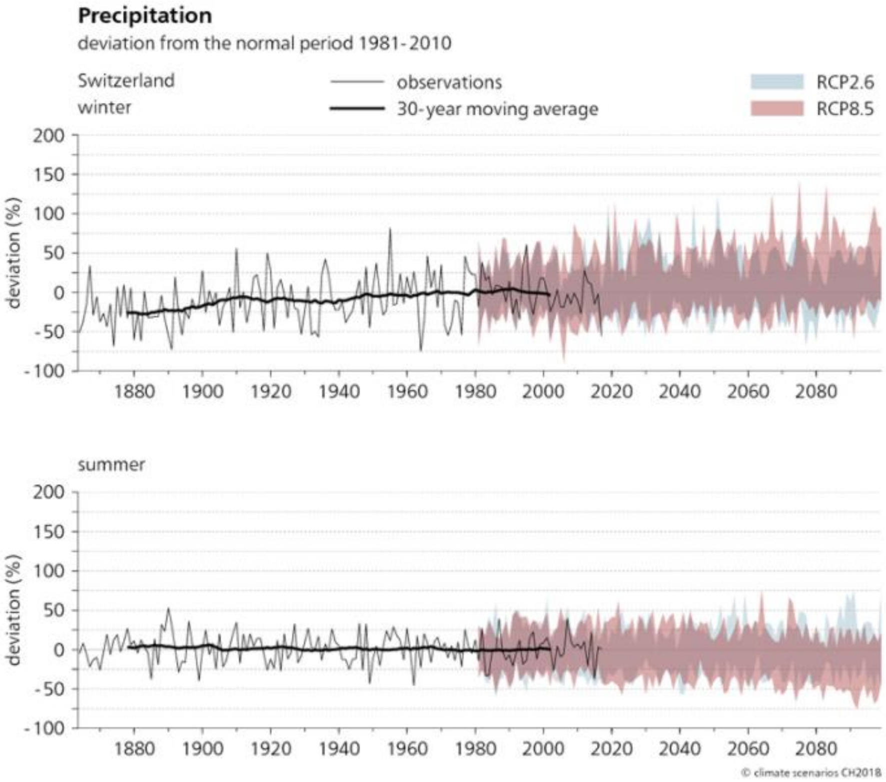



Figure 1-3 Past and expected future changes in seasonal precipitation (%) over north-eastern Switzerland for the scenario RCP2.6 (with mitigation measures) and RCP8.5 (without mitigation measures). The changes are depicted relative to the reference period 1981-2010 (from NCCS 2018).

For the year 2085, the expected changes in annual mean temperature and precipitation are represented in Figure 1-4 in a spatial resolution of 2 km.

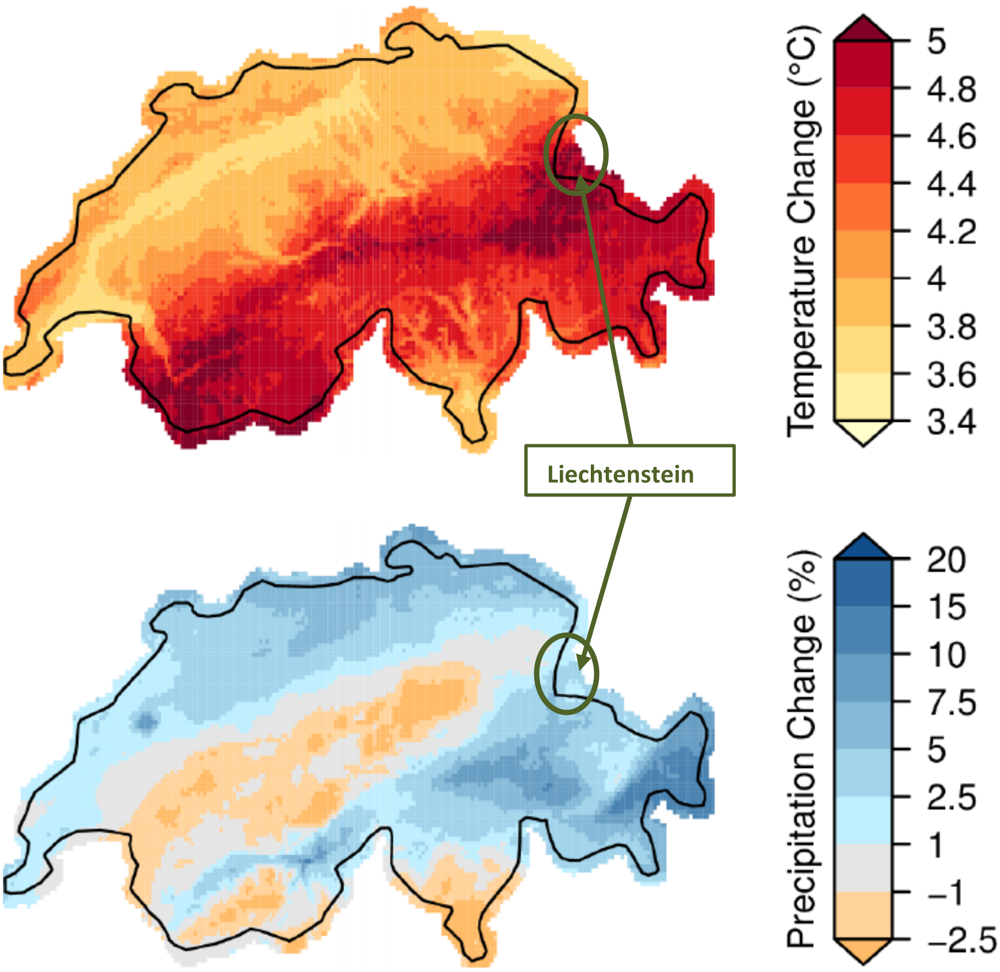



Figure 1-4 Ensemble median changes in annual mean temperature (upper map) and annual mean precipitation (lower map) for the “unabated emissions scenario” period 2085 in the high-resolution grid of 2 km for Switzerland and Liechtenstein (NCCS 2018).

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 day 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 impacts of climate change are being observed even within limited time frames. 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.

### 1.1.1.2 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 2018a):

**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.

#### 1.1.1.3 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) and Action Plan on Air (OEP 2007e). Liechtenstein's climate policy goal is – in the midterm – to fulfil the obligations originating from the Kyoto Protocol. The mitigation measures however will be further developed, especially with respect to sectors that have not yet been totally included into strict climate change regulation (e.g. traffic and transportation). In the longer-term, Liechtenstein aims at a reduction of greenhouse gases by 40% compared to 1990 by 2030. Currently, a long-term climate strategy for Liechtenstein is being elaborated.

**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).

**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".

### 1.1.2 Background information on greenhouse gas inventory

#### 1.1.2.1 Framework

In 1995, the Principality of Liechtenstein ratified the United Nations Framework Convention on Climate Change (UNFCCC). Furthermore, Liechtenstein ratified the Kyoto Protocol to the UNFCCC in 2004. A National Inventory System (NIS) according to Article 5.1 of the Kyoto Protocol has been implemented. 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.

#### 1.1.2.2 Submissions of National Communications and Biennial Reports

In 1995, 1998, 2002, 2006, 2010, 2014 and 2017 Liechtenstein submitted its National Communication Reports (NC1 to NC7) to the secretariat of the UNFCCC.

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

NC7 and BR3 underwent a UN centralized review in Bonn, Germany from 12 to 17 March 2018. For both reports the ERT states that the information reported by Liechtenstein mostly adheres to the UNFCCC reporting guidelines on NCs and BRs (FCCC/TRR 2018, FCCC/IDR 2018).

#### 1.1.2.3 Greenhouse gas inventory: Former submissions and submissions under the first commitment period (2008-2012)

Greenhouse Gas Inventories and National Inventory Reports were submitted in the following years:

- 2005: The first Greenhouse Gas Inventory of Liechtenstein was submitted in the Common Reporting Format (CRF) without National Inventory Report.
- 2006: The first submission took place on May 31 including the national greenhouse gas inventory for 1990 and 2004 as well as the National Inventory Report. A re-submission on 22 December 2006 contained the national greenhouse gas inventory for the full-time period 1990–2004, the National Inventory Report 2006 (OEP 2006) and the Initial Report under Article 7, paragraph 4 of the Kyoto Protocol including a Corrigendum (OEP 2006a, 2007a, 2007b).
- 2007: Submission of the Greenhouse Gas Inventory 1990–2005 together with the National Inventory Report 2007 on 10 May 2007 (OEP 2007).
- 2008: Submission of the Greenhouse Gas Inventory 1990–2006 together with the National Inventory Report 2008 prepared under the UNFCCC and under the Kyoto Protocol on 29 February 2008 (OEP 2008).
- 2009: Submission of the Greenhouse Gas Inventory 1990–2007 together with the National Inventory Report 2009 prepared under the UNFCCC and under the Kyoto Protocol on 2 April 2009 (OEP 2009). Furthermore, the Standard Electronic Format application (SEF) was submitted.

- 2010: Submission of the Greenhouse Gas Inventory 1990–2008 together with the National Inventory Report 2010 prepared under the UNFCCC and under the Kyoto Protocol on 11 March 2010 (OEP 2010). Additionally, the Standard Electronic Format application (SEF) was submitted. Submission 2010 incorporated the new guidelines: Annotated outline of the National Inventory Report including reporting elements under the Kyoto Protocol (UNFCCC 2009).
- 2011: Submission of the Greenhouse Gas Inventory 1990–2009 together with the National Inventory Report 2011 prepared under the UNFCCC and under the Kyoto Protocol on 11 March 2011 (OEP 2011). Additionally, the Standard Electronic Format application (SEF) was submitted.
- 2012: Submission of the Greenhouse Gas Inventory 1990–2010 together with the National Inventory Report 2012 prepared under the UNFCCC and under the Kyoto Protocol on 11 March 2012 (OEP 2012b). Additionally, the Standard Electronic Format application (SEF) was submitted.
- 2013: Submission of the Greenhouse Gas Inventory 1990–2011 together with the National Inventory Report 2013 prepared under the UNFCCC and under the Kyoto Protocol on 15 March 2013 (OE 2013). Additionally, the Standard Electronic Format application (SEF) was submitted.
- 2014: Submission of the Greenhouse Gas Inventory 1990–2012 together with the National Inventory Report 2014 prepared under the UNFCCC and under the Kyoto Protocol on 15 March 2014 (OE 2014). Additionally, the Standard Electronic Format application (SEF) was submitted. The submission 2014 was simultaneously the ending of the first commitment period.

#### 1.1.2.4 Review processes of former submissions and submissions under the first commitment period (2008-2012)

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. Find further information under chp. 1.2.3.1.

#### 1.1.2.5 Greenhouse gas inventory: Submissions under the second commitment period (2013-2020)

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

- 2015: Submission of the Greenhouse Gas Inventory 1990-2013 together with the National Inventory Report 2015 prepared under the UNFCCC and under the Kyoto Protocol on 15 April 2016 (OE 2016a).
- 2016: Submission of the Greenhouse Gas Inventory 1990-2014 together with the National Inventory Report 2016 prepared under the UNFCCC and under the Kyoto Protocol on 27 May 2016 (OE 2016c).

- 2017: Submission of the Greenhouse Gas Inventory 1990-2015 together with the National Inventory Report 2017 prepared under the UNFCCC and under the Kyoto Protocol on 13 April 2017 (OE 2017).
- 2018: Submission of the Greenhouse Gas Inventory 1990-2016 together with the National Inventory Report 2018 prepared under the UNFCCC and under the Kyoto Protocol on 12 April 2018 (OE 2018).
- 2019: Submission of the Greenhouse Gas Inventory 1990-2017 together with the National Inventory Report 2019 prepared under the UNFCCC and under the Kyoto Protocol on 15 April 2019 (OE 2019).
- 2020: Submission of the Greenhouse Gas Inventory 1990-2018 together with the National Inventory Report 2020 prepared under the UNFCCC and under the Kyoto Protocol on 15 April 2020 (OE 2020).
- The present report is Liechtenstein's 16th National Inventory Report, NIR 2021, prepared under the UNFCCC and under the Kyoto Protocol. The present report includes, as separate files, Liechtenstein's 1990–2019 Inventory in the CRF Reporter format and the updated Standard Electronic Format application (SEF).

#### 1.1.2.6 Review processes and the second commitment period (2013-2020)

The review for the GHG inventories and National Inventory Reports 2015 and 2016 took place simultaneously in September 2016 due to the postponed submission 2015. Due to the fact that the UNFCCC did not have enough resources for reviewing all national inventories in 2017, there was no review of Liechtenstein's GHG inventory and National Inventory Report 2017 (written communication from Vitor Gois to Helmut Kindle (UNFCCC 2017), further information in UNFCCC 2017a, paragraphs 3 and 4).

From 17 to 22 September 2018 the review of 2018 annual submission took place as a centralized review (FCCC/ARR 2018).

As in 2017, there was no review of Liechtenstein's GHG inventory and National Inventory Report 2019 (written communication from SIAR assessment team to Heike Summer (UNFCCC 2019)).

From 7 to 11 September 2020 the review of 2020 annual submission took place as a centralized review (the review report was not yet published by the time of the elaboration of the current submission).

Find further information under chp. 1.2.3.1.

### 1.1.3 Background information on supplementary information required under Art. 7.1. KP

Chapter 11 of this NIR and Liechtenstein's Second Initial Report under the Kyoto Protocol (Government 2016) provide information on KP-LULUCF.

Liechtenstein only accounts for the mandatory activity Forest Management under Article 3, paragraph 4 of the Kyoto Protocol. In accordance with Annex I to Decision 2/CMP.7 (Annex I, Para 13), credits from Forest Management are capped in the second commitment period. Thus, for Liechtenstein the cap amounts to 3.5% of the 1990 emissions (excluding LULUCF).

Liechtenstein has chosen to account over the entire commitment period for emissions and removals from activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol. In addition to the mandatory submission of the inventory years 2013-2019, data for the years 2008-2012 are available and shown in Liechtenstein's NIR.

## 1.2 National inventory arrangements

### 1.2.1 Institutional, legal and procedural arrangements

The Office of Environment (OE) is in charge of compiling the emission data and bears overall responsibility for Liechtenstein's national greenhouse gas inventory. 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.

Liechtenstein is a small central European State between Switzerland and Austria in the Alpine region with a population of 38'749 inhabitants (2019) and with an area of 160 km$^2$.


Figure 1-5 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.

As part of a comprehensive project, the Government mandated its Office of Environment (OE) in 2005 to design and establish the NIS in order to ensure full compliance with the reporting requirements of the UNFCCC and its Kyoto Protocol. With regard to the provisions of Art. 5.1 of the Kyoto Protocol, the project encompasses the following elements:

- Collaboration and cooperation of the different offices involved in data collection.
- Upgrading and updating of central GHG emissions data base.
- Setting up a simplified QA/QC system.
- Official consideration and approval of the data.

### 1.2.2 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, the project manager assistant as well as the emission modeler and the NIR authors participate. At the initial meeting, the work scheduled and priorities with regard to inventory development are set. Decisions regarding planned improvements are taken as well 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 Annex A8.3, Table A - 9). 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 realized, 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 NIR is passed through a multistage quality control cycle too (see Table 1-1). NIR authors, the emission modeler, the head of the inventory group, the project manager and the project manager assistant as well as additional people of the Office of Environment (OE) and sector experts review the drafts of the NIR 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 too. 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 | | | | | | | | | | | | |

Further inventory preparation and management activities are described in chapter 1.3.

### 1.2.3 Quality assurance, quality control and verification plan

According to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) 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.

The implementation status of these quality elements is described in the following chapters. 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 persons involved. Therefore, the National System manages with little number of written documents.

The QA/QC activities are coordinated by the Mr. Stefan Hassler, 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 System depicted in Figure 1-6.

Operational tasks are delegated to the NIR lead author. She distributes checklists to the project manager being also the National Inventory Compiler, to the sectoral experts and to other NIR 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 NIR (see Annex 8).

The quality management shall enable the party to principally fulfil the requirements of the articles 3, 5 and 7 of the Kyoto Protocol. 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.

### 1.2.3.1 QA/QC plan

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 sections below. All activities are planned and documented in checklists (see Annexes A8.1 for QC and A8.2 for QA activities).
- Liechtenstein maintains an inventory development plan (IDP). The IDP summarizes 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 prioritized according to the latest key category analysis and with regard to the uncertainty analyses (see Annex A8.3).
- Liechtenstein has conducted specific verification activities in various steps of the development of the inventory. In particular, the close collaboration with Switzerland (concerning methods and models used) allows comparing and verifying the results of the calculations within the two inventories. Due to this close collaboration,

Liechtenstein does also profit of Switzerland's past and future QA activities and its QA/QC plan.

**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 NIR 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 NIR 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 NIR authors (see Annex 8).
- 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 NIR 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 NIR, an annual internal review takes place shortly before the submission. Every chapter of the NIR is being proofread by specialists not involved in the emission modelling or in the NIR 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 NIR (NIR 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 and 2020). 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.

**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 Heike Summer (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 NIR authors accomplish a number of QC activities:

- The NIR 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 NIR, the correct transcription of CRF data into NIR data tables and figures, the consistency between data tables and text in the NIR as well as the completeness of references in the NIR. 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 NIR. 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 NIR: monitoring of the GHG emission modelling and key category analysis. The project manager checks the NIR 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 2019 were compared with those of the year 2018 within the current Reporting Table Summary2.
  - The emissions of the year 2018 were compared between the current Reporting Table Summary2 of submission 2021 and the Reporting Table Summary2 of submission 2020.
  - The emissions of the base year 1990 were compared between the current Reporting Table Summary2 of submission 2021 and the Reporting Table Summary2 of the submission 2020.
- 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 NIR passed several quality controls. Table 1-1 illustrates the official quality control procedure of Liechtenstein's NIR. The first internal NIR draft is cross-checked by the NIR authors in terms of correctness, completeness, consistency and layout. The Office of environment (OE) and the emission modeller review the entire NIR as external experts because experts of the OE and the emission modeller are not directly involved in updating the NIR. They check the first draft of the NIR 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 8. Afterwards, the NIR authors improve the NIR considering the revisions made by the OE experts and prepare the second internal draft, which also undergoes an internal cross-check. This second NIR draft again is reviewed by the OE and the emission modeller. Their inputs are implemented within the NIR, too. The NIR authors complete the final NIR version including last internal cross-checks. The Office of Environment (OE) carries out a last check and then submits the official National Inventory Report (NIR). This process guarantees the compliance of the QA/QC requirements according to the IPCC guidelines (IPCC 2006).

**Inventory development plan (IDP)**

In the NIR 2020, IDP tables depicted recommendations and encouragements from the ERT and other improvements concerning the NIR which:

- had been incorporated into the NIR 2020, see pp. 38-40 of OE (2020),
- planned improvements for future submissions, improvements that will not be implemented and improvements that are already implemented, see annex A8.3.

From the planned improvements mentioned above the following have been realised for the current submission 2021:

| IDP No. | Identified Issues, e.g. recommendations or planned improvements | Reference | Status | Comment/Reason NIR | Sector |
|---|---|---|---|---|---|
| 14 | Documentation of the use of results of the uncertainty analysis in the improvement of the national inventory. The ERT considers that the explanation could be enhanced by including a discussion of the linkages between the key source, uncertainty analysis and the inventory development plan. This could be achieved with the inclusion of specific references in the inventory development plan where uncertainty and key category analysis have been used to inform a particular priority improvement. | ARR 2018, ID#G.8, PMF 2020, ID#G.7 | Implemented in submission 2021 | The use of results from the KCA and the uncertainty analysis are generally used for prioritizing planned improvements (as described in chapters 1.5 and 1.6, respectively). The description of how the results of the inventory report are used in the improvement of the national inventory was added in Annex A8.3. Where relevant, the link between the IDP and the results of the uncertainty analysis and the KCA is mentioned in the respective entries of the current IDP. | 0 General |
| 15 | Methods: The ERT identified a number of instances where the use of Swiss AD, EFs and methods are not well justified and where transparency could be improved in the explanations of the applicability of Swiss parameters to Liechtenstein (see issues #E.12, I.5, A.11, W.1 and W.8)<br>The ERT encourages the Party to provide further information as specified in the issues listed to support the continued use of Swiss AD, EFs and methods and to consider undertaking further country-specific research to derive AD, EFs and methods reflective of local circumstances as resources allow. | PMF 2020, ID#G.11 | Implemented in submission 2021 | Liechtenstein provides further information as specified in the issues mentioned (see comments to issues #E.12, I.5, A.11, W.1 and W.8) that explain, why the application of Swiss AD, EFs and methods is appropriate for Liechtenstein and is applicable to the national circumstances. Liechtenstein considers undertaking further country-specific research to derive AD, EFs and methods reflective of local circumstances within the available resources. | 0 General |
| 59 | Fuel combustion- reference approach - liquid fuels - CO2: Use the correct notation key "NO" for bitumen and lubricants | PMF 2020. ID#E.5, (ARR 2018 ID#E.14), PMF 2020 ID#E.6 (ARR 2018 ID#E.15) | Implemented in submission 2021 | For lubricants, the fraction of oxidized carbon was set to 1 instead oft NO, since the net carbon emissions are not equal to zero and since. This leads to an automatic calculation of actual CO2 emissions by the CRF reporter that is consistent. | 1 Energy |
| 60 | 1.A.2.e Food processing, beverages and tobacco- Gaseous fuel -CH4: The ERT recommends the Party to provide more information and justification of selection the country specific EF in the next NIR. | PMF 2020, ID#E.13 | Implemented in submission 2021 | An additional reference is provided for the country specific EF in chp.3.2.6.2 - Methodological issues - Emission factors . | 1 Energy |
| 71 | Data for 2G3b were not updated for Submission 2021. | Internal decision | Implemented in submission 2021 | Emission data for 2G3b were updated in Submission 2021. | 2 IPPU |
| 72 | 2.F.1 Refrigeration and air conditioning – HFCs and PFCs<br>The ERT notes the practicality of this approach of borrowing from the Swiss methodology, but considers that the current descriptions in the NIR are not fully representative of the methodology applied by Liechtenstein, and recommends that the Party transparently explain in the NIR how it applies the Swiss methodology to its inventory, in particular why certain gas species that are reported in the Swiss inventory are considered to not occur in Liechtenstein. | PMF 2020, ID#I.3 (ARR 2018, ID#I.4) | Implemented in submission 2021 | The description of the procedure to determine emissions of HFC and PFC was enhanced in chp. 4.7.2.<br>A more detailed description of how the threshold is applied per sub-category is provided in the NIR of submission 2021 in chp. 4.7.2.1. | 2 IPPU |
| 97 | 3I: The ERT recommends that Liechtenstein reports “NE” under CO2 emissions from Other Carbon-containing Fertilizers in the next inventory submission, if justifications for the application of the insignificance threshold defined in para. 37(b) of the UNFCCC Annex I inventory reporting guidelines) have been tested and met. | ARR 2018, ID#A.11 | Implemented in submission 2021 | Urea ammonium nitrate (UAN) is used in Switzerland. On average, the share of UAN is <1% of total urea applied in Switzerland. The share of UAN used in Liechtenstein cannot be determined. However, it is very likely <1% as well, and therefore negligible. Liechtenstein will change the notation key from "NO" to "NE" in Submission 2021. Furthermore, the assumption that other carbon-containing fertilizers are insignificant has been justified in chapter 5.10 of the NIR. | 3 Agriculture |

| IDP No. | Identified Issues, e.g. recommendations or planned improvements | Reference | Status | Comment/Reason NIR | Sector |
|---|---|---|---|---|---|
| 98 | 3B(a): Use notation key NO instead of 0.00 | ARR 2018, ID#A.7 | Implemented in submission 2021 | The problems in CRF table 3B(a) have been resolved. | 3 Agriculture |
| 121 | 4: The ERT recommends that the Party be consistent in the application of Swiss data for reporting and verification purposes and highlight the use of Swiss data from the pre-Alps region prominently at the beginning of the LULUCF chapter, as done in the KP-LULUCF chapter (NIR, chapter 11.3.1.1, p.278), to make this approach more transparent. | ARR 2018, ID#L.15 | Implemented in submission 2021 | Adopted new carbon contents in biomass and soil for 4B and 4C from Swiss model results (NIR 2020). Text inserted in chp. 6.1.1. | 4 LULUCF |
| 122 | 4A: The ERT recommends that Liechtenstein improve the accuracy of emission/removal estimates for deadwood and litter and ensure that estimates are consistent with the UNFCCC Annex I inventory reporting guidelines (para. 4) by, for example, using expansion factors for woody components only and separating non-woody and woody litter. | ARR 2018, ID#L.16 | Implemented in submission 2021 | A new expansion factor for dead wood was derived from results of the 4th Swiss NFI (NIR chp. 6.4.2.2). Emissions/removals from deadwood and litter are now based on results of the Swiss Yasso07-model application (NIR chp. 6.4.2.5). | 4 LULUCF |
| 123 | 4A: The ERT recommends that the Party verifies that the BEFs and wood densities are still accurate for recent years or uses information from more recent Swiss NFIs to estimate BEFs and wood densities. | PMF 2020. ID#L.11 | Implemented in submission 2021 | New BEFs and densities (BCEFs) were derived from Swiss NFI4 as described in NIR chp. 6.4.2.2 | 4 LULUCF |
| 144 | 5B: NIR 2019, Table 7-7: The waste amount stated n row "composted centrally" is referring to wet matter (70%), and not to dry matter (30%). This mistakte might affect the calculation of respective GHG emissions. | Internal decision | Implemented in submission 2021 | Correction of error in the submission 2021 | 5 Waste |
| 145 | 5B: Activity data stated in CRF tables are referring to amounts treated in centralised composting plants only. Activity data for backyard composting need to be added. | Internal decision | Implemented in submission 2021 | Correction of error in the submission 2021 | 5 Waste |
| 146 | 5B: Activity data in CRF tables are stating amounts of organic waste composted in centralized plants, only. Activity data for backyard composting are missing. However, greenhouse gas emission estimates are taking into acoount backyard composting. Activity data in CRF tables will be revised in next submission accordingly. | Internal decision | Implemented in submission 2021 | Correction of error in the submission 2021 | 5 Waste |
| 147 | CH4 emission estimation from wastewater sewered to the wastewatertreatment plant from 2014 – 2018 was not complete. | Internal decision | Implemented in submission 2021 | A mistake in the last submission has been corrected. CH4 emission estimation from wastewater sewered to the wastewatertreatment plant from 2014 – 2018 was not complete. This leads to a considerable increase of CH4-emissions for this period. | 5 Waste |
| 162 | Forest Management: The ERT recommends that the Party estimate emissions and removals for litter for the complete time series and report these in its next submission | PMF 2020. ID#KL.6 | Implemented in submission 2021 | Results from the Swiss Yasso07 model was adopted for litter and dead wood | 6 KP-LULUCF |
| 163 | Deforestation: The ERT recommends that the Party correct the error in the deforested area and report the correct numbers in its next (2021) submission. | PMF 2020. ID#KL.5, ID#L.12 | Implemented in submission 2021 | The error was corrected and the documentation of the calculation was improved (NIR Table 11-5) | 6 KP-LULUCF |

Planned improvements see sector chapters and a summary in chp. 10.4 of this NIR. Improvements that are already implemented and improvements that will not be implemented are documented in Annex A8.3, Table A - 9.

In the prioritization of planned improvements of the national inventory, Liechtenstein takes into account the results of the uncertainty analyses.

**Former reviews and recommendations made by the ERT**

From 11 to 15 June 2007 an individual review (in-country review) took place in Vaduz: The submission documents, the Initial Report and the GHG inventory 1990-2004 including CRF tables and National Inventory Report were objects of the review. Following the recommendations of the expert review team, some minor corrections were carried out in the emission modelling leading to recalculations and some methodological changes (revision of the definition of forests). The consequences are documented in the reports of the review of the initial report of Liechtenstein (FCCC/IRR 2007) and of the individual review of the greenhouse gas inventory of Liechtenstein submitted in 2006 (FCCC/ARR 2007). Due to the recalculation, the time series of the national total of emissions slightly changed and therefore, Liechtenstein's assigned amount has been adjusted by -0.407%. The modifications are documented in a Response by Party and a Corrigendum to the Initial Report (OEP 2007a, 2007b). After this correction, Liechtenstein's assigned amount has been fixed to 1'055.623 kt $CO_2$ equivalents.

Furthermore, in September 2008, a centralized review of Liechtenstein's GHG inventories and NIRs of 2007 and 2008 took place in Bonn, Germany with results documented in FCCC/ARR (2009). Further centralized reviews took place in September 2009 (inventory and NIR of 2009, FCCC/ARR 2010), in September 2010 (inventory and NIR 2010, FCCC/ARR 2010a), in September 2011 (inventory 1990–2009 and NIR 2011, FCCC/ARR 2011) and in September 2012 (inventory 1990–2010 and NIR 2012, FCCC/ARR 2012). Important recommendations were integrated in former versions of Liechtenstein's IDP.

Between 2nd and 6th September 2013 the second in-country review was conducted in Vaduz. Again, the submission documents, GHG inventory 1990-2011 including CRF tables and the National Inventory Report were examined during the review. Following the recommendations of the expert review team, numerous improvements were implemented in the submission 2014. Amongst others, this included methodological changes where data is delineated from the Swiss inventory (sectors Energy, Industrial processes and Solvents) and complementation of the text in the NIR for transparency reasons. The recommendations by the ERT are documented in the report of the individual review of the greenhouse gas inventory of Liechtenstein submitted in 2013 (FCCC/ARR 2013). However, since the report was finalized late in the update phase of the NIR, not all of the recommendations were already implemented for the submission 2014. Furthermore, recommendations from ARR 2012 and from discussions during the in-country review were considered for the report 2014. From the in-country review no "Friday Paper" resulted and no resubmission of the inventory 2011 was requested for the submission 2014.

Another centralized review of Liechtenstein's GHG inventory and NIR of the submission 2014 took place in September 2014. The findings were summarized in the ARR (FCCC/ARR 2014). Although the report was published before the final submission 2015 not all recommendations were incorporated in the current inventory development plan due to focus on the implementation of Liechtenstein's emissions into the current CRF reporter as well as on the implementation of the requirements related to the new reporting guidelines (IPCC 2006) in the NIR. More details see next paragraph.

The next centralized review for the GHG inventories and National Inventory Reports 2015 and 2016 took place simultaneously in September 2016 due to the postponed submission 2015. The ERT found potential methodical issues concerning land use changes from forest to non-forest as well as solid waste disposal and wastewater treatment (FCCC/ARR 2015 and FCCC/ARR 2016). Liechtenstein recalculated the emissions in the waste sector in a resubmission of 14 November 2016 (OE 2016d), taking into account the specific recommendations by the ERT. The potential problems with forest land use changes are addressed and corrected in the National Inventory Report 2017, as recommended by the ERT.

Due to the fact that the UNFCCC did not have enough resources for reviewing all national inventories in 2017, there was no review of Liechtenstein's GHG inventory and National Inventory Report 2017 (written communication from Vitor Gois to Helmut Kindle (UNFCCC 2017), further information in UNFCCC 2017a, paragraphs 3 and 4).

Another centralized review for the GHG inventories and National Inventory Reports 2018 took place from 7 to 22 September 2018.The findings were summarized in the ARR (FCCC/ARR 2018).

As in 2017, there was no review of Liechtenstein's GHG inventory and National Inventory Report 2019 (written communication from SIAR assessment team to Heike Summer (UNFCCC 2019)).

The latest centralized review for the GHG inventories and National Inventory Reports 2020 took place from 7 to 12 September 2020. Originally, an in-country review was planned for 2020. However, due to the Covid-19 pandemic a centralized review was held instead. Provisional main findings of the ERT have been sent to OE on 12 September 2020, and the OE submitted its answers within the given deadline back to the ERT. The final report of the review had not been published by the time of the elaboration of the current submission. Therefore, only preliminary findings were implemented.

**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.

### 1.2.3.2 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 is taking place.

In many cases the same emission factors as in the Swiss NIR are applied. Therefore, those factors are checked when copied from the Swiss NIR and correlation thus depends on activity data. As both countries have used 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 may be 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 2020). 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 2020c).

### 1.2.3.3 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 NIR and thus also for this report.

## 1.2.4 Changes in national inventory arrangements since previous inventory submission

**Changes to institutional, legal and procedural arrangements (24/CP.19, 22. (a))**

There are no changes to arrangements with other institutions. The agreements regarding responsibilities and deliverables are maintained. On the other hand, the NIR authors and the emission modeller remained the same as for previous submissions. This also guaranteed continuity in inventory preparation.

**Changes in staff and capacity (24/CP.19, 22. (b)**

No changes in staff occurred the current submission

**Changes to national entity with overall responsibility for the inventory (24/CP.19, 22. (c))**

No changes occurred in the current submission

**Changes to the process of inventory planning (24/CP.19, 22.(d,e)/23./24.)**

No changes occurred in the current submission

**Changes to the process of inventory preparation (24/CP.19, 25./26.)**

No changes occurred in the current submission

**Changes to the process of inventory management (24/CP.19, 27.)**

No changes occurred in the current submission

## 1.3 Inventory preparation, and data collection, processing and storage

### 1.3.1 GHG Inventory and KP-LULUCF inventory

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

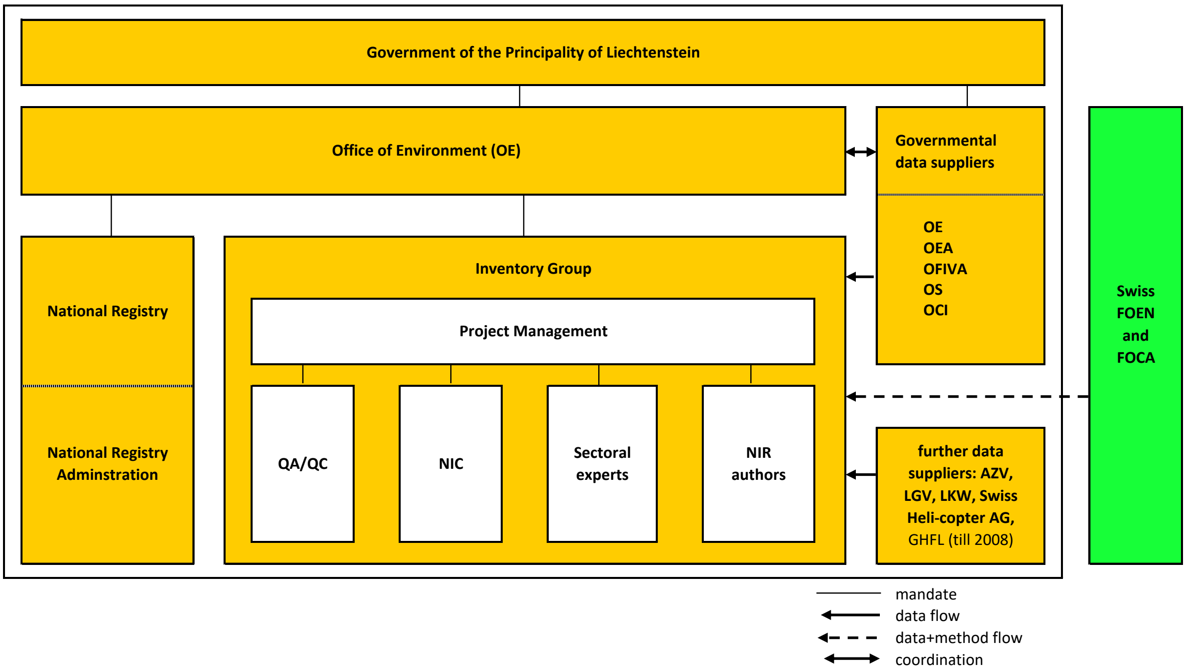



Figure 1-6 National Inventory System: Institutional setting and data suppliers. OE: Office of Environment; OEA: Office of Economic Affairs; OFIVA: Office of Food Inspections and Veterinary Affairs; OS: Office of Statistics: OCI: Office of Construction and Infrastructure; AZV: Liechtenstein's wastewater 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 establishing of the National Inventory System (NIS) under the Kyoto Protocol. The responsibility of the OE for establishing the NIS is also described in the report of the Government to the parliament for ratifying the Kyoto Protocol. The Government mandated the realisation of the NIS to its Office of Environment (OE). Please note that the Office of Environment is reorganized since 2013. The Office of Agriculture (OA), the Office of Forest, Nature and Land Management (OFNLM) and the Office of Environmental Protection (OEP) have been merged to the Office of Environment (OE). The former Office of Land Use Planning (SLP) is reorganized since 2013 and the Local Land Use Planning Bureau is now incorporated into the Office of Construction and Infrastructure (OCI).

The Office of Environment (OE) plays a major role in the National Inventory System and is acting as the National Registry Administrator. Its representative, the head of the OE, is the registered National Focal Point. He also coordinates in cooperation with the responsible head of the unit the data flow from the governmental data suppliers to the Inventory Group.

The Inventory group consists of the project manager, the person responsible for the QA/QC activities, the National Inventory Compiler (NIC) who is represented by the project manager and his assistant. Furthermore, several external experts belong to the Inventory Group: Sectoral specialists for modelling the greenhouse gas emissions and removals and the NIR authors.

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 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 2020) also includes the fossil fuel consumption of the Principality of Liechtenstein, except for gas consumption of Liechtenstein, which is excluded from SFOE (2020). 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.

# 1.4 Methodologies and data sources

## 1.4.1 GHG inventory

### 1.4.1.1 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. 1.2.1). 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 2020).

#### 1.4.1.2 Specific assumptions for the year 2017

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 2018 of the Swiss inventory 2020 were available in the EMIS (Swiss Emission Information System) database of the Swiss Federal Office for the Environment dated from April 2020 corresponding to the emission data which Switzerland submitted in April 2020 in its NIR to the UNFCCC (FOEN 2020).

Table 1-2 Notation keys for applied methods and emission factors 2019 (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.

### 1.4.1.3 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.

### 1.4.2 KP-LULUCF Inventory

The information in this Inventory is provided in accordance with Decision 2/CMP.7 and the KP-Supplement (IPCC 2014) and based on the information given in Liechtenstein's Initial Report (OEP 2006a), the Corrigendum to the Initial Report of 19 Sep 2007 (OEP 2007b) and Liechtenstein's second Initial Report (Government 2016, resubmitted on 19 December 2016).

Liechtenstein had to determine for each activity of the LULUCF sector whether removal units (RMUs) shall be issued annually or for the entire commitment period. Liechtenstein chose to account over the entire commitment period for emissions and removals from activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol (see Government 2016). The decision remains fixed for the entire second commitment period.

Liechtenstein adopts the forest definition of the Land Use Statistics (AREA) of the Swiss Federal Statistical Office. AREA provides an excellent data base to derive accurate, detailed information not only for forest areas, but for all types of land use and land cover. Thus, AREA offers a comprehensive, consistent and high-quality data set to estimate the surface area of the different land use categories in reporting under the Kyoto Protocol. For Liechtenstein, the Land Use Statistics was built up identically to Switzerland (same method and data structures, same realisation).

The following forest definition is used (OEP 2007b):

- minimum area of land: 0.0625 hectares (with a minimum width of 25 m)
- minimum crown cover: 20 percent
- minimum height of the dominant trees: 3 m (dominant trees must have the potential to reach 3 m at maturity in situ)

## 1.5 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 2019 level and trend assessment without LULUCF categories
- Reporting year 2019 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.

## 1.5.1 GHG Inventory

### 1.5.1.1 KCA excluding LULUCF categories

For 2019, 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 96.4% of the national total emissions (see Table 1-3). Ten categories are key categories according to level assessment and nine according to trend assessment.

Within those eleven key categories, seven stem from the energy sector, contributing 79.8% to total $CO_2$ equivalent emissions in 2019. The other key categories are from the sectors Agriculture (three categories, contribution 11.5%) and Industrial Processes and Product Use IPPU (one category, contribution 5.1%).

The three major sources, all from the energy sector, sum up to a contribution of 64.5% 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 2018), the following changes have occurred in the KCA for the reporting year 2019 of the current submission:

- 1A2 Fuel combustion – Manufacturing Industries and Construction – Gaseous Fuels is not a (trend) key category anymore

Table 1-3 List of Liechtenstein's Approach 1 key categories 2019 excluding LULUCF. Sorted by share of total emissions.

| **Key Category Analysis 2019 (excluding LULUCF)**<br>**IPCC Source Categories (and fuels, if applicable)** | GHG | Emissions 2019 [kt CO2eq] | Share of Total Emissions | Cumulative Total | Result of Assessment |
|---|---|---|---|---|---|
| 1.A.3.b Road Transportation | CO2 | 56.17 | 30.0% | 30.0% | KC Level, KC Trend |
| 1.A.4 Other Sectors - Gaseous Fuels | CO2 | 33.83 | 18.1% | 48.1% | KC Level, KC Trend |
| 1.A.4 Other Sectors - Liquid Fuels | CO2 | 30.77 | 16.4% | 64.5% | KC Level, KC Trend |
| 3.A Enteric Fermentation | CH4 | 14.20 | 7.6% | 72.1% | KC Level, KC Trend |
| 1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels | CO2 | 12.74 | 6.8% | 78.9% | KC Level |
| 1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels | CO2 | 11.21 | 6.0% | 84.9% | KC Level, KC Trend |
| 2.F.1 Refrigeration and Air conditioning | F-gases | 9.57 | 5.1% | 90.1% | KC Level, KC Trend |
| 3.D.1 Direct N2O Emissions From Managed Soils | N2O | 4.47 | 2.4% | 92.4% | KC Level, KC Trend |
| 1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels | CO2 | 3.38 | 1.8% | 94.2% | KC Level, KC Trend |
| 3.B Manure Management | CH4 | 2.78 | 1.5% | 95.7% | KC Level |
| 1.B.2.b Fugitive Emissions from Fuels - Oil and Natural Gas - Natural Gas | CH4 | 1.19 | 0.6% | 96.4% | KC Trend |

For the base year 1990, the level key category analysis is given in Table 1-4 below. There are eight level key categories. The only change compared to the previous submission is that 3B Manure management ($CH_4$) is a new key category.

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)**<br>**IPCC Source Categories (and fuels, if applicable)** | GHG | Emissions 1990 [kt $CO_2$eq] | Share of Total Emissions | Cumulative Total | Result of Assessment |
|---|---|---|---|---|---|
| 1.A.4 Other Sectors - Liquid Fuels | CO2 | 76.71 | 33.6% | 33.6% | KC Level |
| 1.A.3.b Road Transportation | CO2 | 75.29 | 32.9% | 66.5% | KC Level |
| 1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels | CO2 | 20.99 | 9.2% | 75.7% | KC Level |
| 1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels | CO2 | 15.20 | 6.6% | 82.4% | KC Level |
| 3.A Enteric Fermentation | CH4 | 13.92 | 6.1% | 88.4% | KC Level |
| 1.A.4 Other Sectors - Gaseous Fuels | CO2 | 10.21 | 4.5% | 92.9% | KC Level |
| 3.D.1 Direct N2O Emissions From Managed Soils | N2O | 4.72 | 2.1% | 95.0% | KC Level |
| 3.B Manure Management | CH4 | 2.93 | 1.3% | 96.3% | KC Level |

### 1.5.1.2 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 2019 including LULUCF categories consists of a total of 223 categories, whereof 20 are key categories (see Table 1-5). Six categories are identified key from the LULUCF sector and contribute with a total of 5.6% 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, $CO_2$
- 4F2 Land converted to Other Land, $CO_2$
- 4G Harvested wood products, $CO_2$

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

- 1A3b Road Transportation, $CH_4$
- 3B Manure management, $N_2O$
- 3D2 Indirect $N_2O$ emissions from managed soils

Compared to newest inventory year of the previous submission (reporting year 2018), the following changes have occurred in the KCA for the reporting year 2019 of the current submission:

- 1A3b Road Transportation ($CH_4$) is a new (trend) key category
- 3D2 Indirect $N_2O$ emissions from managed soils is a new (level) key category
- 4A1 Forest Land Remaining Forest Land ($CO_2$) is not a (level) key category anymore
- 4B1 Cropland Remaining Cropland ($CO_2$) is – in addition to level – newly also a key category according to the trend assessment
- 5D Wastewater Treatment and Discharge ($CH_4$) 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, $CO_2$

Table 1-5 List of Liechtenstein's Approach 1 key categories 2019 including LULUCF. Sorted by share of total emissions.

| **Key Category Analysis 2019 (including LULUCF)**<br>**IPCC Source Categories (and fuels, if applicable)** | GHG | Emissions 2019 abs. values [kt CO2eq] | Share of Total Emissions | Cumulative Total | Result of Assessment |
|---|---|---|---|---|---|
| 1.A.3.b Road Transportation | CO2 | 56.17 | 27.9% | 27.9% | KC Level, KC Trend |
| 1.A.4 Other Sectors - Gaseous Fuels | CO2 | 33.83 | 16.8% | 44.7% | KC Level, KC Trend |
| 1.A.4 Other Sectors - Liquid Fuels | CO2 | 30.77 | 15.3% | 60.0% | KC Level, KC Trend |
| 3.A Enteric Fermentation | CH4 | 14.20 | 7.1% | 67.1% | KC Level, KC Trend |
| 1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels | CO2 | 12.74 | 6.3% | 73.4% | KC Level |
| 1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels | CO2 | 11.21 | 5.6% | 79.0% | KC Level, KC Trend |
| 2.F.1 Refrigeration and Air conditioning | F-gases | 9.57 | 4.8% | 83.8% | KC Level, KC Trend |
| 3.D.1 Direct N2O Emissions From Managed Soils | N2O | 4.47 | 2.2% | 86.0% | KC Level, KC Trend |
| 4.B.1 Cropland Remaining Cropland | CO2 | 3.96 | 2.0% | 87.9% | KC Level, KC Trend |
| 1.A.1 Fuel combustion - Energy Industries - Gaseous Fuels | CO2 | 3.38 | 1.7% | 89.6% | KC Level, KC Trend |
| 3.B Manure Management | CH4 | 2.78 | 1.4% | 91.0% | KC Level |
| 4.E.2 Land Converted to Settlements | CO2 | 2.73 | 1.4% | 92.4% | KC Level |
| 4.C.2 Land Converted to Grassland | CO2 | 2.46 | 1.2% | 93.6% | KC Level, KC Trend |
| 3.B Manure Management | N2O | 1.56 | 0.8% | 94.4% | KC Level |
| 3.D.2 Indirect N2O Emissions From Managed Soils | N2O | 1.45 | 0.7% | 95.1% | KC Level |
| 1.B.2.b Fugitive Emissions from Fuels - Oil and Natural Gas - Natural Gas | CH4 | 1.19 | 0.6% | 95.7% | KC Trend |
| 4.A.1 Forest Land Remaining Forest Land | CO2 | 1.13 | 0.6% | 96.2% | KC Trend |
| 4.F.2 Land Converted to Other Land | CO2 | 0.88 | 0.44% | 96.7% | KC Trend |
| 4.G Harvested Wood Products | CO2 | 0.18 | 0.1% | 96.8% | KC Trend |
| 1.A.3.b Road Transportation | CH4 | 0.08 | 0.0% | 96.8% | 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)**<br>**IPCC Source Categories (and fuels, if applicable)** | GHG | Emissions 1990 abs. values [kt $CO_2$eq] | Share of Total Emissions | Cumulative Total | Result of Assessment |
|---|---|---|---|---|---|
| 1.A.4 Other Sectors - Liquid Fuels | CO2 | 76.71 | 31.7% | 31.7% | KC Level |
| 1.A.3.b Road Transportation | CO2 | 75.29 | 31.1% | 62.7% | KC Level |
| 1.A.2 Fuel combustion - Manufacturing Industries and Construction - Liquid Fuels | CO2 | 20.99 | 8.7% | 71.4% | KC Level |
| 1.A.2 Fuel combustion - Manufacturing Industries and Construction - Gaseous Fuels | CO2 | 15.20 | 6.3% | 77.7% | KC Level |
| 3.A Enteric Fermentation | CH4 | 13.92 | 5.7% | 83.4% | KC Level |
| 1.A.4 Other Sectors - Gaseous Fuels | CO2 | 10.21 | 4.2% | 87.6% | KC Level |
| 3.D.1 Direct N2O Emissions From Managed Soils | N2O | 4.72 | 1.9% | 89.6% | KC Level |
| 4.B.1 Cropland Remaining Cropland | CO2 | 4.18 | 1.7% | 91.3% | KC Level |
| 3.B Manure Management | CH4 | 2.93 | 1.2% | 92.5% | KC Level |
| 4.E.2 Land Converted to Settlements | CO2 | 2.82 | 1.2% | 93.7% | KC Level |
| 4.G Harvested Wood Products | CO2 | 2.69 | 1.1% | 94.8% | KC Level |
| 3.D.2 Indirect N2O Emissions From Managed Soils | N2O | 1.90 | 0.8% | 95.6% | KC Level |

### 1.5.2 KP-LULUCF inventory

Liechtenstein identified four key categories for activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol (Afforestation, Deforestation, Forest Management and Harvested Wood Products). The approach relies on full inventory KCA (with LULUCF), KP - CRF association and qualitative assessment. A detailed description is presented in chp. 11.6 and in Table 11-3.

## 1.6 Uncertainty evaluation

### 1.6.1 GHG inventory

#### 1.6.1.1 Approach 1

In the current inventory, Approach 1 uncertainty is evaluated with level (2019, 1990) and trend (1990-2019) analyses. Approach 1 is based on propagation of error. Uncertainty in the emission level in 2019 and in the trend between the reporting year (2019) 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 A7.1 for further information).

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

### 1.6.1.2 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 NIR (FOEN 2021) 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<br>medium<br>high | 2%<br>10%<br>40% |
| $CH_4$ | low<br>medium<br>high | 15%<br>30%<br>60% |
| $N_2O$ | low<br>medium<br>high | 40%<br>80%<br>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.

### 1.6.1.3 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 $CO_2$eq emissions **excluding LULUCF:**
The Approach 1 level uncertainty for the year 2019 is estimated to be 5.43%, trend uncertainty (1990-2019) is 5.14% (see Table 1-8). The level uncertainty for the year 1990 amounts 7.11% (see Table 1-9).

Uncertainty of national total $CO_2$eq emissions **including LULUCF**:
The Approach 1 level uncertainty for the year 2019 is estimated to be 5.27%, trend uncertainty (1990-2019) is 4.94% (see Table 1-10). The level uncertainty for the year 1990 amounts 7.02% (see Table 1-11).

Compared to the **previous submission in 2020 (reporting year 2018),** the results of the current Approach 1 analyses show similar uncertainties for the assessment including excluding LULUCF and lower uncertainties for the assessment including LULUCF.

- Level uncertainty 2018 (previous submission): 5.40% (excluding LULUCF) and 6.34% (including LULUCF)
- Trend uncertainty 1990-2018 (previous submission): 4.92% (excluding LULUCF) and 6.00% (including LULUCF)

The results for the uncertainty analysis for the year 2019 excluding LULUCF categories are very similar to the previous submission, since both, the emissions (per sectors) and the uncertainty estimates per category have remained similar. However, the results for the uncertainty analysis for 2019 including LULUCF categories are around one percentage point lower than for the previous submission (for both, the level and the trend assessment). This decrease is mainly driven by a decrease of emissions from source category 4A1 Forest land remaining forest land between the years 2018 and 2019 (see Table 6-2). Furthermore, the emission factor uncertainty for 4A1 was slightly reduced in the current submission (see chp. 6.1.5).

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 (2019) and trend (1990-2019) 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 2019 emissions or removals** | **AD unc.** | **EF unc.** | **Comb. unc.** | **Contr. to variance by Category in 2019** | **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 | 3.38 | 5.0 | 0.9 | 5.1 | 0.008 | 0.01 | 0.01 | 0.01 | 0.10 | 0.011 |
| **1A2** | **1. Energy** | A. Fuel combustion activities | 2. Manufacturing industries & construction | Liquid F. | $CO_2$ | 20.99 | 11.21 | 20.0 | 0.1 | 20.0 | 1.437 | 0.03 | 0.05 | 0.00 | 1.39 | 1.927 |
| **1A2** | **1. Energy** | A. Fuel combustion activities | 2. Manufacturing industries & construction | Gaseous F. | $CO_2$ | 15.20 | 12.74 | 5.0 | 0.9 | 5.1 | 0.120 | 0.00 | 0.06 | 0.00 | 0.39 | 0.155 |
| **1A3b** | **1. Energy** | A. Fuel combustion activities | 3. Transp.; b. Road Transp. | | $CO_2$ | 75.29 | 56.17 | 9.2 | 0.1 | 9.2 | 7.686 | 0.02 | 0.25 | 0.00 | 3.21 | 10.306 |
| **1A4** | **1. Energy** | A. Fuel combustion activities | 4. Other Sectors | Liquid F. | $CO_2$ | 76.71 | 30.77 | 15.8 | 0.1 | 15.8 | 6.782 | 0.14 | 0.13 | 0.01 | 3.02 | 9.094 |
| **1A4** | **1. Energy** | A. Fuel combustion activities | 4. Other Sectors | Gaseous F. | $CO_2$ | 10.21 | 33.83 | 4.0 | 0.7 | 4.1 | 0.541 | 0.11 | 0.15 | 0.08 | 0.84 | 0.710 |
| **1B2b** | **1. Energy** | B. Fugitive Emissions from Fuels | 2. Oil and Natural Gas; b. Nat. Gas | | $CH_4$ | 0.36 | 1.19 | 35.4 | 35.4 | 50.0 | 0.100 | 0.00 | 0.01 | 0.14 | 0.26 | 0.086 |
| **2F1** | **2. IPPU** | F. Product uses as substitutes for ODS | 1. Refrigeration and air conditioning | | F-gases | 0.00 | 9.57 | 10.7 | 10.7 | 15.1 | 0.597 | 0.04 | 0.04 | 0.45 | 0.63 | 0.600 |
| **3A** | **3. Agriculture** | A. Enteric Ferment. | | | $CH_4$ | 13.92 | 14.20 | 6.5 | 16.9 | 18.1 | 1.890 | 0.01 | 0.06 | 0.21 | 0.57 | 0.365 |
| **3B** | **3. Agriculture** | B. Manure Management | | | $CH_4$ | 2.93 | 2.78 | 6.5 | 54.0 | 54.4 | 0.656 | 0.00 | 0.01 | 0.09 | 0.11 | 0.021 |
| **3D1** | **3. Agriculture** | D. Agricul-tural Soils | 1. Direct Soil Emissions | | $N_2O$ | 4.72 | 4.47 | 16.6 | 94.7 | 96.2 | 5.281 | 0.00 | 0.02 | 0.25 | 0.46 | 0.274 |
| **non-key rest** | | | | | $CO_2$ | 0.44 | 0.29 | 7.1 | 7.1 | 10.0 | 0.000 | 0.00 | 0.00 | 0.00 | 0.01 | 0.000 |
| **non-key rest** | | | | | $CH_4$ | 2.03 | 1.45 | 21.2 | 21.2 | 30.0 | 0.054 | 0.00 | 0.01 | 0.02 | 0.19 | 0.037 |
| **non-key rest** | | | | | $N_2O$ | 5.57 | 4.84 | 56.6 | 56.6 | 80.0 | 4.289 | 0.00 | 0.02 | 0.07 | 1.70 | 2.881 |
| **non-key rest** | | | | | F-gases | - | 0.21 | 14.1 | 14.1 | 20.0 | 0.000 | 0.00 | 0.00 | 0.01 | 0.02 | 0.000 |
| **Total** | | | | | | **228.51** | **187.11** | | | | **29.44** | | | | | **26.47** |
| | | | | | | | | | | *Percentage uncertainty in total inventory:* | **5.43** | | | | *Trend uncertainty:* | **5.14** |

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 | 3.376 |
| | | | | Gaseous F. | $CO_2$ | 15.20 | 5.0 | 0.9 | 5.1 | 0.114 |
| **1A3b** | | | 3. Transp.; b. Road Transp. | | $CO_2$ | 75.29 | 9.2 | 0.1 | 9.2 | 9.256 |
| **1A4** | | | 4. Other Sectors | Liquid F. | $CO_2$ | 76.71 | 15.8 | 0.1 | 15.8 | 28.258 |
| | | | | Gaseous F. | $CO_2$ | 10.21 | 4.0 | 0.7 | 4.1 | 0.033 |
| **3A** | **3. Agriculture** | A. Enteric Fermentation | | | $CH_4$ | 13.92 | 6.5 | 16.9 | 18.1 | 1.219 |
| **3B** | | B. Manure Management | | | $CH_4$ | 2.93 | 6.5 | 54.0 | 54.4 | 0.487 |
| **3D1** | | D. Agricul-tural Soils | 1. Direct Soil Emissions | | $N_2O$ | 4.72 | 16.6 | 94.7 | 96.2 | 3.951 |
| **non-key rest** | | | | | $CO_2$ | 0.57 | 7.1 | 7.1 | 10.0 | 0.001 |
| | | | | | $CH_4$ | 2.39 | 21.2 | 21.2 | 30.0 | 0.099 |
| | | | | | $N_2O$ | 5.57 | 56.6 | 56.6 | 80.0 | 3.808 |
| | | | | | F-gases | 0.00 | 14.1 | 14.1 | 20.0 | 0.000 |
| **Total** | | | | | | **228.51** | | | | **50.60** |
| | | | | | | | *Percentage uncertainty in total inventory:* | | | **7.11** |

Table 1-10 Approach 1 level (2019) and trend (1990-2019) 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 2019 emissions or removals | AD unc. | EF unc. | Comb. unc. | Contr. to variance by Category in 2019 | 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. introduced 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 | 3.38 | 5.0 | 0.9 | 5.1 | 0.007 | 0.01 | 0.01 | 0.01 | 0.10 | 0.010 |
| 1A2 | | | 2. Manufacturing ind. & constr. | Liquid F. | $CO_2$ | 20.99 | 11.21 | 20.0 | 0.1 | 20.0 | 1.272 | 0.03 | 0.05 | 0.00 | 1.35 | 1.814 |
| | | | | Gaseous F. | $CO_2$ | 15.20 | 12.74 | 5.0 | 0.9 | 5.1 | 0.106 | 0.00 | 0.05 | 0.00 | 0.38 | 0.146 |
| 1A3b | | | 3. Transport; b. Road Transportation | | $CO_2$ | 75.29 | 56.17 | 9.2 | 0.1 | 9.2 | 6.804 | 0.03 | 0.24 | 0.00 | 3.12 | 9.706 |
| | | | | | $CH_4$ | 0.59 | 0.08 | 8.3 | 45.2 | 46.0 | 0.000 | 0.00 | 0.00 | 0.08 | 0.00 | 0.007 |
| 1A4 | | | 4. Other Sectors | Liquid F. | $CO_2$ | 76.71 | 30.77 | 15.8 | 0.1 | 15.8 | 6.003 | 0.14 | 0.13 | 0.01 | 2.93 | 8.564 |
| | | | | Gaseous F. | $CO_2$ | 10.21 | 33.83 | 4.0 | 0.7 | 4.1 | 0.479 | 0.11 | 0.14 | 0.08 | 0.81 | 0.668 |
| 1B2b | | B. Fugitive Emissions from Fuels | 2. Oil, nat. gas, other em. from energy prod. | | $CH_4$ | 0.36 | 1.19 | 35.4 | 35.4 | 50.0 | 0.089 | 0.00 | 0.01 | 0.13 | 0.25 | 0.081 |
| 2F1 | 2. IPPU | F. Prod. uses as subst. for ODS | 1. Refriger. & air cond. | | F-gases | 0.00 | 9.57 | 10.7 | 10.7 | 15.1 | 0.529 | 0.04 | 0.04 | 0.43 | 0.61 | 0.565 |
| 3A | 3. Agriculture | A. Enteric Ferment. | | | $CH_4$ | 13.92 | 14.20 | 6.5 | 16.9 | 18.1 | 1.673 | 0.01 | 0.06 | 0.18 | 0.55 | 0.334 |
| 3B | | B. Manure Managem. | | | $CH_4$ | 2.93 | 2.78 | 6.5 | 54.0 | 54.4 | 0.580 | 0.00 | 0.01 | 0.07 | 0.11 | 0.017 |
| | | | | | $N_2O$ | 1.37 | 1.56 | 31.4 | 152.7 | 155.9 | 1.498 | 0.00 | 0.01 | 0.26 | 0.29 | 0.155 |
| 3D1 | | D. Agricultural Soils | 1. Dir. Soil Em. | | $N_2O$ | 4.72 | 4.47 | 16.6 | 94.7 | 96.2 | 4.675 | 0.00 | 0.02 | 0.19 | 0.45 | 0.237 |
| 3D2 | | D. Agricultural Soils | 2. | | $N_2O$ | 1.90 | 1.45 | 29.5 | 173.0 | 175.5 | 1.633 | 0.00 | 0.01 | 0.11 | 0.26 | 0.079 |
| 4A1 | 4. LULUCF | A. Forest Land | 1. Forest land remaining forest land | | $CO_2$ | -0.49 | -1.13 | 2.7 | 46.7 | 46.8 | 0.071 | 0.00 | 0.00 | 0.14 | 0.02 | 0.021 |
| 4B1 | | B. Cropland | 1. Cropland remaining cropland | | $CO_2$ | 4.18 | 3.96 | 30.8 | 23.0 | 38.4 | 0.584 | 0.00 | 0.02 | 0.04 | 0.73 | 0.536 |
| 4C2 | | | 2. Land converted to grassland | | $CO_2$ | 0.44 | 2.46 | 13.6 | 57.0 | 58.6 | 0.524 | 0.01 | 0.01 | 0.50 | 0.20 | 0.295 |
| 4E2 | | E. Settlements | 2. Land converted to settlements | | $CO_2$ | 2.82 | 2.73 | 19.4 | 33.4 | 38.6 | 0.281 | 0.00 | 0.01 | 0.05 | 0.32 | 0.103 |
| 4F2 | | F. Other land | 2. Land converted to other land | | $CO_2$ | 0.42 | 0.88 | 40.9 | 34.1 | 53.3 | 0.056 | 0.00 | 0.00 | 0.08 | 0.22 | 0.053 |
| 4G | | G. HWP | | | $CO_2$ | -2.69 | 0.18 | 50.0 | 57.0 | 75.8 | 0.005 | 0.01 | 0.00 | 0.59 | 0.05 | 0.355 |
| non-key rest | | | | | $CO_2$ | 2.42 | 2.58 | 7.1 | 7.1 | 10.0 | 0.017 | 0.00 | 0.01 | 0.02 | 0.11 | 0.012 |
| | | | | | $CH_4$ | 1.44 | 1.37 | 21.2 | 21.2 | 30.0 | 0.043 | 0.00 | 0.01 | 0.01 | 0.17 | 0.031 |
| | | | | | $N_2O$ | 2.60 | 2.24 | 56.6 | 56.6 | 80.0 | 0.809 | 0.00 | 0.01 | 0.01 | 0.76 | 0.577 |
| | | | | | F-gases | - | 0.21 | 14.1 | 14.1 | 20.0 | 0.000 | 0.00 | 0.00 | 0.01 | 0.02 | 0.000 |
| **Total** | | | | | | **235.47** | **198.87** | | | | **27.74** | | | | | **24.37** |
| | | | | | | | *Percentage uncertainty in total inventory:* | | | | **5.27** | | | | *Trend uncertainty:* | **4.94** |

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 | 3.179 |
| **1A2** | | A. Fuel combustion activities | 2. Manufacturing industries & construction | Gaseous F. | $CO_2$ | 15.20 | 5.0 | 0.9 | 5.1 | 0.107 |
| **1A3b** | | A. Fuel combustion activities | 3. Transp.; b. Road Transp. | | $CO_2$ | 75.29 | 9.2 | 0.1 | 9.2 | 8.717 |
| **1A4** | | A. Fuel combustion activities | 4. Other Sectors | Liquid F. | $CO_2$ | 76.71 | 15.8 | 0.1 | 15.8 | 26.611 |
| **1A4** | | A. Fuel combustion activities | 4. Other Sectors | Gaseous F. | $CO_2$ | 10.21 | 4.0 | 0.7 | 4.1 | 0.031 |
| **3A** | **3. Agriculture** | A. Enteric Ferment. | | | $CH_4$ | 13.92 | 6.5 | 16.9 | 18.1 | 1.148 |
| **3B** | **3. Agriculture** | B. Manure Management | | | $CH_4$ | 2.93 | 6.5 | 54.0 | 54.4 | 0.458 |
| **3D1** | **3. Agriculture** | D. Agricul-tural Soils | 1. Direct Soil Emissions | | $N_2O$ | 4.72 | 16.6 | 94.7 | 96.2 | 3.720 |
| **3D2** | **3. Agriculture** | D. Agricul-tural Soils | 2. Indir. Em. | | $N_2O$ | 1.90 | 29.5 | 173.0 | 175.5 | 2.001 |
| **4B1** | **4. LULUCF** | B. Cropland | 1. Cropland remaining cropland | | $CO_2$ | 4.18 | 30.8 | 23.0 | 38.4 | 0.466 |
| **4E2** | **4. LULUCF** | E. Settle-ments | 2. Land con-verted to settlements | | $CO_2$ | 2.82 | 19.4 | 33.4 | 38.6 | 0.213 |
| **4G** | **4. LULUCF** | G. HWP | | | $CO_2$ | -2.69 | 50.0 | 57.0 | 75.8 | 0.750 |
| **non-key rest** | | | | | $CO_2$ | 2.92 | 7.1 | 7.1 | 10.0 | 0.015 |
| **non-key rest** | | | | | $CH_4$ | 2.39 | 21.2 | 21.2 | 30.0 | 0.093 |
| **non-key rest** | | | | | $N_2O$ | 3.97 | 56.6 | 56.6 | 80.0 | 1.824 |
| **non-key rest** | | | | | F-gases | 0.00 | 14.1 | 14.1 | 20.0 | 0.000 |
| **Total** | | | | | | **235.47** | | | | **49.33** |
| | | | | | | *Percentage uncertainty in total inventory:* | | | | **7.02** |

The level uncertainties are also evaluated by gas according to the results of the Approach 1 uncertainty assessment excluding LULUCF for the year 2019.

Table 1-12 Level uncertainties by gas 2019 for the total national emissions excluding LULUCF.

| Gas | Emissions 2019 (excluding LULUCF) kt CO2 eq | Mean absolute uncertainty kt CO2 eq | Mean relative uncertainty |
|---|---|---|---|
| CO2 | 148.40 | 7.62 | 5% |
| CH4 | 19.61 | 3.07 | 16% |
| N2O | 9.31 | 5.79 | 62% |
| F-gases | 9.78 | 1.45 | 15% |
| **Total** | **187.11** | **10.2** | **5.43%** |

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.

An Approach 2 uncertainty analysis was not conducted in the current reporting year. However, Approach 2 uncertainty results from a previous submission (reporting year 2016, see box below) show that the resulting uncertainties with Approach 1 for the reporting year 2019 are in a similar range as with Approach 2. 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 current reporting year tend to increase trend uncertainty when assessed with Approach 2 with a Monte Carlo Simulation. This effect is slightly enforced for the analysis including LULUCF due to the strong trends and rather high uncertainty values in this sector.

**Results of the Approach 2 uncertainty analysis for the reporting year 2016:**

The Approach 2 level uncertainty (2016) in the national total annual CO2 equivalent emissions **excluding LULUCF** was 5.04% (95% confidence interval from -4.96% to 5.13%), trend uncertainty (1990-2016) was 6.26%.

The Approach 2 level uncertainty (2016) in the national total annual CO2 equivalent emissions **including LULUCF** was 5.35% (95% confidence interval from -5.30% to 5.41%), trend uncertainty (1990-2016) was 6.56%.

### 1.6.2 Data Collection, processing and storage, including for KP-LULUCF inventory

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

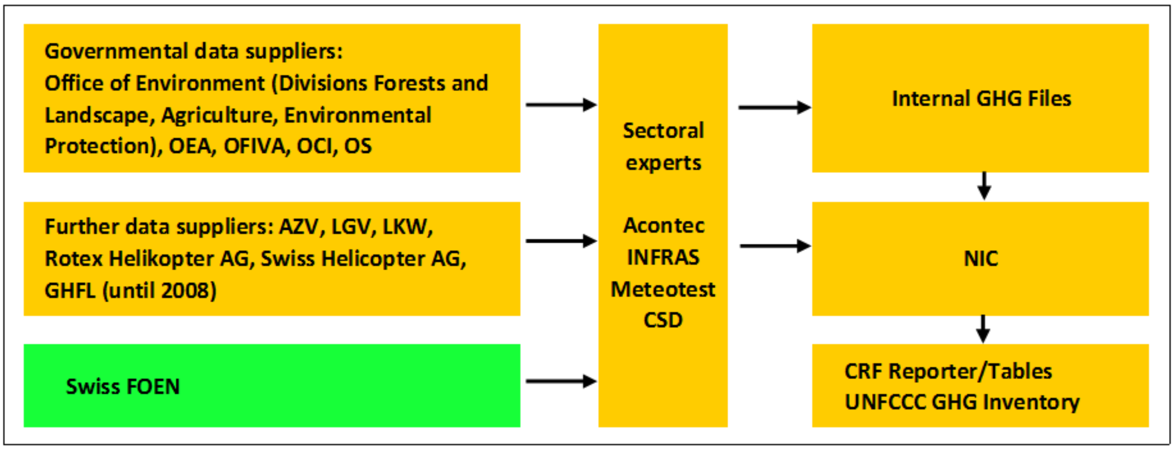



Figure 1-7 Data suppliers and data collection for setting up the UNFCCC GHG Inventory (see Glossary for abbreviations).

#### Documentation and archiving procedures

For the submission 2008, the 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 8. The classification of the QC activities follows the IPCC Guidelines (IPCC 2006). The following persons are involved in the QC activities:

- Sectoral experts,
- NIC / Project manager,
- NIR authors.

Special attention of the QC activities for emissions has been directed to the key categories.

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.

In addition to the administrational archiving system, the external experts of Acontec AG, who are mandated with the emission modelling and CRF generation, save all CRF and background tables yearly on CD ROM/DVD ROM. The disks are stored in a bank safe of the Liechtensteinische Landesbank (Liechtenstein's National Bank). Also, the data generated in the NIR compilation process such as the NIR 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 (IQNet 2017).

Finally, the entire information exchange by email between all people involved in updating the NIR 2021 is stored in PST format.

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

### 1.6.3 KP-LULUCF inventory

The net $CO_2$ emissions in 2019 are 5.04 kt $CO_2$eq ± 2.66 kt $CO_2$eq (see chp. 11.3.2 for details of the calculation).

## 1.7 Assessment of completeness

### 1.7.1 GHG inventory

Liechtenstein's current GHG inventory is complete for all gases concerning the second commitment period.

### 1.7.2 KP-LULUCF inventory

Liechtenstein's current KP-LULUCF Inventory is complete.

# 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 1990–2019. Data shown in chp. 2.1-2.4 are relevant for reporting under the UNFCCC, whereas data shown in chp. 2.5 refer to accounting under the Kyoto Protocol.

## 2.1 Aggregated greenhouse gas emissions 2019

Liechtenstein's greenhouse gas emissions in the year 2019 amount to 187.1 kt $CO_2$ equivalent ($CO_2$eq) excluding LULUCF sources or sinks (including LULUCF: 198.9 kt $CO_2$eq). This refers to 4.95 t $CO_2$eq per capita.

Total emissions in 2019 (excl. LULUCF) have declined by 18.1% compared to 1990. Compared to 2018, they increased by 3.6%. When including LULUCF categories, total emissions decreased by 1.8% between 2018-2019 and by 15.5% between 1990-2019.

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 2019. 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 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.

| **Emissions 2019** | **$CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **$SF_6$** | **Total** |
|---|---|---|---|---|---|---|---|
| | **$CO_2$ equivalent (kt)** | | | | | | |
| 1 Energy | 148.2 | 1.69 | 1.01 | - | - | - | 150.9 |
| 2 IPPU | 0.12 | NO | 0.14 | 9.7 | 0.00 | 0.05 | 10.0 |
| 3 Agriculture | 0.05 | 16.98 | 7.48 | - | - | - | 24.5 |
| 5 Waste | 0.01 | 0.94 | 0.68 | - | - | - | 1.63 |
| **Total (excluding LULUCF)** | **148.4** | **19.6** | **9.31** | **9.7** | **0.00** | **0.05** | **187.1** |
| 4 LULUCF | 11.4 | NO | 0.40 | - | - | - | 11.8 |
| **Total (including LULUCF)** | **159.8** | **19.6** | **9.7** | **9.7** | **0.00** | **0.05** | **198.9** |
| *International Bunkers* | *1.12* | *0.0002* | *0.01* | - | - | - | *1.13* |

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 2019 (excluding emissions from LULUCF), $CO_2$ is the most dominant greenhouse gas emitted in Liechtenstein. $CH_4$ emissions represent 10.5% and $N_2O$ emissions 5.0% of the total emissions.

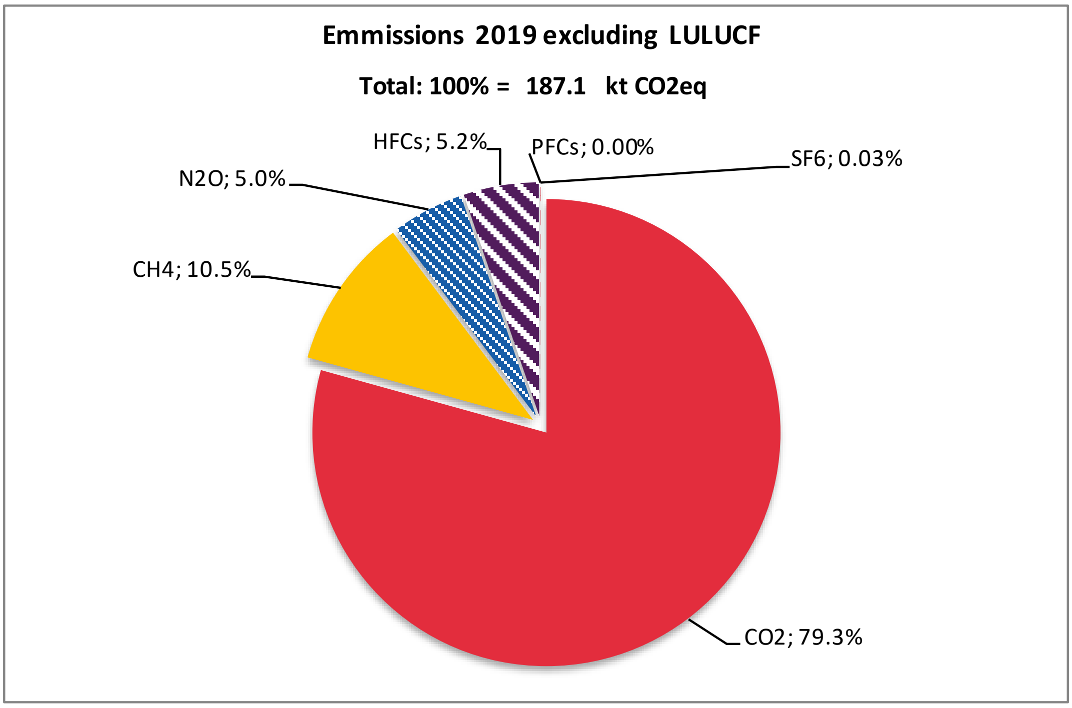



Figure 2-1 Liechtenstein's GHG emissions by gases excluding LULUCF emissions.

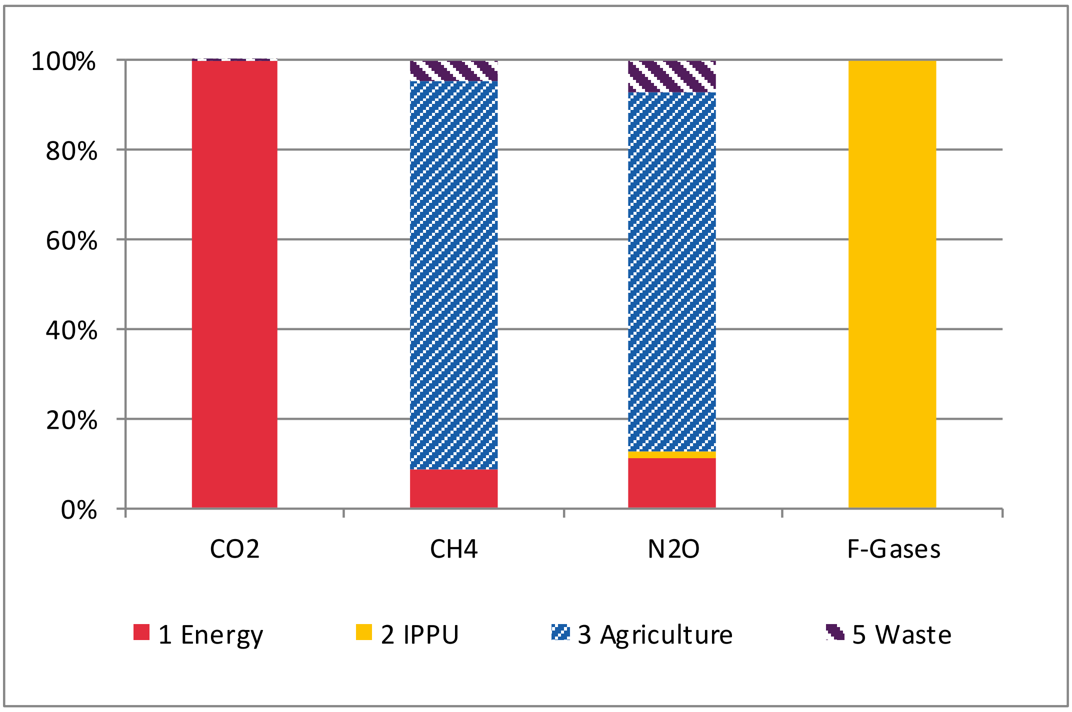



Figure 2-2 Relative contributions of the individual sectors (excluding LULUCF) to GHG emissions in 2019.

## 2.2 Emission trends by gas

Emission trends 1990–2019 by gas are summarised in Table 2-2 and in Figure 2-3.

Table 2-2 Summary of Liechtenstein's GHG emissions in $CO_2$eq (kt) by gas. The last column shows the percentage change in emissions in 2019 as compared to the base year 1990. HFC emissions have increased by about a factor of 100'000 in 2019 compared to 1990.

| **Greenhouse Gas Emissions** | **1990** | **1995** | **2000** | **2005** | **2010** |
|---|---|---|---|---|---|
| | **$CO_2$ equivalent (kt)** | | | | |
| $CO_2$ emissions incl. net $CO_2$ from LULUCF | 205.6 | 208.6 | 241.0 | 237.3 | 210.7 |
| $CO_2$ emissions excl. net $CO_2$ from LULUCF | 199.0 | 204.2 | 216.8 | 229.0 | 190.8 |
| $CH_4$ emissions incl. $CH_4$ from LULUCF | 19.2 | 18.0 | 16.7 | 18.6 | 19.1 |
| $CH_4$ emissions excl. $CH_4$ from LULUCF | 19.2 | 18.0 | 16.7 | 18.6 | 19.1 |
| $N_2O$ emissions incl. $N_2O$ from LULUCF | 10.6 | 10.5 | 9.8 | 9.5 | 9.7 |
| $N_2O$ emissions excl. $N_2O$ from LULUCF | 10.3 | 10.2 | 9.5 | 9.1 | 9.3 |
| HFCs | 0.0 | 1.2 | 3.9 | 6.7 | 9.0 |
| 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)** | 235.5 | 238.3 | 271.6 | 272.4 | 248.5 |
| **Total (excluding LULUCF)** | 228.5 | 233.6 | 247.0 | 263.7 | 228.2 |

| **Greenhouse Gas Emissions** | **2011** | **2012** | **2013** | **2014** | **2015** |
|---|---|---|---|---|---|
| | **$CO_2$ equivalent (kt)** | | | | |
| $CO_2$ emissions incl. net $CO_2$ from LULUCF | 200.4 | 209.2 | 209.0 | 177.6 | 170.8 |
| $CO_2$ emissions excl. net $CO_2$ from LULUCF | 176.7 | 185.3 | 192.5 | 161.2 | 159.6 |
| $CH_4$ emissions incl. $CH_4$ from LULUCF | 19.4 | 19.8 | 19.0 | 19.2 | 19.1 |
| $CH_4$ emissions excl. $CH_4$ from LULUCF | 19.4 | 19.8 | 19.0 | 19.2 | 19.1 |
| $N_2O$ emissions incl. $N_2O$ from LULUCF | 10.1 | 10.0 | 9.7 | 9.6 | 9.6 |
| $N_2O$ emissions excl. $N_2O$ from LULUCF | 9.7 | 9.5 | 9.2 | 9.1 | 9.2 |
| HFCs | 9.4 | 9.8 | 9.8 | 10.0 | 10.1 |
| PFCs | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| $SF_6$ | 0.0 | 0.0 | 0.2 | 0.1 | 0.0 |
| Unspecified mix of HFCs and PFCs | NO | NO | NO | NO | NO |
| $NF_3$ | NO | NO | NO | NO | NO |
| **Total (including LULUCF)** | **239.4** | **248.9** | **247.6** | **216.5** | **209.6** |
| **Total (excluding LULUCF)** | **215.3** | **224.5** | **230.7** | **199.7** | **198.0** |

| **Greenhouse Gas Emissions** | **2016** | **2017** | **2018** | **2019** | **1990-2019** |
|---|---|---|---|---|---|
| | **$CO_2$ equivalent (kt)** | | | | **%** |
| $CO_2$ emissions incl. net $CO_2$ from LULUCF | 158.9 | 165.9 | 163.6 | 159.8 | -22% |
| $CO_2$ emissions excl. net $CO_2$ from LULUCF | 149.5 | 155.3 | 142.3 | 148.4 | -25% |
| $CH_4$ emissions incl. $CH_4$ from LULUCF | 19.2 | 18.7 | 18.9 | 19.6 | 2% |
| $CH_4$ emissions excl. $CH_4$ from LULUCF | 19.2 | 18.7 | 18.9 | 19.6 | 2% |
| $N_2O$ emissions incl. $N_2O$ from LULUCF | 9.5 | 9.4 | 9.6 | 9.7 | -8% |
| $N_2O$ emissions excl. $N_2O$ from LULUCF | 9.0 | 9.0 | 9.2 | 9.3 | -10% |
| HFCs | 9.8 | 10.0 | 10.2 | 9.7 | see caption |
| PFCs | 0.0 | 0.0 | 0.0 | 0.0 | - |
| $SF_6$ | 0.0 | 0.0 | 0.1 | 0.0 | - |
| Unspecified mix of HFCs and PFCs | NO | NO | NO | NO | - |
| $NF_3$ | NO | NO | NO | NO | - |
| **Total (including LULUCF)** | **197.3** | **204.1** | **202.4** | **198.9** | **-16%** |
| **Total (excluding LULUCF)** | **187.5** | **193.0** | **180.7** | **187.1** | **-18%** |

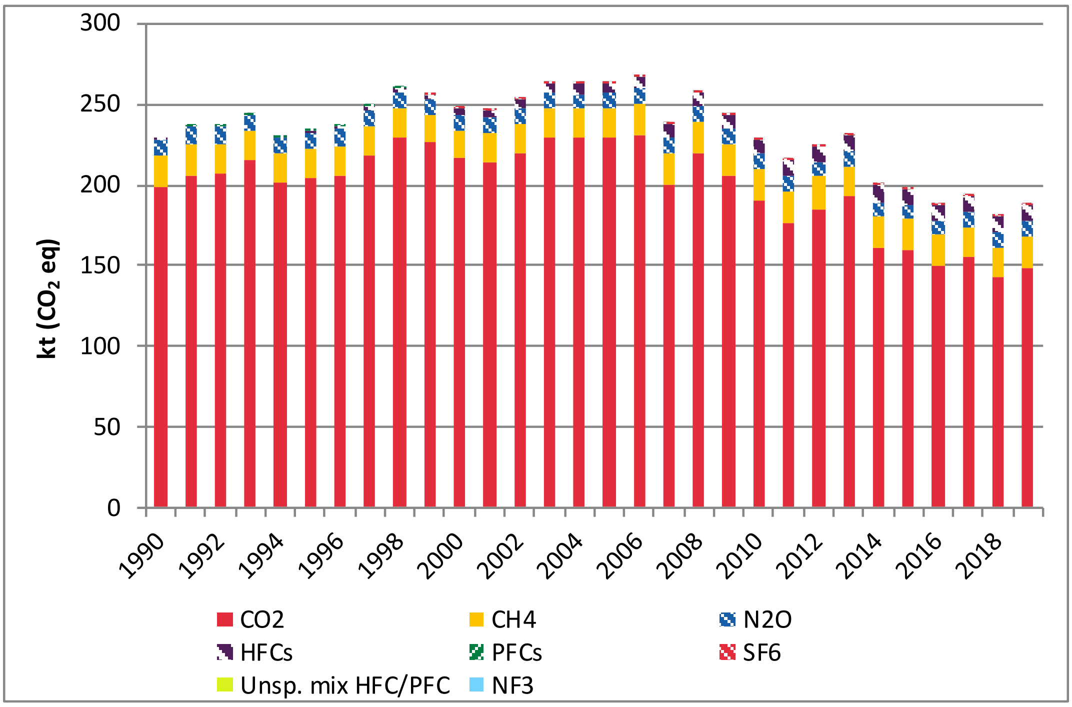



Figure 2-3 Trend of Liechtenstein's greenhouse gas emissions by gases. $CO_2$, $CH_4$ and $N_2O$ correspond to the respective total emissions excluding LULUCF. Note that $NF_3$ emissions are not occurring.

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 in the period 1990-2006. From 2006 onwards, a decreasing trend starts to develop. The emission maximum occurred in 2006. Emission trends for the individual gases can be described as follows:

- Total emissions (in $CO_2$eq) excluding LULUCF sources or sinks decreased by 18.1% from 1990 to 2019.
- Total emissions (in $CO_2$eq) including LULUCF show a decrease of 15.5% in 2019 compared to 1990 levels.
- $CO_2$ emissions (excluding net $CO_2$ from LULUCF) have declined by 25.4% between 1990 and 2019. In comparison to the previous reporting year 2018, $CO_2$ emissions (excluding net $CO_2$ from LULUCF) increased by 4.3% in 2019. 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 (see chp. 2.3). The share of $CO_2$ emissions decreased from 87.1% in 1990 to 79.3% in 2019 (excl. LULUCF).
- $CH_4$ emissions (excluding $CH_4$ from LULUCF) have increased by 1.9% since 1990. Compared to 2018, $CH_4$ emissions (excluding LULUCF) show an increase by 3.5% in 2019. 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 8.4% in 1990 to 10.5% in 2019 (excl. LULUCF).

- $N_2O$ emissions (excluding $N_2O$ from LULUCF) have declined by 9.5% in 2019 compared to 1990. Compared to 2018, $N_2O$ emissions (without LULUCF) in 2019 increased by 1.6%. The main source of $N_2O$ emissions is agriculture (manure management and agricultural soils). The share of $N_2O$ slightly increased from 4.5% (1990) to 5.0% (2019).
- 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 0.00005% (1990) to 5.2% (2019).

## 2.3 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 $CO_2$eq (kt). The last column shows the percent change in emissions in 2019 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** | **217.9** | **203.9** | **207.1** | **208.9** | **221.5** | **232.4** | **229.7** |
| 1A1 Energy industries | 0.2 | 0.9 | 1.9 | 2.0 | 1.8 | 2.1 | 2.6 | 2.5 | 2.9 | 2.9 |
| 1A2 Manufacturing industries & constr. | 36.3 | 36.0 | 36.4 | 37.6 | 35.7 | 35.7 | 35.8 | 37.6 | 40.4 | 39.9 |
| 1A3 Transport | 76.9 | 90.2 | 89.6 | 87.5 | 80.1 | 82.1 | 83.4 | 87.0 | 86.6 | 90.8 |
| 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 | 0.4 | 0.5 | 0.5 | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 | 0.8 |
| **2 IPPU** | **0.7** | **0.6** | **0.7** | **0.8** | **1.0** | **1.8** | **2.1** | **2.4** | **3.0** | **3.6** |
| **3 Agriculture** | **24.9** | **24.9** | **24.2** | **23.1** | **23.3** | **23.1** | **23.3** | **22.9** | **22.5** | **21.5** |
| **5 Waste** | **1.7** | **1.6** | **1.7** | **1.6** | **1.6** | **1.6** | **1.6** | **1.6** | **1.6** | **1.6** |
| ***Total (excluding LULUCF)*** | ***228.5*** | ***236.1*** | ***236.3*** | ***243.4*** | ***229.8*** | ***233.6*** | ***235.9*** | ***248.5*** | ***259.4*** | ***256.4*** |
| **4 LULUCF** | **7.0** | **-8.7** | **2.2** | **-1.1** | **18.0** | **4.7** | **-3.5** | **7.8** | **0.2** | **-0.9** |
| ***Total (including LULUCF)*** | ***235.5*** | ***227.4*** | ***238.4*** | ***242.3*** | ***247.8*** | ***238.3*** | ***232.4*** | ***256.3*** | ***259.6*** | ***255.5*** |

| Source and Sink Categories | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | | | | | | |
| **1 Energy** | **220.1** | **217.8** | **223.0** | **232.3** | **231.9** | **231.5** | **233.6** | **203.3** | **222.1** | **208.0** |
| 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 industries & constr. | 36.5 | 36.4 | 37.9 | 41.2 | 39.9 | 39.2 | 40.6 | 33.9 | 36.4 | 27.6 |
| 1A3 Transport | 91.6 | 88.2 | 84.1 | 83.8 | 82.2 | 81.8 | 79.2 | 83.3 | 87.8 | 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 | 0.8 | 0.9 | 0.9 | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 | 1.2 | 1.1 |
| **2 IPPU** | **4.4** | **5.2** | **5.9** | **6.6** | **7.3** | **7.5** | **7.9** | **8.8** | **9.4** | **9.0** |
| **3 Agriculture** | **20.9** | **21.9** | **22.3** | **22.5** | **22.5** | **23.1** | **24.1** | **24.4** | **24.7** | **24.5** |
| **5 Waste** | **1.6** | **1.7** | **1.7** | **1.7** | **1.7** | **1.7** | **1.6** | **1.6** | **1.6** | **1.6** |
| ***Total (excluding LULUCF)*** | ***247.0*** | ***246.6*** | ***252.9*** | ***263.1*** | ***263.3*** | ***263.7*** | ***267.3*** | ***238.1*** | ***257.9*** | ***243.1*** |
| **4 LULUCF** | **24.5** | **1.6** | **2.5** | **6.5** | **8.7** | **8.8** | **13.5** | **22.6** | **24.7** | **21.8** |
| ***Total (including LULUCF)*** | ***271.6*** | ***248.2*** | ***255.5*** | ***269.6*** | ***272.0*** | ***272.4*** | ***280.8*** | ***260.7*** | ***282.6*** | ***264.9*** |

| Source and Sink Categories | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 1990-2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | | | | | | | % |
| **1 Energy** | **193.4** | **179.3** | **187.9** | **195.1** | **163.6** | **162.1** | **152.0** | **157.8** | **144.8** | **150.9** | **-25.0%** |
| 1A1 Energy industries | 3.3 | 3.1 | 2.8 | 3.0 | 2.5 | 2.0 | 2.2 | 2.1 | 2.2 | 3.4 | 1844.0% |
| 1A2 Manufacturing industries & constr. | 26.1 | 23.6 | 25.7 | 26.4 | 27.4 | 27.6 | 26.0 | 27.7 | 24.6 | 24.1 | -33.7% |
| 1A3 Transport | 77.7 | 76.9 | 79.9 | 79.6 | 73.7 | 61.7 | 60.2 | 60.4 | 58.3 | 56.8 | -26.1% |
| 1A4 Other sectors | 85.2 | 74.7 | 78.3 | 84.9 | 58.9 | 69.5 | 62.5 | 66.4 | 58.6 | 65.4 | -25.3% |
| 1A5 Other | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO | - |
| 1B Fugitive emissions from fuels | 1.1 | 1.1 | 1.1 | 1.2 | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 225.6% |
| **2 IPPU** | **9.4** | **9.9** | **10.2** | **10.3** | **10.5** | **10.5** | **10.1** | **10.4** | **10.5** | **10.0** | **1432.3%** |
| **3 Agriculture** | **23.7** | **24.5** | **24.8** | **23.6** | **24.0** | **23.9** | **23.9** | **23.3** | **23.7** | **24.5** | **-1.6%** |
| **5 Waste** | **1.6** | **1.7** | **1.6** | **1.7** | **1.6** | **1.6** | **1.6** | **1.6** | **1.6** | **1.6** | **-2.4%** |
| ***Total (excluding LULUCF)*** | ***228.2*** | ***215.3*** | ***224.5*** | ***230.7*** | ***199.7*** | ***198.0*** | ***187.5*** | ***193.0*** | ***180.7*** | ***187.1*** | ***-18.1%*** |
| **4 LULUCF** | **20.4** | **24.1** | **24.4** | **16.9** | **16.8** | **11.6** | **9.8** | **11.1** | **21.7** | **11.8** | **68.9%** |
| ***Total (including LULUCF)*** | ***248.5*** | ***239.4*** | ***248.9*** | ***247.6*** | ***216.5*** | ***209.6*** | ***197.3*** | ***204.1*** | ***202.4*** | ***198.9*** | ***-15.5%*** |

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.

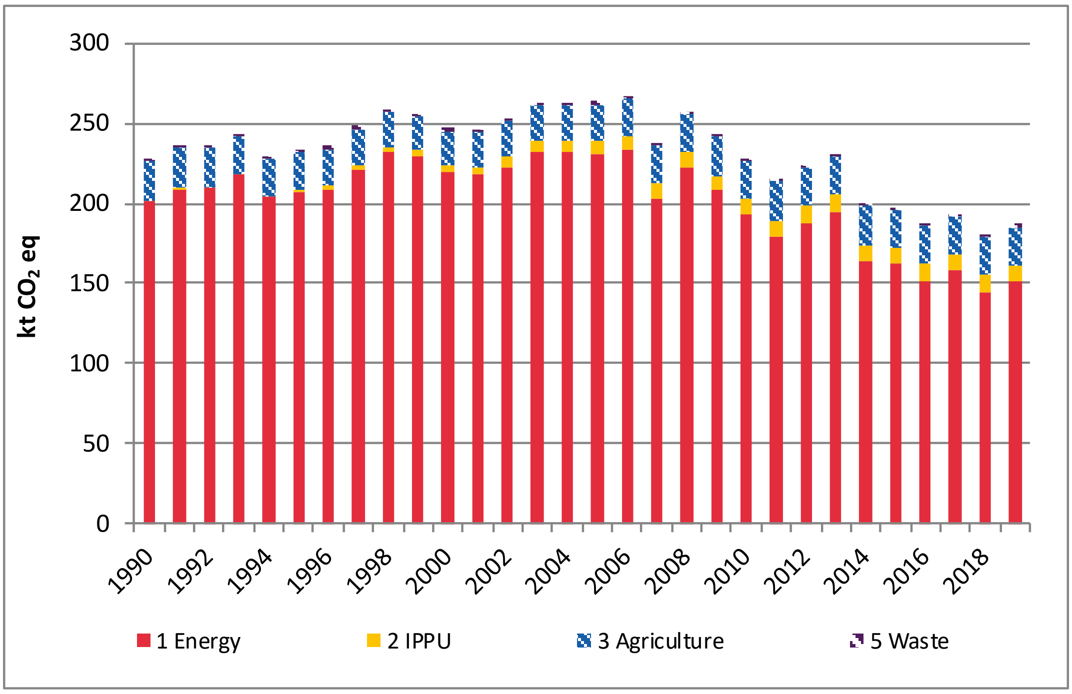



Figure 2-4 Trend of Liechtenstein's greenhouse gas emissions by main source categories in $CO_2$eq (kt) (excl. net $CO_2$ from LULUCF).

The following emission trends are observed in the sectors:

**Sector 1 Energy:** In 2019, 80.7% of Liechtenstein's GHG emissions (excluding LULUCF) originate from sector 1 Energy, which is 0.5 percentage points more than in 2018. The share of sector 1 Energy in the total emissions declined by 7.4 percentage points since 1990. Also, the total emissions of the sector 1 Energy clearly decreased in comparison to 1990 levels (by 25.0%). The source categories within sector 1 Energy show the following trends between 1990 and 2019:

- 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 19 since 1990.
- 1A2 Manufacturing industries and construction: Total emissions from this source category have declined by 33.7% since 1990. Gaseous fuels are the more important energy carrier in Liechtenstein in 2019. In 2019, emissions from gaseous fuels decreased by 16.1% compared to 1990 and by 11.4% compared to 2018. Liquid fuel emissions decreased by 46.5% 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 have started decreasing since 2012. Between 2018 and 2019, emissions of 1A3 decreased by 2.5%. The overall trend shows a decrease of 26.1% (1990-2019). 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 increased by 11.6% compared to the previous reporting year 2018. 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.

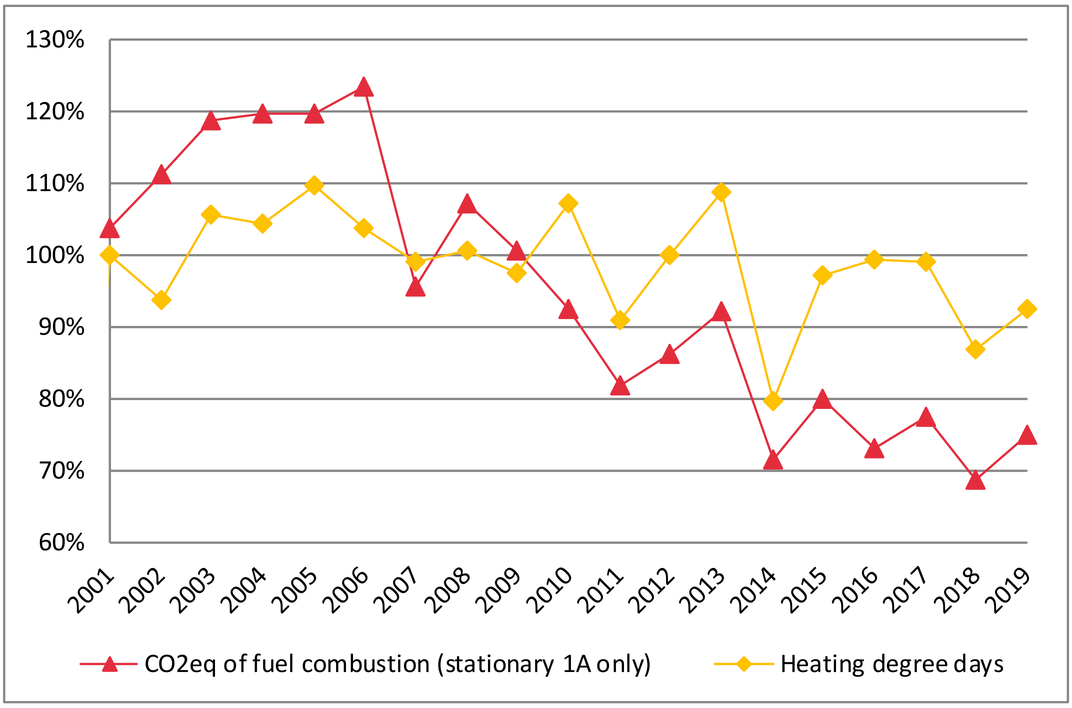



Figure 2-5 Relative trend for $CO_2$ emissions from 1A Fuel Combustion compared with the number of heating degree days. The drop of emissions in 2007 is driven by high oil and gas prices.

- 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 1990-2019 (225.6%).

**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 1990-2019, which leads to a relative increase of emissions in sector 2 approximately by a factor of 15. The most important source category is 2F Product uses as substitutes for ozone-depleting substances (ODS) due to the replacement of CFCs with HFCs.

**Sector Agriculture:** In 2019, emissions are below the 1990 level by 1.6%. The main parameter influencing $CH_4$ and $N_2O$ emissions from agriculture are animal numbers (in particular cattle and swine). Since the numbers of these animals declined in comparison with 1990, emissions have also been reduced.

**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.

The total net emissions increased by 68.9% between 1990 and 2019.

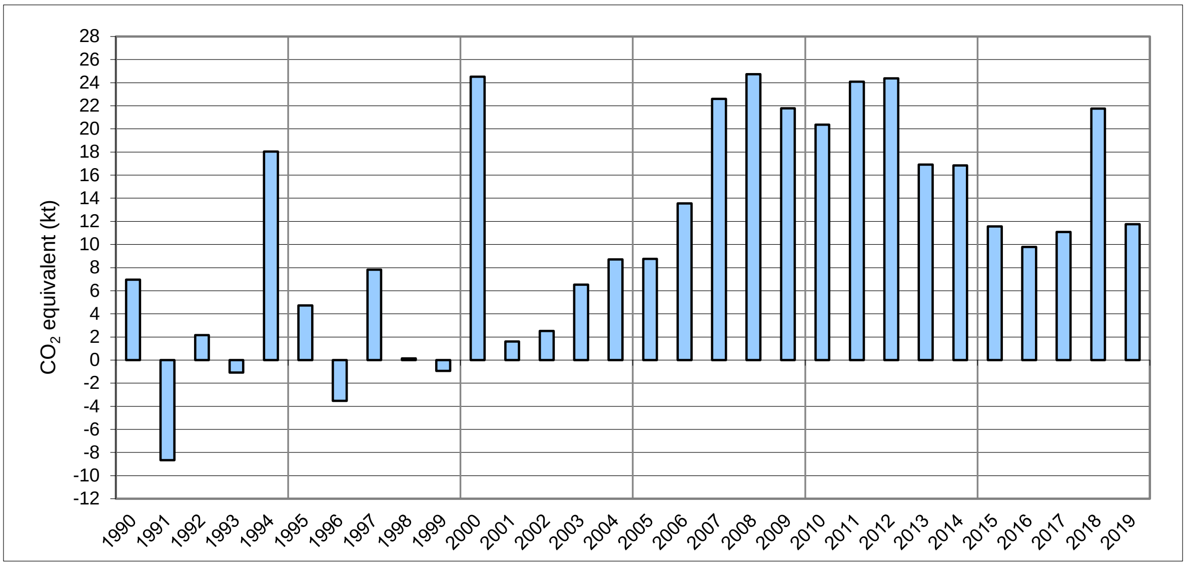



Figure 2-6 Liechtenstein's $CO_2$ emissions/removals of source category 4 LULUCF in kt $CO_2$ equivalent.

**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 2019 (2.4%). The development of the greenhouse gas emissions is dominated by source category 5D Wastewater treatment and discharge and to a lesser extent by source category 5A Solid waste disposal. 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.

## 2.4 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 2021 will take place at the end of April 2021, and **the overview and results provided below are from the submission to CLRTAP in 2020**. (Therefore, results for 2019 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 2020). 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 2020 (OE 2020f).

| Precursor gases and $SO_2$ | 1990 | 1995 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| | tonnes | | | | |
| $NO_x$ | 614 | 570 | 542 | 510 | 425 |
| CO | 1’516 | 919 | 721 | 576 | 594 |
| NMVOC | 1’288 | 812 | 550 | 366 | 336 |
| $SO_x$ | 115 | 73 | 47 | 37 | 22 |

| Precursor gases and $SO_2$ | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|
| | tonnes | | | | |
| $NO_x$ | 422 | 424 | 422 | 402 | 389 |
| CO | 602 | 594 | 544 | 566 | 578 |
| NMVOC | 331 | 330 | 318 | 312 | 305 |
| $SO_x$ | 19 | 18 | 17 | 12 | 12 |

| Precursor gases and $SO_2$ | 2016 | 2017 | 2018 | 1990-2018 |
|---|---|---|---|---|
| | tonnes | | | % |
| $NO_x$ | 364 | 350 | 335 | -45% |
| CO | 553 | 530 | 560 | -63% |
| NMVOC | 297 | 297 | 292 | -77% |
| $SO_x$ | 10 | 10 | 9 | -92% |

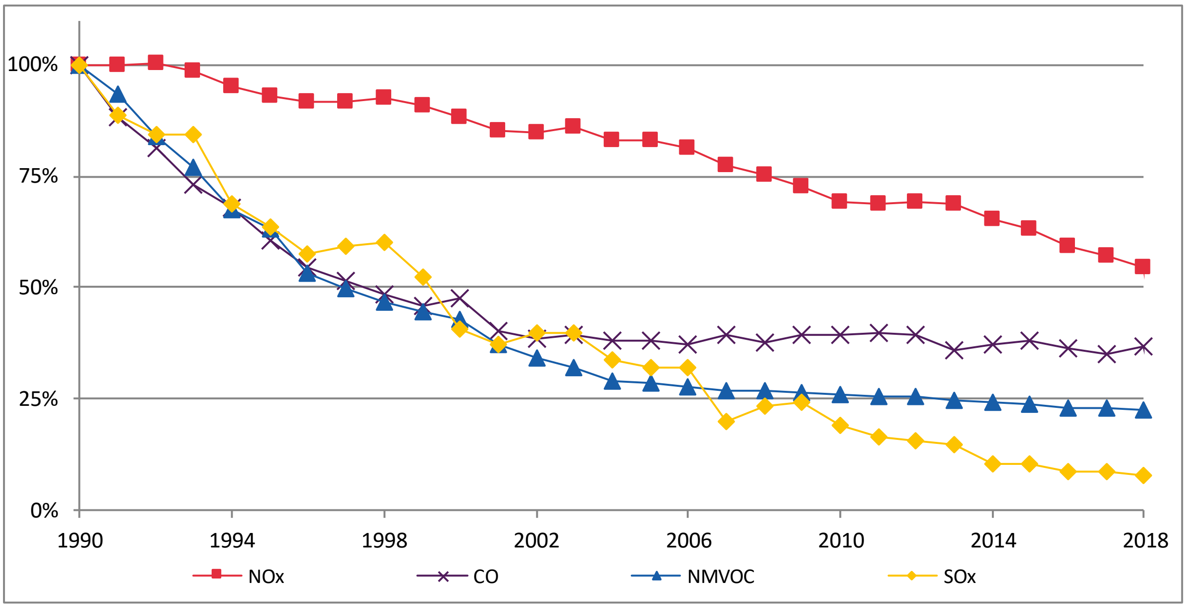



Figure 2-7 Trend of $NO_x$, CO, NMVOC and $SO_x$ emissions as of CLRTAP submission 2020 (OE 2020f).

The complete CLRTAP Inventory data can be found on the internet (see OE 2020f):
https://www.ceip.at/status-of-reporting-and-review-results/2020-submissions.

## 2.5 Emission trends in KP-LULUCF inventory

Table 2-5 and Figure 2-8 illustrates the total net emissions occurring from activities under KP-LULUCF. Deforestation and HWP are emission sources over the whole period 2008-2019 while afforestation is a sink. The development of emissions from forest management is mainly driven by the harvesting rate (see chp. 2.3 “Sector 4 LULUCF”): In most years, forest management is an emission source, but in years with low harvesting it is a sink (2015-2017). Reforestation does not occur in Liechtenstein.

Table 2-5 Development of net $CO_2$ equivalent emissions of afforestation, deforestation, forest management and HWP in Liechtenstein.

| KP-LULUCF | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | | | | | | | | |
| **Afforestation** | -0.30 | -0.30 | -0.31 | -0.31 | -0.32 | -0.32 | -0.32 | -0.33 | -0.33 | -0.34 | -0.34 | -0.35 |
| **Deforestation** | 4.21 | 4.30 | 4.39 | 4.49 | 4.58 | 4.68 | 4.77 | 4.87 | 4.96 | 4.80 | 4.63 | 4.46 |
| **Forest Mangement** | 13.32 | 10.20 | 8.64 | 12.45 | 12.73 | 5.06 | 4.98 | -0.46 | -2.31 | -0.64 | 10.74 | 0.75 |
| **HWP** | 0.04 | 0.13 | 0.21 | 0.21 | 0.21 | 0.20 | 0.20 | 0.19 | 0.19 | 0.19 | 0.18 | 0.18 |
| **Total** | 17.27 | 14.32 | 12.94 | 16.84 | 17.21 | 9.63 | 9.62 | 4.28 | 2.51 | 4.01 | 15.21 | 5.04 |

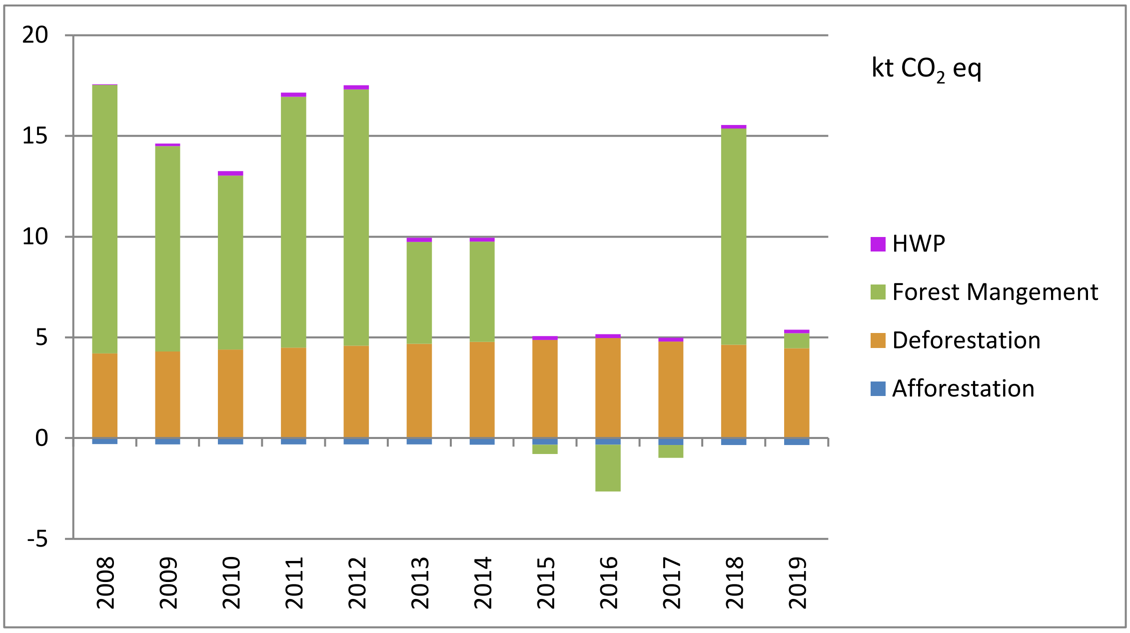



Figure 2-8 Trend of emissions of afforestation, deforestation, forest management and HWP in Liechtenstein.

# 3. Energy

## 3.1 Overview

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. 150.9 kt $CO_2$ equivalents were emitted within this sector, which corresponds to 80.7% of total emissions (187.1 kt $CO_2$ equivalent, excluding LULUCF). The emissions of the time period 1990–2019 are depicted in Figure 3-1.

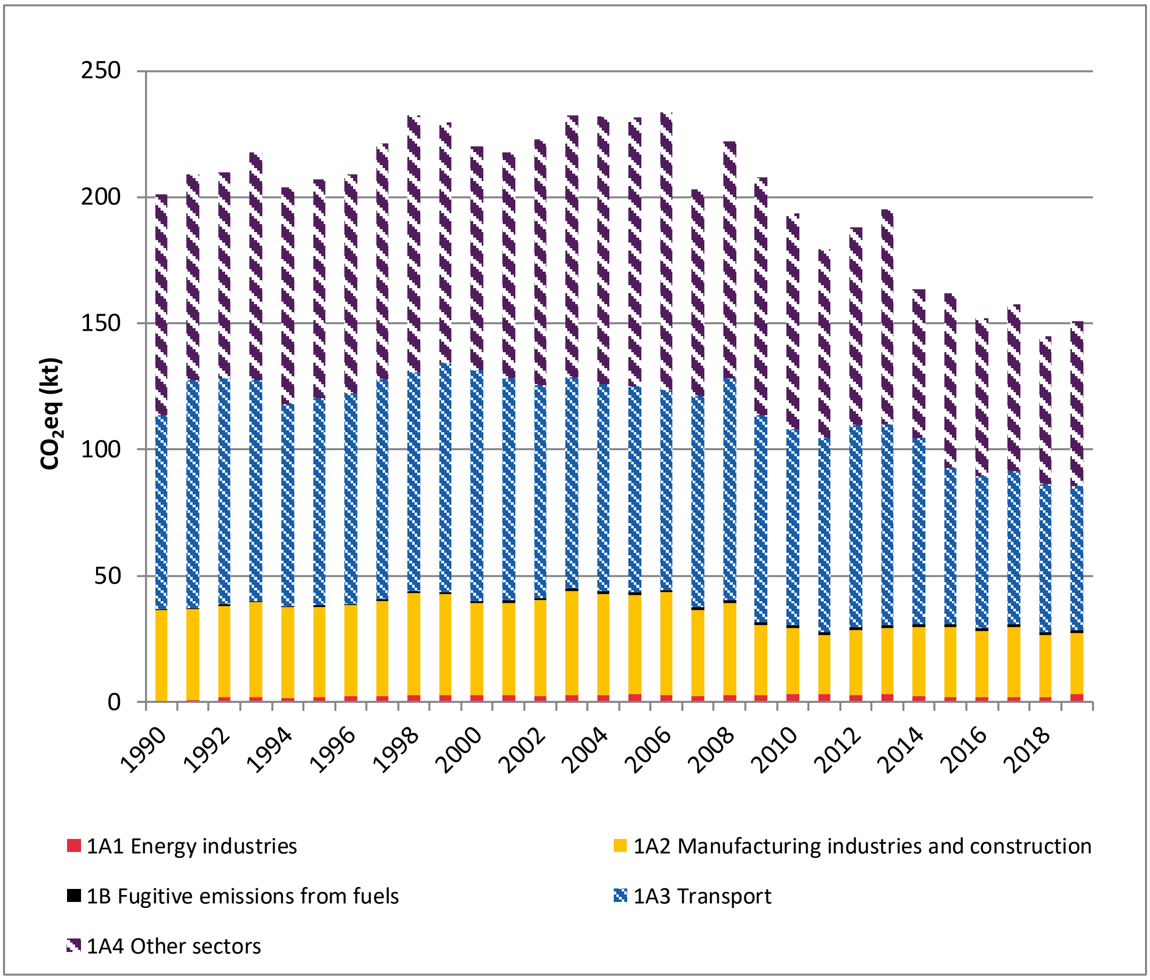



Figure 3-1 Liechtenstein's GHG emissions of the sector 1 Energy by sub-sectors. Note that there are no emissions in sub-sector 1A5.

Table 3-1 summarises the emissions from sector 1 Energy by individual gases 1990–2019. 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 and the Kyoto Protocol.

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 |
| $CH_4$ | 1.3 | 1.3 | 1.5 | 1.8 | 1.7 |
| $N_2O$ | 1.3 | 1.8 | 1.9 | 1.0 | 1.1 |
| **Sum** | **201.3** | **207.1** | **220.1** | **231.5** | **193.4** |

| Gas | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | |
| $CO_2$ | 176.5 | 185.1 | 192.3 | 161.0 | 159.4 |
| $CH_4$ | 1.7 | 1.7 | 1.7 | 1.6 | 1.7 |
| $N_2O$ | 1.1 | 1.1 | 1.1 | 1.0 | 1.0 |
| **Sum** | **179.3** | **187.9** | **195.1** | **163.6** | **162.1** |

| Gas | 2016 | 2017 | 2018 | 2019 | 1990-2019 |
|---|---|---|---|---|---|
| | $CO_2$ equivalent (kt) | | | | % |
| $CO_2$ | 149.4 | 155.1 | 142.1 | 148.2 | -25.4% |
| $CH_4$ | 1.6 | 1.7 | 1.7 | 1.7 | 32.3% |
| $N_2O$ | 1.0 | 1.0 | 1.0 | 1.0 | -22.5% |
| **Sum** | **152.0** | **157.8** | **144.8** | **150.9** | **-25.0%** |

Table 3-2 shows more details of the emissions of sector 1 Energy in 2019. 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 and the Kyoto Protocol.

Table 3-2 Summary of sector 1 Energy, emissions in 2019 in kt $CO_2$ equivalent (rounded values).

| **Emissions 2019** | **$CO_2$** | **$CH_4$** | **$N_2O$** | **Total** | |
|---|---|---|---|---|---|
| Sources | **$CO_2$ equivalent (kt)** | | | | **%** |
| **1 Energy** | **148.2** | **1.7** | **1.0** | **150.9** | ***100.0%*** |
| **1A Fuel Combustion** | **148.2** | **0.5** | **1.0** | **149.7** | ***99.2%*** |
| 1A1 Energy industries | 3.4 | 0.0 | 0.0 | 3.4 | ***2.3%*** |
| 1A2 Manufacturing industries and construction | 24.0 | 0.0 | 0.1 | 24.1 | ***16.0%*** |
| 1A3 Transport | 56.3 | 0.1 | 0.5 | 56.8 | ***37.7%*** |
| 1A4 Other sectors | 64.6 | 0.3 | 0.4 | 65.4 | ***43.3%*** |
| 1A5 Other | NO | NO | NO | NO | - |
| **1B Fugitive emissions from fuels** | **0.0** | **1.2** | **NO,NA** | **1.2** | ***0.8%*** |
| **International Bukers** | **1.1** | **0.0** | **0.0** | **1.1** | - |
| **$CO_2$ Emissions from Biomass** | **27.3** | - | - | **27.3** | - |

Emissions from sector 1 Energy may be characterised as follows:

- Concerning the total emissions ($CO_2$ eq) from sector 1 Energy, a trend of -25% can be observed between 1990 and 2019. From 2018 to 2019 emissions increased by 4.2%, which is mainly caused by the increase in the consumption of gas oil in 1A4 Other sectors. The increasing number of heating degree days in 2019 compared to 2018 only marginally contributed to the increase in the emissions from 1A4 Others. The increase is mainly due to the increase in the $CO_2$ levy by January 1, 2018, which caused an increase in sales of gas oil in 2017 and a reduced apparent consumption in 2018 and subsequently again an increase in 2019, since gas oil tanks had to be filled again in 2019. The emissions of the sector 1 Energy reached a minimum in 2018.
- The three source categories 1A2, 1A3 and 1A4 dominate the emissions of sector 1 Energy and cover altogether 96.9% (146.3 kt $CO_2$ eq) of total emissions of sector 1.
    - 1A3 Transport accounts for 37.7% of the emissions in 2019.
    - 1A4 Other sectors (commercial/institutional, residential) contributes to 43.3% of the total energy-related emissions.
    - 1A2 Manufacturing industries and construction contributes to 16.0% of the emissions.
    - 1A1 Energy industries and 1B Fugitive emissions only play a minor role. In 2019, they cover 2.3% and 0.8%, 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 1.1 kt $CO_2$ eq.

- $CO_2$ emissions from biomass add up to 27.3 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 98.2% of the category in 1990 and for 98.7% in 2019.
- In 2019, $CH_4$ emissions accounted for 1.1% of total emissions in the sector 1 Energy. The increasing trend since 1990 (+32.3%) is the result of the increase in consumption of natural gas and the subsequent increase of fugitive emissions of methane (increase by 225.6%). The $CH_4$ emissions of source category 1A4 have increased by 29.6% in the same period. The $CH_4$ emissions from road transportation show a reduction of 86.5%, mainly due to the growing number of gasoline passenger cars with catalytic converters.
- $N_2O$ emissions accounted for 0.7% of the total sector 1 Energy emissions in 1990 as well as in 2019.

The Liechtenstein greenhouse gas inventory identifies 7 key categories within the energy sector (key category analysis excluding LULUCF categories, see Chapter 1.5). The emissions in 1990 and 2019 of these categories are depicted in Figure 3-2. In 2019, $CO_2$ emissions from 1A3b Road Transportation are most dominant.

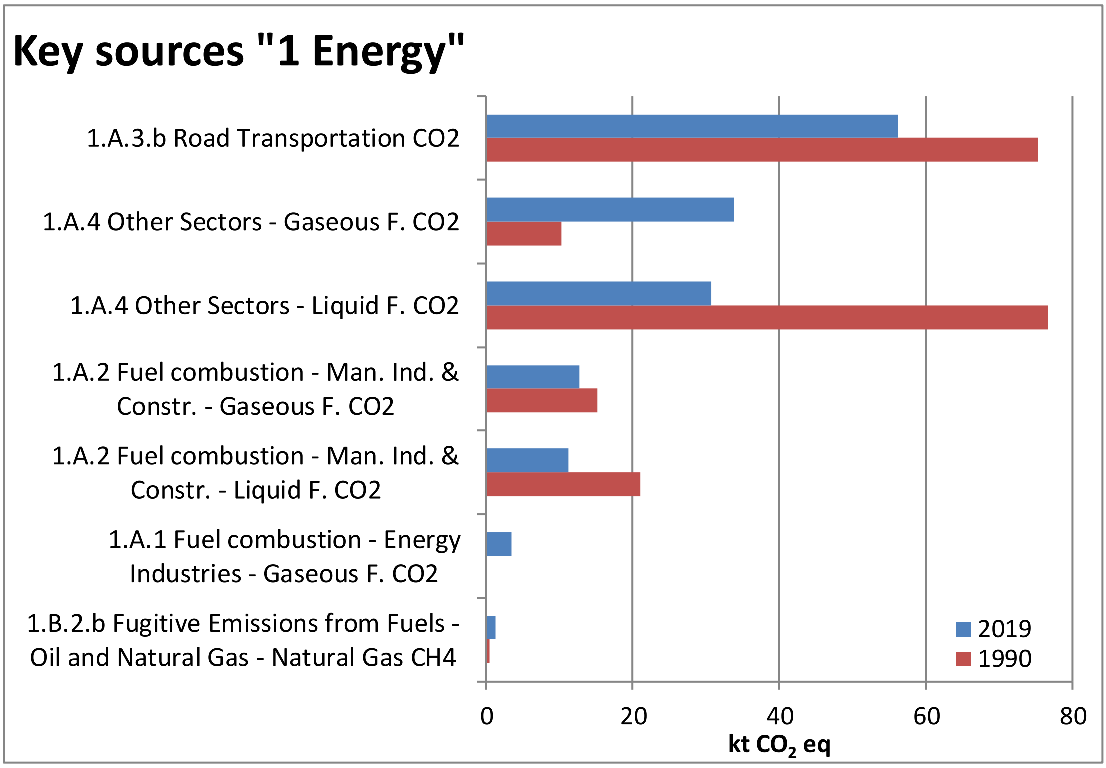



Figure 3-2 Key sources in the energy sector (KCA excl. LULUCF). Emissions in $CO_2$ equivalents (kt) per key source category in 2019 and in the base year 1990.

## 3.2 Source category 1A – Fuel combustion

### 3.2.1 Comparison of the sectoral approach and 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 and the Kyoto Protocol 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 2021 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 1990–2019. Energy consumption differs by 0.0% in 2019, whereas $CO_2$ emissions show a maximum difference of 2.11% in 2019.

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 2020a), 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 results of the reference approach, are larger 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 | 0.10 | 0.15 |
| | | | | | |
| | 2011 | 2012 | 2013 | 2014 | 2015 |
| | percent (%) | | | | |
| Energy consumption | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $CO_2$ emissions | 0.19 | 0.21 | 0.20 | 0.34 | 0.61 |
| | | | | | |
| | 2016 | 2017 | 2018 | 2019 | |
| | percent (%) | | | | |
| Energy consumption | 0.00 | 0.00 | 0.00 | 0.00 | |
| $CO_2$ emissions | 1.05 | 1.57 | 2.19 | 2.11 | |

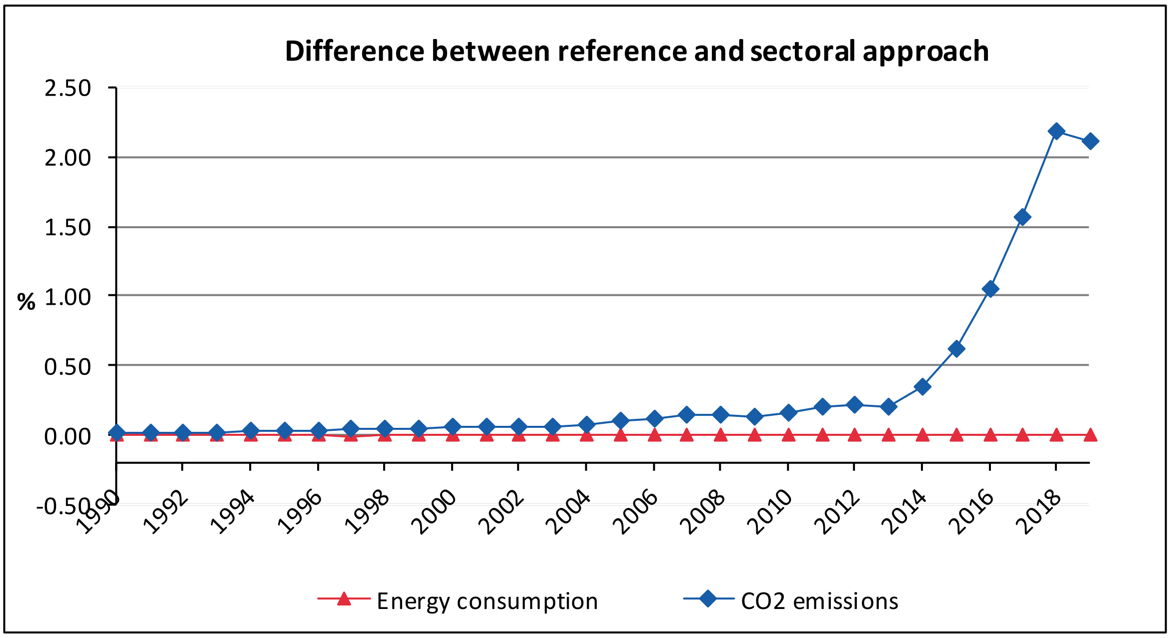



Figure 3-3 Time series for the differences between reference and sectoral approach. Numbers are taken from the table above.

**Recalculation in the Reference Approach**

- Activity data for diesel and gasoline between 1997 and 2018 were updated, since updated shares of biodiesel and bioethanol are available from Switzerland's road transportation model (INFRAS 2020). This leads to a recalculation of $CO_2$, $CH_4$ and $N_2O$ emissions.
- 1AB: The amount of natural gas transported in transit pipelines changed in the statistic of the LGV for the year 2017.
- For gasoline and diesel, emission factors of $CO_2$, $CH_4$ and $N_2O$ were updated based on Switzerland's Handbook of emission factors version 4.1 for the entire time series (INFRAS 2020). This leads to a recalculation of $CO_2$, $CH_4$ 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 2019, 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, …, 2020). 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 2012-2020).

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

In 2019, there are only four 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). Since 2019, an additional helicopter is in operation, thus leading to an increase in kerosene consumption between 2018 and 2019.

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 2006-2020).

| 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;<br>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;<br>Domestic aviation: Survey* | 6.82 |
| 2002 | 7.26 | 1.14 | | 6.12 |
| 2003 | 7.93 | 1.11 | *Total consumption: collected data;<br>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 |

### 3.2.3 Feedstocks and non-energy use of fuels

Energy data are taken from Liechtenstein's energy statistics (OS 2020a). 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 2020b). 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 2020b). 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 2019 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 2019. 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 2019 | | 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 1990-2019. 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** | **2011** | **2012** | **2013** | **2014** | **2015** |
| 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 | 72.9 | 72.8 | 72.8 | 72.8 | 72.8 |
| | | | | | | |
| **Fuel** | **unit** | **2016** | **2017** | **2018** | **2019** | **1990-2019 %** |
| Gasoline | t $CO_2$/TJ | 73.8 | 73.8 | 73.8 | 73.8 | -0.1% |
| Diesel | t $CO_2$/TJ | 73.3 | 73.3 | 73.3 | 73.3 | -0.4% |
| Kerosene | t $CO_2$/TJ | 72.8 | 72.8 | 72.8 | 72.8 | -0.5% |

## 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 energy statistic of Liechtenstein (OS 2020a). For bioethanol and biodiesel, the NCV are taken from the Handbook of Emission Factors for Road Transport HBEFA 4.1 (INFRAS 2019).

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 (2019).
- The emission factor of LPG is based on FOEN 2020
- The emission factor of natural gas is taken from the IPCC 2006 Guidelines (IPCC 2006).
- The emission factor of sewage gas is based on the assumption 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 2020a). 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 (2020a), OEP (2006c), OEP (2008) and Rotex Helicopter AG (2006–2020).

| **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 | 0.89 |
| **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 | 0.4 | 1.4 | 2.1 |
| ***Sum biomass*** | **58.5** | **53.2** | **110.0** | **112.3** | **207.3** |

| **Fuel** | **2011** | **2012** | **2013** | **2014** | **2015** |
|---|---|---|---|---|---|
| | | | TJ | | |
| Gasoline | 565 | 583 | 563 | 510 | 410 |
| Diesel | 498 | 556 | 578 | 556 | 498 |
| Gas Oil | 606 | 634 | 686 | 470 | 569 |
| Natural Gas | 954 | 971 | 1’030 | 856 | 914 |
| LPG | 4.2 | 4.1 | 3.9 | 3.6 | 3.7 |
| Hard Coal | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 |
| Kerosene (domestic) | 0.86 | 0.83 | 0.74 | 0.85 | 0.81 |
| **Sum** | **2’628** | **2’749** | **2’862** | **2’397** | **2’395** |
| 1990=100% | 94% | 98% | 102% | 85% | 85% |
| | | | | | |
| *Kerosene (bunker)* | 12.48 | 15.28 | 14.44 | 16.20 | 16.36 |
| | | | | | |
| ***Biomass*** | | | | | |
| *Wood* | 198.9 | 202.8 | 172.5 | 187.0 | 209.4 |
| *Sewage gas* | 22.5 | 22.8 | 24.3 | 1.0 | 0.5 |
| *Biofuel* | 2.6 | 3.2 | 3.1 | 4.9 | 9.9 |
| ***Sum biomass*** | **224.0** | **228.8** | **199.9** | **193.0** | **219.8** |

| **Fuel** | **2016** | **2017** | **2018** | **2019** | **1990-2019** |
|---|---|---|---|---|---|
| | | | TJ | | % |
| Gasoline | 384 | 376 | 369 | 363 | -56% |
| Diesel | 518 | 546 | 531 | 514 | 105% |
| Gas Oil | 452 | 487 | 395 | 491 | -61% |
| Natural Gas | 908 | 953 | 884 | 896 | 97% |
| LPG | 3.6 | 3.5 | 3.8 | 3.6 | -73% |
| Hard Coal | 0.00 | 0.00 | 0.00 | 0.00 | -100% |
| Kerosene (domestic) | 0.56 | 0.35 | 0.40 | 1.14 | 11% |
| **Sum** | **2’266** | **2’366** | **2’183** | **2’268** | **-19%** |
| 1990=100% | 81% | 84% | 78% | 81% | -19% |
| | | | | | |
| *Kerosene (bunker)* | 12.59 | 11.75 | 14.98 | 15.34 | 163% |
| | | | | | |
| ***Biomass*** | | | | | |
| *Wood* | 202.5 | 189.1 | 225.4 | 206.9 | 382% |
| *Sewage gas* | 1.8 | 2.5 | 1.8 | 1.4 | -91% |
| *Biofuel* | 17.1 | 27.7 | 36.0 | 36.0 | - |
| ***Sum biomass*** | **221.4** | **219.3** | **263.2** | **244.4** | **318%** |

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 |

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 2020a), 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 2020a) 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 1990-2019are 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 2020e). 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 2020e).
- 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 2001-2019 (see Rotex Helicopter AG 2006, -2020) 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 2019: The Energy Statistics of Liechtenstein (e.g. OS 2020a) 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 2019. 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 2019.

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 2020) and published in the national energy statistics (OS 2020a).

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 1990-2019 (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 2020). 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.

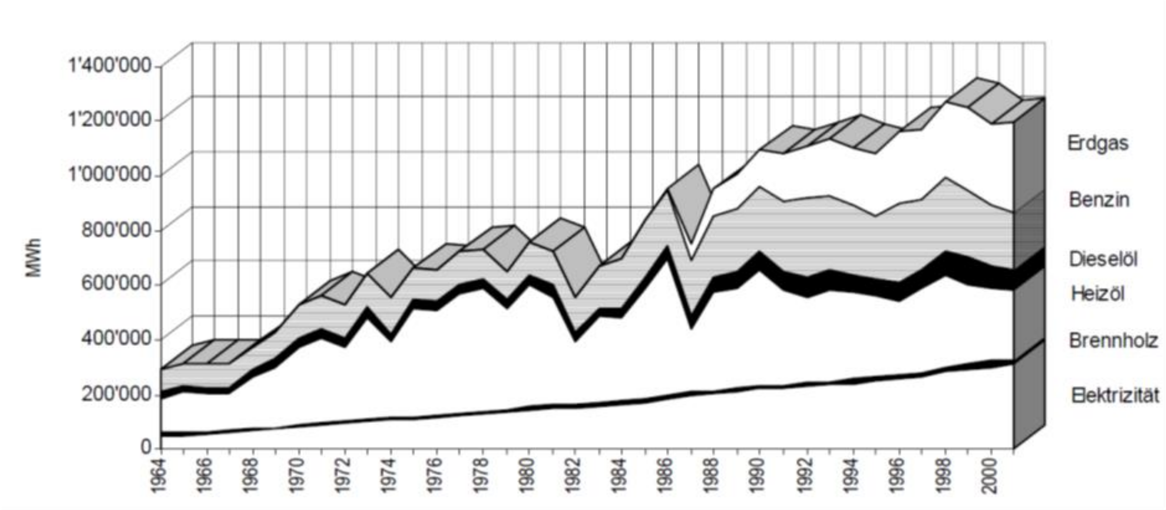



Figure 3-4 Liechtenstein's energy consumption and fuel shares 1964-2001 (OS 2001) in MWh. From top to bottom, the following fuels are shown: natural gas (Erdgas), gasoline (Benzin), diesel (Dieselöl), gas oil (Heizöl), wood (Brennholz), electricity (Elektrizität).

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 2011). 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 Source category 1A1 – Energy industries

### 3.2.5.1 Source 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 2019, 25% of Liechtenstein's electricity consumption was produced domestically and 75% was imported (see Table 3-15). In absolute values, the electricity consumption 2019 amounts to around 410 GWh. This corresponds to an increase of 0.25% since 2018. Domestic electricity generation increased by 16%. The electricity imports decreased by 4.1% compared to 2018.

Table 3-15 Electricity consumption, generation and imports in Liechtenstein (OS 2020a).

| **Electricity consumption, generation and imports in Liechtenstein 2019** | **MWh** | **Share** |
|---|---|---|
| Total electricity consumption in Liechtenstein | 409'964 | 100% |
| Electricity generation in Liechtenstein 2019 | 102'573 | 25% |
| Hydro power | 74'497 | 18% |
| Natural gas co-generation | 1'979 | 0.5% |
| Biogas co-generation | 53 | 0.0% |
| Photovoltaic | 26'044 | 6.4% |
| Electricity imports in Liechtenstein 2019 | 307'391 | 75% |

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.

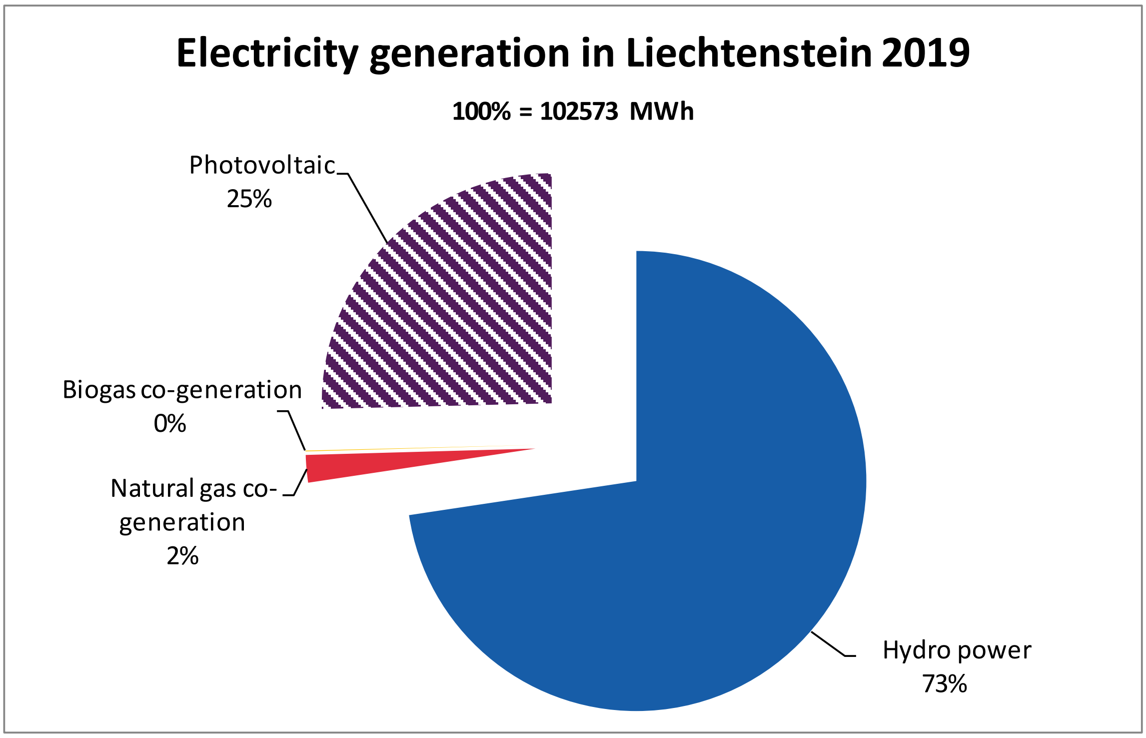



Figure 3-5 Structure of electricity generation in Liechtenstein 2019. Data source: Energy Statistics 2019 (OS 2020a).

Renewable sources account for 98.1% of domestic electricity generation in Liechtenstein. Compared to 2018, the electricity produced by photovoltaic plants has increased by 6.8%. Photovoltaic is thus representing 25% of the total domestic electricity production in 2019.

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 2020a) 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 2019 (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 2020a). Activity data on sewage gas consumption from wastewater treatment plants is provided by plant operators (for data see section 7.5.2). In 2019, natural gas accounts for 95% 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 28 from 1990 to 2019. 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. The increase between 2018 and 2019 is due to additional combined heat and power plants, that were put into operation in 2019.

Biomass consumption increased from 1990 to 2014. Between 2013 and 2014 there is a strong decrease in biomass consumption, since the 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 5% in 2019.

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 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|
| **1A1a Public electricity and heat production** | TJ | | | | |
| Natural gas | 52.56 | 48.24 | 52.13 | 44.24 | 36.02 |
| Biomass | 22.49 | 22.79 | 24.40 | 2.13 | 1.39 |

| Source/fuel | 2016 | 2017 | 2018 | 2019 | 1990-2019 |
|---|---|---|---|---|---|
| **1A1a Public electricity and heat production** | TJ | | | | % |
| Natural gas | 38.16 | 37.26 | 38.32 | 60.17 | 2686% |
| Biomass | 2.63 | 3.38 | 2.85 | 3.06 | -80% |

### 3.2.5.3 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.

### 3.2.5.4 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 Source category 1A2 – Manufacturing industries and construction

### 3.2.6.1 Source 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.

$CO_2$ 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.

In Liechtenstein, there are two companies participating in the European Emission Trading Scheme (EU-ETS):

- Hilcona AG in Schaan
- Herbert Ospelt Anstalt in Bendern.

The emissions of the EU-ETS companies represent only a small part of the source category emissions. In 2019, only 0.198 kt $CO_2$eq, representing approximately 1% of source category 1A2.

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 2020a) 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.

$CO_2$ emissions from combustion of natural gas are also calculated using the IPCC default emission factors (IPCC 2006). Emission factors for $CH_4$ however are country-specific based on an analysis of industrial boilers documented in SAEFL 2000 (pp. 14-27) and in FOEN 2015a. Boilers in Liechtenstein are similar to the technology applied in Switzerland and therefore, the Swiss data are considered to reflect national circumstances of Liechtenstein sufficiently well. Therefore, it is considered as a country-specific emission factor. 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 2019.

| 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 | - | 6.0 | 0.1 |
| Biomass (Biogas from WWTP) | | 56.1 | 6.0 | 0.1 |
| **1A2g Other off-road vehicles and machinery** | | | | |
| Diesel | 73.3 | - | 0.5 | 3.3 |
| Biodiesel | 73.3 | - | 0.5 | 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 2020a). 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 2019). Data are taken from OS (2020a).

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 2020).

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 | 47.9 | 47.6 |
| Biodiesel | NO | NO | 0.06 | 0.19 | 0.23 |
| | | | | | |
| **Source/fuel** | **2011** | **2012** | **2013** | **2014** | **2015** |
| **1A2e Food processing, beverages and tobacco** | | | TJ | | |
| Gas oil | 121.3 | 126.8 | 137.2 | 94.0 | 113.8 |
| Natural gas | 188.7 | 208.2 | 206.7 | 276.5 | 258.6 |
| Biomass (Biogas from WWTP) | NO | NO | 0.3 | 6.8 | 6.3 |
| **1A2g Other off-road vehicles and machinery** | | | | | |
| Diesel | 53.8 | 62.5 | 62.5 | 65.2 | 62.4 |
| Biodiesel | 0.25 | 0.32 | 0.28 | 0.51 | 1.05 |
| | | | | | |
| **Source/fuel** | **2016** | **2017** | **2018** | **2019** | **1990-2019** |
| **1A2e Food processing, beverages and tobacco** | | | TJ | | % |
| Gas oil | 90.4 | 97.5 | 78.9 | 98.2 | -61% |
| Natural gas | 260.2 | 277.9 | 256.5 | 227.2 | -16% |
| Biomass (Biogas from WWTP) | 5.8 | 6.6 | 6.9 | 6.3 | - |
| **1A2g Other off-road vehicles and machinery** | | | | | |
| Diesel | 62.3 | 64.8 | 57.7 | 54.2 | 69% |
| Biodiesel | 1.92 | 3.28 | 4.03 | 3.86 | - |

Table 3-20 documents the decrease of gas oil consumption by 61% from 1990 to 2019. 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 2019 consumption of gaseous fuels decreased by 16% 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 2019 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 in category 1A2 being key categories with regards to the trend 1990-2019. Between 2013 and 2014, there is a strong increase in biomass consumption, since 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 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.

### 3.2.6.4 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

The following recalculations lead to a decrease in $CO_2$ emissions by 0.18 kt $CO_2$eq in 2018. Changes in $N_2O$ and $CH_4$ emissions are negligible.

- 1A2g: Activity data for diesel between 1997 and 2018 were updated, since updated shares of biodiesel are available from the Swiss customs statistic, which is applied in Switzerland's road transportation model (INFRAS 2020). This leads to a recalculation of $CO_2$, $CH_4$ and $N_2O$ emissions.

For 1990, there are no recalculations in source category 1A2, which means that there are no changes in emissions from 1A2.

### 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 Source Category 1A3 - Transport

### 3.2.7.1 Source 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. |

The source 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 (see activity data below for additional information or chapter 3.2.2). Liechtenstein's emissions are calculated based on the fuel consumption, flying hours and the fleet composition of its single helicopter base at Balzers "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 2020). For $CH_4$ and $N_2O$, country-specific emission factors from Switzerland's road transportation model (INFRAS 2020) 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 2020a) provides only data on total fuel consumption, it is not possible to split emissions further 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. Therefore, 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 (2019: 40‘611 registered employees, and about 22‘715 commuters, whereof 42.6% are non-Swiss citizens, see OS 2020f) and buying 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 1990-2019.

| 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 (FOEN 2020a) (see Table 3-5 and Table 3-6 in chp. 3.2.4.1), which is 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 1990-2019 (INFRAS 2020). The road transportation model applies the emission factors from Switzerland's Handbook of Emission Factors (INFRAS 2019). 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 $CH_4$ the emission factor from Switzerland's road transportation model is used (INFRAS 2020), for $N_2O$ the default emission factor from 2006 IPCC Guidelines for mobile combustion is used (IPCC 2006).
- $CH_4$, $N_2O$ 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 A3.1 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 | 28.32 | 17.35 | 12.63 | 10.36 | 8.28 |
| $N_2O$ | kg/TJ | 3.60 | 5.04 | 4.76 | 1.67 | 1.09 |
| | | | | Diesel | | |
| $CO_2$ | t/TJ | 73.6 | 73.6 | 73.6 | 73.5 | 73.4 |
| $CH_4$ | kg/TJ | 2.49 | 2.01 | 1.33 | 0.87 | 0.62 |
| $N_2O$ | kg/TJ | 0.58 | 0.67 | 0.89 | 1.23 | 2.21 |
| | | | | Gaseous fuels | | |
| $CO_2$ | t/TJ | NA | NA | NA | 56.1 | 56.1 |
| $CH_4$ | kg/TJ | NA | NA | NA | 16.93 | 15.12 |
| $N_2O$ | kg/TJ | NA | NA | NA | 3.00 | 3.00 |
| | | | | Lubricants | | |
| $CO_2$ | t/TJ | 73.3 | 73.3 | 73.3 | 73.3 | 73.3 |
| $CH_4$ | kg/TJ | 28.32 | 17.35 | 12.63 | 10.36 | 8.28 |
| $N_2O$ | kg/TJ | 3.60 | 5.04 | 4.76 | 1.67 | 1.09 |
| | | | | | | |
| **Gas** | **unit** | **2011** | **2012** | **2013** | **2014** | **2015** |
| | | | | Gasoline | | |
| $CO_2$ | t/TJ | 73.8 | 73.8 | 73.8 | 73.8 | 73.8 |
| $CH_4$ | kg/TJ | 8.04 | 7.72 | 7.41 | 6.99 | 6.71 |
| $N_2O$ | kg/TJ | 1.00 | 0.91 | 0.83 | 0.78 | 0.74 |
| | | | | Diesel | | |
| $CO_2$ | t/TJ | 73.3 | 73.3 | 73.3 | 73.3 | 73.3 |
| $CH_4$ | kg/TJ | 0.66 | 0.74 | 0.82 | 0.93 | 1.13 |
| $N_2O$ | kg/TJ | 2.36 | 2.50 | 2.58 | 2.67 | 2.78 |
| | | | | Gaseous fuels | | |
| $CO_2$ | t/TJ | 56.1 | 56.1 | 56.1 | 56.1 | 56.1 |
| $CH_4$ | kg/TJ | 15.38 | 15.79 | 16.18 | 16.62 | 16.49 |
| $N_2O$ | kg/TJ | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| | | | | Lubricants | | |
| $CO_2$ | t/TJ | 73.3 | 73.3 | 73.3 | 73.3 | 73.3 |
| $CH_4$ | kg/TJ | 8.04 | 7.72 | 7.41 | 6.99 | 6.71 |
| $N_2O$ | kg/TJ | 1.00 | 0.91 | 0.83 | 0.78 | 0.74 |
| | | | | | | |
| **Gas** | **unit** | **2016** | **2017** | **2018** | **2019** | **1990-2019** |
| | | | | Gasoline | | % |
| $CO_2$ | t/TJ | 73.8 | 73.8 | 73.8 | 73.8 | 0% |
| $CH_4$ | kg/TJ | 6.80 | 6.65 | 6.38 | 6.06 | -79% |
| $N_2O$ | kg/TJ | 0.71 | 0.69 | 0.66 | 0.66 | -82% |
| | | | | Diesel | | |
| $CO_2$ | t/TJ | 73.3 | 73.3 | 73.3 | 73.3 | 0% |
| $CH_4$ | kg/TJ | 1.47 | 1.82 | 2.05 | 2.19 | -12% |
| $N_2O$ | kg/TJ | 2.92 | 3.08 | 3.20 | 3.31 | 471% |
| | | | | Gaseous fuels | | |
| $CO_2$ | t/TJ | 56.1 | 56.1 | 56.1 | 56.1 | - |
| $CH_4$ | kg/TJ | 15.83 | 15.17 | 15.21 | 14.86 | - |
| $N_2O$ | kg/TJ | 3.00 | 3.00 | 3.00 | 3.00 | - |
| | | | | Lubricants | | |
| $CO_2$ | t/TJ | 73.3 | 73.3 | 73.3 | 73.3 | 0% |
| $CH_4$ | kg/TJ | 6.80 | 6.65 | 6.38 | 6.06 | -79% |
| $N_2O$ | kg/TJ | 0.71 | 0.69 | 0.66 | 0.66 | -82% |

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 | 28.32 | 17.35 | 12.63 | 10.36 | 8.28 |
| $N_2O$ | kg/TJ | 3.60 | 5.04 | 4.76 | 1.67 | 1.09 |
| | | Biodiesel | | | | |
| $CO_2$ | t/TJ | 73.6 | 73.6 | 73.6 | 73.5 | 73.4 |
| $CH_4$ | kg/TJ | 2.49 | 2.01 | 1.33 | 0.87 | 0.62 |
| $N_2O$ | kg/TJ | 0.58 | 0.67 | 0.89 | 1.23 | 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 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|
| | | Bioethanol | | | | |
| $CO_2$ | t/TJ | 73.8 | 73.8 | 73.8 | 73.8 | 73.8 |
| $CH_4$ | kg/TJ | 8.04 | 7.72 | 7.41 | 6.99 | 6.71 |
| $N_2O$ | kg/TJ | 1.00 | 0.91 | 0.83 | 0.78 | 0.74 |
| | | Biodiesel | | | | |
| $CO_2$ | t/TJ | 73.3 | 73.3 | 73.3 | 73.3 | 73.3 |
| $CH_4$ | kg/TJ | 0.66 | 0.74 | 0.82 | 0.93 | 1.13 |
| $N_2O$ | kg/TJ | 2.36 | 2.50 | 2.58 | 2.67 | 2.78 |
| | | Biogas (since 2013) | | | | |
| $CO_2$ | t/TJ | NA | NA | 56.1 | 56.1 | 56.1 |
| $CH_4$ | kg/TJ | NA | NA | 16.18 | 16.62 | 16.49 |
| $N_2O$ | kg/TJ | NA | NA | 3.00 | 3.00 | 3.00 |

| Gas | unit | 2016 | 2017 | 2018 | 2019 | 1990-2019 |
|---|---|---|---|---|---|---|
| | | Bioethanol | | | | % |
| $CO_2$ | t/TJ | 73.8 | 73.8 | 73.8 | 73.8 | -0.1% |
| $CH_4$ | kg/TJ | 6.80 | 6.65 | 6.38 | 6.06 | -78.6% |
| $N_2O$ | kg/TJ | 0.71 | 0.69 | 0.66 | 0.66 | -81.7% |
| | | Biodiesel | | | | |
| $CO_2$ | t/TJ | 73.3 | 73.3 | 73.3 | 73.3 | -0.4% |
| $CH_4$ | kg/TJ | 1.47 | 1.82 | 2.05 | 2.19 | -12.3% |
| $N_2O$ | kg/TJ | 2.92 | 3.08 | 3.20 | 3.31 | 471.4% |
| | | Biogas (since 2013) | | | | |
| $CO_2$ | t/TJ | 56.1 | 56.1 | 56.1 | 56.1 | - |
| $CH_4$ | kg/TJ | 15.83 | 15.17 | 15.21 | 14.86 | - |
| $N_2O$ | kg/TJ | 3.00 | 3.00 | 3.00 | 3.00 | - |

## Activity data

### *Domestic aviation (1A3a)*

The operating company of the helicopter base "Heliport Balzers" provided data on fuel consumption for 1995, 2001–2019 as well as domestic fuel consumption for 2012–2019 (Rotex Helicopter AG 2006 -2020). The fleet consists of four 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 1990-2019 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** | **2011** | **2012** | **2013** | **2014** | **2015** |
| **1A3a Domestic aviation (helicopters only)** | TJ | | | | |
| Kerosene (domestic) | 0.86 | 0.83 | 0.74 | 0.85 | 0.81 |
| **Source/fuel** | **2016** | **2017** | **2018** | **2019** | **1990-2019** |
| **1A3a Domestic aviation (helicopters only)** | TJ | | | | % |
| Kerosene (domestic) | 0.56 | 0.35 | 0.40 | 1.14 | 11% |

### *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 2020).

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 | 0.3 | 1.1 | 1.8 |
| **Sum** | **1’020** | **1’086** | **1’216** | **1’107** | **1’061** |
| 1990=100% | 100% | 107% | 119% | 109% | 104% |
| | | | | | |
| **Fuel** | **2011** | **2012** | **2013** | **2014** | **2015** |
| | TJ | | | | |
| | 564 | 582 | 562 | 508 | 406 |
| Diesel | 428 | 476 | 493 | 470 | 412 |
| Natural Gas | 57 | 23 | 23 | 19 | 17 |
| Lubricants (1A3biv) | 0.0011 | 0.0011 | 0.0007 | 0.0008 | 0.0008 |
| Biogas | NO | NO | 0.03 | 0.48 | 0.43 |
| Bioethanol | 0.49 | 0.62 | 0.67 | 0.95 | 2.30 |
| Biodiesel | 1.81 | 2.19 | 2.02 | 3.33 | 6.27 |
| **Sum** | **1’050** | **1’084** | **1’080** | **1’002** | **844** |
| 1990=100% | 103% | 106% | 106% | 98% | 83% |
| | | | | | |
| **Fuel** | **2016** | **2017** | **2018** | **2019** | **1990-2019** |
| | TJ | | | | % |
| Gasoline | 379 | 370 | 363 | 356 | -57% |
| Diesel | 425 | 439 | 416 | 404 | 101% |
| Natural Gas | 9 | 6 | 7 | 5 | - |
| Lubricants (1A3biv) | 0.0008 | 0.0008 | 0.0014 | 0.0014 | -45% |
| Biogas | 0.21 | 0.13 | 0.19 | 0.15 | - |
| Bioethanol | 2.89 | 3.54 | 4.14 | 4.67 | - |
| Biodiesel | 11.87 | 20.09 | 26.34 | 26.00 | - |
| **Sum** | **828** | **839** | **817** | **796** | **-22%** |
| 1990=100% | 81% | 82% | 80% | 78% | |

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 a decrease in $CO_2$ emissions from 1997-2018. In 2018 a total decrease of 1.2 kt is noted:

- 1A3b: The activity data for biodiesel and bioethanol 1997-2019 were updated, since updated shares of biofuels are available from the Swiss customs statistics, which is applied in Switzerland's road transportation model (INFRAS 2020). This leads to increased shares of biofuels and thus to a decrease in fossil $CO_2$ emissions.

Small changes in $CH_4$ and $N_2O$ emissions occur in the complete time series. $CH_4$ emissions have slightly increased from 1990-1996 and from 2001-2018 and decreased from 1997-2000. $N_2O$ emissions have increased from 1990-2018. For 2018 there is a difference in $CH_4$ and $N_2O$ emissions of 0.0014 kt and 0.0005 kt $CO_{2eq}$, respectively. This is due to the following recalculations:

- 1A3b: In the current submission the latest version of the Handbook Emission Factors for Road Transport (HBEFA 4.1) is used (INFRAS 2019). Hence, $CH_4$ and $N_2O$ emission factors for gasoline and diesel were updated for the complete time series.

### 3.2.7.6 Category-specific planned improvements

No category-specific improvements are planned.

## 3.2.8 Source category 1A4 – Other sectors (commercial/institutional, residential, agriculture/forestry/fishing)

### 3.2.8.1 Source 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 2020a) 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 2020 (FOEN 2020).

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 2020 (FOEN 2020). 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 taken from FOEN 2015a. 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 2019.

| 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 | 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 | 8.0 | 4.0 |
| Biomass (Wood combustion 1A4b) | - | 112.0 | 81.0 | 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 2019.

| 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 | - | 1.1 | 3.0 |
| Biodiesel | 73.3 | - | 1.1 | 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 2020a). 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 2020e). 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** | **2011** | **2012** | **2013** | **2014** | **2015** |
| | TJ | | | | |
| **1A4a Commercial/institutional** | **728.02** | **768.32** | **792.29** | **529.41** | **645.60** |
| Gas oil | 363.79 | 380.39 | 411.48 | 282.03 | 341.39 |
| LPG | 4.23 | 4.14 | 3.86 | 3.63 | 3.68 |
| Natural gas | 240.66 | 262.08 | 273.12 | 128.39 | 170.73 |
| Coal | NO | NO | NO | NO | NO |
| Biomass | 119.34 | 121.71 | 103.83 | 115.36 | 129.81 |
| **1A4b Residential** | **616.47** | **636.85** | **681.70** | **565.83** | **639.13** |
| Gas oil | 121.26 | 126.80 | 137.16 | 94.01 | 113.80 |
| Alkylate gasoline | 0.12 | 0.13 | 0.12 | 0.16 | 0.12 |
| Natural gas | 415.47 | 428.78 | 474.83 | 387.37 | 430.90 |
| Coal | 0.06 | NO | NO | NO | NO |
| Biomass | 79.56 | 81.14 | 69.60 | 84.29 | 94.32 |
| | | | | | |
| **Source/fuel** | **2016** | **2017** | **2018** | **2019** | **1990-2019** |
| | TJ | | | | % |
| **1A4a Commercial/institutional** | **561.29** | **588.32** | **538.53** | **567.10** | **-40%** |
| Gas oil | 271.17 | 292.35 | 236.73 | 294.70 | -61% |
| LPG | 3.63 | 3.50 | 3.82 | 3.59 | -73% |
| Natural gas | 161.40 | 174.91 | 158.49 | 140.78 | 0% |
| Coal | NO | NO | NO | NO | - |
| Biomass | 125.09 | 117.56 | 139.49 | 128.04 | 397% |
| **1A4b Residential** | **620.03** | **640.90** | **604.66** | **656.06** | **110%** |
| Gas oil | 90.39 | 97.45 | 78.91 | 98.23 | -61% |
| Alkylate gasoline | 0.20 | 0.20 | 0.12 | 0.12 | - |
| Natural gas | 438.68 | 456.84 | 424.07 | 462.20 | 1021% |
| Coal | NO | NO | NO | NO | - |
| Biomass | 90.75 | 86.41 | 101.56 | 95.51 | 456% |

Since 1990, gas oil consumption decreased by approximately 61% 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 1$^{st}$ 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.

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 2020b) 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 2020e).

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 | 17.49 | 18.16 | 18.43 |
| Biodiesel | NO | NO | 0.03 | 0.07 | 0.09 |
| | | | | | |
| **Source/fuel** | **2011** | **2012** | **2013** | **2014** | **2015** |
| **1A4c Other Sectors - Agriculture/forestry** | TJ | | | | |
| Alkylate gasoline | 0.49 | 0.51 | 0.47 | 0.62 | 0.47 |
| Diesel | 13.53 | 14.30 | 19.52 | 16.16 | 15.49 |
| Biodiesel | 0.07 | 0.08 | 0.09 | 0.13 | 0.27 |
| | | | | | |
| **Source/fuel** | **2016** | **2017** | **2018** | **2019** | **1990-2019** |
| **1A4c Other Sectors - Agriculture/forestry** | TJ | | | | % |
| Alkylate gasoline | 0.80 | 0.82 | 0.49 | 0.48 | - |
| Diesel | 14.30 | 14.97 | 21.50 | 20.94 | 17% |
| Biodiesel | 0.47 | 0.80 | 1.54 | 1.52 | - |

#### 3.2.8.3 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.

#### 3.2.8.4 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

For 2018, the following recalculations lead to a decrease of $CO_2$ emissions by 0.07 kt $CO_2$eq:

- 1A4c: Activity data for diesel between 1997 and 2018 were updated, since updated shares of biodiesel are available from the Swiss customs statistic, which is applied in Switzerland’s road transportation model (INFRAS 2020). This leads to a recalculation of $CO_2$, $CH_4$ and $N_2O$ emissions.

For 1990, there are no recalculations in source category 1A4 Other sectors, which means that there are no changes in emissions from 1A4.

#### 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 Source category 1A5 – Other

#### 3.2.9.1 Source category description: Other (1A5)

Emissions of source category 1A5 do not occur in Liechtenstein.

### 3.2.10 Uncertainties and time-series consistency 1A

#### 3.2.10.1 Uncertainties 1A – Fuel combustion activities

For the current submission, a simplified uncertainty analysis has been carried out as described in chp. 1.6.1. 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, 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 1.6.1.3 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 NIR (FOEN 2021):

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 2021). Liechtenstein adopts these uncertainty estimates for the uncertainty analysis. The following uncertainties have been applied for the emission factors:

- Natural gas (1A1, 1A2): U(EF $CO_2$) = 0.88%
- Natural gas (1A4): U(EF $CO_2$) = 0.7%
- Liquid fuels (1A2, 1A4): U(EF $CO_2$) = 0.07%
- 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 7 shows the procedure for uncertainty aggregation. The results are:

1A3b/$CO_2$: U(AD) = 9.2%, 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) = 0.07%

1A4 gaseous/$CO_2$: U(AD) = 4.0%, U(EF) = 0.71%

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 1.6.1).

### 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 1990-2019. The entire time series are therefore consistent.

**Completeness**

The emissions for the entire time series 1990–2019 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 1A – Fuel combustion activities

**General QA/QC activities**

The category-specific QA/QC activities have been carried out as mentioned in section 1.2.3 also 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 NIR 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 2020a).

**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 2019 (INFRAS 2019). 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 4.1 (INFRAS 2019), 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 Source category 1B – Fugitive emissions from solid fuels and oil and natural gas and other emission from energy production

### 3.3.1 Source category 1B1- Fugitive emissions from solid fuels

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

### 3.3.2 Source category 1B2- Fugitive emissions from oil and natural gas and other emissions from energy production

#### 3.3.2.1 Source 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 NIR 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 2019 (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 [m³/h/km]** | **1-5 bar [m³/h/km]** | **> 5 bar [m³/km*year]** | **Gas meters [m³/number*year]** |
|---|---|---|---|---|
| **1B2b Fugitive emissions from natural gas** | | | | |
| Steel cath. | - | - | 249 | - |
| HDPE (polyethylene) | 0.0080 | 0.0024<br>*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 | | 1990-2019 |
|---|---|---|
| **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 | | 1990-2019 |
|---|---|---|
| **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 2020, edition 2019 includes data up to 2019). 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** | | **2011** | **2012** | **2013** | **2014** | **2015** |
| **1B2b Fugitive emissions from natural gas** | **Unit** | | | | | |
| Steel cath. > 5 bar | km | 26.6 | 26.7 | 26.7 | 26.7 | 26.7 |
| HDPE (Polyethylene) 1-5 bar | km | 51.5 | 51.6 | 51.9 | 52.1 | 52.1 |
| HDPE (Polyethylene) < 100 mbar | km | 319.3 | 323.8 | 328.8 | 336.1 | 341.2 |
| Connections | number | 4'209 | 4'311 | 4'337 | 4'411 | 4'486 |
| | | | | | | |
| **Source/fuel** | | **2016** | **2017** | **2018** | **2019** | **1990-2019** |
| **1B2b Fugitive emissions from natural gas** | **Unit** | | | | | % |
| Steel cath. > 5 bar | km | 26.7 | 26.7 | 26.7 | 26.7 | 1% |
| HDPE (Polyethylene) 1-5 bar | km | 52.1 | 52.1 | 52.1 | 52.1 | 83% |
| HDPE (Polyethylene) < 100 mbar | km | 347.0 | 352.0 | 355.6 | 360.7 | 438% |
| Connections | number | 4'491 | 4'571 | 4'651 | 4'715 | 884% |

Table 3-36 documents the continuous increase of Liechtenstein's gas supply network since 1990. By 2019, 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** | **2011** | **2012** | **2013** | **2014** | **2015** |
| **1B2b Fugitive emissions from natural gas** | | | | | | |
| Natural gas volume industry | Mio. $m^3$ | 5.2 | 5.8 | 5.7 | 7.6 | 7.1 |
| Natural gas volume other | Mio. $m^3$ | 21.1 | 21.1 | 22.7 | 16.0 | 18.1 |
| **Sum natural gas volume** | Mio. $m^3$ | **26.3** | **26.8** | **28.4** | **23.6** | **25.2** |
| | | | | | | |
| **Source/fuel** | **Unit** | **2016** | **2017** | **2018** | **2019** | **1990-2019** |
| **1B2b Fugitive emissions from natural gas** | | | | | | % |
| Natural gas volume industry | Mio. $m^3$ | 7.2 | 7.7 | 7.1 | 6.3 | -16% |
| Natural gas volume other | Mio. $m^3$ | 17.9 | 18.6 | 17.3 | 18.5 | 263% |
| **Sum natural gas volume** | Mio. $m^3$ | **25.1** | **26.3** | **24.4** | **24.7** | **97%** |

#### 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. 1.6.1. 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 1.1.3 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2018 and for the changing rates 2018/2019).

#### 3.3.2.5 Category-specific recalculations

No category-specific recalculations were carried out.

#### 3.3.2.6 Category-specific planned improvements

According to Liechtenstein’s inventory development plan no future improvements are planned for activities in source category 1B2 - Fugitive emissions from oil and natural gas and other emissions from energy production.

## 3.4 Source category 1C – $CO_2$ transport and storage

Source category 1C is not occurring in Liechtenstein.

# 4. Industrial processes and product use

## 4.1 Overview

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 2013. Since then they show a decreasing tendency, with a slight increase in 2017 and 2018 (Table 4-1).

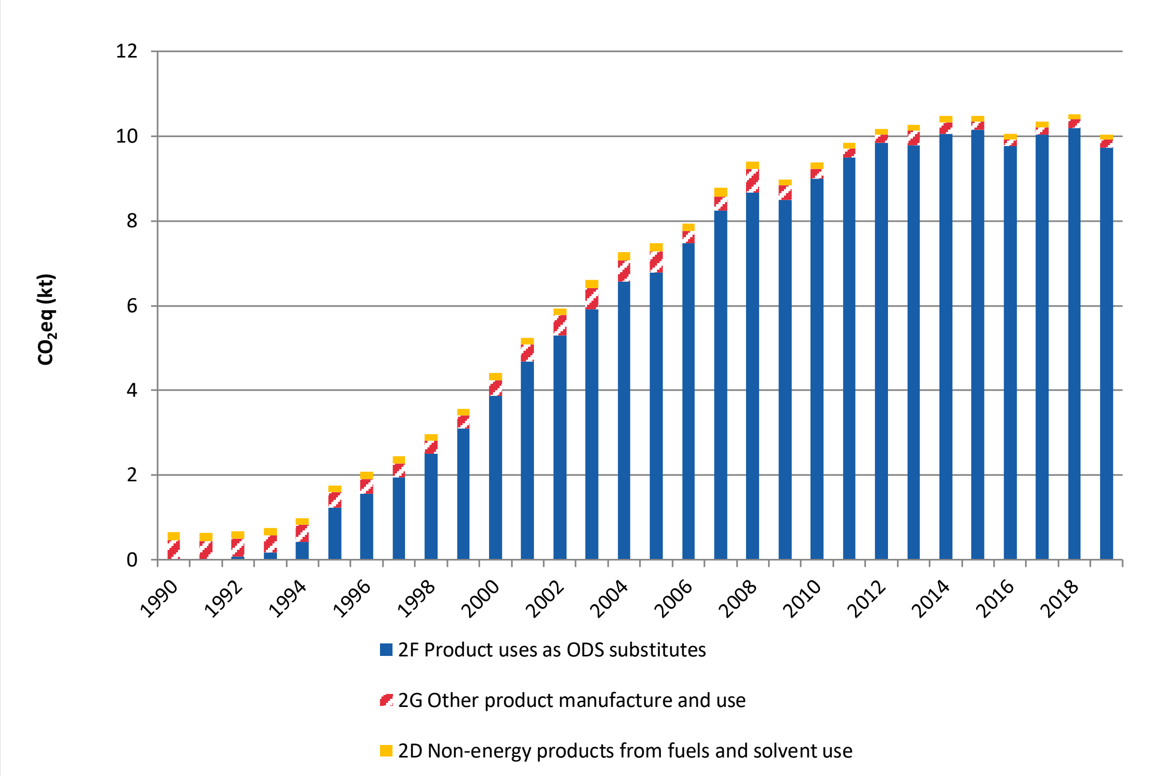



Figure 4-1 Liechtenstein's GHG emissions of sector 2 Industrial processes and product use. Note that there are no emissions in sectors 2A, 2B, 2C, 2E and 2H.

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 10.0 kt $CO_2$ equivalent in 2019. Emissions of the IPPU sector play therefore a minor role in Liechtenstein's inventory and contribute to 5.4% of the total emissions excluding LULUCF. 9.7 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 almost 16 since 1990. This trend is in particular dominated by the increase in HFC emissions. $CO_2$ emissions decreased by 39% and $N_2O$ emissions decreased by 69% between 1990 and 2019.

Since 2018, the total F-gas emissions decreased by 4.7%, HFC emissions decreased by 4.5% and PFC emissions decreased by 10.2% and $SF_6$ emissions decreased by 31.5%.

Further details on the methodological approach used for the calculation of emissions from source category 2D, 2F and 2G are documented in Annex A3.3.

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 |
| $N_2O$ | 0.45 | 0.37 | 0.27 | 0.24 | 0.20 |
| F-Gases | 0.00 | 1.24 | 3.97 | 7.04 | 9.03 |
| **Sum** | **0.66** | **1.76** | **4.40** | **7.48** | **9.38** |

| **Gas** | **2011** | **2012** | **2013** | **2014** | **2015** |
|---|---|---|---|---|---|
| | **CO2 equivalent (kt)** | | | | |
| $CO_2$ | 0.15 | 0.14 | 0.14 | 0.14 | 0.14 |
| $N_2O$ | 0.19 | 0.19 | 0.16 | 0.16 | 0.16 |
| F-Gases | 9.52 | 9.85 | 9.97 | 10.17 | 10.18 |
| **Sum** | **9.86** | **10.18** | **10.28** | **10.48** | **10.48** |

| **Gas** | **2016** | **2017** | **2018** | **2019** | **1990-2019** |
|---|---|---|---|---|---|
| | **CO2 equivalent (kt)** | | | | **%** |
| $CO_2$ | 0.14 | 0.13 | 0.12 | 0.12 | -39% |
| $N_2O$ | 0.14 | 0.14 | 0.14 | 0.14 | -69% |
| F-Gases | 9.78 | 10.08 | 10.27 | 9.78 | 9363197% |
| **Sum** | **10.06** | **10.35** | **10.53** | **10.05** | **1432%** |

## 4.2 Source category 2A – Mineral industry

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

## 4.3 Source category 2B – Chemical industry

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

# 4.4 Source category 2C – Metal industry

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

# 4.5 Source category 2D – Non-energy products from fuels and solvent use

## 4.5.1 Source 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 | 6'796'000 | 7'081'000 | 7'209'000 | 7'501'000 | 7'870'000 |
| 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 | 6.92 | 5.11 | 5.14 | 5.69 | 4.14 |
| | | | | | | |
| **Emission factors 2D Non-energy products from fuels and solvents** | | **2011** | **2012** | **2013** | **2014** | **2015** |
| Inhabitants Switzerland | number | 7'954'700 | 8'039'100 | 8'139'600 | 8'237'700 | 8'327'100 |
| Emissions 2D1 Switzerland | kt | 31.8 | 30.2 | 31.7 | 31.9 | 30.6 |
| 2D1 EF $CO_2$ from Lubricant use - $CO_2$ | kg/inhabitant | 4.00 | 3.76 | 3.90 | 3.87 | 3.68 |
| | | | | | | |
| **Emission factors 2D Non-energy products from fuels and solvents** | | **2016** | **2017** | **2018** | **2019** | **1990-2019 %** |
| Inhabitants Switzerland | number | 8'419'600 | 8'419'550 | 8'544'527 | 8'606'033 | 27% |
| Emissions 2D1 Switzerland | kt | 30.3 | 29.3 | 27.1 | 27.1 | -42% |
| 2D1 EF $CO_2$ from Lubricant use - $CO_2$ | kg/inhabitant | 3.60 | 3.49 | 3.17 | 3.15 | -54% |

#### 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 2020b). 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** | **2011** | **2012** | **2013** | **2014** | **2015** |
| | **Number of inhabitants** | | | | |
| Liechtenstein | 36’475 | 36’838 | 37’129 | 37’366 | 37’623 |
| | | | | | |
| **Number of inhabitants for AD calculations** | **2016** | **2017** | **2018** | **2019** | **1990-2019 %** |
| | **Number of inhabitants** | | | | |
| Liechtenstein | 37’810 | 38’114 | 38’380 | 38’749 | 33% |

### 4.5.3 Uncertainties and time-series consistency

For the current submission, a simplified uncertainty analysis has been carried out as described in chp. 1.6.1. 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 1.1.3.

### 4.5.5 Category-specific recalculations

For source category 2D1 no category specific recalculations were carried out.

### 4.5.6 Category-specific planned improvements

No category-specific improvements are planned.

## 4.6 Source category 2E – Electronic industry

### 4.6.1 Source category description: Electronic industry (2E)

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

# 4.7 Source category 2F – Product uses as ODS substitutes

## 4.7.1 Source 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 2020a) 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 A3.3.

**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 2020 (FOEN 2020).

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 2020 (FOEN 2020), citations are written in bold. It is considered as valid for Liechtenstein as well, since Liechtenstein's data are based on Switzerland's national inventory database EMIS (FOEN 2020a):

*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 2020).*

*Commercial and industrial refrigeration have been evaluated together in former years. Since the submission 2018 calculations are carried out separately. The total bulk refrigerant for commercial and industrial application is split considering typical use of refrigerant blends and information on commercial and industrial equipment provided to FOEN (Carbotech 2020). Parameters for commercial and industrial applications are given in Table 4 48. 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 one approach. Noteworthy, in the hypothetical but possible case of incomplete 'bottom up' evaluations, remaining imported refrigerant would be attributed to the production and maintenance of industrial and commercial refrigeration equipment. This might be a 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<br>HFC-134a<br>HFC-143a<br>$C_3F_8$ | Total emissions reported for Switzerland | Number of persons employed in industrial and service sector |
| Transport Refrigeration | HFC-125<br>HFC-134a<br>HFC-143a | Total emissions reported for Switzerland | Number of inhabitants |
| Industrial Refrigeration | Included in commercial refrigeration | | |
| Stationary Air Conditioning | HFC-32<br>HFC-125<br>HFC-134a<br>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 2020 (FOEN 2020), 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 have been calculated (Tier 1a) as residual balance between FOEN import statistics and consumption in PU spray, PU and XPS foams.*

### 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 2020 (FOEN 2020), given below.

*The Tier 2a emission model for Aerosol / MDI 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 2020a). The following explanations are taken from Switzerland's National Inventory Report 2020 (FOEN 2020):

*Emission factors for 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 quality (confidential data from retailers and other type of industry). 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 2018 are indicated with values in brackets. The parameters in brackets are applied for the inventory 2018. For product life emission factors of some equipment types, a dynamic model is applied, which implies that emission decrease 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 end of life for different applications has been analysed considering the technical minimal charge of equipment and the expected frequency of 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 at 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 2018 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 2020).

| 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 2020a). The following explanations are taken from Switzerland’s National Inventory Report 2020 (FOEN 2020):

*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 2020).

| 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 2020a). The following explanations are taken from Switzerland’s National Inventory Report 2020 (FOEN 2020):

*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 | | 2019 | |
|---|---|---|---|---|
| **Number of households** | | | | |
| Liechtenstein | 10 556 | Source: National census 1990 (OEA 2010) | 17 384 | Source: National census 2010 with trend extrapolation (OEA 2010) |
| Switzerland | 2 841 850 | Source: National census 1990 (SFSO 2005) | 3 741 378 | Source: National census 2014 with trend extrapolation |
| Conversion Factor CH→LIE | 0.371% | | 0.465% | |
| **Number of employees in industrial and service sector** | | | | |
| Liechtenstein | 19 554 | Source: Employment statistics Liechtenstein (OS 2020e) | 39'360 | Source: Employment statistics Liechtenstein (OS 2020e) |
| Switzerland | 3 658 406 | Source: National census of enterprises (SFSO 2020b) | 4'959'785 | Source: National census of enterprises (SFSO 2020b) |
| Conversion Factor CH→LIE | 0.534% | | 0.794% | |
| **Number of registered passenger cars** | | | | |
| Liechtenstein | 16 891 | Source: Statistical Yearbook Liechtenstein (OS 2020c) | 30 248 | Source: Statistical Yearbook Liechtenstein (OS 2020c) |
| Switzerland | 2 985 397 | Source: National motorcar statistics for Switzerland (SFSO 2020c) | 4 623 952 | Source: National motorcar statistics for Switzerland (SFSO 2020c) |
| Conversion factor CH→LIE | 0.566% | | 0.654% | |

**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 2019 | | |
|---|---|---|
| Liechtenstein | 38 749 | Source: OS 2020d |
| Switzerland | 8 606 033 | Source: SFSO 2020d |
| Conversion Factor CHE→LIE | 0.45% | |

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 2021 (FOEN 2021) 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 seems to be justified.

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 1.1.3 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2018 and for the changing rates 2018/2019).

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 2021 was not yet available for Liechtenstein's submission 2020. For Switzerland, the following recalculations have been carried out in submission 2020, which also influence Liechtenstein's emission time series reported in Submission 2021:

- 2F1 mobile air-conditioning: Vehicles statistics for trucks were harmonized with data on the time period 1991 to 2018 provided by SFSO/Astra.
- 2F1 mobile air-conditioning: HFC-134a model calculation have been adapted considering higher service activities and on the other hand no recycling of HFC-134a at the disposal of vehicles (use of filtration equipment for service activities in garages only).
- 2F1 stationary air-conditioning: Split of refrigerants was adapted for stationary air-conditioning and heat pumps with data from the Swiss Registration Office for Refrigeration Systems and Heat Pumps (SMKW) covering the years 2015–2018. New refrigerants added to the evaluation.

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

- 2F2 Foam blowing agents: Minor recalculations due to an error that occurred in the data preparation. This error will be corrected in Submission 2022 (see IDP Annex A8.3 Nr. 73)
- 2F4 Aerosols: Minor recalculations due to an error that occurred in the data preparation. This error will be corrected in Submission 2022 (see IDP Annex A8.3 Nr. 73)

These recalculations lead to an overall increase in HFC emissions by about 0.25 kt $CO_2$eq in 2018.

### 4.7.6 Category-specific planned improvements

There was an error in the preparation of the data for sectors 2F2 and 2F4 leading to a minor recalculation of the time series 2015-2018. This error will be corrected in the next submission.

# 4.8 Source category 2G - Other product manufacture and use

## 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 A3.3.

### 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 2020a). 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 2020a) 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 1990-2019.

| 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 | 0.3597 | 0.4032 | 0.0329 |
| 2G3 $N_2O$ from product uses - $N_2O$ (g/inhabitant) | 52.6 | 39.9 | 27.3 | 23.3 | 18.9 |
| **Emission factors 2G Other product manufacture and use** | **2011** | **2012** | **2013** | **2014** | **2015** |
| 2G1 Electrical equipment - SF6 product life factor (% per annum) | 0.0185 | 0.0005 | 0.2006 | 0.1300 | 0.0413 |
| 2G3 $N_2O$ from product uses - $N_2O$ (g/inhabitant) | 17.9 | 17.3 | 14.7 | 14.7 | 13.9 |
| **Emission factors 2G Other product manufacture and use** | **2016** | **2017** | **2018** | **2019** | **1990-2019 %** |
| 2G1 Electrical equipment - SF6 product life factor (% per annum) | 0.0158 | 0.0492 | 0.0744 | 0.0530 | - |
| 2G3 $N_2O$ from product uses - $N_2O$ (g/inhabitant) | 12.8 | 12.4 | 12.3 | 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 inh. 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** | **2011** | **2012** | **2013** | **2014** | **2015** |
| 2G1 Electrical equipment - $SF_6$ amount in operating systems (average annual stocks) in kt | 0.0032 | 0.0037 | 0.0038 | 0.0039 | 0.0040 |
| 2G3 $N_2O$ from product uses - number of inhabitants | 36'475 | 36'838 | 37'129 | 37'366 | 37'623 |
| **Emission factors 2G Other product manufacture and use** | **2016** | **2017** | **2018** | **2019** | **1990-2019 %** |
| 2G1 Electrical equipment - $SF_6$ amount in operating systems (average annual stocks) in kt | 0.0040 | 0.0040 | 0.0041 | 0.0039 | - |
| 2G3 $N_2O$ from product uses - number of inhabitants | 37'810 | 38'114 | 38'380 | 38'749 | 33% |

#### Electrical equipment

Activity data is based on industry information. Before 1995/1996 a different technology was applied, which did not use SF6 (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 2020d. Data on the Swiss inhabitants (see Table 4-9) are taken from SFSO 2020d.

### 4.8.3 Uncertainties and time-series consistency

For the current submission, a simplified uncertainty analysis has been carried out as described in chp. 1.6.1. 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 2G is not a key category, its uncertainties are accounted in the “rest” categories with mean uncertainty, which is 20% combined uncertainty for SF6 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 1.1.3 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2018 and for the changing rates 2018/2019).

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

2G3: In the Swiss GHG inventory, the emission factor of $N_2O$ from 2G3b Use of aerosol cans in households and restaurants has been updated and revised for 2017 and 2003, respectively, based on sales data yielding recalculated EF values for 1990–2010 and 2012-2018. Liechtenstein adopts these emission factors in Submission 2021, which leads to a decrease of 0.07 kt $CO_2$ eq in 2018.

### 4.8.6 Category-specific planned improvements

No category-specific improvements are planned.

## 4.9 Source category 2H - Other

### 4.9.1 Source category description: Other (2H)

Emissions from source category 2H are not occurring in Liechtenstein.

# 5. Agriculture

## 5.1 Overview

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 Annex A8.3, Table A - 9). The latest update has been conducted for submission 2020.

Greenhouse gas emissions from agriculture amount to 24.5 kt $CO_2$ equivalents in 2019, which is a contribution of 13.1% to the total of Liechtenstein's greenhouse gas emissions (excluding LULUCF). Main agricultural sources of greenhouse gases in 2019 were enteric fermentation emitting 14.2 kt $CO_2$eq, followed by agricultural soils with 5.9 kt $CO_2$eq, manure management with 4.3 kt $CO_2$eq and urea application with 0.05 kt $CO_2$eq. A decrease of 1.6% can be observed between 1990 and 2019 regarding overall emissions from agriculture (see Table 5-1 and Figure 5-1). A period of decreasing emissions between 1990-2000 turned into increasing emissions from 2001-2008. From 2009 on, emissions are fluctuating without showing a clear trend. Compared to the previous reporting year, emissions have increased between 2018 and 2019 by around 3.2%.

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 22.4% in 2019 compared to 1990. The development of urea application is similar as in the Swiss inventory (see FOEN 2019 chp. 5.1). $CH_4$ emissions are 0.8% above 1990 levels. $N_2O$ emissions decreased by 6.4% between 1990 and 2019. 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).

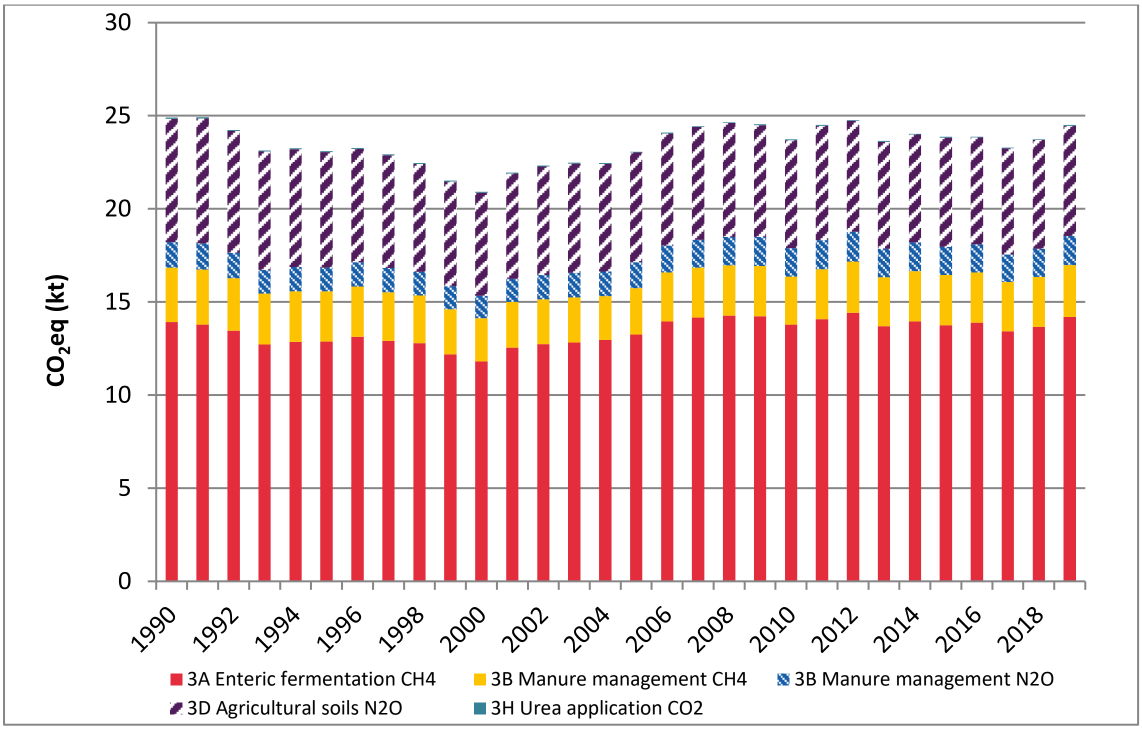



Figure 5-1 Liechtenstein's GHG emissions of the sector 3 Agriculture by sub-sectors. Note that emissions in sub-sectors 3C, 3E, 3F, 3G, 3I are not occurring.

Table 5-1 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 |
| $CH_4$ | 16.85 | 15.57 | 14.13 | 15.75 | 16.36 |
| $N_2O$ | 7.99 | 7.48 | 6.74 | 7.28 | 7.33 |
| **Sum** | **24.90** | **23.10** | **20.91** | **23.07** | **23.73** |

| **Gas** | **2011** | **2012** | **2013** | **2014** | **2015** |
|---|---|---|---|---|---|
| | **$CO_2$ equivalent (kt)** | | | | |
| $CO_2$ | 0.05 | 0.04 | 0.04 | 0.04 | 0.05 |
| $CH_4$ | 16.76 | 17.17 | 16.34 | 16.66 | 16.45 |
| $N_2O$ | 7.70 | 7.55 | 7.27 | 7.33 | 7.37 |
| **Sum** | **24.50** | **24.77** | **23.65** | **24.03** | **23.87** |

| **Gas** | **2016** | **2017** | **2018** | **2019** | **1990-2019** |
|---|---|---|---|---|---|
| | **$CO_2$ equivalent (kt)** | | | | **%** |
| $CO_2$ | 0.04 | 0.04 | 0.05 | 0.05 | -22.4% |
| $CH_4$ | 16.59 | 16.07 | 16.34 | 16.98 | 0.8% |
| $N_2O$ | 7.25 | 7.18 | 7.35 | 7.48 | -6.4% |
| **Sum** | **23.88** | **23.29** | **23.74** | **24.50** | -1.6% |

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 absolute emission numbers for the base year 1990 and the reporting year 2019.

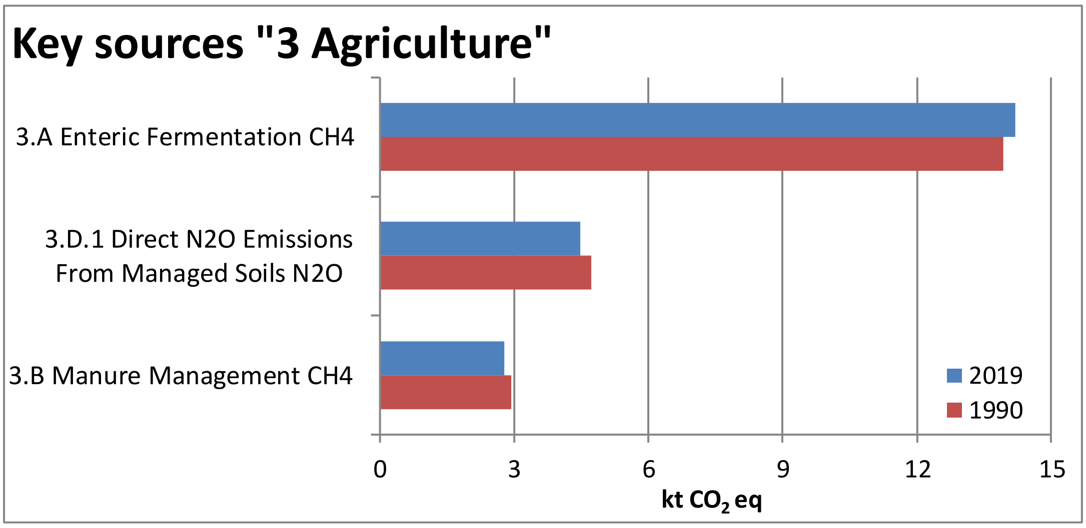



Figure 5-2 Key categories from agriculture (KCA excl. LULUCF). Emissions in $CO_2$ equivalents (kt) per key source category in 2019 and in the base year 1990.

## 5.2 Source category 3A – Enteric fermentation

### 5.2.1 Source 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 also 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<br>Other mature cattle<br>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<br>Milksheep |
| 3A3 | Swine | Swine |
| 3A4a | Goats | Goats |
| 3A4b | Horses | Horses < 3 years<br>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) chapter 10, Figure 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 (for further information 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 the emissions from 3A Enteric fermentation is collected specifically for Liechtenstein.

### 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 Annex A3.2.

**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.

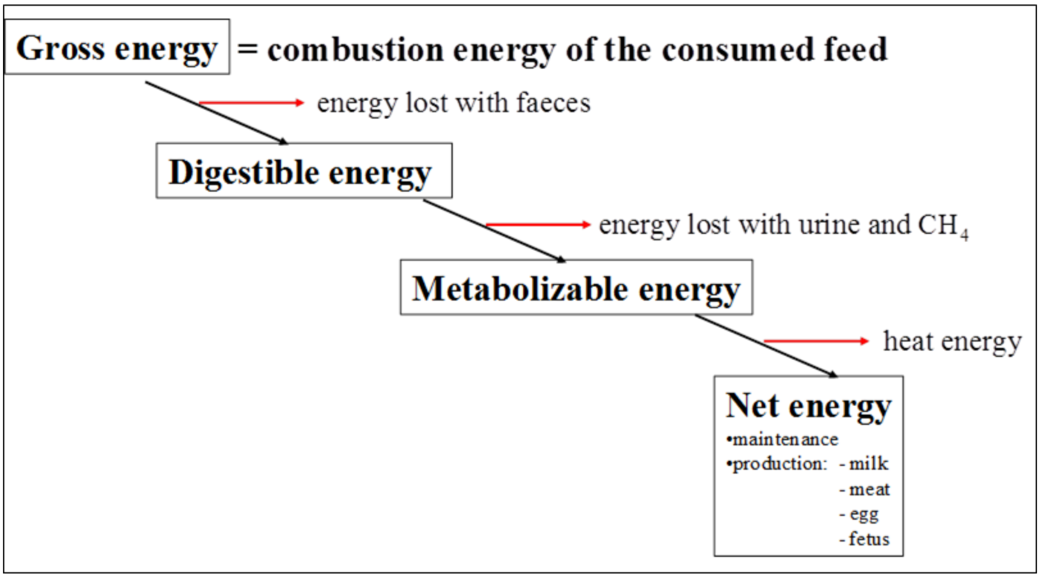



Figure 5-3 Levels of feed energy conversion (Soliva 2006a).

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 2019** | |
|---|---|---|---|
| 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.

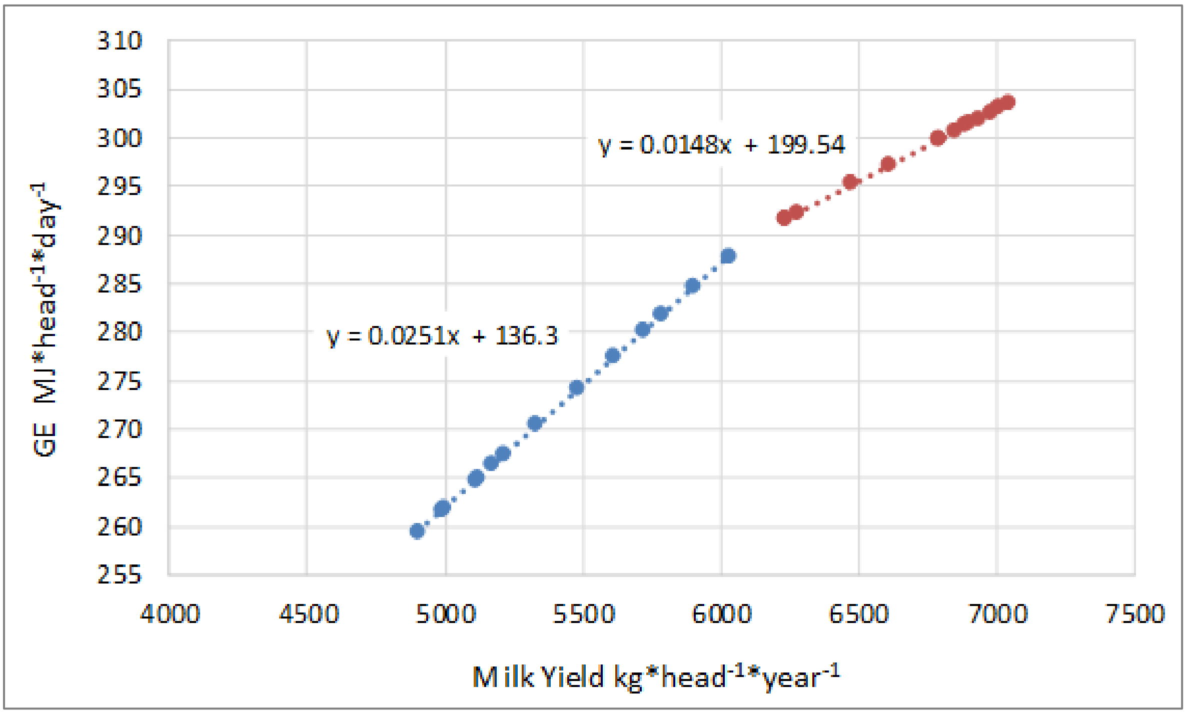



Figure 5-4 Linear regressions relating gross energy intake (GE) to milk yield for mature dairy cattles for Switzerland (based on FOEN 2019).

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 7’481 kg per head and year in 2019 (24.53 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. 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** | | **2011** | **2012** | **2013** | **2014** | **2015** |
| Population Size Mature Dairy Cattle | head | 2’435 | 2’456 | 2’363 | 2’367 | 2’299 |
| Lactation Period | day | 305 | 305 | 305 | 305 | 305 |
| Milk Yield Mature Dairy Cattle | kg/head/day | 22.09 | 22.40 | 22.19 | 22.16 | 22.73 |
| Milk Yield Other Mature Cattle | kg/head/day | 8.20 | 8.20 | 8.20 | 8.20 | 8.20 |
| **Milk Production Cattle** | | **2016** | **2017** | **2018** | **2019** | |
| Population Size Mature Dairy Cattle | head | 2’232 | 2’246 | 2’271 | 2’332 | |
| Lactation Period | day | 305 | 305 | 305 | 305 | |
| Milk Yield Mature Dairy Cattle | kg/head/day | 23.09 | 23.15 | 23.55 | 24.53 | |
| Milk Yield Other Mature Cattle | kg/head/day | 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 6 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** | **2011** | **2012** | **2013** | **2014** |
|---|---|---|---|---|---|---|---|---|---|
| | MJ/head/day | | | | | | | | |
| Cattle | 643.4 | 642.2 | 651.6 | 657.0 | 655.9 | 656.2 | 656.4 | 656.3 | 657.1 |
| Mature Dairy Cattle | 281.7 | 283.2 | 293.1 | 299.9 | 298.2 | 299.2 | 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 | 250.6 |
| Growing Cattle (weighted average) | 111.1 | 108.4 | 107.9 | 106.5 | 107.0 | 106.4 | 105.2 | 106.0 | 106.9 |
| *Fattening Calves* | *47.1* | *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* | *60.1* |
| *Breeding Cattle 1st Year* | *75.4* | *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* | *143.6* |
| *Breeding Cattle 3rd Year* | *143.6* | *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* | *103.7* |
| Sheep | 22.5 | 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 | 28.1 |
| Goats | 25.4 | 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 | 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* | *101.4* |
| *Horses >3 years* | *109.0* | *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 | 39.6 |
| Poultry [1)] | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |

| **Gross Energy Intake** | **2015** | **2016** | **2017** | **2018** | **2019** |
|---|---|---|---|---|---|
| | MJ/head/day | | | | |
| Cattle | 659.1 | 662.4 | 661.0 | 662.8 | 667.0 |
| Mature Dairy Cattle | 302.1 | 303.8 | 304.0 | 305.9 | 310.3 |
| Other Mature Cattle | 250.6 | 250.6 | 250.6 | 250.6 | 250.6 |
| Growing Cattle (weighted average) | 106.4 | 108.1 | 106.4 | 106.3 | 106.1 |
| *Fattening Calves* | *47.1* | *47.1* | *47.1* | *47.1* | *47.1* |
| *Pre-Weaned Calves* | *60.1* | *60.1* | *60.1* | *60.1* | *60.1* |
| *Breeding Cattle 1st Year* | *75.4* | *75.4* | *75.4* | *75.4* | *75.4* |
| *Breeding Cattle 2nd Year* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* |
| *Breeding Cattle 3rd Year* | *143.6* | *143.6* | *143.6* | *143.6* | *143.6* |
| *Fattening Cattle* | *103.7* | *103.7* | *103.7* | *103.7* | *103.7* |
| Sheep | 22.5 | 22.5 | 22.5 | 22.5 | 22.5 |
| Swine | 28.1 | 28.1 | 28.1 | 28.1 | 28.1 |
| Goats | 25.4 | 25.4 | 25.4 | 25.4 | 25.4 |
| Horses (weighted average) | 108.2 | 108.5 | 108.6 | 108.6 | 108.5 |
| *Horses <3 years* | 101.4 | 101.4 | 101.4 | 101.4 | 101.4 |
| *Horses >3 years* | *109.0* | *109.0* | *109.0* | *109.0* | *109.0* |
| Mules and Asses | 39.6 | 39.6 | 39.6 | 39.6 | 39.6 |
| Poultry [1)] | 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 2019. 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. 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** | **2011** | **2012** | **2013** | **2014** |
|---|---|---|---|---|---|---|---|---|---|
| | 1000 head | | | | | | | | |
| Cattle | 6.33 | 5.86 | 4.95 | 5.57 | 5.99 | 6.15 | 6.29 | 6.01 | 6.21 |
| Mature Dairy Cattle | 2.85 | 2.64 | 2.44 | 2.49 | 2.43 | 2.44 | 2.46 | 2.36 | 2.37 |
| Other Mature Cattle | 0.02 | 0.05 | 0.07 | 0.36 | 0.38 | 0.45 | 0.54 | 0.46 | 0.45 |
| Growing Cattle (weighted average) | 3.46 | 3.17 | 2.43 | 2.72 | 3.19 | 3.27 | 3.29 | 3.18 | 3.40 |
| *Fattening Calves* | *0.05* | *0.08* | *0.11* | *0.08* | *0.08* | *0.08* | *0.08* | *0.08* | *0.08* |
| *Pre-Weaned Calves* | *0.02* | *0.04* | *0.01* | *0.27* | *0.28* | *0.33* | *0.40* | *0.34* | *0.33* |
| *Breeding Cattle 1st Year* | *1.14* | *1.06* | *0.65* | *0.60* | *0.81* | *0.82* | *0.79* | *0.79* | *0.88* |
| *Breeding Cattle 2nd Year* | *0.90* | *0.70* | *0.54* | *0.68* | *0.81* | *0.81* | *0.79* | *0.78* | *0.87* |
| *Breeding Cattle 3rd Year* | *0.63* | *0.58* | *0.34* | *0.35* | *0.46* | *0.46* | *0.45* | *0.44* | *0.49* |
| *Fattening Cattle* | *0.72* | *0.73* | *0.77* | *0.74* | *0.74* | *0.76* | *0.79* | *0.75* | *0.75* |
| Sheep | 2.78 | 2.63 | 2.98 | 3.06 | 3.66 | 3.63 | 3.80 | 3.52 | 3.58 |
| Swine | 3.25 | 2.43 | 1.99 | 1.70 | 1.69 | 1.79 | 1.74 | 1.66 | 1.71 |
| Goats | 0.17 | 0.15 | 0.16 | 0.32 | 0.43 | 0.46 | 0.39 | 0.27 | 0.28 |
| Horses (weighted average) | 0.17 | 0.16 | 0.16 | 0.27 | 0.34 | 0.33 | 0.33 | 0.30 | 0.31 |
| *Horses <3 years* | *0.03* | *0.03* | *0.02* | *0.03* | *0.03* | *0.03* | *0.05* | *0.03* | *0.03* |
| *Horses >3 years* | *0.13* | *0.14* | *0.14* | *0.24* | *0.30* | *0.30* | *0.28* | *0.27* | *0.28* |
| Mules and Asses | 0.07 | 0.13 | 0.22 | 0.14 | 0.15 | 0.19 | 0.18 | 0.17 | 0.18 |
| Poultry | 4.44 | 6.25 | 8.06 | 10.45 | 12.92 | 12.49 | 12.53 | 13.03 | 12.68 |

| **Population size** | **2015** | **2016** | **2017** | **2018** | **2019** | **1990-2019** |
|---|---|---|---|---|---|---|
| | 1000 head | | | | | % |
| Cattle | 6.03 | 6.23 | 5.79 | 5.89 | 6.12 | -3% |
| Mature Dairy Cattle | 2.30 | 2.23 | 2.25 | 2.27 | 2.33 | -18% |
| Other Mature Cattle | 0.47 | 0.41 | 0.43 | 0.45 | 0.49 | 2345% |
| Growing Cattle (weighted average) | 3.27 | 3.59 | 3.11 | 3.17 | 3.30 | -5% |
| *Fattening Calves* | *0.08* | *0.08* | *0.08* | *0.08* | *0.08* | *56%* |
| *Pre-Weaned Calves* | *0.34* | *0.30* | *0.32* | *0.33* | *0.36* | *2293%* |
| *Breeding Cattle 1st Year* | *0.83* | *0.98* | *0.79* | *0.80* | *0.83* | *-27%* |
| *Breeding Cattle 2nd Year* | *0.82* | *0.97* | *0.78* | *0.79* | *0.82* | *-9%* |
| *Breeding Cattle 3rd Year* | *0.47* | *0.55* | *0.44* | *0.45* | *0.47* | *-26%* |
| *Fattening Cattle* | *0.73* | *0.70* | *0.71* | *0.72* | *0.75* | *3%* |
| Sheep | 3.89 | 4.05 | 4.12 | 3.99 | 3.88 | 40% |
| Swine | 1.75 | 1.79 | 1.88 | 1.77 | 1.72 | -47% |
| Goats | 0.29 | 0.33 | 0.36 | 0.43 | 0.43 | 152% |
| Horses (weighted average) | 0.30 | 0.27 | 0.26 | 0.24 | 0.25 | 52% |
| *Horses <3 years* | *0.03* | *0.02* | *0.01* | *0.01* | *0.02* | *-52%* |
| *Horses >3 years* | *0.27* | *0.25* | *0.24* | *0.23* | *0.24* | *77%* |
| Mules and Asses | 0.16 | 0.17 | 0.16 | 0.23 | 0.22 | 199% |
| Poultry | 12.50 | 12.83 | 12.46 | 12.92 | 15.01 | 238% |

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 at a slightly lower level than 1990. 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. From 2008 to 2017, the poultry population size remained at a constant level with some fluctuations. Figure 5-5 illustrates the development of the sizes of Liechtenstein's animal populations.

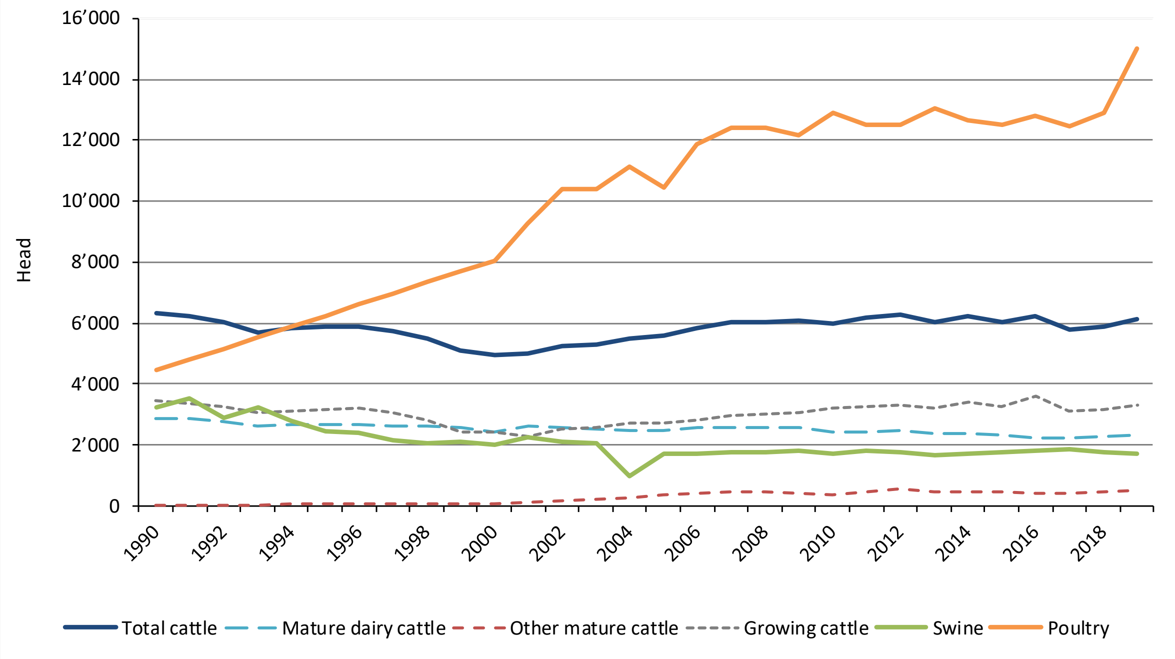



Figure 5-5 Development of population size of main animal categories (Division of Agriculture).

### 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 1990–2019 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 1.2.3 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 2018 as well as an analysis of the increase or decrease of emissions between 2018 and 2019 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 NIR author report their QC activities in a checklist (see Annex 8).

### 5.2.5 Category-specific recalculations

In 2018, the recalculations for 3A lead to an increase of $CH_4$ emissions by around 0.05 kt $CO_2$eq.

- 3A/3B: The animal number of horses < 3 years or the year 2018 (activity data) was corrected from 13 horses to 11 horses due to a change in the statistics.
- 3A/3B: Milk yield for the year 2018 (activity data) was corrected from 7'060 to 7'184 kg/head/year due to a change in the statistics from the Division for Agriculture.

### 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 Source category 3B – Manure management

## 5.3.1 Source 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. Significant contributors to $CH_4$ emissions in 2019 are cattle with approximatively 87%. Likewise, cattle and sheep contribute significantly to $N_2O$ emissions with around 72% 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<br>Other mature cattle<br>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<br>Milk sheep |
| 3B3 | Swine | Piglets<br>Fattening pig over 25 kg<br>Dry sows<br>Nursing sows<br>Boars |
| 3B4 | Other livestock | Goats<br>Horses (Horses < 3 years, Horses > 3 years)<br>Poultry<br>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.

| 3B | $CH_4$ | | $N_2O$ | |
|---|---|---|---|---|
| Cattle | Mature Dairy Cattle | | Mature Dairy Cattle | |
| | Other Mature Cattle | | Other Mature Cattle | |
| | Growing Cattle | Fattening Calves<br>Pre-Weaned Calves<br>Breeding Cattle 1st year<br>Breeding Cattle 2nd year<br>Breeding Cattle 3rd year<br>Fattening Cattle | Growing Cattle | Fattening Calves<br>Pre-Weaned Calves<br>Breeding Cattle 1st year<br>Breeding Cattle 2nd year<br>Breeding Cattle 3rd year<br>Fattening Cattle |
| Sheep | Sheep | | Fattening Sheep<br>Milk Sheep | |
| Swine | Swine | | Piglets<br>Fattening Pig over 25 kg<br>Dry Sows<br>Nursing Sows<br>Boars | |
| Goats | Goats | | Goat places | |
| Horses | Horses < 3 years<br>Horses > 3 years | | Horses < 3 years<br>Horses > 3 years | |
| Mules and Asses | Mules an Asses | | Mules an Asses | |
| Poultry | Poultry | | Growers<br>Layers<br>Broilers<br>Turkey<br>Other Poultry (Geese, Ducks, Ostriches, Quails) | |

### 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/m$^3$ = conversion factor of m$^3$ $CH_4$ to kilograms $CH_4$

$MCF_S$ = $CH_4$ conversion factors for each manure management system S (%)

$MS_{TS}$ = fraction of livestock category T's manure handled using manure management system S (dimensionless)

**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 2015a) 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 2019. 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 dereases 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 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 high MCF of 10% (which is justified according to the literature mentioned), leads to a clearly higher methane emission factor for sheep in Liechtenstein than in 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 2019. 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).

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 facor (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 (2019).

| 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 |

### 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 ata 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 | 2015 | 2016 | 2017 | 2018 | 2019 | 1990 - 2019 (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fattening Calves | 50 | 81 | 112 | 83 | 81 | 77 | 75 | 75 | 76 | 78 | 56% |
| Pre-Weaned Calves | 15 | 35 | 11 | 266 | 281 | 342 | 304 | 318 | 331 | 359 | 2293% |
| Breeding Cattle 1st Year | 1'136 | 1'057 | 649 | 601 | 814 | 828 | 982 | 785 | 801 | 828 | -27% |
| Breeding Cattle 2nd Year | 903 | 699 | 544 | 676 | 808 | 822 | 974 | 778 | 794 | 822 | -9% |
| Breeding Cattle 3rd Year | 631 | 575 | 343 | 348 | 459 | 466 | 553 | 442 | 451 | 467 | -26% |
| Fattening Cattle | 723 | 725 | 774 | 743 | 743 | 732 | 700 | 709 | 720 | 747 | 3% |
| Growing Cattle | 3'458 | 3'172 | 2'433 | 2'717 | 3'186 | 3'267 | 3'588 | 3'107 | 3'173 | 3'301 | -5% |
| Mature Dairy Cattle | 2'850 | 2'643 | 2'440 | 2'489 | 2'425 | 2'299 | 2'232 | 2'246 | 2'271 | 2'332 | -18% |
| Other Mature Cattle | 20 | 47 | 74 | 362 | 382 | 465 | 413 | 432 | 450 | 489 | 2345% |
| **Total Cattle** | **6'328** | **5'862** | **4'947** | **5'568** | **5'993** | **6'031** | **6'233** | **5'785** | **5'894** | **6'122** | **-3%** |
| Fattening Sheep | 1'636 | 1'079 | 1'522 | 2'005 | 2'061 | 2'094 | 2'087 | 2'168 | 2'165 | 2'225 | 36% |
| Milksheep | 0 | 0 | 0 | 41 | 0 | 1 | 0 | 0 | 0 | 0 | - |
| **Total Sheep** | **2'781** | **2'632** | **2'983** | **3'063** | **3'656** | **3'892** | **4'050** | **4'123** | **3'989** | **3'884** | **40%** |
| Goat Places | 111 | 100 | 96 | 171 | 253 | 182 | 217 | 242 | 293 | 267 | 141% |
| **Total Goats** | **171** | **145** | **164** | **324** | **434** | **285** | **330** | **361** | **431** | **431** | **152%** |
| Horses <3 years Agr. | 33 | 27 | 20 | 28 | 31 | 29 | 17 | 12 | 11 | 16 | -52% |
| Horses >3 years Agr. | 133 | 135 | 136 | 237 | 304 | 272 | 249 | 243 | 233 | 236 | 77% |
| **Total Horses Agr.** | **166** | **162** | **156** | **265** | **335** | **301** | **266** | **255** | **244** | **252** | **52%** |
| **Total Mules and Asses Agr.** | **73** | **133** | **223** | **144** | **154** | **163** | **172** | **157** | **230** | **218** | **199%** |
| Piglets | 506 | 452 | 398 | 222 | 301 | 285 | 226 | 197 | 183 | 172 | -66% |
| Fattening Pig over 25 kg | 1'006 | 1'091 | 1'229 | 1'162 | 1'058 | 1'206 | 1'153 | 1'309 | 1'149 | 1'131 | 12% |
| Dry Sows | 207 | 191 | 91 | 96 | 101 | 87 | 77 | 70 | 68 | 73 | -65% |
| Nursing Sows | 66 | 62 | 22 | 21 | 18 | 12 | 25 | 25 | 27 | 25 | -62% |
| Boars | 5 | 5 | 4 | 3 | 3 | 10 | 2 | 2 | 2 | 2 | -60% |
| **Total Swine** | **3'251** | **2'429** | **1'992** | **1'703** | **1'690** | **1'747** | **1'789** | **1'875** | **1'772** | **1'724** | **-47%** |
| Growers | 105 | 53 | 0 | 0 | 61 | 246 | 141 | 131 | 95 | 100 | -5% |
| Layers | 4'145 | 5'506 | 6'866 | 10'112 | 12'175 | 12'056 | 12'438 | 12'141 | 12'371 | 14'322 | 246% |
| Broilers | 0 | 500 | 1'000 | 250 | 390 | 0 | 100 | 0 | 300 | 400 | - |
| Turkey | 22 | 55 | 87 | 52 | 103 | 43 | 44 | 46 | 13 | 37 | 68% |
| Other Poultry | 163 | 134 | 106 | 39 | 191 | 153 | 104 | 137 | 137 | 151 | -7% |
| **Total Poultry** | **4'435** | **6'248** | **8'059** | **10'453** | **12'920** | **12'498** | **12'827** | **12'455** | **12'916** | **15'010** | **238%** |

### 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.

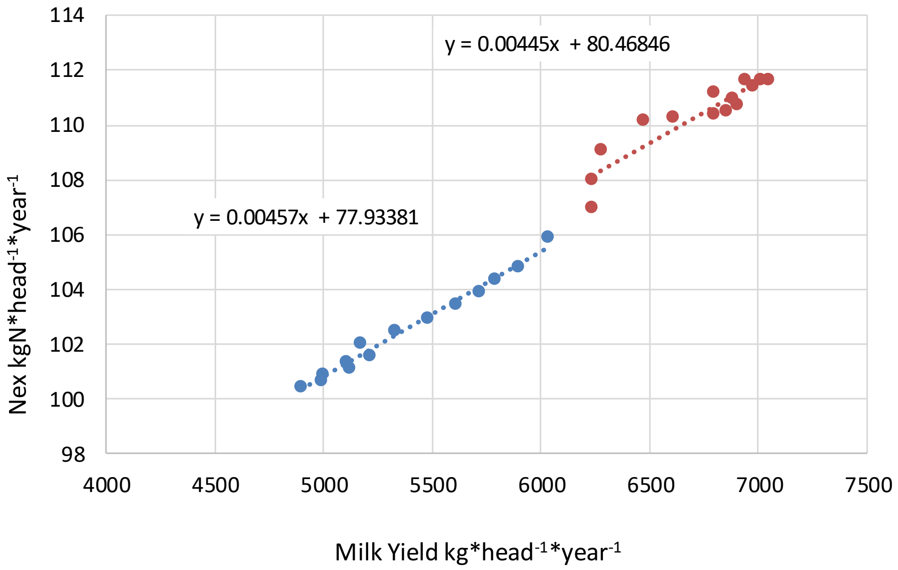



Figure 5-6 Linear regression relating nitrogen excretion (NexDC) of mature dairy cattle to milk yield (based on FOEN 2019.

Table 5-15 Nitrogen excretion rates of Liechtenstein's livestock.

| Nitrogen Excretion | 1990 | 1995 | 2000 | 2005 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|
| | kg N/head/year | | | | | | | | |
| Cattle | 225.3 | 224.9 | 228.2 | 230.1 | 230.3 | 230.6 | 230.8 | 230.8 | 231.1 |
| Mature Dairy Cattle | 104.4 | 104.7 | 108.6 | 110.7 | 110.1 | 110.4 | 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 | 85.0 |
| Growing Cattle (weighted average) | 35.9 | 35.2 | 34.6 | 34.5 | 35.2 | 35.1 | 34.9 | 35.2 | 35.5 |
| *Fattening Calves* | *13.0* | *13.0* | *13.0* | *14.2* | *16.0* | *16.4* | *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* | *22.0* |
| *Breeding Cattle 1st Year* | *25.0* | *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* | *40.0* |
| *Breeding Cattle 3rd Year* | *55.0* | *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* | *36.4* | *36.8* | *37.2* | *37.6* |
| Sheep (weighted average) | 8.8 | 6.1 | 7.7 | 10.1 | 8.5 | 8.7 | 8.5 | 8.8 | 8.8 |
| Swine (weighted average) | 8.8 | 11.9 | 11.5 | 11.0 | 10.3 | 10.1 | 9.5 | 10.3 | 10.0 |
| Goats | 11.0 | 11.7 | 10.0 | 9.0 | 9.9 | 9.4 | 9.5 | 11.8 | 10.2 |
| Horses (weighted average) | 43.6 | 43.7 | 43.7 | 43.8 | 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 | 16.0 |
| Poultry (weighted average) | 0.7 | 0.7 | 0.7 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |

| Nitrogen Excretion | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|
| | kg N/head/year | | | | |
| Cattle | 231.8 | 232.6 | 232.4 | 232.9 | 234.2 |
| Mature Dairy Cattle | 111.3 | 111.8 | 111.9 | 112.4 | 113.8 |
| Other Mature Cattle | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 |
| Growing Cattle (weighted average) | 35.5 | 35.8 | 35.5 | 35.5 | 35.4 |
| *Fattening Calves* | *18.0* | *18.0* | *18.0* | *18.0* | *18.0* |
| *Pre-Weaned Calves* | *22.0* | *22.0* | *22.0* | *22.0* | *22.0* |
| *Breeding Cattle 1st Year* | *25.0* | *25.0* | *25.0* | *25.0* | *25.0* |
| *Breeding Cattle 2nd Year* | *40.0* | *40.0* | *40.0* | *40.0* | *40.0* |
| *Breeding Cattle 3rd Year* | *55.0* | *55.0* | *55.0* | *55.0* | *55.0* |
| *Fattening Cattle* | *38.0* | *38.0* | *38.0* | *38.0* | *38.0* |
| Sheep (weighted average) | 8.1 | 7.7 | 7.9 | 8.1 | 8.6 |
| Swine (weighted average) | 10.2 | 9.6 | 10.0 | 9.5 | 9.6 |
| Goats | 10.9 | 11.2 | 11.4 | 11.6 | 10.5 |
| Horses (weighted average) | 43.8 | 43.9 | 43.9 | 43.9 | 43.9 |
| Mules and Asses | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| Poultry (weighted average) | 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 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 A3.2.

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 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 2019. 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 1990–2019 are 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 1.2.3 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 2018 as well as an analysis of the increase or decrease of emissions between 2018 and 2019 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 NIR author report their QC activities in a checklist (see Annex 8).

### 5.3.5 Category-specific recalculations

In 2018, the recalculations for 3B lead to an increase of $CH_4$ emissions by 0.01 kt $CO_2$eq. For $N_2O$, the increase amounts to 0.003 kt $CO_2$eq.

- 3B/3A: The animal number of horses < 3 years or the year 2018 (activity data) was corrected from 13 horses to 11 horses due to a change in the statistics.
- 3B/3A: Milk yield for the year 2018 (activity data) was corrected from 7’060 to 7’184 kg/head/year due to a change in the statistics from the Division for Agriculture.

### 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 Source category 3C – Rice cultivation

Rice cultivation does not occur in Liechtenstein.

## 5.5 Source category 3D – Agricultural soils

### 5.5.1 Source 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 2019 were animal manure applied to soils (25.1%), nitrogen input from atmospheric deposition (16.8%), inorganic nitrogen fertilisers (14.6%), urine and dung deposition by grazing animals (14.3%) and nitrogen in crop residues returned to soils (9.5%).

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<br>2. Organic N fertilisers (animal manure applied to soils, sewage sludge applied to soils, other organic fertilisers applied to soils)<br>3. Urine and dung deposited by grazing animals<br>4. Crop residues (inc. residues from meadows and pasture)<br>5. Mineralisation/immobilisation associated with loss/gain of soil organic matter<br>6. Cultivation of organic soils (i.e. histosols)<br>7. Other (Domestic synthetic fertiliser) |
| 3Db | Indirect $N_2O$ emissions from managed soils | 1. Atmospheric deposition<br>2. Nitrogen leaching and run-off |

Direct and indirect $N_2O$ emissions have decreased by 5.3% and 23.7% in 2019 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.

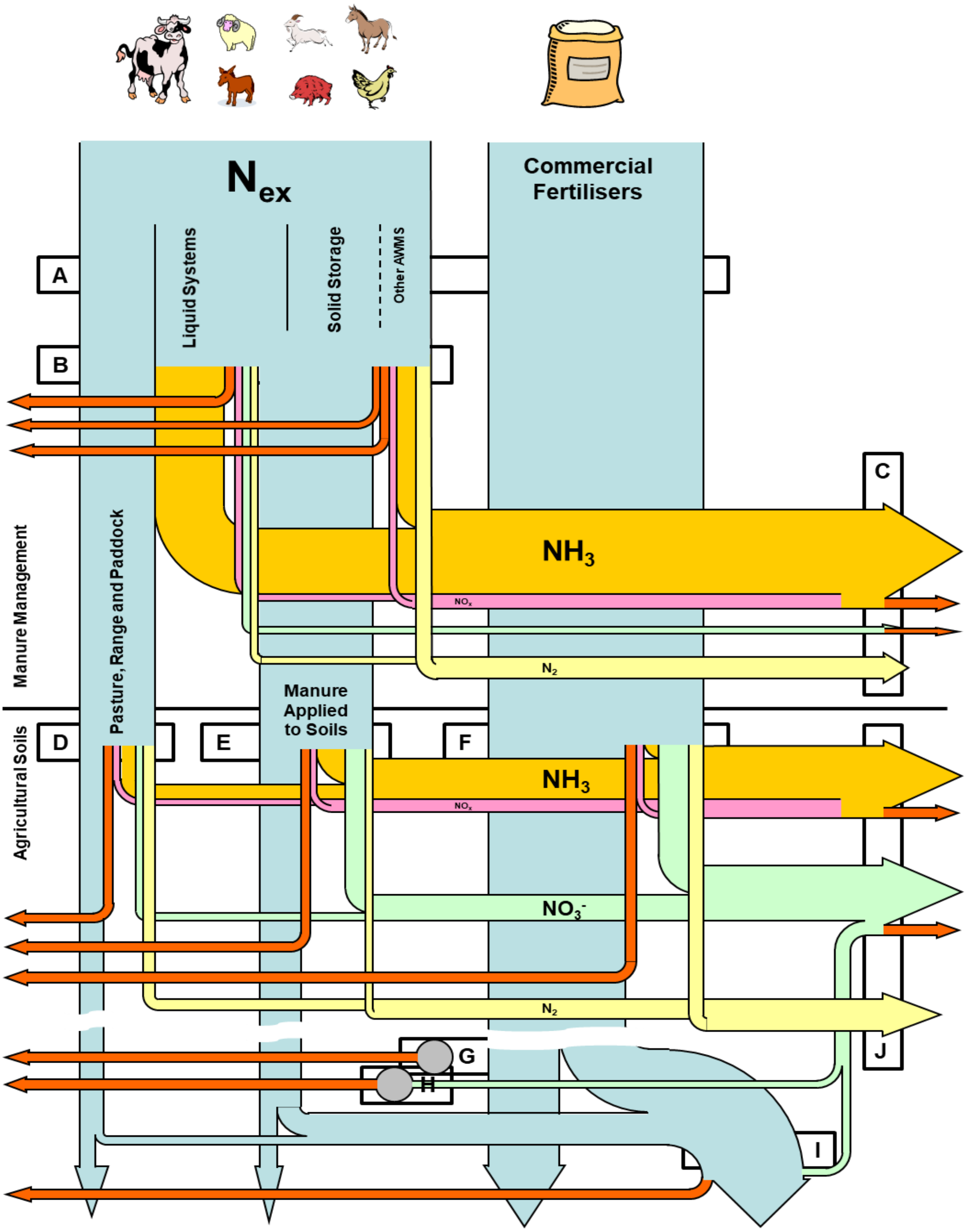



Figure 5-7 Diagram depicting the methodology of the approach to calculate the $N_2O$ emissions in agriculture (red arrows). Black frames and the respective letters refer to the nitrogen flows in

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 | 2019 | | |
| | | tN | | *equals* | |
| A | 1 Pasture, range and paddock | 53.58 | 98.31 | = B | 3.Da3 |
| | 2 Liquid/slurry systems | 281.62 | 291.57 | | 3.B(b) |
| | 3 Solid storage | 131.11 | 76.69 | | 3.B(b) |
| | 4 Other AWMS | 23.60 | 38.09 | | 3.B(b) |
| | 5 Commercial fertiliser | 278.07 | 192.59 | = F | 3.Da1,2,7 |
| B | 1 Pasture, range and paddock | 53.58 | 98.31 | = A1-A4 | 3.Da3 |
| | 2 $NH_3$ volatilisation housing | 28.57 | 50.40 | | 3.B(b)5 |
| | 3 $N_2O$ emission liquid/slurry | 0.56 | 0.58 | | 3.B(b) |
| | 4 $NO_x$ volatilisation liquid/slurry and digester | 0.56 | 0.58 | | 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 | 5.83 | | |
| | 7 Manure applied to soils | 364.49 | 316.81 | | 3.Da2 |
| | 8 N2O emission solid storage | 0.66 | 0.38 | | 3.B(b) |
| | 9 N2O emission other AWMS | 0.21 | 0.28 | | 3.B(b) |
| | 10 NOx volatilisation solid storage and deep litter | 0.86 | 0.67 | | 3.B(b)5 |
| | 11 NH3 volatilisation storage | 30.41 | 27.24 | | 3.B(b)5 |
| | 12 N2 volatilization solid storage and deep litter | 4.38 | 3.55 | | |
| C | 1 $NH_3$ deposition manure management | 58.98 | 77.65 | = 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 | 73.56 | = B1 | |
| | 2 $N_2O$ emission PR&P | 0.99 | 1.81 | | 3.Da3 |
| | 3 $NO_x$ volatilisation PR&P | 0.29 | 0.54 | | |
| | 4 $NH_3$ volatilisation PR&P | 2.51 | 4.86 | | |
| | 5 Leaching and run-off PR&P | 11.04 | 17.54 | | |
| E | 1 Available N animal manure | 193.89 | 191.81 | = B6 | |
| | 2 $N_2O$ emission application animal manure | 3.64 | 3.17 | | 3.Da2 |
| | 3 $NO_x$ volatilisation application animal manure | 2.00 | 1.74 | | |
| | 4 $NH_3$ volatilisation application animal manure | 89.83 | 63.58 | | |
| | 5 Leaching and run-off application animal manure | 75.11 | 56.52 | | |
| F | 1 Available N com. fertiliser | 199.77 | 146.86 | = A5 | |
| | 2 $N_2O$ emission application com. fertiliser | 2.78 | 1.93 | | 3.Da1,2,7 |
| | 3 $NO_x$ volatilisation application com. fertiliser | 1.53 | 1.06 | | |
| | 4 $NH_3$ volatilisation application com. fertiliser | 16.68 | 8.39 | | |
| | 5 Leaching and run-off application com. fertiliser | 57.31 | 34.36 | | |
| G | 1 Cultivation of organic soils (ha) | *191.50* | *181.17* | | 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 | 86.50 | | 3.Da4 |
| | 2 N in crop residues arable crops | 34.11 | 32.96 | | |
| J | 1 $NH_3$ deposition fertiliser appl. and PR&P | 109.02 | 76.83 | = D4+E4+F4 | 3.Db1 |
| | 2 $NO_x$ deposition fertiliser appl. and PR&P | 3.83 | 3.34 | = D3+E3+F3 | |
| | 3 Leaching and run-off fertiliser appl. and PR&P | 143.46 | 108.41 | = 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 | 21.31 | | |

### 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 2020). Since 2003, the use of sewage sludge as fertiliser is prohibited in Liechtenstein (see Annex A6.1). 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 2020).

**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 3.2.

Table 5-20 Activity data for calculating direct $N_2O$ emissions from managed soils.

| Activity Data | | 1990 | 1995 | 2000 | 2005 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | t N/yr | | | | | | | | |
| 1. Inorganic N fertilisers | Urea | 37 | 31 | 29 | 29 | 27 | 31 | 28 | 27 | 26 |
| | Other mineral fertilisers | 200 | 169 | 155 | 158 | 147 | 170 | 151 | 147 | 142 |
| 2. Organic N fertilisers | a. Animal manure | 364 | 333 | 279 | 297 | 308 | 315 | 321 | 307 | 312 |
| | b. Sewage sludge | 30.4 | 31.3 | 10.8 | 0.0 | 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 | 0.5 |
| 3. Urine and dung deposited by grazing animals | | 54 | 51 | 71 | 98 | 97 | 99 | 102 | 96 | 98 |
| 4. Crop residues | Arable crops | 34 | 44 | 32 | 30 | 27 | 27 | 27 | 27 | 31 |
| | Residues PR&P | 80 | 84 | 86 | 93 | 86 | 105 | 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 | 0.0 |
| 6. Cultivation of organic soils (ha) | | 192 | 189 | 187 | 184 | 182 | 183 | 183 | 184 | 184 |
| 7. Other (domestic inorganic fertilisers) | | 9.9 | 8.4 | 7.6 | 7.8 | 7.3 | 8.4 | 7.5 | 7.2 | 7.0 |

| Activity Data | | 2015 | 2016 | 2017 | 2018 | 2019 | 1990 -2019 |
|---|---|---|---|---|---|---|---|
| | | t N/yr | | | | | % |
| 1. Inorganic N fertilisers | Urea | 30 | 27 | 28 | 31 | 29 | -22% |
| | Other mineral fertilisers | 162 | 145 | 152 | 166 | 155 | -22% |
| 2. Organic N fertilisers | a. Animal manure | 307 | 307 | 300 | 305 | 317 | -13% |
| | b. Sewage sludge | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | - |
| | c. Other organic fertilisers | 0.4 | 0.5 | 0.5 | 0.4 | 0.6 | *115%* |
| 3. Urine and dung deposited by grazing animals | | 95 | 96 | 92 | 94 | 98 | *83%* |
| 4. Crop residues | Arable crops | 30 | 30 | 32 | 32 | 33 | *-3%* |
| | Residues PR&P | 85 | 85 | 86 | 86 | 86 | *9%* |
| 5. Min./imm. associated with loss/gain of SOM | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | - |
| 6. Cultivation of organic soils (ha) | | 183 | 183 | 182 | 182 | 181 | *-5%* |
| 7. Other (domestic inorganic fertilisers) | | 8.0 | 7.2 | 7.5 | 8.2 | 7.7 | -22% |

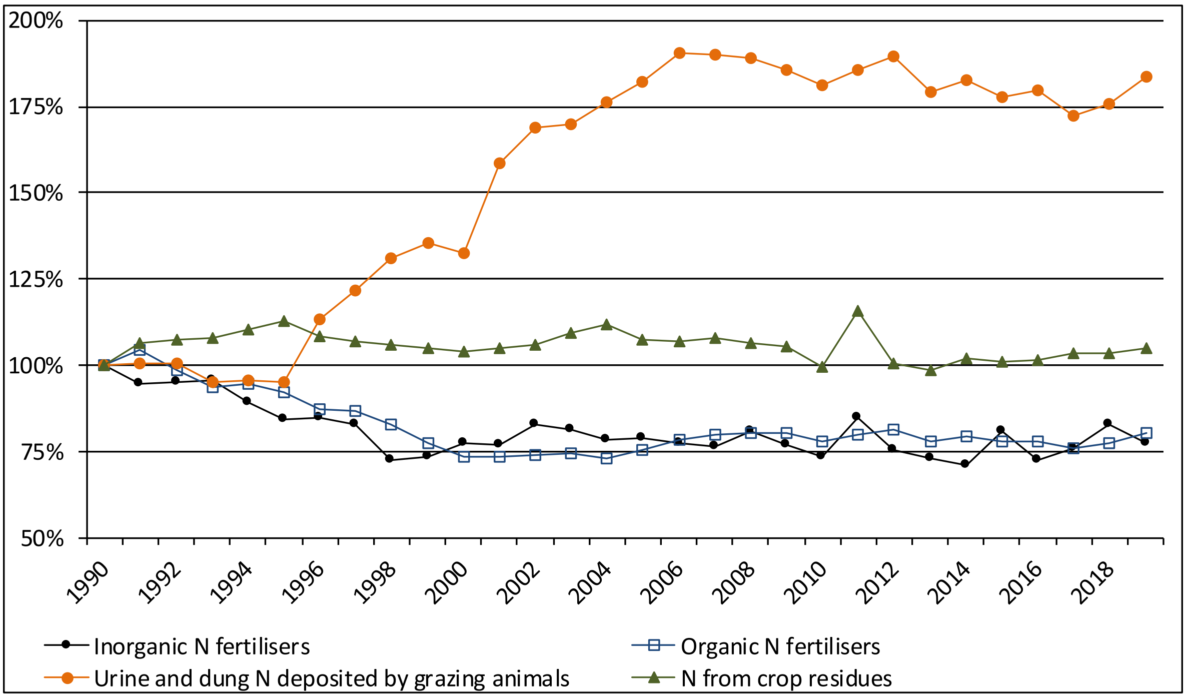



Figure 5-8 Relative development of the most important activity data for source category 3Da direct $N_2O$ emissions from managed soils

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:

$$N_2O_{(ATD)} - N = \left\{ \left[ \sum_i \left( F_{CN_i} * Frac_{GASF_i} \right) + \sum_T \left( F_{AM_T} * Frac_{GASM_T} \right) + \sum_T \left( F_{PRP_T} * Frac_{GASP_T} \right) \right] + \left[ \left( F_{CN} + F_{AM} \right) * Frac_{NOXA} + F_{PRP} * Frac_{NOXP} \right] \right\} * EF_4$$

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 2019 due to a change in the shares of the different commercial fertilisers: the use of urea and sewage sludge (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 24.7% in 1990 to 20.1% in 2019.

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 5.0%.

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 Annex 3.2.

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 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|
| | % | | | | | | | | |
| $NH_3$ from commercial fertiliser N ($Frac_{GASFi}$) | 6.00 | 6.84 | 5.27 | 4.31 | 4.57 | 4.50 | 4.61 | 4.62 | 4.55 |
| Urea | 13.11 | 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 | 2.99 | 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 | 3.43 |
| Sewage Sludge | 20.00 | 23.94 | 26.07 | NO | NO | NO | NO | NO | NO |
| Compost | 3.43 | 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 | 21.00 | 20.81 | 20.58 | 20.35 |
| Mature Dairy Cattle | 26.69 | 26.78 | 25.38 | 25.30 | 23.76 | 23.44 | 23.12 | 22.81 | 22.50 |
| Other Mature Cattle | 24.16 | 23.68 | 21.76 | 22.65 | 22.45 | 22.28 | 22.11 | 21.94 | 21.77 |
| Growing Cattle (weighted average) | 24.84 | 24.75 | 22.72 | 22.86 | 21.99 | 21.79 | 21.57 | 21.42 | 21.28 |
| Sheep (weighted average) | 3.72 | 4.38 | 4.14 | 5.23 | 5.50 | 5.39 | 5.27 | 5.16 | 5.04 |
| Swine (weighted average) | 21.52 | 21.02 | 19.79 | 20.02 | 18.82 | 18.69 | 18.52 | 18.38 | 18.21 |
| Other Livestock (weighted average) | 5.73 | 7.32 | 7.32 | 7.70 | 8.26 | 8.20 | 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 | 4.87 | 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 | 4.59 |
| Other Mature Cattle | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 | 4.56 | 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 | 4.57 |
| Sheep (weighted average) | 5.00 | 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 | 14.00 |
| Other Livestock (weighted average) | 5.00 | 6.01 | 8.11 | 9.96 | 9.22 | 9.21 | 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 | 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 | 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 | 0.55 |

| Emission Factors Volatilisation | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|
| | % | | | | |
| $NH_3$ from commercial fertiliser N ($Frac_{GASFi}$) | 4.83 | 4.36 | 4.36 | 4.36 | 4.36 |
| Urea | 13.11 | 13.10 | 13.10 | 13.10 | 13.10 |
| Other Mineral Fertilisers | 3.37 | 2.82 | 2.82 | 2.82 | 2.82 |
| Recycling Fertilisers (weighted average) | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 |
| Sewage Sludge | NO | NO | NO | NO | NO |
| Compost | 3.43 | 3.43 | 3.43 | 3.43 | 3.43 |
| $NH_3$ from application of animal manure N ($Frac_{GASMT}$) | 20.10 | 20.11 | 20.05 | 20.04 | 20.07 |
| Mature Dairy Cattle | 22.19 | 22.19 | 22.19 | 22.19 | 22.19 |
| Other Mature Cattle | 21.61 | 21.61 | 21.61 | 21.61 | 21.61 |
| Growing Cattle (weighted average) | 21.07 | 21.12 | 21.07 | 21.07 | 21.07 |
| Sheep (weighted average) | 4.92 | 4.92 | 4.92 | 4.92 | 4.92 |
| Swine (weighted average) | 18.05 | 18.04 | 18.05 | 18.03 | 18.03 |
| Other Livestock (weighted average) | 8.59 | 8.74 | 8.73 | 8.60 | 8.94 |
| $NH_3$ from urine and dung N deposited on PR&P ($Frac_{GASPT}$) | 4.91 | 4.91 | 4.92 | 4.92 | 4.95 |
| Mature Dairy Cattle | 4.59 | 4.59 | 4.59 | 4.59 | 4.59 |
| Other Mature Cattle | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 |
| Growing Cattle (weighted average) | 4.57 | 4.57 | 4.57 | 4.57 | 4.57 |
| Sheep (weighted average) | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Swine (weighted average) | 14.00 | 14.00 | 14.00 | 14.00 | 14.00 |
| Other Livestock (weighted average) | 10.58 | 11.10 | 11.17 | 10.88 | 11.65 |
| $NH_3$ from Agricultural Soils (kg/ha/year) | 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 |
| $NO_x$ from urine and dung N deposited on PR&P ($Frac_{NOXP}$) | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |

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 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | t N/yr | | | | | | | | |
| | Animals manure N applied to soils | 364 | 333.0 | 279.2 | 296.8 | 307.8 | 314.9 | 320.6 | 307.4 | 312.5 |
| | Commercial fertiliser | 278.1 | 240.7 | 202.4 | 195.7 | 182.3 | 210.4 | 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 | 5'476 |
| | Alpine area (ha) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Deposition | Sum volatised N ($NH_3$ and $NO_x$) | 112.8 | 104.7 | 81.2 | 83.5 | 81.7 | 83.9 | 83.6 | 79.6 | 79.6 |
| | $NH_3$ emissions from commercial fertilisers | 16.7 | 16.5 | 10.7 | 8.4 | 8.3 | 9.5 | 8.6 | 8.4 | 8.0 |
| | $NH_3$ emissions from applied animal manure | 89.8 | 82.4 | 64.1 | 67.1 | 65.4 | 66.1 | 66.7 | 63.3 | 63.6 |
| | $NH_3$ emissions from pasture, range and paddock | 2.51 | 2.38 | 3.39 | 4.75 | 4.73 | 4.84 | 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 | 0.0 |
| | $NO_x$ emissions from commercial fertilisers | 1.53 | 1.32 | 1.11 | 1.08 | 1.00 | 1.16 | 1.03 | 1.00 | 0.97 |
| | $NO_x$ emissions from applied animal manure | 2.00 | 1.83 | 1.54 | 1.63 | 1.69 | 1.73 | 1.76 | 1.69 | 1.72 |
| | $NO_x$ emissions from PR&P | 0.29 | 0.28 | 0.39 | 0.54 | 0.53 | 0.55 | 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 | 135.0 | 129.1 | 124.3 | 125.3 |
| | Leaching and run-off from commercial fertilisers | 57.3 | 49.6 | 39.8 | 36.7 | 32.5 | 37.5 | 33.4 | 32.4 | 31.4 |
| | Leaching and run-off from applied animal manure | 75.1 | 68.6 | 55.0 | 55.7 | 54.9 | 56.2 | 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 | 17.7 | 18.1 | 17.1 | 17.4 |
| | Leaching and run-off from crop residues | 23.4 | 26.4 | 23.3 | 22.9 | 20.2 | 23.5 | 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 | 0.0 |

| Nitrogen Pools and Flows | | 2015 | 2016 | 2017 | 2018 | 2019 | 1990 -2019 |
|---|---|---|---|---|---|---|---|
| | | t N/yr | | | | | % |
| | Animals manure N applied to soils | 307 | 306.6 | 300.0 | 304.6 | 316.8 | -13% |
| | Commercial fertiliser | 200.0 | 180.0 | 188.4 | 204.7 | 192.6 | -31% |
| | Area of agricultural soils (ha) | 5'476 | 5'476 | 5'476 | 5'476 | 5'476 | 4% |
| | Alpine area (ha) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | - |
| Deposition | Sum volatised N ($NH_3$ and $NO_x$) | 79.4 | 77.4 | 76.1 | 77.9 | 80.2 | -29% |
| | $NH_3$ emissions from commercial fertilisers | 9.7 | 7.8 | 8.2 | 8.9 | 8.4 | -50% |
| | $NH_3$ emissions from applied animal manure | 61.7 | 61.7 | 60.1 | 61.0 | 63.6 | -29% |
| | $NH_3$ emissions from pasture, range and paddock | 4.68 | 4.73 | 4.54 | 4.63 | 4.86 | 94% |
| | $NH_3$ emissions from agricultural soils | 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 | -31% |
| | $NO_x$ emissions from applied animal manure | 1.69 | 1.69 | 1.65 | 1.68 | 1.74 | -13% |
| | $NO_x$ emissions from PR&P | 0.52 | 0.53 | 0.51 | 0.52 | 0.54 | 83% |
| Leaching and run-off | Sum leaching and run-off | 128.0 | 124.6 | 124.6 | 128.7 | 129.7 | -22% |
| | Leaching and run-off from commercial fertilisers | 35.7 | 32.1 | 33.6 | 36.5 | 34.4 | -40% |
| | Leaching and run-off from applied animal manure | 54.8 | 54.7 | 53.5 | 54.3 | 56.5 | -25% |
| | Leaching and run-off from pasture, range and paddock | 17.0 | 17.2 | 16.5 | 16.8 | 17.5 | 59% |
| | Leaching and run-off from crop residues | 20.5 | 20.6 | 21.0 | 21.0 | 21.3 | -9% |
| | Leaching and run-off from mineralisation of SOM | 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.

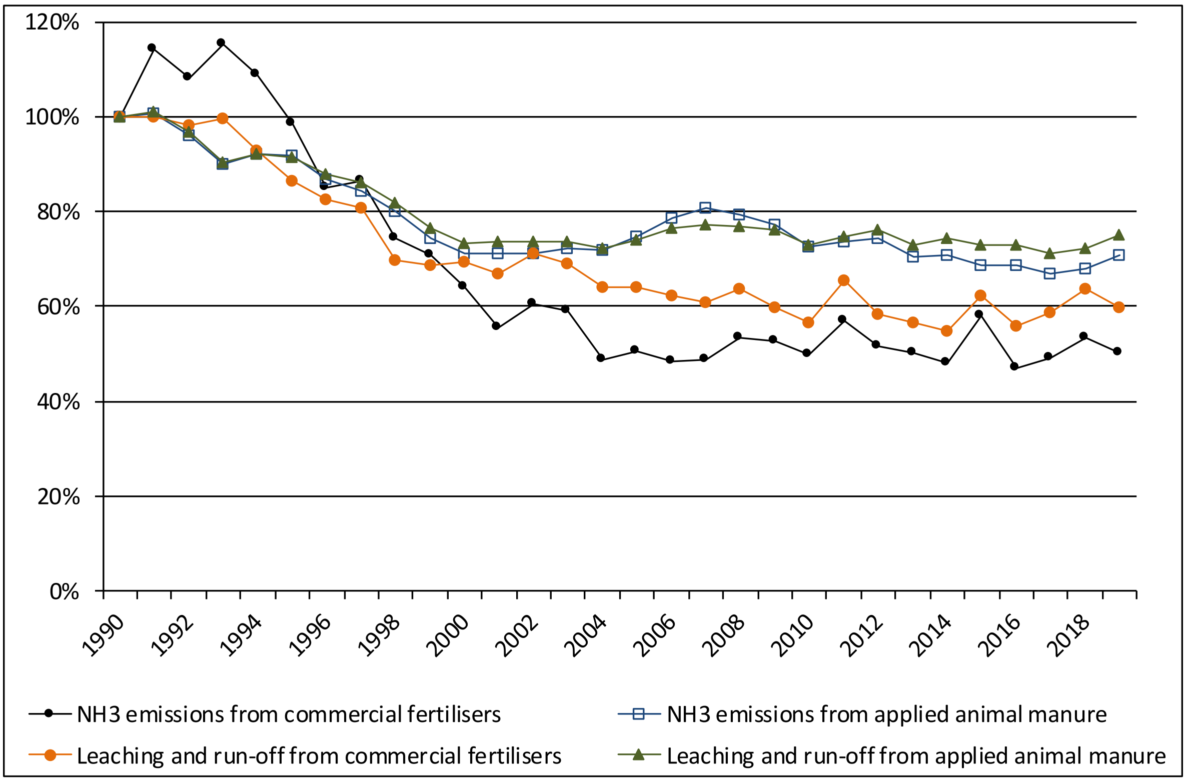



Figure 5-9 Relative development of the most important activity data for source category 3Db indirect $N_2O$ emissions from managed soils.

### 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. 1.6.1.

Table 5-23 Approach 1 uncertainties for 3D Agricultural soils in 2019. 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 | 16.6 | 94.7 | 96.2 |
| 3D2 Indirect soil emissions | Atmospheric deposition | 41.8 | 240.0 | 243.6 |
| | Leaching and run-off | 22.2 | 163.3 | 164.8 |
| | 3D2 aggregate | 29.5 | 173.0 | 175.5 |

For further uncertainty results also consult chp. 1.6.

The time series 1990–2019 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 1.2.3 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 2018 as well as an analysis of the increase or decrease of emissions between 2018 and 2019 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 NIR author report their QC activities in a checklist (see Annex 8).

### 5.5.5 Category-specific recalculations

In 2018, the recalculations for 3D lead to a decrease of $N_2O$ emissions by 0.003 kt $CO_2$eq.

- 3D: A minor error in the area of cultivated organic soils was corrected for the entire time series 1990-2018. The area of cultivated organic soils now 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).

### 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 Source category 3E – Prescribed burning of savannas

Burning of savannas does not occur (NO) as this is not an agricultural practice in Liechtenstein.

## 5.7 Source category 3F – Field burning of agricultural residues

Field burning of agricultural residues is not occurring (NO) in Liechtenstein.

## 5.8 Source category 3G – Liming

According to a research of the OE, liming is not occurring (NO) in Liechtenstein (OE 2015b).

# 5.9 Source category 3H – Urea application

## 5.9.1 Source 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 show a generally decreasing trend from 1990 to 2019 and range 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. 1.6.1. 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 NIR chp. 1.2.3. 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 Source category 3I – Other carbon-containing fertilisers

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 <0.00045 kt $CO_2$ in the year 2019 (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)

## 6.1 Overview of LULUCF

### 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 1990-2019 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 1990-2019. The total net emissions of $CO_2$ equivalent vary between -8.67 kt (1991) and 24.73 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 0.43 $CO_2$ 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.

| **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 | 7.22 | 7.41 | 7.60 | 7.78 | 7.96 | 8.14 | 8.32 | 8.88 | 9.43 | 9.99 |
| **Sector 4 LULUCF (total)** | **6.97** | **-8.67** | **2.17** | **-1.08** | **18.04** | **4.73** | **-3.52** | **7.82** | **0.15** | **-0.95** |

| **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 | 10.53 | 11.01 | 11.49 | 11.76 | 12.03 | 12.30 | 12.56 | 12.83 | 13.09 | 13.25 |
| **Sector 4 LULUCF (total)** | **24.52** | **1.60** | **2.52** | **6.52** | **8.70** | **8.76** | **13.55** | **22.61** | **24.73** | **21.79** |

| **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 | 13.40 | 13.46 | 13.51 | 13.57 | 13.63 | 13.68 | 13.73 | 13.39 | 13.06 | 12.72 |
| **Sector 4 LULUCF (total)** | **20.37** | **24.09** | **24.36** | **16.91** | **16.83** | **11.56** | **9.78** | **11.07** | **21.75** | **11.76** |

| **LULUCF** | **Mean** |
|---|---|
| | kt CO2 eq |
| Gain of living biomass in forest | -50.97 |
| Loss of living biomass in forest | 50.70 |
| Land-use change, soil and HWP | 11.26 |
| **Sector 4 LULUCF (total)** | **10.98** |

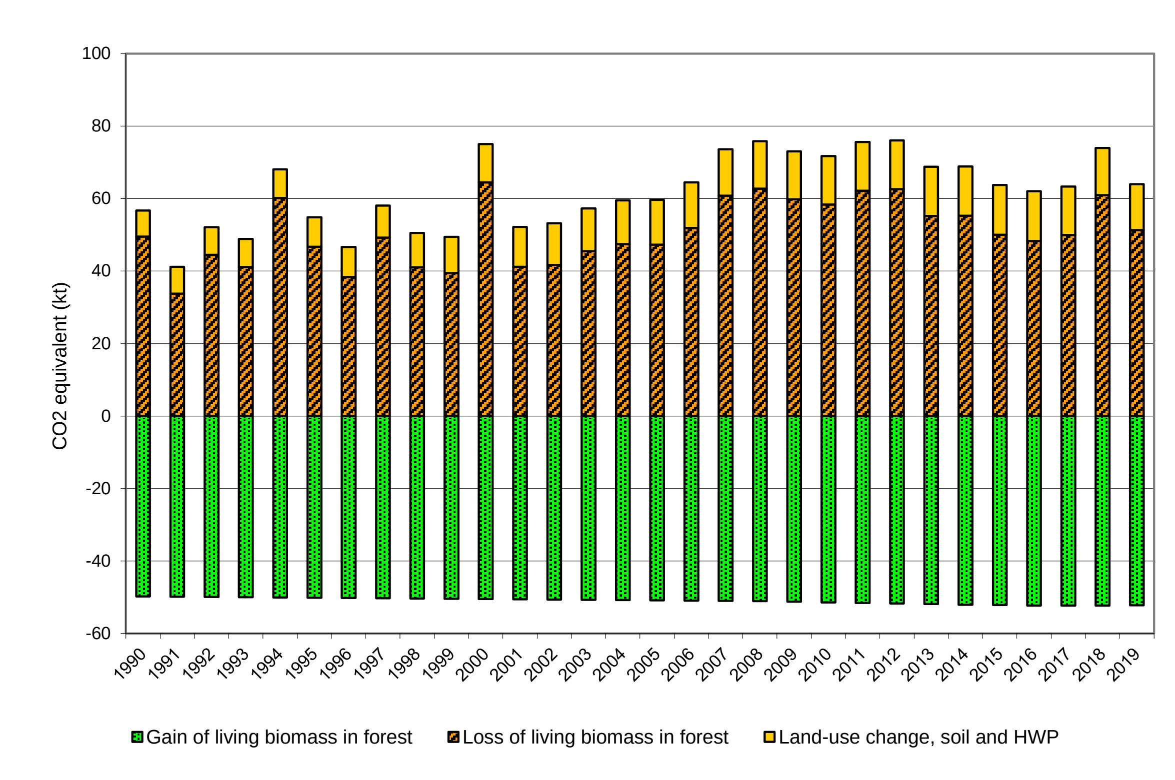



Figure 6-1 Liechtenstein's $CO_2$ removals due to the increase (growth) of living biomass on forest land, the $CO_2$ emissions due to the decrease (harvest and mortality) of living biomass on forest land and the net $CO_2$ equivalent emissions due to land-use changes and from use of soils.

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. 2.3 "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.

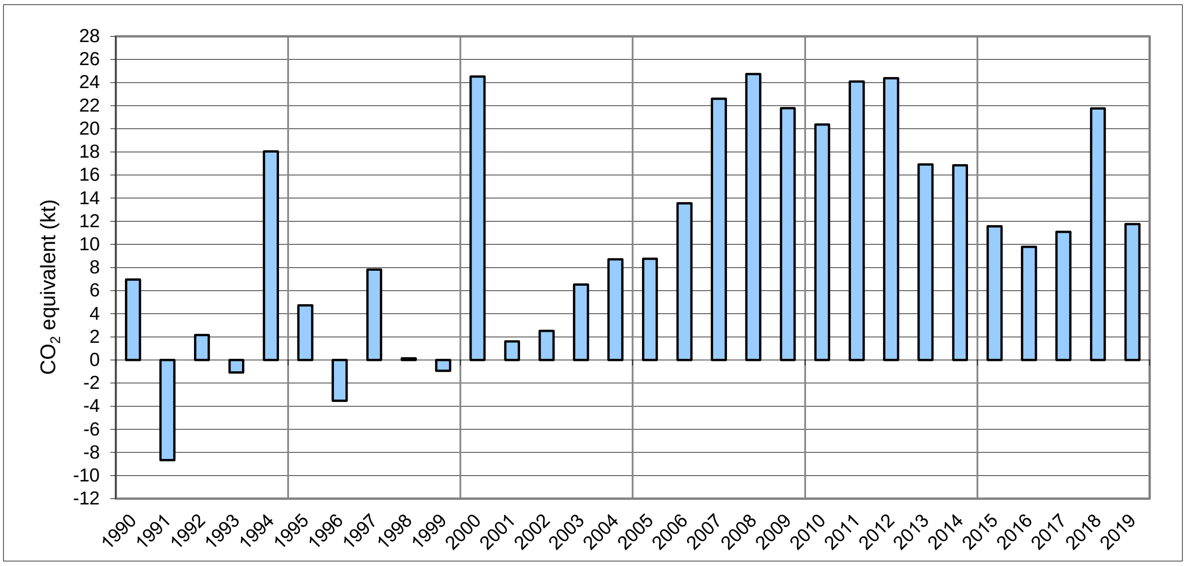



Figure 6-2 Liechtenstein's CO2 emissions/removals of sector 4 LULUCF.

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** | **6.67** | **-8.96** | **1.87** | **-1.38** | **17.75** | **4.43** | **-3.81** | **7.51** | **-0.17** | **-1.28** |
| **A. Forest Land** | **-0.74** | **-16.56** | **-5.91** | **-9.35** | **9.59** | **-3.90** | **-12.32** | **-1.54** | **-9.76** | **-11.42** |
| 1. Forest Land remaining Forest Land | -0.49 | -16.31 | -5.67 | -9.10 | 9.84 | -3.65 | -12.07 | -1.30 | -9.52 | -11.19 |
| 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** | **4.47** | **4.46** | **4.45** | **4.44** | **4.44** | **4.44** | **4.44** |
| 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 | 0.32 | 0.32 |
| **C. Grassland** | **1.97** | **1.96** | **1.95** | **1.94** | **1.93** | **1.93** | **1.92** | **2.14** | **2.36** | **2.58** |
| 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 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.67 | 0.89 | 1.12 |
| **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** | **3.05** | **3.05** | **3.05** | **3.05** | **3.05** | **3.05** | **3.05** | **3.09** | **3.13** | **3.16** |
| 1. Settlements remaining Settlements | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.25 | 0.26 | 0.27 |
| 2. Land converted to Settlements | 2.82 | 2.82 | 2.82 | 2.82 | 2.82 | 2.82 | 2.82 | 2.84 | 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** | **24.17** | **1.24** | **2.15** | **6.15** | **8.31** | **8.37** | **13.15** | **22.21** | **24.32** | **21.38** |
| **A. Forest Land** | **13.50** | **-9.90** | **-9.45** | **-5.71** | **-3.78** | **-3.97** | **0.57** | **9.38** | **11.26** | **8.18** |
| 1. Forest Land remaining Forest Land | 13.73 | -9.67 | -9.23 | -5.50 | -3.58 | -3.79 | 0.75 | 9.55 | 11.42 | 8.33 |
| 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** | **4.39** | **4.37** | **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 | 0.33 | 0.33 | 0.34 | 0.33 | 0.32 | 0.31 | 0.29 | 0.28 | 0.27 | 0.28 |
| **C. Grassland** | **2.80** | **3.03** | **3.25** | **3.37** | **3.49** | **3.61** | **3.73** | **3.85** | **3.96** | **4.00** |
| 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 | 1.34 | 1.57 | 1.80 | 1.94 | 2.09 | 2.24 | 2.38 | 2.53 | 2.67 | 2.72 |
| **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** | **3.28** | **3.29** | **3.30** | **3.31** | **3.31** | **3.32** | **3.32** |
| 1. Settlements remaining Settlements | 0.28 | 0.29 | 0.30 | 0.31 | 0.31 | 0.32 | 0.33 | 0.34 | 0.35 | 0.36 |
| 2. Land converted to Settlements | 2.92 | 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** | **19.95** | **23.67** | **23.94** | **16.49** | **16.41** | **11.13** | **9.35** | **10.65** | **21.34** | **11.36** |
| **A. Forest Land** | **6.63** | **10.30** | **10.53** | **3.04** | **2.92** | **-2.39** | **-4.20** | **-2.55** | **8.47** | **-1.16** |
| 1. Forest Land remaining Forest Land | 6.76 | 10.42 | 10.64 | 3.13 | 2.99 | -2.33 | -4.15 | -2.51 | 8.51 | -1.13 |
| 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** | **4.31** | **4.31** | **4.31** | **4.31** | **4.32** | **4.31** | **4.29** | **4.28** | **4.26** | **4.25** |
| 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 | 0.28 | 0.28 | 0.29 | 0.29 | 0.29 | 0.29 | 0.30 | 0.29 | 0.29 | 0.29 |
| **C. Grassland** | **4.03** | **4.06** | **4.09** | **4.12** | **4.15** | **4.18** | **4.21** | **4.02** | **3.82** | **3.63** |
| 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 | 2.76 | 2.80 | 2.84 | 2.89 | 2.93 | 2.97 | 3.01 | 2.82 | 2.64 | 2.46 |
| **D. Wetlands** | **0.34** | **0.36** | **0.37** | **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 | 0.37 | 0.39 | 0.41 | 0.42 | 0.44 | 0.43 | 0.42 | 0.42 |
| **E. Settlements** | **3.31** | **3.31** | **3.31** | **3.30** | **3.30** | **3.29** | **3.29** | **3.25** | **3.21** | **3.17** |
| 1. Settlements remaining Settlements | 0.37 | 0.38 | 0.39 | 0.40 | 0.41 | 0.42 | 0.44 | 0.44 | 0.44 | 0.44 |
| 2. Land converted to Settlements | 2.95 | 2.93 | 2.92 | 2.90 | 2.89 | 2.87 | 2.86 | 2.81 | 2.77 | 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** |

## 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 2019). 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 (delta$C_l$), in dead organic matter (delta$C_d$) and in soil (delta$C_s$) 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, unproductive grassland, surface waters, unproductive wetland and other land (rocks, sand, glaciers).

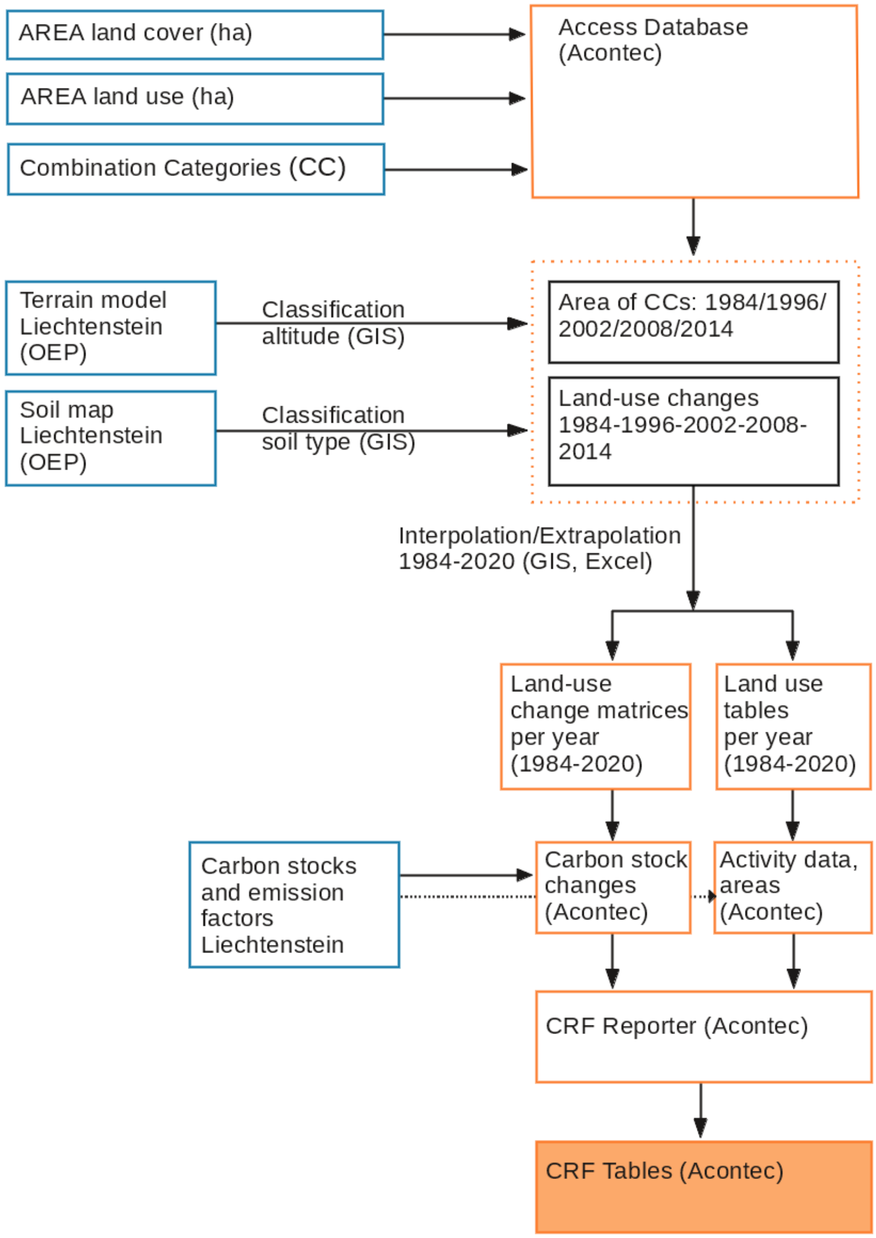



Figure 6-3 Procedure of calculating emissions and removals from LULUCF in Liechtenstein.

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 (2020).

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 (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 (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 (deltaCl), in dead organic matter (deltaCd) and in soil (deltaCs) 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 1990-2019 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 1990-2019, except the cells highlighted in orange. (see main text). Values in coloured cells were recalculated in Submission 2021.

| land-use code CC | altitude zone z | carbon stock in living biomass (stockCl,i) 1990 | 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 | 0.0536 | -0.037 | 0 | NO |
| | 2 | 121.94 | 8.96 | 16.29 | 75.91 | NO | 2.77 | -2.83 | 0.0536 | -0.037 | 0 | NO |
| | 3 | 122.18 | 11.01 | 26.21 | 95.78 | NO | 2.27 | -2.32 | 0.0094 | -0.043 | 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 | 6.81 | 0 | 0 | 50.45 | 240.00 | 0 | 0 | 0 | 0 | 0 | -9.52 |
| 31 Permanent Grassland | 1 | 5.63 | 0 | 0 | 58.74 | 240.00 | 0 | 0 | 0 | 0 | 0 | -9.52 |
| | 2 | 5.27 | 0 | 0 | 63.99 | 240.00 | 0 | 0 | 0 | 0 | 0 | -9.52 |
| | 3 | 3.30 | 0 | 0 | 63.91 | 240.00 | 0 | 0 | 0 | 0 | 0 | -9.52 |
| 32 Shrub Vegetation | 1 | 20.45 | 0 | 0 | 58.74 | NO | 0 | 0 | 0 | 0 | 0 | NO |
| | 2 | 20.45 | 0 | 0 | 63.99 | NO | 0 | 0 | 0 | 0 | 0 | NO |
| | 3 | 20.45 | 0 | 0 | 63.91 | NO | 0 | 0 | 0 | 0 | 0 | NO |
| 33 Vineyards et al. | all | 5.57 | 0 | 0 | 50.58 | 240.00 | 0 | 0 | 0 | 0 | 0 | -9.52 |
| 34 Copse | 1 | 20.45 | 0 | 0 | 58.74 | NO | 0 | 0 | 0 | 0 | 0 | NO |
| | 2 | 20.45 | 0 | 0 | 63.99 | NO | 0 | 0 | 0 | 0 | 0 | NO |
| | 3 | 20.45 | 0 | 0 | 63.91 | NO | 0 | 0 | 0 | 0 | 0 | NO |
| 35 Orchards | all | 23.34 | 0 | 0 | 59.79 | 240.00 | 0 | 0 | 0 | 0 | 0 | -9.52 |
| 36 Stony Grassland | all | 7.16 | 0 | 0 | 22.36 | NO | 0 | 0 | 0 | 0 | 0 | NO |
| 37 Unproductive Grassland | all | 3.45 | 0 | 0 | 63.69 | 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 | 62.86 | 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 | 50.58 | NO | 0 | 0 | 0 | 0 | 0 | NO |
| 53 Shrubs in Settlements | all | 15.43 | 0 | 0 | 50.58 | NO | 0 | 0 | 0 | 0 | 0 | NO |
| 54 Trees in Settlements | all | 20.72 | 0 | 0 | 50.58 | 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 240 t C ha$^{-1}$ for stock Cs was assumed for all land-use categories that occur on organic soils (FOEN 2020, based on Leifeld et al. 2003, 2005). 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. 6.3.3); 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 | 43.3 | |
| 4C1 | Grassland remaining Grassland | $CO_2$ | 6.0 | 55.0 | 55.3 | |
| 4C2 | Land converted to Grassland | $CO_2$ | 13.6 | 57.0 | 58.6 | yes |
| 4D1 | Wetlands remaining Wetlands | $CO_2$ | 10.5 | 50.0 | 51.1 | |
| 4D2 | Land converted to Wetlands | $CO_2$ | 40.9 | 31.8 | 51.8 | |
| 4E1 | Settlements remaining Settlements | $CO_2$ | 6.5 | 34.9 | 35.5 | |
| 4E2 | Land converted to Settlements | $CO_2$ | 19.4 | 33.4 | 38.6 | yes |
| 4F1 | Other Land remaining Other Land | $CO_2$ | NA | NA | NA | |
| 4F2 | Land converted to Other Land | $CO_2$ | 40.9 | 34.1 | 53.3 | yes |
| 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 | 57.0 | 75.8 | yes |

## 6.2 Land-use definitions and classification systems

### 6.2.1 Combination Categories (CC) as derived from 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 sparly (see Table 6-7). Anyway, comparability with the Swiss GHGI is improved by using identical CC definitions.

Table 6-6 Relation between the land-use (NOLU04) and land-cover (NOLC04) categories of the AREA survey and the derived combination categories (CC).

**18 Combination Categories (CC)**

Land Use (NOLU04) acc. to AREA — Settlement and urban areas: Building areas; Transport surfaces

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **10 Artificial areas** | | | | | | | | | | | | | |
| 11 Sealed surfaces | 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 |
| 13 Greenhouses | 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 |
| 15 Lawns | 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 |
| 17 Mix of small structures | 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 |
| **30 Brush vegetation** | | | | | | | | | | | | | |
| 31 Shrub | 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 |
| 33 Short-stem fruit trees | 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 | |
| 35 Permanent garden plants and brush crops | 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 | | |
| 42 Forest edges | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | | 54 | | |
| 43 Forest strips | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | | 54 | | |
| 44 Open forest | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | | 54 | | |
| 45 Brush forest | | | | | | | | | | | | | |
| 46 Linear woods | 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 |
| **50 Bare land** | | | | | | | | | | | | | |
| 51 Solid rock | 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 |
| 53 Rocky areas | 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 |
| 62 Glacier, perpetual snow | | | | | | | | | | | | | |
| 63 Wetlands | 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 |

Land Use (NOLU04) acc. to AREA — Settlement and urban areas: Special urban areas; Recreational areas and cemeteries

| Land Cover (NOLC04) acc. to AREA | 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 |
| 12 Buildings | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 |
| 13 Greenhouses | | | | | | 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 |
| 15 Lawns | 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 |
| 17 Mix of small structures | 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 |
| **30 Brush vegetation** | | | | | | | | | | | | | |
| 31 Shrub | 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 |
| 33 Short-stem fruit trees | | | | | | | 53 | 53 | | | | 53 | 53 |
| 34 Vines | | | | | | | 53 | 53 | | | | 53 | 53 |
| 35 Permanent garden plants and brush crops | | | | | | | 52 | 52 | | | | 52 | 52 |
| **40 Tree vegetation** | | | | | | | | | | | | | |
| 41 Closed forest | | | | | | | 54 | 54 | 54 | | 54 | 54 | 54 |
| 42 Forest edges | 54 | 54 | 54 | | | | 54 | 54 | 54 | 54 | 54 | 54 | 54 |
| 43 Forest strips | 54 | 54 | 54 | | | | 54 | 54 | 54 | | 54 | 54 | 54 |
| 44 Open forest | 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 |
| 47 Clusters of trees | 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 |
| 52 Granular soil | 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 |
| **60 Watery areas** | | | | | | | | | | | | | |
| 61 Water | 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 |
| 64 Reedy marshes | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 | 42 |

Land Use (NOLU04) acc. to AREA — Agricultural areas: Orchards, vineyards, horticulture; Arable and grassland; Alpine grazing areas

| 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 |
|---|---|---|---|---|---|---|---|---|---|
| **10 Artificial areas** | | | | | | | | | |
| 11 Sealed surfaces | | 51 | 51 | | | | | | |
| 12 Buildings | | | | | | | | | |
| 13 Greenhouses | | | 21 | | | | | | |
| 14 Gardens with border and patch structures | | 21 | 21 | 21 | 21 | | 21 | | |
| 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 |
| **30 Brush vegetation** | | | | | | | | | |
| 31 Shrub | | 32 | 32 | | | | | | |
| 32 Brush meadows | | 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 | | | | | | |
| **40 Tree vegetation** | | | | | | | | | |
| 41 Closed forest | 35 | | | | | | | | |
| 42 Forest edges | 35 | | | | | | | | |
| 43 Forest strips | 35 | | | | | | | | |
| 44 Open forest | 35 | | | | 12 | 12 | 12 | 12 | 13 |
| 45 Brush forest | | | | | | | | | |
| 46 Linear woods | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 |
| 47 Clusters of trees | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 13 | 34 |
| **50 Bare land** | | | | | | | | | |
| 51 Solid rock | | | | | | | | | |
| 52 Granular soil | | 61 | 61 | | | | | | |
| 53 Rocky areas | | 36 | 36 | | | 36 | 36 | 36 | |
| **60 Watery areas** | | | | | | | | | |
| 61 Water | | | | | | | | | |
| 62 Glacier, perpetual snow | | | | | | | | | |
| 63 Wetlands | | | | | 42 | 42 | 42 | 42 | 42 |
| 64 Reedy marshes | | | | 21 | 42 | 42 | 42 | 42 | 42 |

Land Use (NOLU04) acc. to AREA — Forest areas: Forest (not used for agriculture); Unproductive areas: Lakes and rivers; Unproductive land

| Land Cover (NOLC04) acc. to AREA | 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 |
| 12 Buildings | | | | | | | | | | | |
| 13 Greenhouses | | | | | | | | | | | |
| 14 Gardens with border and patch structures | 12 | | | | | | | | | | |
| 15 Lawns | | | | | | | | | | | |
| 16 Trees in artificial areas | | | | | | | | | | | |
| 17 Mix of small structures | | | | | | | | | | | |
| **20 Grass and herb vegetation** | | | | | | | | | | | |
| 21 Grass and herb vegetation | | 11 | 12 | 12 | 37 | 37 | 37 | 37 | 37 | 37 | 31 |
| **30 Brush vegetation** | | | | | | | | | | | |
| 31 Shrub | | 11 | 12 | 12 | 32 | 32 | 32 | 32 | 32 | 32 | 32 |
| 32 Brush meadows | | 11 | 12 | 12 | 32 | 32 | 32 | 32 | 32 | 32 | 32 |
| 33 Short-stem fruit trees | | | | | | | | | | | |
| 34 Vines | | | | | | | | | | | |
| 35 Permanent garden plants and brush crops | 12 | | | | | | | | | | |
| **40 Tree vegetation** | | | | | | | | | | | |
| 41 Closed forest | 12 | 11 | | | | | 12 | | 12 | | |
| 42 Forest edges | 12 | 11 | 12 | 12 | | | 12 | | 12 | | |
| 43 Forest strips | 12 | 11 | | | | | 12 | | 12 | | |
| 44 Open forest | 12 | 11 | 12 | 12 | | | 12 | | 12 | 12 | 12 |
| 45 Brush forest | 13 | | | | | | 13 | | 13 | | |
| 46 Linear woods | | 11 | 12 | 12 | 34 | 34 | 34 | 34 | 34 | 34 | 34 |
| 47 Clusters of trees | | 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 | | | 12 | 12 | 61 | 61 | 61 | 61 | 61 | 61 | 61 |
| 53 Rocky areas | | 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 | | | 12 | 13 | 42 | 42 | 42 | 42 | 42 | 42 | 42 |
| 64 Reedy marshes | | | | | 42 | 42 | 42 | 42 | | | |

Combination Categories (CC):

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | Afforestations | 31 | Permanent grassland | 34 | Copse | 41 | Surface waters | 51 | Buildings and construction | 61 | Other land |
| 12 | Productive forest | 32 | Shrub vegetation | 35 | Orchards | 42 | Unproductive wetland | 52 | Herbaceous biomass in settlements | | |
| 13 | Unproductive forest | 33 | Vineyards, Low-stem Orchards, Tree nurseries | 36 | Stony grassland | | | 53 | Shrubs in settlements | | |
| 21 | Cropland | | | 37 | Unproductive grassland | | | 54 | Trees in settlements | | |

### 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.

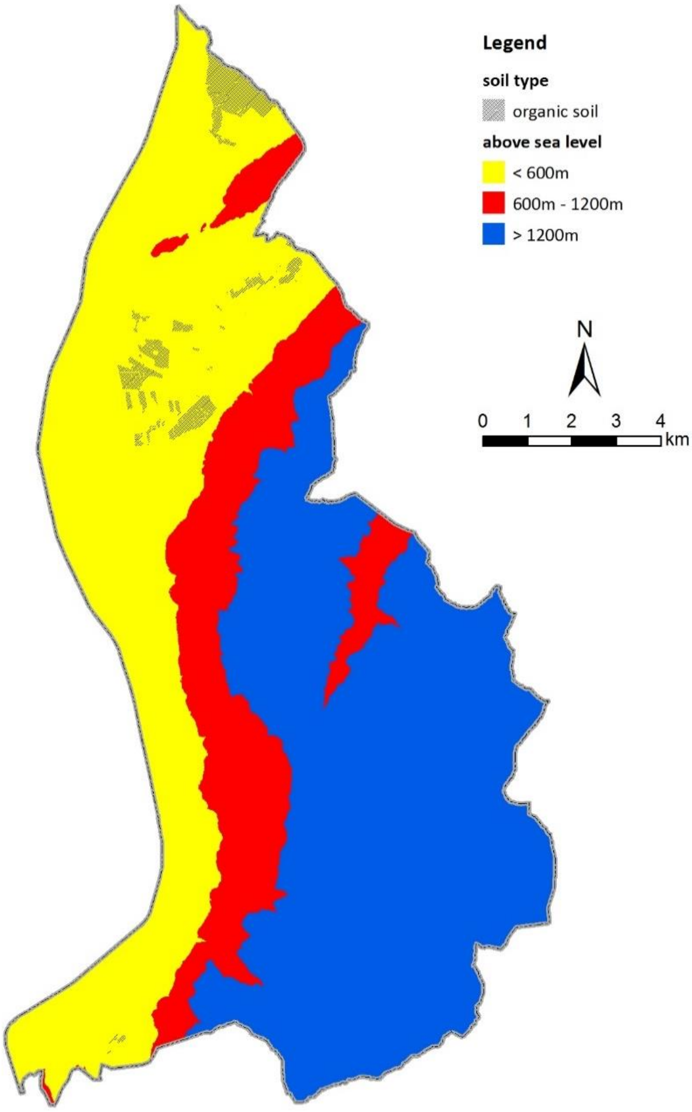



Figure 6-4 Map of Liechtenstein showing the altitude classes and soil types. Reference: OEP 2006d.

### 6.2.3 The land-use tables and change matrices (activity data)

Table 6-7 shows the trends of land-use changes at the level of the disaggregated land-use categories (CC). The data is resulting from interpolation and extrapolation in time and from spatial stratification (altitude classes and soil types). For example, the areas of afforestation (CC11) decrease in all altitude classes between 68% and 100% from 1990 to 2019, 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 304 ha, mineral and organic soils), grassland CC31-CC37 (decrease by 373 ha) and settlements CC51-CC54 (increase by 468 ha).

Table 6-7 Statistics of land use (CC = combination categories) for the period 1990-2018 (in ha) and change between 1990 and 2019. (n.s. = no stratification)

| CC | altitude | soil type | 1990 | 2000 | 2010 | 2015 | 2016 | 2017 | 2018 | 2019 | Change 1990-2019 (ha) | Change 1990-2019 (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | ≤ 600 | n.s. | 9 | 7 | 1 | 1 | 1 | 1 | 1 | 1 | -8 | -88% |
| | 601-1200 | n.s. | 7 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | -7 | -100% |
| | > 1200 | n.s. | 26 | 16 | 11 | 10 | 9 | 9 | 9 | 8 | -18 | -68% |
| 12 | ≤ 600 | n.s. | 966 | 967 | 958 | 948 | 946 | 944 | 942 | 940 | -25 | -3% |
| | 601-1200 | n.s. | 1970 | 1967 | 1961 | 1963 | 1962 | 1962 | 1961 | 1961 | -9 | 0% |
| | > 1200 | n.s. | 2171 | 2220 | 2269 | 2340 | 2354 | 2369 | 2383 | 2397 | 226 | 10% |
| 13 | ≤ 600 | n.s. | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -100% |
| | 601-1200 | n.s. | 9 | 10 | 8 | 3 | 2 | 2 | 1 | 1 | -8 | -94% |
| | > 1200 | n.s. | 880 | 919 | 943 | 954 | 957 | 959 | 961 | 964 | 84 | 10% |
| 21 | n.s. | mineral | 1826 | 1771 | 1634 | 1575 | 1564 | 1552 | 1540 | 1529 | -297 | -16% |
| | n.s. | organic | 127 | 124 | 120 | 120 | 120 | 120 | 120 | 120 | -7 | -5% |
| 31 | ≤ 600 | mineral | 1131 | 1076 | 1118 | 1143 | 1148 | 1153 | 1158 | 1163 | 32 | 3% |
| | ≤ 600 | organic | 64 | 61 | 64 | 63 | 63 | 63 | 62 | 62 | -1 | -2% |
| | 601-1200 | mineral | 364 | 347 | 342 | 337 | 336 | 335 | 334 | 333 | -30 | -8% |
| | 601-1200 | organic | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | > 1200 | mineral | 1668 | 1647 | 1629 | 1623 | 1622 | 1621 | 1619 | 1618 | -49 | -3% |
| | > 1200 | organic | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 32 | ≤ 600 | n.s. | 20 | 23 | 27 | 28 | 29 | 29 | 29 | 30 | 10 | 48% |
| | 601-1200 | n.s. | 10 | 9 | 12 | 13 | 13 | 14 | 14 | 14 | 4 | 46% |
| | > 1200 | n.s. | 563 | 514 | 500 | 456 | 447 | 439 | 430 | 421 | -142 | -25% |
| 33 | n.s. | mineral | 31 | 33 | 34 | 37 | 37 | 38 | 38 | 39 | 8 | 26% |
| | n.s. | organic | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 34 | ≤ 600 | n.s. | 382 | 347 | 302 | 286 | 282 | 279 | 276 | 272 | -109 | -29% |
| | 601-1200 | n.s. | 81 | 74 | 75 | 76 | 76 | 77 | 77 | 77 | -4 | -5% |
| | > 1200 | n.s. | 255 | 252 | 237 | 223 | 221 | 218 | 215 | 213 | -42 | -17% |
| 35 | n.s. | mineral | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | -100% |
| | n.s. | organic | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 36 | n.s. | n.s. | 347 | 345 | 337 | 331 | 330 | 329 | 327 | 326 | -20 | -6% |
| 37 | n.s. | n.s. | 399 | 382 | 368 | 369 | 370 | 370 | 370 | 371 | -28 | -7% |
| 41 | n.s. | n.s. | 203 | 208 | 207 | 207 | 207 | 207 | 207 | 207 | 5 | 2% |
| 42 | n.s. | n.s. | 160 | 162 | 164 | 169 | 170 | 171 | 172 | 173 | 13 | 8% |
| 51 | n.s. | n.s. | 904 | 1044 | 1185 | 1246 | 1259 | 1271 | 1283 | 1296 | 392 | 43% |
| 52 | n.s. | n.s. | 305 | 327 | 374 | 383 | 385 | 387 | 388 | 390 | 86 | 28% |
| 53 | n.s. | n.s. | 15 | 16 | 19 | 15 | 15 | 14 | 13 | 13 | -2 | -16% |
| 54 | n.s. | n.s. | 144 | 158 | 139 | 138 | 137 | 137 | 137 | 136 | -7 | -5% |
| 61 | n.s. | n.s. | 1027 | 1026 | 1016 | 997 | 993 | 990 | 986 | 982 | -45 | -4% |
| **Sum** | | | 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 are equal to the total increase of one specific category. The totals of the rows are equal to 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 1990-2019.

Table 6-8 Land-use change in 2010 (change matrix). Units: ha/year.

| | main category | CC | To: Forest Land 11 | 12 | 13 | Cropl. 21 | Grassland 31 | 32 | 33 | 34 | 35 | 36 | 37 | Wetlands 41 | 42 | Settlement 51 | 52 | 53 | 54 | Other L. 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 Approaches used for representing land areas and land-use databases

## 6.3.1 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 1990-2018 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).

### 6.3.2 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 and 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.

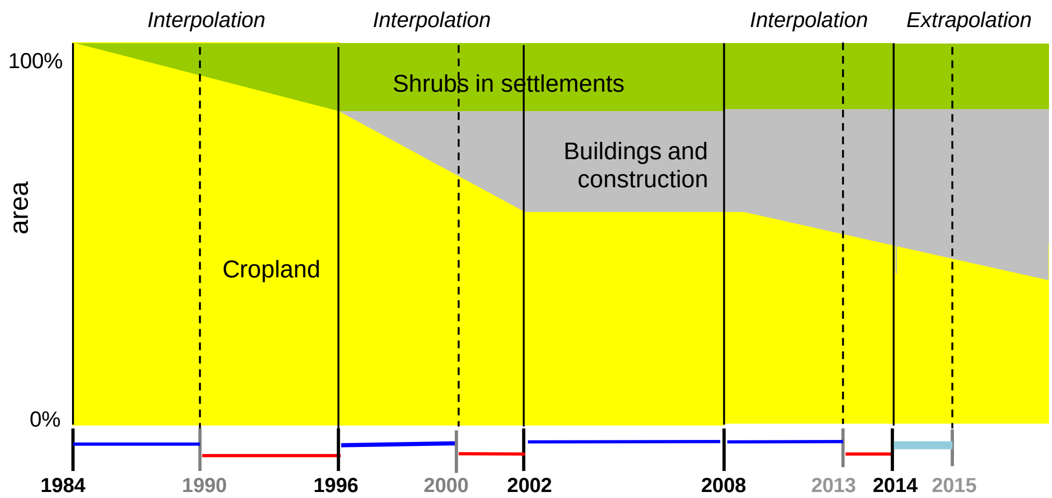



Figure 6-5 Hypothetical linear development of land-use changes between the five Land-usesurveys (1984, 1996, 2002, 2008, 2014) with the example of areas changing 1984-1996 from “cropland” to “shrubs in settlements” and then 1996-2002 and again 2008-2014 to “buildings and constructions". The dotted lines 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 1990-2018 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).

### 6.3.3 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 $U_{sampling}$ 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.

### 6.3.4 QA/QC and verification of activity data

The general QA/QC measures are described in Chapter 1.2.3.

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.

### 6.3.5 Recalculations of activity data

There were no recalculations of AREA data.

### 6.3.6 Planned improvements for activity data

An update of the AREA survey is planned; results are expected to be available in summer 2022.

# 6.4 Source Category 4A – Forest Land

## 6.4.1 Source category description

**Key category information 4A1 and 4A2**

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 3.9% between 1990 and 2019. The annual net $CO_2$ emissions/removals are in the range -16.56 kt $CO_2$ (1991) to 13.50 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. 6.2. 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 2019.

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 most recent results of the 4$^{th}$ 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 (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 $ha^{-1}$), assuming wood densities of 0.40 and 0.55 t $m^{-3}$ for coniferous and deciduous trees, respectively (see Thürig and Schmid 2008). Table 6-12 shows those previously used BCEFs for coniferous and deciduous species stratified for altitude.

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 $ha^{-1}$), assuming wood densities of 0.40 and 0.55 t $m^{-3}$ for coniferous and deciduous trees, respectively (see Thürig and Schmid 2008). Table 6-12 shows those 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) | | Region 3 (Pre-Alps) | | |
|---|---|---|---|---|
| | Units | 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 stratfied 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 NIRs.

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 1986-2019 and the annual harvesting relative to the reference period of the NFI (1999-2010). Source: OE 2020b.

| 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 |
| Mean 1999-2010 | 20'714 | |

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 1990-2019 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 |

### 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 (seeTable 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 2020, Chapter 6.4.2.8). 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 (2020) 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 2020).

| 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 (seeTable 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 2020) 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 (2020), 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 2019) 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.
- 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 CP2 (2013-2019):

- Deadwood: 0.054 t C $ha^{-1}yr^{-1}$ below 1200 m altitude, 0.009 t C $ha^{-1}yr^{-1}$ above 1200 m altitude
- Litter: -0.037 t C $ha^{-1}yr^{-1}$ below 1200 m altitude, -0.043 t C $ha^{-1}yr^{-1}$ above 1200 m altitude

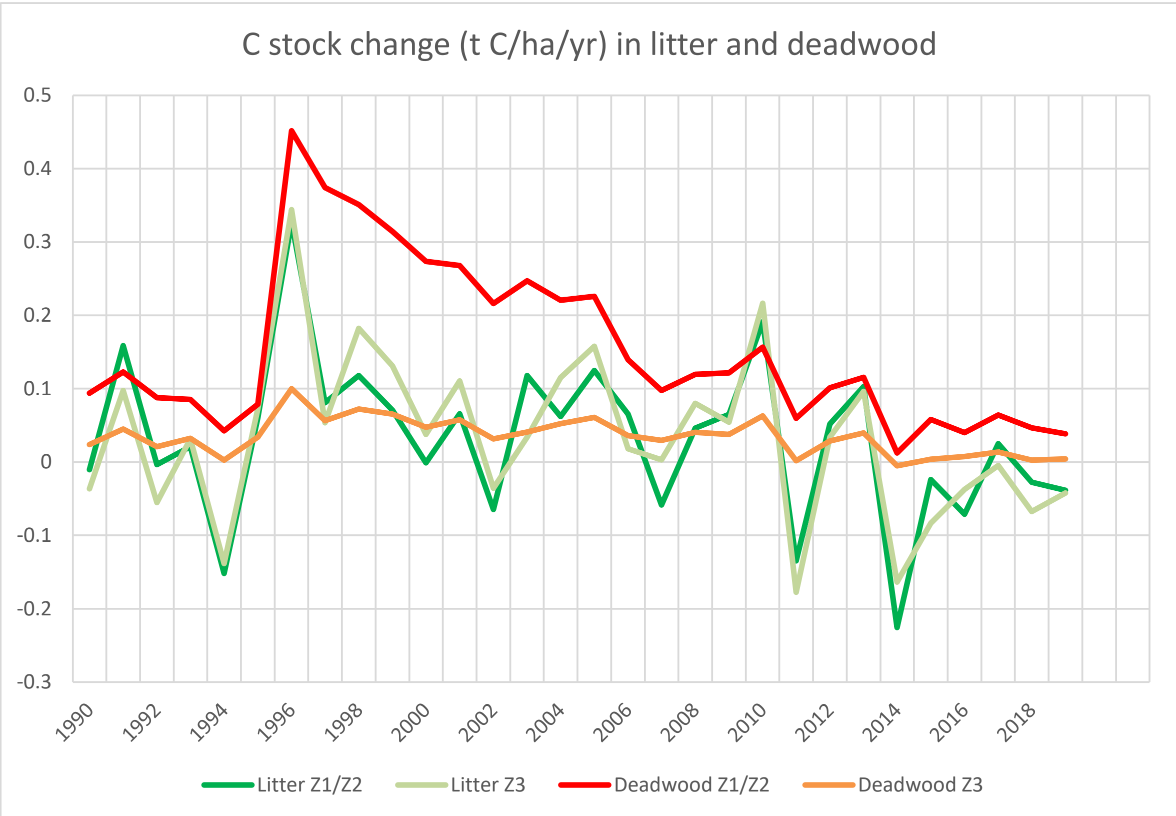



Figure 6-6 Carbon stock changes in deadwood and litter modelled with Yasso for different elevation zones (Z1/Z2: ≤1'200m, 3: >1'200 m) in the NFI-region 3. Data source: FOEN 2021.

### 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 2020):

*"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 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 (2020), 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 2019 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 2020) 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. Therefore, a net increase in SOC is reported under KP-LULUCF (see chp. 11.3.1.1 Afforestations). In sector 4A2 however, those sinks are not reported (see chp. 6.1.3.2, factor $W_S$).

### 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 1985 as confirmed by Summer (2020). 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. 6.3.3.

The EF uncertainty for categories 4A1 and 4A2 was estimated to 46.7%. This value was adopted from Switzerland (FOEN 2020) 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 Table4.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 1.2.3 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2018 and for the changing rates 2018/2019).

The LULUCF expert, the NIC and the NIR author report their QC activities in a checklist (see Annex 8).

### 6.4.5 Category-specific recalculations

- 4A, 1990-2018: BCEFs for living biomass and deadwood were updated with data from the 4$^{th}$ Swiss NFI (2017) replacing the previous values originating from the 2$^{nd}$ NFI (2008). See chp. 6.4.2.2.
- 4A, 1990-2018: In former submissions, a Tier 1 approach was applied for the pools of deadwood and litter (assuming no carbon stock change). It was replaced by a Tier 2 approach using average carbon stock changes modelled with Yasso07 in Switzerland for the CP2 (2013-2019). See chp. 6.4.2.5.
- 4A, 2018: A calculation error was corrected in the harvesting data of the year 2018 and the corresponding loss of living biomass was recalculated.

### 6.4.6 Category-specific planned improvements

No category-specific improvements are planned.

# 6.5 Source Category 4B – Cropland

## 6.5.1 Source category description

| **Key category information 4B1** |
| --- |
| $CO_2$ emissions from 4B1 Cropland remaining Cropland is a key source by level. |

10.3% 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 2018 by 15.6%.

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. Carbon stocks are taken from Switzerland (FOEN 2020) as shown in Table 6-4. Details are described in the following paragraphs.

**a) Carbon in living biomass**

When cropland remains cropland, the carbon stocks in living biomass of crops are assumed to be constant. Thus, there is no net change in carbon storage. The carbon stock value given in Table 6-4 (6.81 t C $ha^{-1}$) represents the average 1990-2018 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 2020).

**b) Carbon in soils**

The Swiss mean carbon stocks for cropland on mineral soils in altitude zone 1 (50.45 t C $ha^{-1}$) was applied. It represents the average 1990-2018 of Swiss crops calculated with the model RothC (FOEN 2020, Wüst-Galley et al. 2019).

For cultivated, drained organic soils 240 ± 48 t C $ha^{-1}$ were applied in Liechtenstein. This value is based on studies from Leifeld et al. (2003) and Leifeld et al. (2005).

**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 are assumed to be zero for cropland remaining cropland.

### 6.5.2.2 Land converted to Cropland (4B2)

The activity data collection follows the methods described in chapter 6.3. Carbon factors are displayed in the following paragraphs.

#### a) Carbon in living biomass

When a conversion of a land to cropland occurs, the stock-difference approach is applied for living biomass.

#### 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.

#### 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 A7.2 for 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 NIR authors considering the scale and quality of the soil map produced by Büchel et al. (2006). As shown in Table 6-5 and A7.2, 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 A7.2).

For the current submission, a simplified uncertainty analysis has been carried out as described in chp. 1.6.1. 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 1.2.3 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2017 and for the changing rates 2017/2018).

The LULUCF expert, the NIC and the NIR author report their QC activities in a checklist (see Annex 8). No additional category-specific QA/QC activities have been carried out.

### 6.5.5 Category-specific recalculations

- 4B, 1990-2018: The carbon stocks in biomass and mineral soils were updated with input from the latest Swiss NIR, including results from the soil model RothC (FOEN 2020).

### 6.5.6 Category-specific planned improvements

No category-specific improvements are planned.

## 6.6 Source Category 4C – Grassland

### 6.6.1 Source category description

**Key category information 4C1 and 4C2**

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.

30.8% 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 7.0% in 2019 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 (‘Niederstammobst’) 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 Chapter 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 chapter 6.2.2. Carbon stocks are taken from Switzerland (FOEN 2020) 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 (corresponding to those used in source category 4A - Forest Land).

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 2020). Root biomass was estimated based on allometric function as described in Wüst-Galley et al. (2019).

### Shrub Vegetation (CC32) and Copse (CC34)

Swiss values for living biomass in shrub vegetation and copse were applied (FOEN 2020). 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 2020). Cl of vineyards is 5.44 t C $ha^{-1}$, Cl of low-stem orchards is 12.25 t C $ha^{-1}$. For tree nurseries no stand densities are available. The weighted mean carbon stock of this combination category is 5.57 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 2020). The total biomass stock of this combination category is 23.34 t C $ha^{-1}$ including woody biomass (17.78 t C $ha^{-1}$) and the grass layer (5.56 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 2020). 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 2020).

**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 2020). They represent the average 1990-2018 of Swiss permanent grassland calculated with the model RothC (FOEN 2020, Wüst-Galley et al. 2019). 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 inTable 6-4.

The mean soil organic carbon stock (0-30 cm) for organic soils is (240 ± 48) t C $ha^{-1}$. This value is based on studies from Leifeld et al. (2003) and Leifeld et al. (2005).

**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 1990–2018) was taken: 50.58 t C $ha^{-1}$ (0–30 cm) (see FOEN 2020).

The mean soil organic carbon stock (0-30 cm) for organic soils is (240 ± 48) t C $ha^{-1}$. This value is based on studies from Leifeld et al. (2003) and Leifeld et al. (2005).

**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 1990–2018 was taken, weighted with the area of CC35 per elevation zone: 59.79 t C $ha^{-1}$ (0–30 cm).

The mean soil organic carbon stock (0-30 cm) for organic soils is (240 ± 48) t C $ha^{-1}$. This value is based on studies from Leifeld et al. (2003) and Leifeld et al. (2005).

**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:

$$Cs(CC36) = 0.35 * Cs(\text{permanent grassland} > 1200\text{ m}) = 22.36\text{ t C ha}^{-1}$$

**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 1990–2018, weighted with the area of CC37 per elevation zone: 63.69 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 are assumed to be zero for grassland remaining in the same combination category (CC).

### 6.6.2.2 Land converted to Grassland (4C2)

The activity data collection follows the methods described in chapter 6.2.2.

**a) Carbon in biomass**

When a conversion of a land to grassland occurs, the stock-difference approach is applied for living and dead biomass. The carbon stocks in living biomass and in soil are reported in detail under "Grassland remaining grassland" 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.

**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 A7.2 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 NIR authors considering the scale and quality of the soil map produced by Büchel et al. (2006). As shown in Annex A7.2, 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 55.0% for the sum of the pools in organic and mineral soils of category 4C1 (Annex A7.2).

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 0.338 t C $ha^{-1}$ $yr^{-1}$.
- Mineral soils: Carbon stock change in mineral soils are assumed to have a mean uncertainty of 50.0%. Therefore, 0.21 t C $ha^{-1}$ $yr^{-1}$ was used as absolute uncertainty for 4C2.
- 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 2018 (OE 2020) is 0.063 t C $ha^{-1}$ $yr^{-1}$ (related to the total area of 4C2) as shown in Annex A7.2.

The root sum squares of those three absolute uncertainties are 0.380 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 2018 (OE 2020), the mean net carbon stock changes were -0.67 t C $ha^{-1}$ for 4C2 (calculated from CRF Table4.C of OE 2020). The resulting relative EF-uncertainty is 57.0% 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 2020, Chapter 6.4.3)
- Biomass expansion functions: 21.2% (see FOEN 2020, Chapter 6.4.3)
- Sampling uncertainty: 22.2% (FOEN 2020, 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 1.2.3 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2018 and for the changing rates 2018/2019).

The LULUCF expert, the NIC and the NIR author report their QC activities in a checklist (see Annex 8). No additional category-specific QA/QC activities have been carried out.

### 6.6.5 Category-specific recalculations

- 4C, 1990-2018: The carbon stocks in biomass and mineral soils were updated with input from the latest Swiss NIR, including results from the soil model RothC (FOEN 2020).

### 6.6.6 Category-specific planned improvements

No further category-specific improvements are planned.

# 6.7 Source Category 4D – Wetlands

## 6.7.1 Source category description

**Key category information 4D**

Source categories 4D1 "Wetlands remaining Wetlands" and 4D2 "Land converted to Wetlands" are not key categories.

2.4% 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. Carbon stocks are taken from Switzerland (FOEN 2020). 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 1990–2018 of CC31 (see chp. 6.6.2.3) were calculated and weighted with the area per altitude zone of CC42: 62.86 t C $ha^{-1}$ (0–30 cm) as proposed in FOEN 2020.

**c) $N_2O$ 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 6.2. 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 as described in chp. 6.1.3.

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 A7.2). The resulting relative EF uncertainty for 4D2 is 31.8% (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. 1.6.1. 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 1.2.3 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2018 and for the changing rates 2018/2019).

The LULUCF expert, the NIC and the NIR author report their QC activities in a checklist (see Annex 8). No additional category-specific QA/QC activities have been carried out.

### 6.7.5 Category-specific recalculations

- 4D, 1990-2018: The carbon stocks in mineral soils of CC42 were updated with input from the latest Swiss NIR (FOEN 2020).

### 6.7.6 Category-specific planned improvements

No category-specific improvements are planned.

## 6.8 Source Category 4E – Settlements

### 6.8.1 Source category description

**Key category information 4E2**

$CO_2$ emissions from 4E2 "Land converted to Settlements" are a key category by level. Category 4E1 "Settlements remaining Settlements" is not a key category.

11.4% of Liechtenstein's total surface are settlements. Between 1990 and 2019, 468 hectares were converted to settlements, which is an increase of 34.3%. 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 6.2.2. Carbon stocks are taken from Switzerland. As structure and density of Liechtenstein's settlements are very similar to the settlements in Switzerland (FOEN 2020), 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 stock in soil for CC 52, 53 and 54 is 50.58 t C $ha^{-1}$ (0-30 cm). This value corresponds to soil carbon stocks in mineral soils under cropland and was calculated as the area-weighted (across the three altitude zones) mean for 1990–2018.

### 6.8.2.2 Land converted to Settlements (4E2)

The activity data collection follows the methods described in chapter 6.2.2.

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. 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 A7.2).

Thus, the uncertainty of the area (AD) is determined by the uncertainty of the AREA survey (4E1 6.5%, 4E2 19.4% from Table 6-9).

In accordance with the Swiss National Inventory Report (FOEN 2020) 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 34.9% and 33.4%, respectively (see Table 6-5 and Annex A7.2).

For the current submission, a simplified uncertainty analysis has been carried out as described in chp. 1.6.1. 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 1.2.3 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2018 and for the changing rates 2018/2019).

The LULUCF expert, the NIC and the NIR author report their QC activities in a checklist (see Annex 8). No additional category-specific QA/QC activities have been carried out.

### 6.8.5 Category-specific recalculations

- 4E, 1990-2018: The carbon stocks in mineral soils of CC52-53 were updated with input from the latest Swiss NIR (FOEN 2020).

### 6.8.6 Category-specific planned improvements

No category-specific improvements are planned.

## 6.9 Source Category 4F – Other Land

### 6.9.1 Source category description

**Key category information 4F2**

Category 4F2 "Land converted to Other Land" $CO_2$ is a key category by trend.

6.1% of Liechtenstein's total surface are summarized in "Other Land". Between 1990 and 2019 the area of "Other Land" has declined by 4.4%. 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, the net changes in biomass and soil are calculated by the stock-difference approach as described in chp. 6.1.3.

### 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 wetlands. 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% (see Annex A7.2). The resulting relative EF uncertainty for 4F2 is 34.1% (see Table 6-5).

The AD uncertainty (40.9%) for 4F2 comes from the AREA survey as shown in Table 6-9.

The dominant process determining the uncertainty of category 4F2 is the carbon loss by loss of mineral soils. Thus, the uncertainty of the area (AD) is determined by the uncertainty of the AREA survey (40.9% from Table 6-9). For the EF ($CO_2$) it is 50% according to the Swiss National Inventory Report (FOEN 2020).

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 1.2.3 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2018 and for the changing rates 2018/2019).

The LULUCF expert, the NIC and the NIR author report their QC activities in a checklist (see Annex 8). 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 Categories 4(III), 4(IV) – $N_2O$ from nitrogen mineralization

### 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. 1.6.1. 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 1.2.3.

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 Source Category 4G – Harvested Wood Products (HWP)

### 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 as described in chp. 12, Volume 4 of IPCC (2006). The changes in 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.

The estimate uses the product categories, half-lives, and methodologies as described in IPCC (2006) and IPCC (2014).

### 6.11.2 Methodological issues

The same methodology is used for the reporting under UNFCCC and the accounting under KP. It is based on Decision 2/CMP.7, paragraph 29, namely, that "transparent and verifiable activity data for harvested wood products categories are available, and accounting is based on the change in the harvested wood products pool of the second commitment period, estimated using the first-order decay function".

For the estimation of carbon stocks and carbon stock change, the equations described in IPCC (2014) and IPPC 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:

- Emissions occurring during the second commitment period from HWPs removed from forests prior to the start of the second commitment period were also accounted for. 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 2020) 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 Management, as there is practically no harvest in Afforestations in Liechtenstein (here also KP-definitions are referred to as defined in chp. 11).
- 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 2020) 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:

$$V_{1961} = V_{swiss,1961} * Population_{1961} / Population_{swiss,1961} = 3'671 \text{ m}^3$$

where:

$V_{swiss,1961}$ = 1'181'000 m$^3$ (FOEN 2020)
$Population_{1961}$ = 16'894 in Liechtenstein (http://databank.worldbank.org/data)
$Population_{swiss,1961}$ = 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:

- Today, 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 from land under Forest Management (4G under UNFCCC; Art. 3.4 under KP) between 2000 and 2019, in kt $CO_2$. HWPs originating from wood harvested at land converted from forest land to non-forest land (UNFCCC) or from Deforestations (KP) are not taken into account.

| **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** |

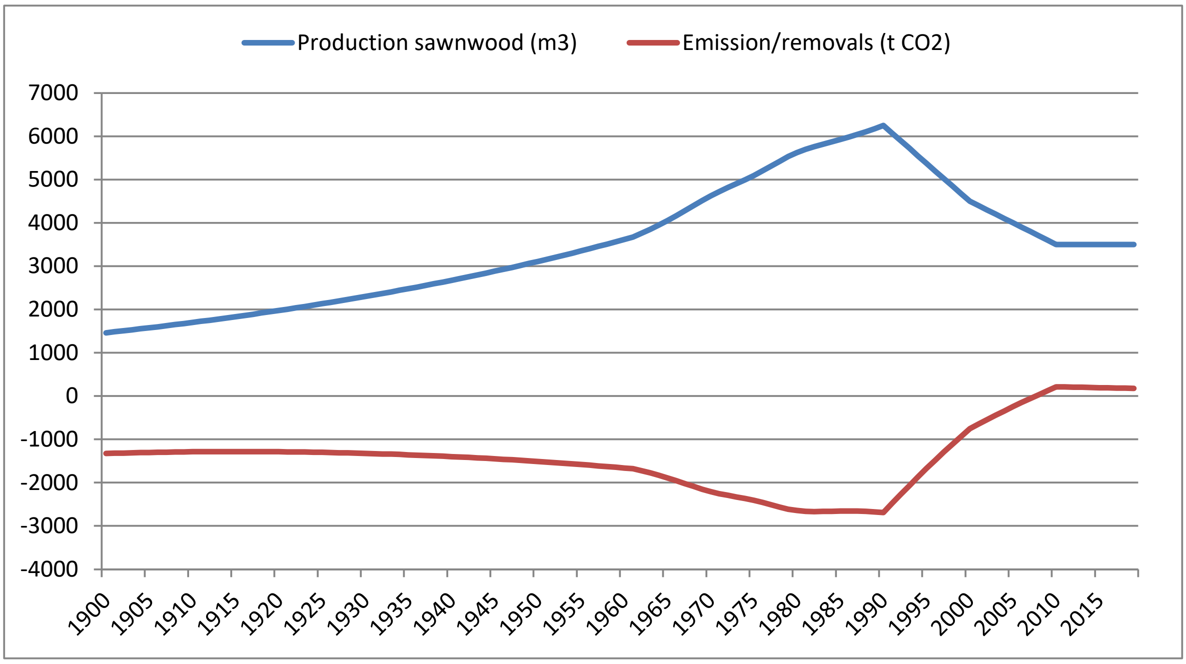



Figure 6-7 Liechtenstein's sawnwood production ($m^3$) and net emissions (positive sign) and removals (negative sign) of $CO_2$ (tons) from Harvested Wood Products between 1900 and 2019 originating from forest land (UNFCCC) or land under Forest Management (KP).

Import and export of sawnwood from 1990 to 2019 are reported in CRF Table4.Gs2. They were estimated on the basis of Swiss import and export data published in the Swiss NIR

(FOEN 2020) as Liechtenstein lacks own customs statistics (Customs Union with Switzerland, see chp. 1.2.1). Imports were calculated as a fraction of 0.045 (ratio of Liechtenstein's and Switzerland's population in 2016) of Swiss sawnwood imports.

Exports of sawnwood were calculated as fraction of 0.045 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).

### 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 judgment.)
- Emission factor, including conversion factors:
  - Wood density: 25% (default from IPCC 2006);
  - 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:

$$U_{HWP}EmissionFactor = \sqrt{25\%^2 + 10\%^2 + 50\%^2} = 57\%$$

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 1.2.3 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2018 and for the changing rates 2018/2019).

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

## 7.1 Overview GHG Emissions

Within the waste sector, emissions from four source 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

Source category 5E Other is not occurring in Liechtenstein.

Figure 7-1 depicts Liechtenstein's greenhouse gas emissions in sector 5 Waste between 1990 and 2019 according to the four source 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 - 2019.

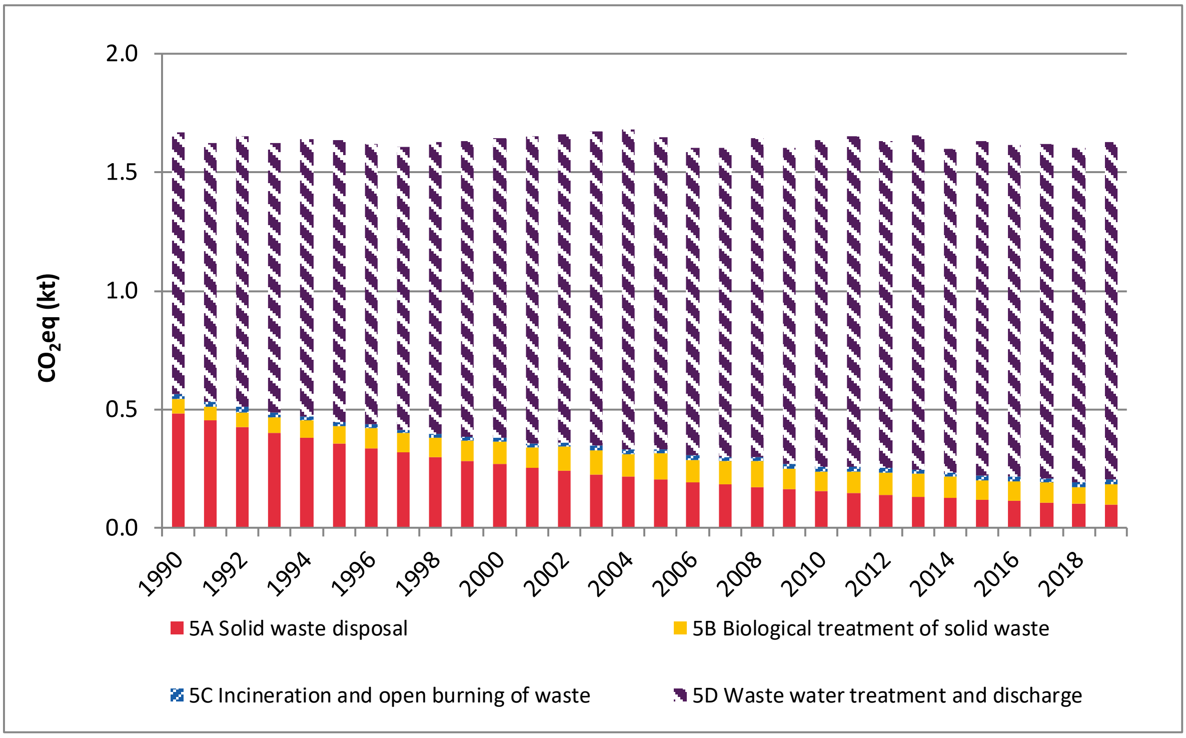



Figure 7-1 Liechtenstein's GHG emissions of sector 5 Waste. Note that there are no emissions in source category 5E Other.

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 |
| $CH_4$ | 1.11 | 1.06 | 1.06 | 1.06 | 0.96 |
| $N_2O$ | 0.54 | 0.57 | 0.58 | 0.58 | 0.66 |
| **Sum** | **1.67** | **1.64** | **1.65** | **1.65** | **1.64** |

| Gas | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|
| | CO2 equivalent (kt) | | | | |
| $CO_2$ | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| $CH_4$ | 0.96 | 0.96 | 0.98 | 0.94 | 0.94 |
| $N_2O$ | 0.69 | 0.66 | 0.67 | 0.65 | 0.68 |
| **Sum** | **1.65** | **1.63** | **1.66** | **1.60** | **1.63** |

| Gas | 2016 | 2017 | 2018 | 2019 | 1990-2019 |
|---|---|---|---|---|---|
| | CO2 equivalent (kt) | | | | % |
| $CO_2$ | 0.01 | 0.01 | 0.01 | 0.01 | -28% |
| $CH_4$ | 0.94 | 0.95 | 0.93 | 0.94 | -16% |
| $N_2O$ | 0.67 | 0.66 | 0.66 | 0.68 | 25% |
| **Sum** | **1.62** | **1.62** | **1.60** | **1.63** | -2% |

In sector 5 Waste a total of 1.63 kt $CO_2$ equivalents of greenhouse gases were emitted in 2019. 5.9% of the total emissions origin from 5A Solid waste disposal, 5.4% from 5B Biological treatment of solid waste, 1.1% from 5C Incineration and open burning of waste and 87.6% 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 2019 by -2.4%. The development of the greenhouse gas emissions is determined by source category 5D Wastewater treatment and discharge and to a lesser extend by source category 5A Solid waste disposal. In source 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 source category 5A Solid waste disposal a steady decrease of greenhouse gas emissions can be observed, due to cease landfilling in 1974.

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 | 814.01 Bundesgesetz über den Umweltschutz (Umweltschutzgesetz, USG) vom 7. Oktober 1983 (Stand am 1. Januar 2021) |
| 814.301.1 2008.245 Luftreinhalteverordnung (LRV) vom 30. September 2008 | 814.318.142.1 Luftreinhalte-Verordnung (LRV) vom 16. Dezember 1985 (Stand am 1. April 2020) |

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 Source Category 5A – Solid waste disposal

### 7.2.1 Source Category Description: Solid waste disposal (5A)

**Key category information 5A**

Source category 5A Solid waste disposal is not a key category.

The source 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 the source 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 incineration plant is reported in the 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 source 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 Liechtensteins conditions.

The following equation is applied to calculate the $CH_4$ generation in the year t:

$$CH_4 \text{ generated in the year t [kt/year]} = \sum_x [A \cdot k \cdot M(x) \cdot L0(x) \cdot e^{-k(t-x)}] \cdot (1-OX)$$

where

| | |
|---|---|
| t = | current year |
| x = | the year of waste input, $x \leq t$ |
| 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 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)

A preliminary uncertainty assessment based on expert judgment results in low confidence in emission estimates.

For the current submission a simplified uncertainty analysis has been carried out as described in chapter 1.6.1. 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 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 1.2.3 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2019 and for the changing rates 2018/2019).

### 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)

No category-specific improvements are planned.

## 7.3 Source Category 5B – Biological treatment of solid waste

### 7.3.1 Source category description: Biological treatment of solid waste (5B)

| **Key category information 5B** |
| --- |
| Source category 5B Biological treatment of solid waste is not a key category. |

Source 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 plantsas 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 source category 5B Biological treatment of solid waste.

| 5B | Source | Specification |
|---|---|---|
| | Composting | Emissions from composting of organic waste<br>- centralized composting plants<br>- 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 2020/5B1 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 2020): 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 2020/5B1 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 2020c).

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 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 probabely 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 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Composted centrally | kt dm/a | 1.07 | 0.92 | 0.99 | 0.99 | 1.24 | 1.12 | 1.41 | 1.29 | 1.25 | 1.34 |

| Waste composting | | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Composted centrally | kt dm/a | 1.56 | 1.27 | 1.65 | 1.65 | 1.60 | 1.98 | 1.63 | 1.79 | 2.06 | 1.58 |

| Waste composting | | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Composted centrally | kt dm/a | 1.55 | 1.79 | 1.93 | 1.94 | 1.81 | 1.60 | 1.67 | 1.67 | 1.35 | 1.76 |

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 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| organic waste | kg wet/inhabitant | 16.2 | 17.4 | 18.7 | 20.0 | 21.3 | 21.9 | 22.5 | 23.2 | 23.8 | 24.4 |
| Population | inhabitants | 29'032 | 29'386 | 29'868 | 30'310 | 30'629 | 30'923 | 31'143 | 31'320 | 32'015 | 32'426 |
| Composted backyard | kt dm/a | 0.47 | 0.51 | 0.56 | 0.61 | 0.65 | 0.68 | 0.70 | 0.73 | 0.76 | 0.79 |

| Waste composting | | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Backyard composting | kg wet/inhabitant | 25.0 | 26.1 | 27.2 | 25.7 | 24.1 | 22.7 | 21.2 | 19.7 | 18.2 | 16.7 |
| Population | inhabitants | 32'863 | 33'525 | 33'863 | 34'294 | 34'600 | 34'905 | 35'168 | 35'356 | 35'589 | 35'894 |
| Composted backyard | kt dm/a | 0.82 | 0.87 | 0.92 | 0.88 | 0.84 | 0.79 | 0.74 | 0.70 | 0.65 | 0.60 |

| Waste composting | | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Backyard composting | kg wet/inhabitant | 15.2 | 13.9 | 12.5 | 12.4 | 12.2 | 12.1 | 11.9 | 11.9 | 11.9 | 11.9 |
| Population | inhabitants | 36'149 | 36'475 | 36'838 | 37'129 | 37'366 | 37'623 | 37'810 | 38'114 | 38'380 | 38'749 |
| Composted backyard | kt dm/a | 0.55 | 0.51 | 0.46 | 0.46 | 0.46 | 0.45 | 0.45 | 0.45 | 0.46 | 0.46 |

### 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 1.6.1. 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 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 1.2.3 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2019 and for the changing rates 2018/2019).

### 7.3.5 Category-specific recalculations: Biological treatment of solid waste (5B)

Correction of activity data calculation for centralized composting concerning the conversion from wet matter to dry matter. The whole time series are affected 1990 - 2018.

### 7.3.6 Category-specific Planned Improvements: Biological treatment of solid waste (5B)

A mistake concerning activity data for backyard composting regarding conversion from wet matter to dry matter will be corrected.

## 7.4 Source Category 5C – Incineration and open burning of waste

### 7.4.1 Source Category Description: Incineration and open burning of waste (5C)

| Key category information 5C |
| --- |
| Source 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 source 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.<br>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 2020).

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 2020, EMIS 2020/5C1 Abfallverbrennung illegal). The following table presents the emission factors used in source category 5C2. Emission factors are referring to kg wet matter.

Table 7-10 Emission Factors for 5C Incineration and open burning of waste (FOEN 2020).

| Source | $CO_2$ biogen (kg/t) | $CO_2$ fossil (kg/t) | $CH_4$ (kg/t) | $N_2O$ (kg/t) |
|---|---|---|---|---|
| Illegal waste incineration | 510 | 510 | 6.0 | 0.150 |

### 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 2020c).

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 2020).

Table 7-11 Activity data for source category 5C Incineration and open burning of waste (OS 2020c).

| 5C Open burning of waste | unit | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MSW generated | kt | 10.64 | 10.44 | 10.93 | 10.16 | 6.29 | 6.73 | 6.80 | 7.02 | 7.27 | 7.65 |
| Fraction incinerated illegally | | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% |
| Waste incinerated illegally | kt | 0.053 | 0.052 | 0.055 | 0.051 | 0.031 | 0.034 | 0.034 | 0.035 | 0.036 | 0.038 |
| Fossil share of MSW | | 49.7% | 50.0% | 50.3% | 50.6% | 50.9% | 51.3% | 51.1% | 50.9% | 50.7% | 50.5% |

| 5C Open burning of waste | unit | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MSW generated | kt | 7.79 | 8.00 | 7.90 | 8.01 | 8.12 | 8.04 | 8.27 | 8.34 | 8.46 | 8.56 |
| Fraction incinerated illegally | | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% |
| Waste incinerated illegally | kt | 0.039 | 0.040 | 0.040 | 0.040 | 0.041 | 0.040 | 0.041 | 0.042 | 0.042 | 0.043 |
| Fossil share of MSW | | 50.5% | 50.5% | 50.5% | 50.5% | 50.5% | 50.5% | 50.1% | 49.7% | 49.3% | 48.9% |

| 5C Open burning of waste | unit | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MSW generated | kt | 8.66 | 8.73 | 8.78 | 8.67 | 8.58 | 8.50 | 8.27 | 8.32 | 8.26 | 7.98 |
| Fraction incinerated illegally | | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% | 0.5% |
| Waste incinerated illegally | kt | 0.043 | 0.044 | 0.044 | 0.043 | 0.043 | 0.043 | 0.041 | 0.042 | 0.041 | 0.040 |
| Fossil share of MSW | | 48.6% | 48.2% | 47.8% | 47.8% | 47.8% | 47.8% | 47.8% | 47.8% | 47.8% | 47.8% |

### 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 1.6.1. 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 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 1.2.3 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2019 and for the changing rates 2018/2019).

### 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)

$CO_2$ emission factor for open buring in the Swiss GHG emission calculation was slightly changed. The new emission factor will be verified and adopted in the next submission.

# 7.5 Source Category 5D – Wastewater treatment and discharge

## 7.5.1 Source Category Description: Wastewater treatment and discharge (5D)

| Key category information 5D |
| --- |
| Source category 5D Wastewater treatment and discharge is not a key source. |

Source category 5D1 Domestic wastewater comprises all emissions from handling of liquid wastes and sludge from housing and commercial sources (including gray 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 2020).

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.

Table 7-12 Specification of source 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 up-graded.

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, methan 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 2020/5D1 Wastewater treatment plants).

Table 7-13 $CH_4$ emission factors of source 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 2020).

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 by SVGW (2016).

Table 7-14 Activity data for $CH_4$ emission calculation from sewage gas treatment in 5D Wastewater treatment and discharge (AZV 2020, SFOE 2002, SVGW 2016).

| Sewage gas treatment | | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sewage gas for boilers | TJ | 5.82 | 6.10 | 6.45 | 6.45 | 7.00 | 6.34 | 6.77 | 6.89 | 7.45 | 8.03 |
| Sewage gas for CHP generation | TJ | 6.27 | 6.74 | 7.31 | 7.49 | 8.33 | 7.72 | 8.43 | 8.77 | 9.70 | 10.67 |
| Sewage gas flared | TJ | 2.46 | 2.40 | 2.37 | 2.18 | 2.17 | 1.79 | 1.72 | 1.56 | 1.48 | 1.37 |
| Sewage gas losses | t CH4 | 1.81 | 1.92 | 2.06 | 2.09 | 2.29 | 2.10 | 2.27 | 2.34 | 2.57 | 2.80 |
| Sewage gas for upgrading | t CH4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Sewage gas treatment | | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sewage gas for boilers | TJ | 8.10 | 7.79 | 7.47 | 7.74 | 8.08 | 0.59 | 8.38 | 10.03 | 10.39 | 11.33 |
| Sewage gas for CHP generation | TJ | 11.00 | 10.80 | 10.56 | 11.16 | 11.88 | 18.85 | 12.66 | 12.62 | 12.98 | 10.75 |
| Sewage gas flared | TJ | 1.15 | 0.89 | 0.65 | 0.45 | 0.25 | 0.02 | 0.01 | 0.01 | 0.04 | 0.03 |
| Sewage gas losses | t CH4 | 2.86 | 2.78 | 2.70 | 2.83 | 2.99 | 2.91 | 0.11 | 0.20 | 0.90 | 0.53 |
| Sewage gas for upgrading | t CH4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Sewage gas treatment | | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sewage gas for boilers | TJ | 9.79 | 9.30 | 8.46 | 8.57 | 0.33 | 0.06 | 0.53 | 0.74 | 0.32 | 0.52 |
| Sewage gas for CHP generation | TJ | 10.97 | 11.70 | 12.82 | 11.68 | 0.64 | 0.39 | 1.11 | 1.56 | 1.35 | 0.78 |
| Sewage gas flared | TJ | 0.04 | 0.02 | 0.02 | 0.07 | 0.00 | 0.02 | 0.03 | 0.03 | 0.02 | 0.01 |
| Sewage gas losses | t CH4 | 0.85 | 0.42 | 0.41 | 1.31 | 0.06 | 0.47 | 0.51 | 0.67 | 0.45 | 0.26 |
| Sewage gas for upgrading | t CH4 | 0 | 0 | 0 | 0 | 448 | 457 | 418 | 462 | 482 | 508 |

### 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 genreal 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 7-15.

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 - 2019 are taken from Switzerland (FOEN 2020).

Table 7-15 Activity data for $N_2O$ emission calculation in 5D Wastewater treatment and discharge (OS 2020d, FOEN 2020).

| 5D Wastewater treatment and discharge | | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Population | inhabitants | 29'032 | 29'386 | 29'868 | 30'310 | 30'629 | 30'923 | 31'143 | 31'320 | 32'015 | 32'426 |
| Degree of Utilization | % | 90.0 | 91.0 | 91.5 | 92.0 | 93.0 | 93.5 | 94.0 | 94.5 | 95.0 | 95.3 |
| Protein Consumption | kg/capita/a | 38.1 | 38.3 | 38.3 | 37.4 | 37.5 | 37.1 | 36.8 | 36.9 | 37.0 | 36.5 |

| 5D Wastewater treatment and discharge | | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Population | inhabitants | 32'863 | 33'525 | 33'863 | 34'294 | 34'600 | 34'905 | 35'168 | 35'356 | 35'589 | 35'894 |
| Degree of Utilization | % | 95.4 | 95.7 | 96.0 | 96.3 | 96.6 | 96.8 | 97.0 | 97.0 | 97.0 | 97.0 |
| Protein Consumption | kg/capita/yr | 37.2 | 36.2 | 35.9 | 36.5 | 36.7 | 36.3 | 37.0 | 37.1 | 37.7 | 37.6 |

| 5D Wastewater treatment and discharge | | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Population | inhabitants | 36'149 | 36'475 | 36'838 | 37'129 | 37'366 | 37'623 | 37'810 | 38'114 | 38'380 | 38'749 |
| Degree of Utilization | % | 97.0 | 97.0 | 97.0 | 97.0 | 97.0 | 97.0 | 97.0 | 97.0 | 97.0 | 97.0 |
| Protein Consumption | kg/capita/yr | 38.0 | 38.7 | 36.8 | 37.1 | 36.6 | 37.3 | 36.1 | 36.1 | 36.1 | 36.1 |

## 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 1.6.1. 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 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 1.2.3 including also the triple check of the CRF table Summary2 (detailed comparison of latest with previous data for the base year, for 2019 and for the changing rates 2018/2019).

## 7.5.5 Category-specific recalculations: Wastewater treatment and discharge (5D)

A mistake in the last submission has been corrected. $CH_4$ emission estimation from wastewater sewered to the wastewatertretment plant from 2014 - 2018 was not complete. This leads to an increase of $CH_4$-emissions during this period.

### 7.5.6 Category-specific Planned Improvements: Wastewater treatment and discharge (5D)

5D: There is a mistake in the time series concerning the activity data of sewage gas losses starting from 2006. Possibilities for correcting this mistake were analysed in submission 2021 and the mistake will be corrected in the next submission 2022.

## 7.6 Source Category 5E – Other

No emissions are occurring in Liechtenstein under this source 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

## 10.1 Explanations and justifications for recalculations

### 10.1.1 Recalculations GHG inventory

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).

**1 Energy**

***Recalculation in the Reference Approach***

- Activity data for diesel and gasoline between 1997 and 2018 were updated, since updated shares of biodiesel and bioethanol are available from Switzerland's road transportation model (INFRAS 2020). This leads to a recalculation of $CO_2$, $CH_4$ and $N_2O$ emissions.
- 1AB: The amount of natural gas transported in transit pipelines changed in the statistic of the LGV for the year 2017.

***Recalculation in 1A1***

No category-specific recalculations were carried out.

***Recalculation in 1A2***

The following recalculations lead to a decrease in $CO_2$ emissions by 0.18 kt $CO_2$eq in 2018. Changes in $N_2O$ and $CH_4$ emissions are negligible.

- 1A2g: Activity data for diesel between 1997 and 2018 were updated, since updated shares of biodiesel are available from the Swiss customs statistic, which is applied in Switzerland's road transportation model (INFRAS 2020). This leads to a recalculation of $CO_2$, $CH_4$ and $N_2O$ emissions.

For 1990, there are no recalculations in source category 1A2, which means that there are no changes in emissions from 1A2.

***Recalculation in 1A3***

The following recalculations lead to a decrease in $CO_2$ emissions from 1997-2018. In 2018 a total decrease of 1.2 kt is noted:

- 1A3b: The activity data for biodiesel and bioethanol 1997-2019 were updated, since updated shares of biofuels are available from the Swiss customs statistics, which is applied in Switzerland's road transportation model (INFRAS 2020). This leads to increased shares of biofuels and thus to a decrease in fossil $CO_2$ emissions.

Small changes in $CH_4$ and $N_2O$ emissions occur in the complete time series. $CH_4$ emissions have slightly increased from 1990-1996 and from 2001-2018 and decreased from 1997-2000. $N_2O$ emissions have increased from 1990-2018. For 2018 there is a difference in $CH_4$ and $N_2O$ emissions of 0.0014 kt and 0.0005 kt $CO_{2eq}$, respectively. This is due to the following recalculations:

- 1A3b: In the current submission the latest version of the Handbook Emission Factors for Road Transport (HBEFA 4.1) is used (INFRAS 2019). Hence, $CH_4$ and $N_2O$ emission factors for gasoline and diesel were updated for the complete time series.

***Recalculation in 1A4***

For 2018, the following recalculations lead to a decrease of $CO_2$ emissions by 0.07 kt $CO_2$eq:

- 1A4c: Activity data for diesel between 1997 and 2018 were updated, since updated shares of biodiesel are available from the Swiss customs statistic, which is applied in Switzerland's road transportation model (INFRAS 2020). This leads to a recalculation of $CO_2$, $CH_4$ and $N_2O$ emissions.

For 1990, there are no recalculations in source category 1A4 Other sectors, which means that there are no changes in emissions from 1A4.

***Recalculation in 1B2***

No category-specific recalculations were carried out.

**2 IPPU**

2D: For source category 2D1 no category specific recalculations were carried out.

2F: Switzerland's GHG inventory 2021 was not yet available for Liechtenstein's submission 2020. For Switzerland, the following recalculations have been carried out in submission 2020, which also influence Liechtenstein's emission time series reported in Submission 2021:

- 2F1 mobile air-conditioning: Vehicles statistics for trucks were harmonized with data on the time period 1991 to 2018 provided by SFSO/Astra.
- 2F1 mobile air-conditioning: HFC-134a model calculation have been adapted considering higher service activities and on the other hand no recycling of HFC-134a at the disposal of vehicles (use of filtration equipment for service activities in garages only).
- 2F1 stationary air-conditioning: Split of refrigerants was adapted for stationary air-conditioning and heat pumps with data from the Swiss Registration Office for

Refrigeration Systems and Heat Pumps (SMKW) covering the years 2015–2018. New refrigerants added to the evaluation.

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

- 2F2 Foam blowing agents: Minor recalculations due to an error that occurred in the data preparation. This error will be corrected in Submission 2022 (see IDP Annex A8.3 Nr. 73)
- 2F4 Aerosols: Minor recalculations due to an error that occurred in the data preparation. This error will be corrected in Submission 2022 (see IDP Annex A8.3 Nr. 73)

These recalculations lead to an overall increase in HFC emissions by about 0.25 kt $CO_2$eq in 2018.

2G: In the Swiss GHG inventory, the emission factor of $N_2O$ from 2G3b Use of aerosol cans in households and restaurants has been updated and revised for 2017 and 2003, respectively, based on sales data yielding recalculated EF values for 1990–2010 and 2012-2018. Liechtenstein adopts these emission factors in Submission 2021, which leads to a decrease of 0.07 kt $CO_2$ eq in 2018.

**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: In 2018, the recalculations for 3A lead to an increase of $CH_4$ emissions by around 0.05 kt $CO_2$eq.

- 3A/3B: The animal number of horses < 3 years or the year 2018 (activity data) was corrected from 13 horses to 11 horses due to a change in the statistics.
- 3A/3B: Milk yield for the year 2018 (activity data) was corrected from 7'060 to 7'184 kg/head/year due to a change in the statistics from the Division for Agriculture.

3B: In 2018, the recalculations for 3B lead to an increase of $CH_4$ emissions by 0.01 kt $CO_2$eq. For $N_2O$, the increase amounts to 0.003 kt $CO_2$eq.

- 3B/3A: The animal number of horses < 3 years or the year 2018 (activity data) was corrected from 13 horses to 11 horses due to a change in the statistics.
- 3B/3A: Milk yield for the year 2018 (activity data) was corrected from 7'060 to 7'184 kg/head/year due to a change in the statistics from the Division for Agriculture.

3D: In 2018, the recalculations for 3D lead to a decrease of $N_2O$ emissions by 0.003 kt $CO_2$eq.

- 3D: A minor error in the area of cultivated organic soils was corrected for the entire time series 1990-2018. The area of cultivated organic soils now 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).

3H: No category-specific recalculations were carried out.

**4 LULUCF**

- 4A, 1990-2018: BCEFs for living biomass and deadwood were updated with data from the 4th Swiss NFI (2017) replacing the previous values originating from the 2nd NFI (2008). See chp. 6.4.2.2.
- 4A, 1990-2018: In former submissions, a Tier 1 approach was applied for the pools of deadwood and litter (no carbon stock change). It was replaced by a Tier 2 approach using average carbon stock changes modelled with Yasso07 in Switzerland for the CP2 (2013-2019). See chp. 6.4.2.5.
- 4A, 2018: A calculation error was corrected in the harvesting data of the year 2018 and the corresponding loss of living biomass was recalculated (minus 1%).
- 4B, 1990-2018: The carbon stocks in biomass and mineral soils were updated with input from the latest Swiss NIR, including results from the soil model RothC (FOEN 2020).
- 4C, 1990-2018: The carbon stocks in biomass and mineral soils were updated with input from the latest Swiss NIR, including results from the soil model RothC (FOEN 2020).
- 4D, 1990-2018: The carbon stocks in mineral soils of CC42 were updated with input from the latest Swiss NIR (FOEN 2020).
- 4E, 1990-2018: The carbon stocks in mineral soils of CC52-53 were updated with input from the latest Swiss NIR (FOEN 2020).

**5 Waste**

- 5B: Correction of activity data calculation for centralized composting concerning the conversion from wet matter to dry matter. The whole time series are affected 1990 - 2018.
- 5D: A mistake in the last submission has been corrected. $CH_4$ emission estimation from wastewater sewered to the wastewatertretment plant from 2014 – 2018 was not complete. This leads to an increase of $CH_4$ emissions during this period.

### 10.1.2 Recalculations KP-LULUCF

- Afforestation, 2013-2018: The carbon stock in mineral soils of grassland (CC31) was recalculated (see chp. 6.6.5). This led to slightly higher carbon sinks in mineral soils of afforested areas, which are calculated by a stock-difference approach.
- Deforestation, 2013-2018: The carbon stocks in living biomass and dead wood of forest (CC12) as well the carbon stocks in living biomass and mineral soils of cropland, grassland, wetlands and settlements were recalculated (see chp. 10.1.1 and Table 6-4). This led to slightly higher carbon losses on deforested areas, which are calculated by a stock-difference approach.
- Deforestation, 2013-2018: An error in the calculation of permanent forest losses has been corrected. This led to an increase of deforested areas by approximately 10%. Additional information is given in Table 11-5 (chp. 11.1.3.2).
- Forest Management, 2013-2018: BCEFs for living biomass and deadwood were updated with data from the 4$^{th}$ Swiss NFI (2017) replacing the previous values originating from the 2$^{nd}$ NFI (2008). See chp. 6.4.2.2.
- Forest Management, 2013-2018: In former submissions, a Tier 1 approach was applied for the pools of deadwood and litter (no carbon stock change). It was replaced by a Tier 2 approach using average carbon stock changes modelled with Yasso07 in Switzerland for the CP2 (2013-2019). See chp. 6.4.2.5.
- Forest Management, 2018: A calculation error was corrected in the harvesting data of the year 2018 and the corresponding loss of living biomass was recalculated (minus 1%).

## 10.2 Implications for emission levels 1990 and 2018

### 10.2.1 Implications emission levels for GHG inventory

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 amounts to a total increase of 0.12 kt $CO_2$eq (0.053%) without emissions/removals from LULUCF.
- Including LULUCF, the difference in national total emissions amounts to a total increase of 0.14 kt $CO_2$eq (0.057%).

Table 10-1 Overview of implications of recalculations on 1990 data. Emissions are shown before the recalculation according to the previous submission in 2020 “Prev.” (Submission of April 2020, OE 2020) and after the recalculation according to the present submission 2021 “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 | - | 1.2 | 1.3 | *0.06* | 1.1 | 1.3 | *0.16* | 201.1 | 201.3 | *0.22* |
| 2 IPPU (without F-gases) | 0.2 | 0.2 | - | NO | NO | *NO* | 0.5 | 0.5 | *0.00* | 0.7 | 0.7 | *0.00* |
| 3 Agriculture | 0.1 | 0.1 | - | 16.9 | 16.9 | - | 8.0 | 8.0 | *-0.01* | 24.9 | 24.9 | *-0.01* |
| 4 LULUCF | 6.6 | 6.7 | *0.03* | NO | NO | *NO* | 0.3 | 0.3 | *-0.01* | 7.0 | 7.0 | *0.01* |
| 5 Waste | 0.0 | 0.0 | - | 1.2 | 1.1 | *-0.06* | 0.6 | 0.5 | *-0.04* | 1.8 | 1.7 | *-0.10* |
| Sum (without F-gases) | 205.6 | 205.6 | *0.03* | 19.2 | 19.2 | *-0.00* | 10.5 | 10.6 | *0.11* | 235.3 | 235.5 | *0.14* |

| **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 | - | NO | NO | *NO* | NO | NO | *NO* | 0.0 | 0.0 | - |

| **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** | **235.3** | **235.5** | ***0.14*** |
| | 100.0% | 100.1% | *0.057%* |
| **Total $CO_2$ eq Em. without LULUCF** | **228.4** | **228.5** | ***0.12*** |
| | 100.0% | 100.1% | *0.053%* |

The analogous recalculation results for 2018 are shown in Table 10-2 and have the following effects on emissions:

- The difference in national total emissions amounts to a total decrease of 0.38 kt $CO_2$eq (-0.21%) without emissions/removals from LULUCF.
- Including LULUCF, the difference in national total emissions amounts to an decrease of 0.56 kt $CO_2$eq (-0.28%).

Table 10-2 Overview of implications of recalculations on 2018 data. Emissions are shown before the recalculation according to the previous submission in 2020 “Prev.” (OE 2020) and after the recalculation according to the present submission 2021 “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 2018** | 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 | 143.6 | 142.1 | *-1.44* | 1.6 | 1.7 | *0.04* | 0.9 | 1.0 | *0.14* | 146.1 | 144.8 | *-1.26* |
| 2 IPPU (without F-gases) | 0.1 | 0.1 | - | NO | NO | *NO* | 0.2 | 0.1 | *-0.07* | 0.3 | 0.3 | *-0.07* |
| 3 Agriculture | 0.0 | 0.0 | - | 16.3 | 16.3 | *0.06* | 7.3 | 7.3 | *0.01* | 23.7 | 23.7 | *0.06* |
| 4 LULUCF | 21.5 | 21.3 | *-0.18* | NO | NO | *NO* | 0.4 | 0.4 | *0.00* | 21.9 | 21.7 | *-0.18* |
| 5 Waste | 0.0 | 0.0 | - | 0.2 | 0.9 | *0.69* | 0.7 | 0.7 | *-0.05* | 1.0 | 1.6 | *0.64* |
| Sum (without F-gases) | 165.3 | 163.6 | *-1.63* | 18.2 | 18.9 | *0.78* | 9.5 | 9.6 | *0.04* | 193.0 | 192.2 | *-0.81* |

| **Recalculation** | **HFC** | | | **PFC** | | | **$SF_6$** | | | **Sum (F-gases)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Emissions for 2018** | 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) | 9.9 | 10.2 | *0.25* | 0 | 0 | *-0.01* | 0.1 | 0.1 | *0.00* | 10.0 | 10.3 | *0.24* |

| **Recalculation** | **Sum (all gases)** | | |
|---|---|---|---|
| **Emissions for 2018** | Prev. | Latest | Differ. |
| Source and sink categories | $CO_2$ equivalent (kt) | | |
| **Total $CO_2$ eq Em. with LULUCF** | **203.0** | **202.4** | ***-0.56*** |
| | 100.0% | 99.7% | *-0.28%* |
| **Total $CO_2$ eq Em. without LULUCF** | **181.1** | **180.7** | ***-0.38*** |
| | 100.0% | 99.8% | *-0.21%* |

## 10.2.2 Implications emission levels for KP-LULUCF

Table 10-3 shows the differences in the KP-LULUCF tables on emissions/removals in 2018. There were recalculations for Afforestation, Deforestation and Forest Management.

Table 10-3 Overview of implications of recalculations on 2018 data for KP-LULUCF. Emissions are shown according to the previous submission (OE 2019), and after the recalculation according to the present submission “Latest”.

| Year 2018 | $CO_2$ equivalent (kt) | | |
|---|---|---|---|
| Source and Sink Categories | Previous | Latest | Difference |
| Afforestation | -0.330 | -0.341 | -0.010 |
| Deforestation | 4.445 | 4.629 | 0.184 |
| Forest Management | 11.467 | 10.736 | -0.731 |
| Harvested Wood Products | 0.183 | 0.183 | 0.000 |
| Total emission/removal | 15.765 | 15.207 | -0.557 |

# 10.3 Implications for emissions trends, including time series consistency

## 10.3.1 Implications trends GHG inventory

Due to recalculations, the emission trend 1990–2018 reported in submission 2020 has changed. The emission trend showed a decrease by 20.72% before the recalculations (previous submission, national total without emissions/removals from LULUCF). After the recalculations in the latest submission 2021, the decreasing trend is slightly higher (-20.93%).

Table 10-4 Change of the emission trend 1990–2018 due to recalculations carried out in the latest submission 2021. “Previous” refers to the values from submission 2020 (OE 2020)

| **Recalculation** | **1990** | | **2018** | | **change 1990/2018** | |
|---|---|---|---|---|---|---|
| Submission | previous | latest | previous | latest | previous | latest |
| | $CO_2$ eq (kt) | | | | % | |
| Total excl. LULUCF | 228.39 | 228.51 | 181.08 | 180.69 | -20.72% | -20.93% |

All time series in the present submission are consistent.

## 10.3.2 Implications trends KP-LULUCF

The recalculations shown in Table 10-3 (year 2018) are relevant for trends in KP-LULUCF as the year 2018 is covered by the 2nd CP. The years 2008-2012 are not mandatory and are only reported to improve transparency. Nevertheless, the years 2008-2019 form consistent time series.

# 10.4 Recalculations in response to the review process and planned improvements

## 10.4.1 Recalculations GHG Inventory

The NIR of Liechtenstein’s previous submissions contains the recommendations and encouragements of the ERT in the past review processes up to the review in 2018, showing which recommendations had been implemented.

Planned improvements for future submissions – partly motivated by the ERT review process – are indicated in the corresponding sectoral chapters of this NIR and in Annex A8.3. Improvements implemented in the current submission and recommendations and encouragements, which will not be implemented are documented in the inventory development plan is given in Annex A8.3.

## 10.4.2 Recalculations KP-LULUCF

See Chapter 10.1.2

# PART 2: Supplementary information required under the Kyoto Protocol

Part 2 presents the supplementary information required under the Kyoto Protocol (KP), Article 7, paragraph 1.

## 11. KP – LULUCF

The information in this chapter is provided in accordance with the Good Practice Guidance Arising from the Kyoto Protocol (IPCC 2014) and based on the information given in Liechtenstein’s Initial Report for the second commitment period (Government 2016).

Liechtenstein chose to account over the entire commitment period for emissions and removals from the KP-LULUCF sector (Government 2016). The decision remains fixed for the entire second commitment period. In addition to the mandatory submission of the inventory years 2013-2019, data for the years 2008-2012 are available and shown in Liechtenstein's NIR. Liechtenstein accounts for the mandatory activity Forest Management under Article 3, paragraph 4 of the Kyoto Protocol.

Table 11-1 (CRF Table NIR-1) shows the activity coverage and the carbon pools reported for the activities under Article 3, paragraph 3 and Forest Management under paragraph 4 of the Kyoto Protocol. The area and area changes between the previous and the current inventory year are shown in Table 11-2 (CRF Table NIR-2). Table 11-3 (NIR-3) presents KP key categories. Table 11-4 is an overview of results related to KP in 2019.

Table 11-1 The table contains information of country-specific activities under Articles 3.3 and 3.4 (KP(LULUCF) NIR 1)

**TABLE NIR 1. SUMMARY TABLE**

**Activity coverage and other information relating to activities under Article 3, paragraph 3, forest management under Article 3.4, and elected activities under Article 3.4**

| Activity | CHANGE IN CARBON POOL REPORTED[1] | | | | | | | GREENHOUSE GAS SOURCES REPORTED[2] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Above-ground biomass | Below-ground biomass | Litter | Dead wood | Soil | | HWP[4] | Fertilization[5] | Drained, rewetted and other soils[6] | | Nitrogen mineralization in mineral soils[8] | Indirect $N_2O$ emissions from managed soil[5] | Biomass burning[9] | | |
| | | | | | Mineral | Organic[3] | | $N_2O$ | CH4[7] | $N_2O$ | $N_2O$ | $N_2O$ | $CO_2$[10] | $CH_4$ | $N_2O$ |
| **Article 3.3 activities** | | | | | | | | | | | | | | | |
| **Afforestation and reforestation** | R | R | NR | NR | R | NO | NO | NO | NO | NO | NO | NO | NO | NO | NO |
| **Deforestation** | R | R | R | R | R | NO | IO | NO | NO | NO | R | NO | NO | NO | NO |
| **Article 3.4 activities** | | | | | | | | | | | | | | | |
| **Forest management** | R | R | R | R | NR | NO | R | NO | NO | NO | NO | NO | NO | NO | NO |
| **Cropland management** | NA | NA | NA | NA | NA | NA | | | NA | | NA | | NA | NA | NA |
| **Grazing land management** | NA | NA | NA | NA | NA | NA | | | NA | | NA | | NA | NA | NA |
| **Revegetation** | NA | NA | NA | NA | NA | NA | | NA | NA | NA | NA | NA | NA | NA | NA |
| **Wetland drainage and rewetting** | NA | NA | NA | NA | | NA | | NA | NA | NA | | NA | NA | NA | NA |

[1] Indicate R (reported), NR (not reported), IE (included elsewhere) or NO (not occurring), for each relevant activity under Article 3.3, forest management or any elected activity under Article 3.4, or instantaneous oxidation (IO) for carbon stock changes in harvest wood products (HWP). With the exception of HWP, if changes in a carbon pool are not reported , verifiable information in the national inventory report (NIR) must be provided that demonstrates that these unaccounted pools were not a net source of anthropogenic greenhouse gas emissions. Indicate NA (not applicable) for each activity that is not elected under Article 3.4. Explanation about the use of notation keys should be provided in the NIR.

[2] Indicate R (reported), NE (not estimated), IE (included elsewhere) or NO (not occurring) for greenhouse gas sources reported, for each relevant activity under Article 3.3, forest management or any elected activity under Article 3.4. Indicate NA (not applicable) for each activity that is not elected under Article 3.4. Explanation about the use of notation keys should be provided in the NIR.

[3] Includes $CO_2$ emissions/removals from organic soils, including $CO_2$ emissions from dissolved organic carbon associated with drainage and rewetting. On-site $CO_2$ emissions/removals from drainage and rewetting from organic soils and off-site $CO_2$ emissions via water-borne carbon losses from organic soils should be reported here for wetland drainage and rewetting. These emissions could be reported for other activities as appropriate.

[4] HWP from lands reported under deforestation, which originated from the deforestation event at the time of the land-use change shall be accounted for on the basis of instantaneous oxidation (IO).

[5] $N_2O$ emissions from fertilization of afforestation/reforestation, deforestation, forest management, revegetation and wetland drainage and rewetting should be reported here when these emissions are not reported under the agriculture sector.

[6] $CH_4$ and $N_2O$ emissions from drained and rewetted organic soils should be reported here, as appropriate, when emissions are not reported under the agriculture sector. For wetland drainage and rewetting only emissions from organic soils are included.

[7] $CH_4$ emissions from drained soils and drainage ditches should be reported here, as appropriate.

[8] $N_2O$ emissions from nitrogen mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils under afforestation/reforestation, deforestation, forest management, cropland management, grazing land management and revegetation should be reported here when these emissions are not reported under the agriculture sector.

[9] Emissions from burning of organic soils should also be included here, as appropriate.

[10] If $CO_2$ emissions from biomass burning are not already included under changes in carbon stocks, they should be reported under biomass burning. Parties that include $CO_2$ emissions from biomass burning in their carbon stock change

Table 11-2 KP(LULUCF) NIR 2 - Land Transition Matrix 2019.

**Table NIR 2. LAND TRANSITION MATRIX**

**Areas and changes in areas between the previous and the current inventory year[(1), (2)]**

| | ARTICLE 3.3 ACTIVITIES | | ARTICLE 3.4 ACTIVITIES | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Afforestation and reforestation | Deforestation | Forest management[(5)] | Cropland management (if elected) | Grazing land management (if elected) | Revegetation (if elected) | Wetland drainage and rewetting (if elected) | Other[(6)] | Total area at the end of the previous inventory year[(7)] |
| | (kha) | | | | | | | | |
| **Article 3.3 activities** | | | | | | | | | |
| **Afforestation and reforestation** | 0.04 | NO | | | | | | | 0.04 |
| **Deforestation** | | 0.25 | | | | | | | 0.25 |
| **Article 3.4 activities** | | | | | | | | | |
| **Forest management** | | 0.01 | 6.22 | | | | | | 6.23 |
| **Cropland management[(3)] (if elected)** | NA | | NA | NA | NA | NA | NA | | NA |
| **Grazing land management[(3)] (if elected)** | NA | | NA | NA | NA | NA | NA | | NA |
| **Revegetation[(3)] (if elected)** | NA | | NA | NA | NA | NA | NA | | NA |
| **Wetland drainage and rewetting[(3)] (if elected)** | NA | | NA | NA | NA | NA | NA | | NA |
| **Other[(4)]** | NA | NA | NA | NA | NA | NA | NA | 9.54 | 9.54 |
| **Total area at the end of the current inventory year** | 0.04 | 0.26 | 6.22 | NA | NA | NA | NA | 9.54 | 16.05 |

[(1)] This table should be used to report land area and changes in land area subject to the various activities in the inventory year. For each activity it should be used to report area change between the end of the previous inventory year and the end of the current inventory year. For example, the total area of land subject to forest management in the previous inventory year and which was deforested in the current inventory year, should be reported in the deforestation column and in the forest

[(2)] In accordance with relevant decisions. Some of the transitions in the matrix are not possible and the cells concerned have been shaded.

[(3)] Lands subject to cropland management, grazing land management, revegetation or wetland drainage and rewetting that after 2013 are subject to activities other than those under Article 3.3 and 3.4, should still be tracked and reported under

[(4)] Other refers to the area that is reported under Article 3.3 or 3.4 in the current inventory for the first time. This footnote does not apply to the cell belonging to the column and the row "other" to "other".

[(5)] Changes in area from cropland management, grazing land management, revegetation and wetland drainage and rewetting to forest management should be reported only in the case of carbon equivalent forest conversions.

[(6)] "Other", in this column, is the area of the country that has never been subject to any activity under Article 3.3 or 3.4

[(7)] The value in the cell of row "Total area at the end of the current inventory year" corresponds to the total land area of a country. The total land area should be the same for the current inventory year and the previous inventory year in this matrix.

Table 11-3 KP(LULUCF) NIR 3 – Key Categories.

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

| KEY CATEGORIES OF EMISSIONS AND REMOVALS | Gas | CRITERIA USED FOR KEY CATEGORY IDENTIFICATION | | | Comments[4] |
|---|---|---|---|---|---|
| | | Associated category in UNFCCC inventory[1] is key (indicate which category) | Category contribution is greater than the smallest category considered key in the UNFCCC inventory[2] (including LULUCF) | Other[3] | |
| **Specify key categories according to the national level of disaggregation used[1]** | | | | | |
| Afforestation | CO2 | -- | yes | | is key, level |
| Deforestation | CO2 | 4C2, 4E2 | yes | | is key, level & trend |
| Forest Management | CO2 | 4A1 | yes | | is key, level & trend |
| Harvest Wood Products | CO2 | 4G | yes | | is key, trend |

(1) See section 2.3.6 of the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol.
(2) If the emissions or removals of the category exceed the emissions of the smallest category identified as key in the UNFCCC inventory (including LULUCF), Parties should indicate YES. If not, Parties should indicate NO.
(3) This should include qualitative assessment as per section 4.3.3 of the 2006 IPCC Guidelines or any other criteria.
(4) Indicate the criteria (level, trend of both) identifying the category as key.

Table 11-4 Overview on net $CO_2$ equivalent emissions (positive sign) and removals (negative sign) for activities under Article 3, paragraphs 3 and 4 of the Kyoto Protocol in 2019.

| **Activity, year 2019** | **Area** kha | **Net $CO_2$ emission/removal** kt $CO_2$ | **$N_2O$ emission** kt $N_2O$ | **Net $CO_2$ eq emission/removal** kt $CO_2$ eq |
|---|---|---|---|---|
| A.1 Afforestation | 0.036 | -0.35 | NO | -0.35 |
| A.2 Deforestation | 0.248 | 4.39 | 0.00024 | 4.46 |
| B.1 Forest managment (FM) | 6.223 | 0.75 | NO | 0.75 |
| 4.C HWP from FM | --- | 0.18 | NO | 0.18 |
| Total emission/removal | | 4.97 | 0.00024 | 5.04 |
| B.1.1 FMRL 2013-2020 | --- | | | 0.36 |

*FMRL: Forest Management Reference Level, incl. Technical corrections*

# 11.1 General information

The inventory datasets on which the calculations are based (Land Use Statistics AREA and National Forest Inventory NFI) are described in chp. 6.2, 6.3 and 6.4.2.1, respectively.

## 11.1.1 Definition of forest and any other criteria

For activities under Article 3, paragraphs 3 and 4 of the Kyoto Protocol, the Marrakech Accords (in the annex to decision 16/CMP.1) list the definitions to be specified by Parties. Liechtenstein's definitions for Forest, Afforestation and Deforestation are specified in the corrigendum to Liechtenstein's Initial Report (OEP 2007b, see there in chp. 4) and is still valid for the second commitment period: Liechtenstein applies the forest definition of the Swiss Land Use Statistics (AREA) of the Swiss Federal Statistical Office. AREA provides an excellent data base to derive accurate, detailed information of not only forest areas, but all types of land use and land cover. Thus, AREA offers a comprehensive, consistent and high-quality data set to estimate the surface area of the different land use categories in reporting under the Kyoto Protocol. For Liechtenstein, the Land Use Statistics has been built up identically to Switzerland (same method and data structures, same realisation):

- minimum area of land: 0.0625 hectares (with a minimum width of 25 m)
- minimum crown cover: 20 per cent
- minimum height of the dominant trees: 3 m (dominant trees must have the potential to reach 3 m at maturity in situ)

In Liechtenstein's Initial Report, the following precisions are stated (OEP 2006a, p.20f.):

The following forest areas are not subject to the criterion of minimum stand height: shrub forest consisting of dwarf pine (Pinus mugo prostrata) and alpine alder (Alnus viridis).

The following forest areas are not subject of the criteria of minimum stand height and minimum crown cover, but must have the potential to achieve both criteria:

a) afforested area on land not under forest cover for 50 years (afforestations);
b) regenerated forest, as well as burned, cut or damaged areas situated on land classified as forest.

Although orchards, parks, camping grounds, open tree formations in settlements, gardens, cemeteries, sports and parking fields may fulfil the (quantitative) forest definition, they are not considered as forests.

### 11.1.2 Elected activities under Article 3, Paragraph 4, of the Kyoto Protocol

Liechtenstein will account for the mandatory activity Forest Management under Article 3, paragraph 4 of the Kyoto Protocol. In accordance with Annex I to Decision 2/CMP.7 (Annex I, Para 13), credits from Forest Management are capped in the second commitment period. For Liechtenstein, the cap amounts to 3.5% of the 1990 emissions (including LULUCF).

### 11.1.3 Description of how the definitions of each activity under Article 3.3 and each elected activity under Article 3.4 have been implemented and applied consistently over Time

Liechtenstein's definitions of Afforestation, Deforestation and Forest Management are published in its first Initial Report. These definitions are still valid for the second commitment period.

#### 11.1.3.1 Afforestation

Definition: Afforestation is the conversion to forest of an area not fulfilling the definition of forest for a period of at least 50 years if

(a) the definition of forest in terms of minimum area (625 $m^2$) is fulfilled, and

(b) the conversion is a direct human-induced activity.

Natural forest regeneration due to abandonment of agricultural land is not considered to be a direct human-induced activity.

The area of forest land reported for Afforestation under the Kyoto Protocol is equal to the area reported for Land use changes to forest type CC11 (see chp. 6.2.1). I.e., afforestation areas in Liechtenstein are identified by aerial photographs which form the basis of Liechtenstein's Land-Use Statistics. In afforestations, the trees are planted in regular patterns, which may easily be recognised in the identification process. Afforestations since 1990 were not subject to harvesting or clear cutting, since there are no forests with such short rotation lengths. However, small losses caused by natural mortality or cut of single trees occur (see chp. 6.4.2.6). For reporting under the Kyoto Protocol, afforested areas always remain in the "afforestation" category. Therefore, the area of afforestation is increasing since 1990.

### 11.1.3.2 Deforestation

**Definition of deforestation**

Deforestation is the permanent and direct human-induced conversion of areas fulfilling the definition of forest to areas not fulfilling the definition of forest. A conversion from forest land to non-forest land is according to IPCC (2014) also classified as deforestation if it is caused by natural processes and is followed by land use which prevents a re-establishment of forest.

**Implementation**

According to this definition, Liechtenstein calculates the area of deforestation as the sum of forest land converted to cropland, grassland, settlement or wetland according to the land-use changes observed in the AREA surveys (see chp. 6.2 and 6.3). For cropland, grassland and settlement (LULUCF categories 4B2, 4C2 and 4E2, respectively) it is obvious that the new land use prevents regeneration of forest. For the unmanaged wetlands (LULUCF category 4D2), this condition is not given but a human-induced disturbance cannot be excluded on the basis of the AREA data available so far.

The conversion of forest land to other land (LULUCF category 4F2) observed in the AREA surveys is non-anthropogenic and there is no human activity in the converted areas that would prevent a re-establishment of forest. This can be concluded from the data, definitions and processes used in AREA: Other land (CC61) is an area covered by rocks, sand, scree or glaciers. For distinguishing natural areas and human-influenced areas, the human interpreters of the aerial photographs also consider the spatial context of the neighbourhood. E.g., an area covered by scree is either reported as other land (CC61, e.g. a natural mountain slope) or as settlement (CC51 'buildings and construction', e.g. a gravel quarry) depending on the spatial context. Therefore, the areas 'FL-OL' in 4F2 are not classified as deforestation.

**Definition of the time interval for tracking deforestation**

Harvesting or forest disturbance that is followed by the re-establishment of a forest is distinguished from deforestation as follows: If a re-establishment of forest occurs within six years after the observed loss of forest the loss is considered temporary (not permanent) and the land remains forest land. If there is no re-establishment of forest after six years the area is subject to deforestation.

**Consistent application of the time interval for tracking deforestation**

The time interval of six years for tracking deforestation was consistently applied for the whole period 1990-2019 by the following procedure:

An analysis of Liechtenstein's land-use data from the AREA surveys of 1984, 1996, 2002,2008 and 2014 (see chp. 6.3) revealed that for each survey-interval a certain fraction (Frac) of the loss in forest area was not permanent as it was forest again in the following survey six years later. This means that a reduction of crown coverage visible in the aerial photographs in e.g. 2008 led to the use of a non-forest code but natural regeneration led to a forest code again six years later in the 2014 survey. Thus, Liechtenstein does not report the areas with these short-term reductions of crown coverage under the KP-LULUCF activities on the grounds that: (1) if the crown cover reduction resulted from natural hazards the land-use change was not directly human induced and the following land use did not prevent regeneration of the forest; and (2) if the crown cover reduction was directly human induced it should be classified as "management interventions" rather than as real land-use change, because the intervention did not lead to a land-use change in the long term (defined by the time interval for tracking deforestation).

These fractions of temporary forest loss were calculated and applied as follows:

- $Frac_{1996}$ = 0.146 (48 ha forest loss 1985-1996, thereof 7 ha classified as forest again in 2002). This fraction is applied to the forest losses (FL-GL, FL-CL, FL-WL, FL-SL) occurring between 1990 and 1996.
- $Frac_{2002}$ = 0.089 (90 ha forest loss 1997-2002, thereof 8 ha classified as forest again in 2008). This fraction is applied to the forest losses (FL-GL, FL-CL, FL-WL, FL-SL) occurring between 1997 and 2002.
- $Frac_{2008}$ = 0.111 (63 ha forest loss 2003-2008, thereof 7 ha classified as forest again in 2014). This fraction is applied to the forest losses (FL-GL, FL-CL, FL-WL, FL-SL) occurring between 2003 and 2019.

Table 11-5 shows how the fractions of the survey-intervals are applied to the period 1990-2019. It also shows the annual "effective" fraction which is the area-weighted mean fraction of temporary losses. For weighting, the cumulated areas (over 20 years) originating from the respective survey interval (1990-1996, 1997-2002, 2003-2014) are used. Thus, the time interval for tracking deforestation is applied smoothly and consistently for the whole period implying the full information of all AREA surveys. Table 11-5 also shows the resulting deforestation areas: the cumulated gross forest loss (including temporary losses), the cumulated permanent forest loss (i.e. deforestation) as well as the annual deforestation and the deforestation cumulated over 20 years.

Table 11-5 Overview of the fractions of temporary losses for each survey-interval and the effective (area-weighted) fraction. The two last columns show the resulting annual deforested area (permanent losses) and the permanent forest loss cumulated over 20 years.

| Period | 1990 to 1996 | 1997 to 2002 | 2003 to 2008 | 2009 to 2014 | Gross forest loss cumulated | Weighted Frac | Permanent forest loss cumulated | Permanent forest loss annual | Cumulated 20 years |
|---|---|---|---|---|---|---|---|---|---|
| Area | 28.0 | 90.0 | 63.0 | 52.0 | | | | | |
| Frac | 0.146 | 0.089 | 0.111 | 0.111 | | | | | |
| | ha | ha | ha | ha | ha | -- | ha | ha/yr | ha |
| 1990 | 4.0 | 0.0 | 0.0 | 0.0 | 4.0 | 0.146 | 3.4 | 3.4 | 3.4 |
| 1991 | 8.0 | 0.0 | 0.0 | 0.0 | 8.0 | 0.146 | 6.8 | 3.4 | 6.8 |
| 1992 | 12.0 | 0.0 | 0.0 | 0.0 | 12.0 | 0.146 | 10.3 | 3.4 | 10.3 |
| 1993 | 16.0 | 0.0 | 0.0 | 0.0 | 16.0 | 0.146 | 13.7 | 3.4 | 13.7 |
| 1994 | 20.0 | 0.0 | 0.0 | 0.0 | 20.0 | 0.146 | 17.1 | 3.4 | 17.1 |
| 1995 | 24.0 | 0.0 | 0.0 | 0.0 | 24.0 | 0.146 | 20.5 | 3.4 | 20.5 |
| 1996 | 28.0 | 0.0 | 0.0 | 0.0 | 28.0 | 0.146 | 23.9 | 3.4 | 23.9 |
| 1997 | 28.0 | 15.0 | 0.0 | 0.0 | 43.0 | 0.126 | 37.6 | 13.7 | 37.6 |
| 1998 | 28.0 | 30.0 | 0.0 | 0.0 | 58.0 | 0.116 | 51.3 | 13.7 | 51.3 |
| 1999 | 28.0 | 45.0 | 0.0 | 0.0 | 73.0 | 0.111 | 64.9 | 13.7 | 64.9 |
| 2000 | 28.0 | 60.0 | 0.0 | 0.0 | 88.0 | 0.107 | 78.6 | 13.7 | 78.6 |
| 2001 | 28.0 | 75.0 | 0.0 | 0.0 | 103.0 | 0.104 | 92.3 | 13.7 | 92.3 |
| 2002 | 28.0 | 90.0 | 0.0 | 0.0 | 118.0 | 0.102 | 105.9 | 13.7 | 105.9 |
| 2003 | 28.0 | 90.0 | 10.5 | 0.0 | 128.5 | 0.103 | 115.3 | 9.3 | 115.3 |
| 2004 | 28.0 | 90.0 | 21.0 | 0.0 | 139.0 | 0.104 | 124.6 | 9.3 | 124.6 |
| 2005 | 28.0 | 90.0 | 31.5 | 0.0 | 149.5 | 0.104 | 133.9 | 9.3 | 133.9 |
| 2006 | 28.0 | 90.0 | 42.0 | 0.0 | 160.0 | 0.105 | 143.3 | 9.3 | 143.3 |
| 2007 | 28.0 | 90.0 | 52.5 | 0.0 | 170.5 | 0.105 | 152.6 | 9.3 | 152.6 |
| 2008 | 28.0 | 90.0 | 63.0 | 0.0 | 181.0 | 0.105 | 161.9 | 9.3 | 161.9 |
| 2009 | 28.0 | 90.0 | 63.0 | 8.7 | 189.7 | 0.105 | 169.7 | 7.8 | 169.7 |
| 2010 | 28.0 | 90.0 | 63.0 | 17.3 | 198.3 | 0.105 | 177.6 | 7.9 | 174.2 |
| 2011 | 28.0 | 90.0 | 63.0 | 26.0 | 207.0 | 0.104 | 185.6 | 8.0 | 178.7 |
| 2012 | 28.0 | 90.0 | 63.0 | 34.7 | 215.7 | 0.103 | 193.5 | 8.0 | 183.3 |
| 2013 | 28.0 | 90.0 | 63.0 | 43.3 | 224.3 | 0.102 | 201.6 | 8.0 | 187.9 |
| 2014 | 28.0 | 90.0 | 63.0 | 52.0 | 233.0 | 0.100 | 209.6 | 8.0 | 192.5 |
| 2015 | 28.0 | 90.0 | 63.0 | *60.7* | 241.7 | 0.099 | 217.7 | 8.1 | 197.2 |
| 2016 | 28.0 | 90.0 | 63.0 | *69.3* | 250.3 | 0.098 | 225.8 | 8.1 | 201.9 |
| 2017 | 28.0 | 90.0 | 63.0 | *78.0* | 259.0 | 0.099 | 233.4 | 7.6 | 195.8 |
| 2018 | 28.0 | 90.0 | 63.0 | *86.7* | 267.7 | 0.100 | 240.8 | 7.5 | 189.6 |
| 2019 | 28.0 | 90.0 | 63.0 | *95.3* | 276.3 | 0.102 | 248.2 | 7.4 | 183.3 |

**Further Comments:**

Active measures leading to deforestation are prohibited by the National Law on Forests with article 6 (Government 1991). Exceptions need governmental authorisation. The authorisation documents are collected by the formerly Office of Forest, Nature and Landscape (OFNLM) now also part of the Office of Environment and are annually reported to the Parliament. To ensure that the total area of forest does not decrease, areas affected by direct human-induced deforestation have to be compensated, mainly by afforestation of the same spatial extent but not at the same location.

### 11.1.3.3 Reforestation

Reforestation does not occur in Liechtenstein (see Sect. 11.4.1).

#### 11.1.3.4 Forest Management

Forest Management includes all activities serving the purpose of fulfilling the National Law on Forests (Government 1991, Art. 1), i.e. the obligation to conserve forests and to ensure forest functions – such as wood production, protection against natural hazards, preservation of biodiversity, purification of drinking water and maintenance of recreational value – in a sustainable manner.

Since all forests in Liechtenstein are subject to forest management, the area of managed forest corresponds to the forest area derived from the Liechtenstein’s Land Use Statistics AREA (EDI/BFS 2009).

### 11.1.4 Description of precedence conditions and/or hierarchy among 3.4. activities and how they have been consistently applied in determining how land was classified

Since Liechtenstein only accounts for Forest Management from the activities of Article 3, paragraph 4 of the Kyoto Protocol, the hierarchy among 3.4 activities does not affect the reporting.

### 11.1.5 Planned improvements

No category-specific improvements are planned.

## 11.2 Land-related information

### 11.2.1 Spatial assessment unit used for determining the area of the units of land

The spatial assessment unit for the submission of the KP LULUCF tables covers the entire territory of Liechtenstein (16.054 kha).

All activity data for reporting the activities under the Kyoto Protocol are retrieved from Liechtenstein's Land Use Statistics AREA (EDI/BFS 2009; see also Chapter 6.3.1). The AREA surveys (SFSO 2006a) use a georeferenced sample grid with a grid size of 100 m by 100 m. To each grid point a specific combination category is assigned.

### 11.2.2 Methodology used to develop the land transition matrix

The methodology used to develop the land transition matrix is described in detail in chp. 6.3.

#### 11.2.2.1 Maps / database to identify the geographical locations and the system of identification codes for the geographical locations

All Afforestations and Deforestations are accounted for under Article 3, paragraph 3 and are not reported under Forest Management under Article 3, paragraph 4. Afforestations older than the conversion period of 20 years, are still reported under Afforestations: CRF-table 4(KP-I)A.1. The calculation of changes in carbon stocks is described in chp. 11.3.1.1. The changes in areas between the activities under Article 3, paragraph 3 and Article 3, paragraph 4 are listed in CRF-Table NIR-2 (seeTable 11-2).

Forest areas under Forest Management are subdivided into productive forests (CC12) and unproductive forests (CC13; for a description see chp.6.4.2.4). Productive forests reveal a high heterogeneity in terms of elevation, growth conditions and tree species composition. Therefore, Liechtenstein has been stratified into three altitudinal zones (Z1: <601 m, Z2: 601-1200 m, Z3: >1200 m) and two soil types (mineral soils and organic soils; forests are all on mineral soils) as shown in chp. 6.2.2. Carbon gains and losses are calculated separately in the three altitudinal zones.

## 11.3 Activity-specific information

### 11.3.1 Methods for carbon stock change and GHG emission and removal estimates

#### 11.3.1.1 Description of the methodologies and the underlying assumptions used

**General assumptions**

For calculating the shares of above ground biomass and below ground biomass, root-to-shoot ratios given by Brändli (2010, Table 095) for the Swiss NFI-region 3, were used. The average ratio of the three altitude zones is 0.33. This value was used for afforestation, deforestation and forest management.

Data related to dead wood and data related to gain/loss of living biomass in Forest Management were taken from Liechtenstein's own NFI (LWI 2012).

For calculating carbon stock changes in Afforestation, living biomass and soil organic carbon is included. For Deforestation, the gains/losses of living biomass as well as the carbon stock-differences in soils, litter and deadwood as described in chp. 6.4.2 are reported. Although these carbon values are based on studies and surveys carried out in Switzerland, they are perfectly 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.

**Afforestations**

For afforestations ≤20 years old, gains and losses in living biomass (carbon stock change in above and below ground biomass) was calculated with the values of land-use category CC11 given in Table 6-4 and chp.6.4.2.6.

For afforestations >20 years old, growth in living biomass from category CC12 was used. Cut and mortality (loss) of living biomass is assumed to be zero in these young forests.

In Liechtenstein, afforestations mostly occur on grasslands by planting young trees. It is assumed that the soil carbon content increases with the developing young forest. The soil carbon stock changes due to afforestation are calculated according to Equation 6.3 (chp.6.1.3.2) assuming a land-use change from grassland (CC31) to CC11 with Ws=1.

I.e. for afforestations ≤20 years old the increase in soil carbon is calculated with the stock-difference approach. The soil carbon stocks are different for the three altitude zones z1, z2 and z3 (≤ 600 m, 601-1’200 m, > 1’200 m) (Table 6-4). The resulting increase in soil carbon is evenly distributed over the IPCC default conversion time (CT) of 20 years, giving an evenly distributed yearly increase in soil carbon stock to move from the soil carbon stock level of grasslands to the level of forests.

For afforestations >20 years old, no carbon stock change in soil is assumed.

For all afforestations, it is assumed that there is no change in litter (LFH soil horizons) and no change in dead wood. These are conservative assumptions as the non-forest land-use types do not have any litter or dead wood pools. This is a conservative estimate (in terms of IPCC good practice: IPCC 2006, chp. 4.3.2).

The afforested areas (CC11) were calculated by the methods shown in chp.6.2. The areas of afforestation are given in the land-use change-matrices (see example in Table 6-8). Table 11-6 summarises all areas per year and the cumulative areas used for calculating carbon fluxes under this activity.

Table 11-6 Area and cumulative area of afforestations (CC11) 1990-2019. The cumulative area is calculated (1) over 20 years since 1990, (2) for afforestation older than 20 years and (3) total cumulated afforestations since 1990. Units: ha.

| | altitude zone | | | | cumulated | | |
|---|---|---|---|---|---|---|---|
| Year | z1 | z2 | z3 | total | ≤ 20 years | >20 years | total |
| 1990 | 1.00 | 0.08 | 1.58 | 2.67 | 2.67 | | 2.67 |
| 1991 | 1.00 | 0.08 | 1.58 | 2.67 | 5.33 | | 5.33 |
| 1992 | 1.00 | 0.08 | 1.58 | 2.67 | 8.00 | | 8.00 |
| 1993 | 1.00 | 0.08 | 1.58 | 2.67 | 10.67 | | 10.67 |
| 1994 | 1.00 | 0.08 | 1.58 | 2.67 | 13.33 | | 13.33 |
| 1995 | 1.00 | 0.08 | 1.58 | 2.67 | 16.00 | | 16.00 |
| 1996 | 1.00 | 0.08 | 1.58 | 2.67 | 18.67 | | 18.67 |
| 1997 | 0.50 | 0.50 | 0.50 | 1.50 | 20.17 | | 20.17 |
| 1998 | 0.50 | 0.50 | 0.50 | 1.50 | 21.67 | | 21.67 |
| 1999 | 0.50 | 0.50 | 0.50 | 1.50 | 23.17 | | 23.17 |
| 2000 | 0.50 | 0.50 | 0.50 | 1.50 | 24.67 | | 24.67 |
| 2001 | 0.50 | 0.50 | 0.50 | 1.50 | 26.17 | | 26.17 |
| 2002 | 0.50 | 0.50 | 0.50 | 1.50 | 27.67 | | 27.67 |
| 2003 | 0.17 | 0.17 | 0.33 | 0.67 | 28.33 | | 28.33 |
| 2004 | 0.33 | 0.00 | 0.00 | 0.33 | 28.67 | | 28.67 |
| 2005 | 0.33 | 0.00 | 0.00 | 0.33 | 29.00 | | 29.00 |
| 2006 | 0.33 | 0.00 | 0.00 | 0.33 | 29.33 | | 29.33 |
| 2007 | 0.33 | 0.00 | 0.00 | 0.33 | 29.67 | | 29.67 |
| 2008 | 0.33 | 0.00 | 0.00 | 0.33 | 30.00 | | 30.00 |
| 2009 | 0.17 | 0.00 | 0.33 | 0.50 | 30.50 | | 30.50 |
| 2010 | 0.17 | 0.00 | 0.33 | 0.50 | 28.33 | 2.67 | 31.00 |
| 2011 | 0.17 | 0.00 | 0.33 | 0.50 | 26.17 | 5.33 | 31.50 |
| 2012 | 0.17 | 0.00 | 0.33 | 0.50 | 24.00 | 8.00 | 32.00 |
| 2013 | 0.17 | 0.00 | 0.33 | 0.50 | 21.83 | 10.67 | 32.50 |
| 2014 | 0.17 | 0.00 | 0.33 | 0.50 | 19.67 | 13.33 | 33.00 |
| 2015 | 0.17 | 0.00 | 0.33 | 0.50 | 17.50 | 16.00 | 33.50 |
| 2016 | 0.17 | 0.00 | 0.33 | 0.50 | 15.33 | 18.67 | 34.00 |
| 2017 | 0.17 | 0.00 | 0.33 | 0.50 | 14.33 | 20.17 | 34.50 |
| 2018 | 0.17 | 0.00 | 0.33 | 0.50 | 13.33 | 21.67 | 35.00 |
| 2019 | 0.17 | 0.00 | 0.33 | 0.50 | 12.33 | 23.17 | 35.50 |

**Deforestations**

The carbon stock changes due to deforestation are calculated according to Equations 6.1-6.3 (see chp.6.1.3.2) applying the stock-difference approach with the carbon contents shown in Table 6-4.

The carbon stock changes in living biomass, litter and dead wood are taken from the CRF Tables 4B2, 4C2, 4D2 and 4E2.

The $N_2O$ emissions arising from nitrogen mineralization on deforested soils are taken from CRF Table 4(III). The method for calculating those emissions is described in chp.6.10.

The method for consistently tracking the deforestation area as described in chp. 11.1.3.2 is applied. The resulting deforestation areas are listed in Table 11-5.

**Forest Management**

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 chp. 6.4.2.3). For calculating the loss, annual harvesting statistics were used in addition to the NFI results (see Table 6-14 in chp. 6.4.2.3).

Carbon stock changes in litter and dead wood of productive forests (CC12) were derived from results of the model Yasso07 applied in Switzerland (see chp. 6.4.2.5).

Carbon stocks in soil of productive forests (CC12) are assumed to be constant (see chp. 6.4.2.8); on unproductive forest land (CC13), all carbon pools are constant (see chp. 6.4.2.4 and 6.4.2.8).

### 11.3.1.2 Justification when omitting any carbon pool or GHG emissions/removals from activities under Article 3.3 and elected activities under Article 3.4

CRF-Table NIR-1 (see Table 11-1) summarizes the activity coverage and the pools reported. When using the conservative Tier 1 approach (IPCC 2006 Volume 4, Chapter 1.3) assuming a specific carbon pool to be in balance, the carbon pool is indicated as not reported (NR). This is the case for litter and dead wood in afforestations and for mineral soil under forest management.

For grasslands (the most common land-use type before afforestation) there is no litter and no dead wood and a lower soil carbon stock than in forests. Because an increase of carbon in these pools is expected after a conversion from grasslands to forests by afforestation (compare Table 6-4) a Tier 1 approach has been considered in terms of IPCC good practice (IPCC 2006) and no changes (NR) in the litter, soil and dead wood pools for afforestations has been reported.

For forest management (CC12), no data related to carbon stock changes in mineral soil are available for Liechtenstein. Therefore, data from Switzerland (FOEN 2020) were inspected, see chp. 6.4.2.8. Those results of the Yasso07 model show that the changes in mineral soils are close to zero. On this ground, a Tier 1 approach has been considered in terms of IPCC good practice (IPCC 2006) and no changes (NR) in the soil pool for forest management has been reported.

Fertilisation, drainage of soils, and biomass burning are not occurring (NO).

### 11.3.1.3 Information on whether or not indirect and natural GHG emissions and removals have been factored out

No anthropogenic greenhouse gas emissions and removals resulting from LULUCF activities under Article 3, paragraphs 3 and 4 have been factored out.

#### 11.3.1.4 Changes in data and methods since previous submission (recalculations)

See chapters 10.1.2, 10.2.2 and 10.3.2.

### 11.3.2 Uncertainties and time-series consistency

#### 11.3.2.1 Afforestation

AD uncertainty is calculated (as shown in chp. 6.3.3) combining the AREA-interpretation uncertainty (1.1% from 4A2, Table 6-9) and the sampling uncertainty (33.1% using a sample size of 35 ha-points according to Table 11-6): 33.1%.

EF uncertainty is 46.7% adopting the value of LULUCF category 4A2 (see chp. 6.4.3). The combined total uncertainty for afforestation is therefore 57.3%. Thus, the net $CO_2$ removal by afforestation in 2019 is (–0.35 ± 0.20) kt $CO_2$.

#### 11.3.2.2 Deforestation

AD uncertainty is calculated (as shown in chp. 6.3.3) combining the AREA-interpretation uncertainty (5.2% from 4C2, Table 6-9) and the sampling uncertainty (13.4% with a sample size of 214 ha-points according to Table 11-5): 14.4%.

EF uncertainty is of 57.0% adopting the value of LULUCF category 4C2 (see chp. 6.6.3) as this is the main process for conversion of forest land. Therefore, the combined total uncertainty for deforestation is 58.8%. The net $CO_2$ emissions by deforestations in 2019 are (4.46 ± 2.62) kt $CO_2$eq.

#### 11.3.2.3 Forest management

AD and EF uncertainties are adopted from LULUCF-category 4A1 (2.7% and 46.7%, respectively, see chp. 6.4.3). The combined uncertainty is 46.8%. The net emissions attributed to forest management in 2019 are (0.75 ± 0.35) kt $CO_2$.

#### 11.3.2.4 Harvest wood products (HWP)

Uncertainty calculations for HWP are presented in chp. 6.11.3. The combined uncertainty is 75.8%. As result the total HWP removals in 2019 are (0.18 ± 0.14) kt $CO_2$.

#### 11.3.2.5 Total combined uncertainty

The total uncertainty of emissions and sinks by afforestation, deforestation, forest management and HWP in 2019 is 2.66 kt $CO_2$eq. The net $CO_2$ emissions are therefore (5.04 ± 2.66) kt $CO_2$eq.

Time series are consistent.

### 11.3.3 Category-specific QA/QC and verification

In chp. 6.4.4 category-specific QA/QC and verification items for forest land are described in detail. The general QA/QC measures are described in chp. 1.2.3.

## 11.4 Article 3.3. (Afforestation and Deforestation)

Figure 11-1 shows removals of $CO_2$ eq from Afforestations and emissions of $CO_2$ eq from Deforestations. Removals from Afforestations and emissions from Deforestations differ by one order of magnitude. The area of Deforestation is about 5 times larger than the area of Afforestations.

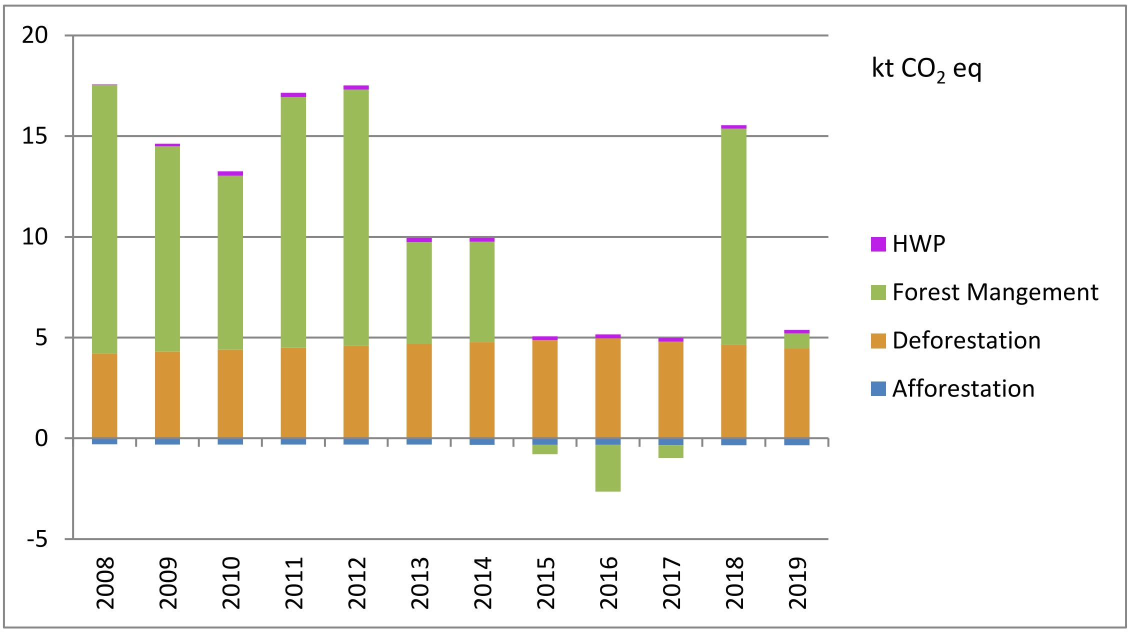



Figure 11-1 The $CO_2$ removals (negative sign) and emissions (positive sign) from Afforestation, Deforestation, Forest Management and HWP, 2008–2019, in kt $CO_2$ eq.

Since carbon from living biomass is immediately removed after clear-cutting, Deforestations can be considered as a “quick carbon-losing process” (except for soil carbon). In contrast, due to the slow increase of living biomass, afforestations are a “more slow process with increasing importance” in terms of carbon accumulation.

### 11.4.1 Information that demonstrates that activities under Article 3.3. began on or after 1 January 1990 and before December 2020 and are direct human-induced

#### 11.4.1.1 Reforestation

For more than 100 years, the area of forest in Liechtenstein has been increasing, and a decrease in forest area as a result of deforestation is prohibited by the National Law on Forests with article 6 (Government 1991). Therefore, reforestation of areas not forested for a period of at least 50 years does not occur in Liechtenstein. Liechtenstein, therefore, only has to consider afforestation and deforestation under Article 3, paragraph 3.

#### 11.4.1.2 Afforestation

Liechtenstein is very restrictive in reporting Afforestations under the Kyoto Protocol and only reports planted or otherwise human-induced Afforestations (land-use code CC11). The annual rate of Afforestation since 1990 is assessed by the AREA survey (see chp. 6.3). For reporting under the Kyoto Protocol, afforested areas always remain in the "afforestation" category. Therefore, the area of Afforestations is increasing since 1990.

#### 11.4.1.3 Deforestation

Deforestation is prohibited by the National Law on Forests with article 6 (Government 1991) and exceptions need governmental authorisation. In addition to human-induced deforestation processes also natural disturbances followed by a land-use change are included. All areas are assessed by the AREA surveys (see chp. 6.3). Only deforestations occurring after 1 January 1990 are considered.

### 11.4.2 Information on how harvesting or forest disturbance that is followed by the re-establishment of forest is distinguished from Deforestation

Liechtenstein's definition of Deforestation only covers permanent conversions from forest land into non-forest land. It is assessed by AREA applying the procedure presented in chp. 11.1.3.2 where the temporary loss of forest cover by natural disturbance or management is estimated.

### 11.4.3 Information on the size and geographical location of forest areas that have lost forest cover but which are not yet classified as deforested

The AREA survey provides a detailed overview of land-use changes with regard to land cover and land use (see chp. 6.2 and 6.3). Temporal changes of land cover can lead to a reclassification in AREA from a forest category to a non-forest category. In chp. 11.1.3.2 the criteria are listed which conversions from a forest combination category to a non-forest combination category are not identified as Deforestation under the Kyoto Protocol.

## 11.5 Article 3.4 (Forest Management)

Net $CO_2$ emissions from the Kyoto Protocol activity Forest Management for the years 2008 until 2019 are shown in Figure 11-1. Gains were adopted from Liechtenstein's NFI (see chp. 6.4.2.1) which covers the period 1998-2010. Losses were calculated with NFI-results and harvesting statistics (see chp. 6.4.2.3). From 2008 to 2014, cut and mortality was generally higher than growth and therefore, Forest Management represents a carbon source in those years. However, in 2015–2017 the harvesting rates were decreasing and therefore Forest Management became a net carbon sink. In 2018, Forest management was a larger source again due to increased harvesting of windfall and bark-beetle wood. In 2019, with a moderate harvesting rate, Forest Management was only a small source.

For the second commitment period the following specific information applies:

- Conversion of natural forests to planted forests is not applicable for Liechtenstein.
- Methodological consistency between the reference level and reporting for forest management is attained as described in chp. 11.7.
- Liechtenstein does not apply the provision of Carbon Equivalent Forests for emissions/removals from the harvest and conversion of forest plantations to non-forest land (decision 2/CMP.7, annex, paragraphs 37–39).

### 11.5.1 Information that demonstrates that activities under Article 3.4. have occurred since 1 January 1990 and are human-induced

According to the National Law on Forests, the extent and the spatial distribution of the total forest area in Liechtenstein has to be preserved (Government 1991) and thus, any change of the forested area has to be authorized. All forests are under observation of the communal forest services and monitored by the NFI. Therefore, all forests in Liechtenstein are subject to Forest Management.

### 11.5.2 Information related to Cropland Management, Grazing Land Management and Revegetation, if elected, for the base year

Not applicable.

### 11.5.3 Information relating to Forest Management

There is a long tradition of forest protection in Liechtenstein since the 19th century. The most recent forest law (Government 1991) reaffirms the long-standing tradition of preserving both forest area and forest as a natural ecosystem. It prescribes sustainable Forest Management, prohibits clearing, and bans Deforestation unless it is replaced by an equal area of afforested land or an equivalent measure to improve biodiversity.

### 11.5.4 Information that demonstrates that emissions and removals resulting from elected Article 3, Paragraph 4, activities are not accounted for under activities under Article 3, Paragraph 3

This information is requested in the Annex to 15/CMP.1 paragraph 9.c. The reporting of Forest Management under article 3, paragraph 4 is clearly separated from the reporting of the activities under article 3, paragraph 3.

Units of lands with ARD (Afforestation, Reforestation and Deforestation) activities are reported under Article 3, paragraph 3. These areas always remain under Article 3, paragraph 3. Afforestations older than 20 years are attributed to growth factors of mature forests under forest management. These units of lands are reported in Table 4(KP-I)A.1 and not under forest management. Thus, there is no double counting of units of lands under article 3, paragraph 3 to Article 3, paragraph 4.

### 11.5.5 Information that indicates to what extent removals from Forest Management offsets the Debit incurred under Article 3, Paragraph 3

This information is shown in the summary CRF-Table "accounting" (Information table on accounting for activities under Articles 3.3 and 3.4 of the Kyoto Protocol).

## 11.6 Key category analysis for Article 3.3 and 3.4 activities

The results of the approach 1 key category analysis including LULUCF are shown and explained in chp. 1.5.1.2 and are displayed in Table 1-5. The smallest UNFCCC category considered key based on the Approach 1 assessment is “1.A.3.b Road Transportation, $CH_4$” with a contribution of 0.08 kt $CO_2$ eq (share <0.1%).

The following LULUCF activities under the Kyoto Protocol are listed in Kyoto Table NIR-3 (Table 11-3):

- Afforestation and Reforestation (-0.35 kt $CO_2$ eq; Table 11-4) is a key category under the Kyoto Protocol because its absolute contribution is higher than the smallest category considered key in the UNFCCC inventory.
- Deforestation (4.46 kt $CO_2$ eq; Table 11-4) is a key category under the Kyoto Protocol because its contribution is higher than the smallest UNFCCC category considered key.
- Forest Management (0.75 kt $CO_2$ eq, Table 11-4) is a key category under the Kyoto Protocol because its absolute contribution is higher than the smallest category considered key in the UNFCCC inventory.
- Harvested Wood Products (0.18 kt $CO_2$ eq; Table 11-4) is a key category under the Kyoto Protocol because its contribution is higher than the smallest UNFCCC category considered key. Exactly the same method is used for calculation of HWP under UNFCCC and KP.

Among the key categories from the LULUCF sector in the UNFCCC inventory, there are several categories which have a relationship to afforestation/reforestation or deforestation, for example:

- 4C2/4E2 Land converted to Grassland/Settlements: related to deforestation
- 4A1 Forest Land remaining Forest Land: related to Forest Management
- 4G Harvested Wood Products (HWP): is the same as in KP-LULUCF.

For Liechtenstein, 4A2 (Land converted to Forest Land) is not quite well related to Afforestation because 4A2 is dominated by natural (not directly human-induced) conversions.

## 11.7 Technical correction Forest Management Reference Level

Liechtenstein's forest management reference level (FMRL) is documented by OEP (2011d). It is inscribed in the appendix to the annex to Decision 2/CMP.7 and amounts to +0.10 kt $CO_2$ eq $yr^{-1}$. OEP (2011d) was subject to a technical assessment. Based on the technical assessment report (UNFCCC 2011) and applying guidance of IPCC (2014), the following technical corrections of Liechtenstein's FMRL have been made in 2016 (see Table 11-7):

- Wood harvesting; carbon stock changes in living biomass: The calculations by OEP (2011d) were based on a forest areaof 4.413 kha. However, the area in 2013 is 18% higher. The FMRL was corrected accordingly.
- Carbon stock changes in mineral soils: The new model version Yasso07 has been implemented in Switzerland since 2013. The results from Switzerland are adopted (FOEN 2015).
- Calculation of carbon stock changes in HWP: carbon stock changes in HWP are calculated following the IPCC methodology (IPCC 2014); the historical time series has been updated (see chp. 6.11.2).

Table 11-7 Summary of the technical correction of the FMRL. Values from FMRL as defined in OEP (2011d) and corrected values (this chapter) are listed per pool.

| **kt $CO_2$ $yr^{-1}$** | **FMRL submitted 2011** | **FMRL corrected 2016** | **Technical correction** |
|---|---|---|---|
| Wood harvesting, stock change in living biomass | 1.30 | 1.54 | 0.24 |
| Stock change in HWP | -2.40 | -1.18 | 1.22 |
| Stock change of organic soil carbon | 1.20 | 0.00 | -1.20 |
| **FMRL 2013-2020** | **0.10** | **0.36** | **0.26** |

The calculations of stock change in living biomass by OEP (2011d) were based on a forest area of 4.413 kha. However, the actual area of productive forest (CC12) in 2013 was 18%

higher (5.187 kha, see Table 6-7). This leads to a correction of the FMRL for this pool by 0.24 kt $CO_2$ eq $yr^{-1}$ (see Table 11-7). OEP (2011d) used a mean net decrease in growing stock of -0.232 $m^3$ $ha^{-1}$ (average of two modelled scenarios). This value was not changed.

The new version of the model Yasso07 has been implemented since Switzerland's GHG inventory 2013 and improvements related to input data, model parameterization and model calibration have been made (see Didion 2014). For the FMRL submitted by OEP (2011d) the results of an older version (2006) of the Swiss Yasso model application was adopted to estimate the carbon stock change in mineral soils for Liechtenstein (1.20 kt $CO_2$/year). The most recent Yasso07 results do not confirm this emission value but indicate that the carbon stock change in mineral soil is practically zero (FOEN 2015, Figure 6-5). This new result is adopted for Liechtenstein (see Table 11-7).

Carbon stock changes in HWP are calculated following the IPCC methodology (IPCC 2014) which is different from the methodology applied in OEP (2011d). For the recalculation of the FMRL only the in-country production of sawnwood from domestic harvest is included. Further, the historical time series has been updated in Submission 2015 (chp. 6.11).

For calculating the carbon stock change in HWP for the FMRL 2013-2020, the annual production of sawnwood 2013-2020 was estimated by the average production from 2000 to 2009. I.e. a business as usual scenario was assumed based on the ten-year average 2000-2009 (7'616 $m^3$). With this production value, the time series of gains and losses shown in chp. 6.11 were extended until 2020 (Table 11-8). The resulting average $CO_2$ removal 2013-2020 is -1.18 kt $CO_2$ $yr^{-1}$, which was used to correct the FMRL (Table 11-7).

Table 11-8 Calculation of the annual $CO_2$ removal by HWP for the FMRL in the 2nd Commitment Period 2013-2020.

| Harvested wood products | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | Mean 2000-2009 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sawnwood production, $m^3$ | 8'125 | 7'000 | 7'100 | 6'725 | 7'525 | 7'955 | 9'331 | 9'331 | 9'331 | 3'732 | 7'616 |
| Gains sawnwood, kt C | 2.03 | 1.75 | 1.78 | 1.68 | 1.88 | 1.99 | 2.33 | 2.33 | 2.33 | 0.93 | |
| Losses sawnwood, kt C | -1.46 | -1.47 | -1.47 | -1.48 | -1.48 | -1.49 | -1.51 | -1.52 | -1.54 | -1.54 | |
| **Net emissions/removals, kt $CO_2$** | **-2.10** | **-1.03** | **-1.11** | **-0.74** | **-1.45** | **-1.82** | **-3.03** | **-2.97** | **-2.91** | **2.23** | |

| Harvested wood products | 2010 | 2011 | 2012 |
|---|---|---|---|
| Sawnwood production, $m^3$ | 7'616 | 7'616 | 7'616 |
| Gains sawnwood, kt C | 1.90 | 1.90 | 1.90 |
| Losses sawnwood, kt C | -1.54 | -1.55 | -1.55 |
| **Net emissions/removals, kt $CO_2$** | **-1.34** | **-1.32** | **-1.29** |

| Harvested wood products | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Mean 2013-2020 |
|---|---|---|---|---|---|---|---|---|---|
| Sawnwood production, $m^3$ | 7'616 | 7'616 | 7'616 | 7'616 | 7'616 | 7'616 | 7'616 | 7'616 | 7'616 |
| Gains sawnwood, kt C | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 | 1.90 |
| Losses sawnwood, kt C | -1.56 | -1.57 | -1.57 | -1.58 | -1.59 | -1.59 | -1.60 | -1.60 | -1.58 |
| **Net emissions/removals, kt $CO_2$** | **-1.26** | **-1.24** | **-1.22** | **-1.19** | **-1.17** | **-1.15** | **-1.12** | **-1.10** | **-1.18** |

# 11.8 Natural disturbances

## 11.8.1 Application of the provision of natural disturbances

As indicated in Liechtenstein's 2nd Initial Report (Government 2016), Liechtenstein intends to apply, in the case of significant magnitude events, the provision of natural disturbances for units of lands under Forest Management during the second commitment period in accordance with decision 2/CMP.7. In cases or events in which emissions from natural disturbances are higher than the nationally established threshold value and all other requirements defined in 2/CMP.7 and IPCC (2014) are met, Liechtenstein will evaluate and decide whether the effort would be justified to exclude them.

In the inventory year 2018, no natural disturbances causing emissions exceeding the upper confidence interval (background level plus margin) occurred. Thus, no emissions from natural disturbances are excluded.

### 11.8.2 Technical correction of the background level and margin

There is no technical correction of the background level and margin for the inventory year 2019.

## 11.9 Harvested Wood Products (HWP)

### 11.9.1 General methodological isssues

Methodology, data and uncertainties of carbon stock changes in the HWP pools are described in chp. 6.11. The same methodology is applied for reporting HWP from forest land under UNFCCC and accounting for HWP from Forest Management under KP. A time series for changes in the HWP-pool is shown in chp. 6.11.2. HWPs originating from wood harvested at land converted from forest land to non-forest land (UNFCCC) or from Deforestations (KP) are not taken into account.

### 11.9.2 Specific issues for the second commitment period

#### 11.9.2.1 How emissions from the HWP pool accounted for in the first commitment period on the basis of instantaneous oxidation have been excluded

As shown in chp. 6.11.2 the methodology from the KP-Supplement (IPCC 2014) is used. Net $CO_2$ emissions and removals from HWP were reported for the first time in the Submission 2015. For calculating the HWP pool, only sawnwood with a half-live of 35 years was included. Thus, Liechtenstein implemented the Annex to decision 2/CMP.7 for the calculation of HWP with paragraph 16 stating: “Emissions from harvested wood products already accounted for during the first commitment period on the basis of instantaneous oxidation shall be excluded” from the accounting for the second commitment period.

### 11.9.2.2 How the HWP resulting from deforestation have been accounted on the basis of instantaneous oxidation

As shown in chp. 6.11.2 the calculation of the HWP pool is made only on the basis of sawnwood production and the wood originating from deforestations is generally unsuitable for sawnwood production as it originates mostly from natural hazards and from management of forest edges at higher altitudes.

### 11.9.2.3 How $CO_2$ emissions from HWP in SWDS and from wood harvested for energy purposes have been accounted on the basis of instantaneous oxidation

There is no numerical input under "solid waste disposal" in Table4.Gs1. In chp. 6.11.2 it is stated that "the same methodology was used for reporting under the UNFCCC and accounting under the KP for HWPs in Liechtenstein." The HWP pool calculated for Liechtenstein only consists of sawnwood.

### 11.9.2.4 How emissions/removals from changes in the HWP pool accounted for do not include imported harvested wood products

As shown in chp. 6.11.2 the feedstock related to sawnwood was derived on the one hand from the data reported by Switzerland where HWPs originating from import were excluded (FOEN 2019), on the other hand from a survey in Liechtenstein including only products from domestic enterprises. Due to the customs union between Liechtenstein and Switzerland (chp. 1.4.1) there are no separate data related to import/export for Liechtenstein alone.

## 11.10 Information relating to Article 6

Liechtenstein currently does not host projects under the Joint Implementation Mechanism.

# 12. Accounting on Kyoto Units

## 12.1 Background Information

Annex I Parties are required to report their national registries' holdings and transactions of Kyoto units and inform about related issues as specified in Decision 15/CMP.1 Section E. The following chapters serve this purpose.

## 12.2 Summary of Information Reported in the SEF Tables

The tables of the Standard Electronic Format (SEF) providing all necessary information on Kyoto units (AAU, CER, ERU, tCER, lCER and RMU) for 2019 were submitted together with this report (NIR 2019). Details are disclosed in the corresponding file RREG1_LI_2020_2.zip. No CP1 units were transferred in the reporting period and therefore no SEF reports for CP1 were submitted.

## 12.3 Discrepancies and Notifications

The following information on Kyoto units are covered by the Annex of Decision 15/CMP.1 Part I.E para 12 to 17:

Para. 12: No discrepant transaction occurred in 2020. Therefore, no R-2 report was submitted.

Para. 13/14: No CDM notifications occurred in 2020. Therefore, no R-3 is submitted.

Para. 15: No non-replacements occurred in 2020. Therefore, no R-4 is submitted.

Para. 16: No invalid units exist as at 31 December 2020. Therefore, no R-5 is submitted.

There were no actions necessary to correct any problem causing a discrepancy because there were no discrepancies in 2020.

## 12.4 Publicly Accessible Information

Pursuant to paragraphs 44 to 48 in section I.E of the annex to decision 13/CMP.1, Liechtenstein makes non-confidential information available to public using Registry Homepage and/or user interface. In Liechtenstein, the following information is considered as non-confidential and publicly accessible on website

https://unionregistry.ec.europa.eu/euregistry/LI/public/reports/publicReports.xhtml

| | |
|---|---|
| **13/CMP.1 annex II paragraph 45**<br>Account information | The requested information is publicly available for all accounts. The data of operator holding accounts can be viewed online at: https://unionregistry.ec.europa.eu/euregistry/LI/public/reports/publicReports.xhtml<br>The data of all accounts can be viewed online at: https://unionregistry.ec.europa.eu/euregistry/LI/public/reports/publicReports.xhtml<br>Representative name and contact information is classified as confidential due to Article 83 paragraph 8 and 9 Registry Regulation No. 1193/2011. |
| **13/CMP.1 annex II paragraph 46**<br>Joint implementation project information | This is information is available on the website:<br>https://www.llv.li/inhalt/11315/amtsstellen/projects-approved-by-liechtenstein |
| **13/CMP.1 annex II paragraph 47**<br>Unit holding and transaction information | The information requested in (a), (d), (f) and (l) is classified as confidential due to Article 83 paragraph 1 Registry Regulation No. 1193/2011 as well as national data protection law and therefore not publicly available. Transactions of units within the most recent five-year period are also classified as confidential, therefore the transactions provided are only those completed more than five years in the past.<br>The information requested in (b), (c), (e), (g), (h), (i), (j) and (k) is publicly available at<br>https://unionregistry.ec.europa.eu/euregistry/LI/public/reports/publicReports.xhtml<br>(b) In 2018 there was no issuance of AAU.<br>(c) In 2018 no ERUs were issued.<br>(e) No RMUs were issued for the reporting year 2019 in 2020. For the current reporting year, no verified units for issuance RMUs are available at the time of submission.<br>(g) No RMUs were cancelled on the basis of activities under Article 3, paragraph 3 and 4 in the reported year.<br>(h) No ERU, CER, AAU and RMU were cancelled on the basis of activities under Article 3, paragraph 1 in the reported year.<br>(i) In 2019, no AAU, no ERU and no CER were voluntary cancelled. No |

<table>
<tr><td></td><td>RMU was cancelled.<br><br>(j) In 2020, no ERUs, no CERs, no AAUs, and no RMUs, no tCER, no lCER were retired.<br><br>(k) There was no actual carry over of ERU, CER, AAU or RMU from the previous commitment period. The planned carry-over will include 42’984 AAUs.</td></tr>
<tr><td>13/CMP.1 annex II paragraph 48<br><br>Authorized legal entities information</td><td>The following legal entities are authorized by the Member State to hold Kyoto units:
<table>
<tr><th></th><th>Legal entities authorised by Liechtenstein to hold units</th></tr>
<tr><td>AAU</td><td>Federal Government, TA</td></tr>
<tr><td>ERU</td><td>Each account holder of OHA, PHA, TA and NHA</td></tr>
<tr><td>CER</td><td>Each account holder of OHA, PHA, TA and NHA</td></tr>
<tr><td>RMU</td><td>Federal Government only, TA</td></tr>
<tr><td>tCER</td><td>Federal Government only, TA</td></tr>
<tr><td>lCER</td><td>Federal Government only, TA</td></tr>
</table>
OHA: Operator Holding Account (installation and aircraft)<br><br>PHA: Person Holding Account<br><br>TA: Trading Account<br><br>NHA: National Holding Account</td></tr>
</table>

Additionally, all required information on Article 6 projects (JI) would be available on the internet website of the Office of Environment (OE) if there would be such a project in Liechtenstein. So far, there are no JI projects in Liechtenstein (https://www.llv.li/inhalt/11315/amtsstellen/projects-approved-by-liechtenstein). This information comprises names of projects, host counties, available documents and dates.

Personalized data and some information of individual holding accounts are considered as business secrets and the disclosure may prejudice their competiveness. Information on acquiring and transferring accounts of legal entities (companies) is therefore regarded as personal data. According to article 36 of the national Act on Data Protection (Datenschutzgesetz vom 4. Oktober 20018, LGBl Nr. 2725) enacts that public authorities may disclose personal data if there is a legal basis or if there is an overriding public interest. Neither case is fulfilled and therefore the registry of Liechtenstein cannot make the information on acquiring and / or transferring accounts publicly available. All related information is considered as confidential and therefore paragraphs 44-40 of the Annex to Decision 13/CMP.1 are not applicable.

## 12.5 Calculation of the Commitment Period Reserve (CPR)

Parties are required by decision 11/CMP.1 under the Kyoto Protocol and paragraph 18 of Decision 1/CMP.8 to establish and maintain a commitment period reserve as part of their responsibility to manage and account for their assigned amount. The commitment period reserve equals the lower of either 90% of a Party’s assigned amount pursuant to Article 3(7bis), (8) and (8bis) or 100% of its most recently reviewed inventory, multiplied by 8.

The assigned amount is 1’556’044 t $CO_2$, therefore the commitment period reserve should read as 90% of the assigned amount which equals to 1’400’440 t $CO_2$. The calculation based on the most recently reviewed inventory, which was in 2020, would result in a higher value. Using the actual emission of 2018(NIR 2020) of 181’076 t $CO_2$ eq times 8 would result in 1’448’608 t $CO_2$ eq, which is higher than the CPR based on 90% of the assigned amount.

## 12.6 KP-LULUCF Accounting

Liechtenstein chose to account over the entire commitment period for emissions and removals from activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol.

12.7 PPSR-Accounts in the National Registry

Since 16 November 2016 the Union Registry provides the technical possibility to open a PPSR (previous period surplus reserve) account. However, prior to opening it, the PPSR account type must be first introduced into the EU legislative framework. This was done by the Annex of Commission Delegated Regulation 2015/1844.

This provision, however, will become applicable, according to Article 2 of the Delegated Regulation, on "the date of publication by the Commission in the Official Journal of the European Union of a communication on the entry into force of the Doha Amendment to the Kyoto Protocol". Consequently, for the moment and until the Doha Amendment enters into force, Liechtenstein is not in a position to open the PPSR account in the National Registry.

# 13. Information on Changes in National System

The National System remained unchanged during the inventory cycle leading to submission 2021.

# 14. Information on Changes in National Registry

The following changes to the national registry of Liechtenstein (LI) have therefore occurred in 2020. Note that the 2020 SIAR confirms that previous recommendations have been implemented and included in the annual report.

| Reporting Item | Description |
|---|---|
| 15/CMP.1 annex II.E paragraph 32.(a)<br><br>Change of name or contact | None |
| 15/CMP.1 annex II.E paragraph 32.(b)<br><br>Change regarding cooperation arrangement | No change of cooperation arrangement occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(c)<br><br>Change to database structure or the capacity of national registry | There has been a new EUCR release (version 11.5) after version 8.2.2 (the production version at the time of the last Chapter 14 submission).<br><br>Due to the new release, some changes were applied to the database. The updated database model is provided in Annex A. No change was required to the application backup plan or to the disaster recovery plan.<br><br>No change to the capacity of the national registry occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(d)<br><br>Change regarding conformance to technical standards | The changes that have been introduced with version 11.5 compared with version 8.2.2 of the national registry are presented in Annex B.<br><br>It is to be noted that each release of the registry is subject to both regression testing and tests related to new functionality. These tests also include thorough testing against the DES and are carried out prior to the relevant major release of the version to Production (see Annex B).<br><br>No other change in the registry's conformance to the technical standards occurred for the reported period. |

| Reporting Item | Description |
|---|---|
| 15/CMP.1 annex II.E paragraph 32.(e)<br><br>Change to discrepancies procedures | No change of discrepancies procedures occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(f)<br><br>Change regarding security | The use of soft tokens for authentication and signature was introduced for the registry end users. |
| 15/CMP.1 annex II.E paragraph 32.(g)<br><br>Change to list of publicly available information | No change to the list of publicly available information occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(h)<br><br>Change of Internet address | No change to the registry internet address during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(i)<br><br>Change regarding data integrity measures | No change of data integrity measures occurred during the reported period. |
| 15/CMP.1 annex II.E paragraph 32.(j)<br><br>Change regarding test results | No change during the reported period. |

# 15. Minimization of Adverse Impacts in Accordance with Article 3, Paragraph 14

The Convention (Art. 4 paragraphs 8 and 10) and its Kyoto Protocol (Art. 2 paragraph 3 and Art. 3 paragraph 14) commit Parties to strive to implement climate policies and measures in such a way as to minimize adverse economic, social and environmental impacts on developing countries when responding to climate change. The concrete assessment of potential impacts on developing countries is extremely complex and uncertain, as the effects are often indirect, potentially positive and negative in nature, displaced over time and interacting with other policies, including those applied in developing countries. In addition, one has to have in mind that Liechtenstein is a very small country (160 $km^2$) with a respective small share in international trade. It is thus not assumed that Liechtenstein's climate change policies have any significant adverse economic, social and environmental impacts in developing countries.

However, Liechtenstein has implemented different instruments striving at minimizing potential adverse impacts of its climate change response measures. Liechtenstein is implementing climate change response measures in all sectors and for different gases. The policies and measures are very much compatible and consistent with those of the European Union in order to avoid trade distortion, non-tariff barriers to trade and to set similar incentives. In accordance with international law, this approach strives at ensuring that Liechtenstein is implementing those climate change response measures, which are least trade distortive and do not create unnecessary barriers to trade.

Tax exemption in Switzerland and consequently also Liechtenstein (tax union) for biofuels is limited to fuels that meet ecological and social criteria. The conditions are set out in such a way that biofuels do not compete with food production and are not causing degradation of rainforests or other valuable ecosystems. The Swiss Centre for Technology Assessment (TA-Swiss) published a study on the assessment of social and environmental impacts of the use of second-generation biomass fuels with the following result: "In summary, 2nd generation biofuels allow a more sustainable mobility than both fossil and 1st generation biofuels based on agriculture. Due to the limited availability of both waste feedstocks and cultivation area, however, sustainable bioenergy-based mobility is restricted to clearly less than 8% of individual mobility in Switzerland, if constant mobility and fleet efficiency is assumed. Nevertheless, 2nd generation biofuels may play a relevant complementary part in supplying our future mobility, in particular for long distance transport and aviation where electric mobility is less suitable." (TA-SWISS 2010).

The Swiss Academies of Arts and Sciences have started a project to assess possible conflicts and synergies between the expansion of renewable energy production and land management. Many forms of renewable energy (solar, wind, water, biomass, geothermal) require considerable floor space and lead to changes in land use, ecosystems, and the views of places and landscape. Large-scale use of areas for energy production thus have to be planned considering the maintenance of ecosystem services, protection of biodiversity, or natural sceneries which are important for tourism.

An assessment of conflicts and synergies between policies and measures to mitigate climate change and biodiversity protection has been made by the biodiversity forum and

ProClim in 2008 (SCNAT 2008). While there are several synergies in the area of ecosystem management and agriculture, conflicts exist concerning the use of renewable energies, be it the adverse effects of increased hydroelectricity generation on natural water flows or the impacts of other renewable energy systems on natural landscapes and ecosystems. The report gives recommendations on how to take advantage of synergies and how to detect conflicts in an early stage.

The issue of adverse impacts of climate related policies and measures (in Liechtenstein) has been addressed by the energy strategy 2030 and energy vision 2050, adopted by the Government (2020). The strategy provides future-oriented impulses for the national energy policy. The focus areas of the concept are the promotion of efficient energy use, the use of renewable energies, and energy conservation. The energy strategy for 2030 sets the following targets:

- 20% reduction of energy consumption 2008-2030
- 30% of renewable energy by 2030 (17% produced within the country)
- 40% reduction of $CO_2$ emissions 1990-2030 (30% reduction within the country)

The long-term goals as defined in the energy vision for 2050 are the following:

- 40% reduction of energy consumption 2008-2050
- 100% of renewable energy by 2050 (as much as possible produced within the country)
- 100% reduction of $CO_2$ emissions 1990-2050

The energy strategy 2030 and energy vision 2050 reflects the need to minimize adverse effects of its proposed measures as required by Art. 3 paragraph 14 of the Convention and Art. 2 paragraph 3 of the Kyoto Protocol. The proposed set of measures has been checked against its compatibility with economic as well as social requirements. The energy strategy 2030 and energy vision 2050 follows the energy strategy 2020 (Government 2012A), for which a mid-time report about the Energy Strategy 2020 has been published by the Government in 2017 (Government 2017).

In 2015 the Government announced that Liechtenstein will aim at a reduction of greenhouse gases by 40% compared to 1990 by 2030. The assumptions underlying this reduction target are based on the possibility to achieve emission reductions abroad which may be accounted towards Liechtenstein’s reduction target in 2030. However, primary focus will be given on domestic emission reductions. In order to minimize adverse impacts related with the possibility to reduce part of its reduction target abroad the Government also decided on certain quality conditions that have to be met to that respect. Emission reductions which have been realized by Liechtenstein outside its territory therefore have to prove added ecological value, need to demonstrate social and ethical eligibility towards the people of the host country. In addition to that projects that lead to these emission reductions have to be in line with the principles of the International Humanitarian Cooperation and Development (IHZE) as contained in Art. 1 of the IHZE Act.

These Conditions have been passed by the Government within its revised Climate Strategy of October 2015 (Government 2015). Currently, a long-term climate strategy is being elaborated for Liechtenstein.

# 16. Other Information

There is no other information to be reported.

# Annexes to the National Inventory Report

## Annex 1: Key categories

All relevant information regarding the key category analysis is given in chp. 1.5.

## Annex 2: Detailed discussion of methodology and data for estimating $CO_2$ emissions from fossil fuel combustion

No supplementary information.

## Annex 3: Other detailed methodological descriptions for individual source or sink categories

### A3.1 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

- *$EF_{hot}$, $EF_{start}$, $EF_{evap,i}$, $EF_{evap-RL}$: 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 and latest in 2019. These emission factors are compiled in the “Handbook of Emission Factors for Road Transport” (HBEFA, see INFRAS 2019). The latest version 4.1 – 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 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.

## A3.2 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.

### Additional data for estimating $CH_4$ emission from 3A Enteric fermentation

Table A - 1 Data for estimating enteric fermentation emission factors for cattle (for 2019).

| Type | Age[a] | Weight[a] kg | Weight Gain[a] kg/day | Feeding Situation / Further Specification[a] | Milk[b] kg/day | Work hrs/day | Pregnant[a] % | Digestibility of feed %[d] | $CH_4$ Conversion[d] % | Em. Factor kg/head/year[e] |
|---|---|---|---|---|---|---|---|---|---|---|
| Mature Dairy Cattle | NA | 650 | 0 | | 18.9-24.5 c | 0 | 305 days of lactation | 72 | 7 | 140 |
| Other Mature Cattle | NA | 550 | 0 | | 8.2 | 0 | | 60 | 7 | 107 |
| Fattening Calves | 0-98 days | 60-200 | 1.43 | Rations of unskimmed milk and supplement feed when life weight exceeds 100 kg. Rations are apportioned on two servings per day. | 0 | 0 | 0 | 65 | 0 | 0 |
| Pre-Weaned Calves | 0-10 month | 60-325 | 1 | "Natura beef" production, milk from mother cow and additional feed. | 0 | 0 | 0 | 65 | 4 | 16 |
| Breeding Cattle 1st Year | 0-12 month | 50-300 | 0.8 | Calves: Feeding plan for a dismission with 14 to 15 weeks. Milk, feed concentrate (100kg in total), hay (80 kg in total). Cattle: Premature race (Milk-race) | 0 | 0 | 0 | 62 | var | 30 |
| Breeding Cattle 2nd Year | 12-24 month | 300-NA | 0.8 | Premature race (Milk-race) | 0 | 0 | 0 | 60 | 7 | 61 |
| Breeding Cattle 3rd Year | 24-36 month | NA-600 | 0.8 | Premature race (Milk-race) | 0 | 0 | 0 | 60 | 7 | 61 |
| Fattening Cattle | 0-12 month | 70-550 | 1.15 | Calves: Diet based on milk or milk-powder and feed concentrate, hay and/or silage Cattle: Feeding recommendations for fattening steers, concentrate based | 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.

## Additional data for estimating CH4 emission from 3B Manure management

Table A - 2 Data for estimating manure management $CH_4$ emission factors (for 2019).

| 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 | 9 - 9 | 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 | 108.5 | 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)

## Additional data for estimating $N_2O$ emissions from 3D Agricultural soils

Table A - 3 Data for estimating $N_2O$ emissions from crop residues.

| 2019 | | 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 | 560’493 | 2.3 | 0.037 |
| | Barley | 202’113 | 1.0 | 0.016 |
| | Maize | 355’810 | 3.3 | 0.053 |
| | Oats | 5’657 | 0.04 | 0.001 |
| | Rye | 0 | 0.00 | 0.000 |
| | Triticale | 28’050 | 0.1 | 0.002 |
| | Spelt | 13’388 | 0.1 | 0.002 |
| | Mix of Fodder Cereals | 25’500 | 0.1 | 0.002 |
| **2. Pulse** | Peas (Eiweisserbsen) | 0 | 0.0 | 0.000 |
| | Soybeans | 34’884 | 1.4 | 0.023 |
| | Leguminous Vegetables | 17’903 | 1.9 | 0.029 |
| **3. Tuber and Root** | Potatoes | 795’410 | 2.9 | 0.046 |
| | Fodder Beet | 72’100 | 0.5 | 0.008 |
| | Sugar Beet | 269’280 | 1.9 | 0.030 |
| **5. Other** | Fruit | 23’664 | 0.2 | 0.003 |
| | Grass | 26’240’127 | 86.5 | 1.359 |
| | Non-Leguminous Vegetables | 995’533 | 11.8 | 0.185 |
| | Rape | 39’564 | 0.7 | 0.011 |
| | Silage Corn | 6’815’400 | 4.0 | 0.063 |
| | Sunflowers | 3’876 | 0.1 | 0.001 |
| | Vine | 22’400 | 0.4 | 0.006 |
| **Total Non-leguminous** | | 10’228’237 | 30 | 0.466 |
| **Total Leguminous** | | 52’787 | 3 | 0.052 |
| **Total excluding grass** | | 10’281’024 | 33 | 0.518 |
| **Total including grass** | | 36’521’151 | 119 | 1.88 |

Table A - 4 Data for estimating $N_2O$ emissions from crop residues (fractions).

| 2019 | | Residue/ Crop ratio kg/kg | Dry matter fraction of residue kg/kg | Nitrogen content of residues kg/kg |
|---|---|---|---|---|
| **1. Cereals** | Wheat | 1.15 | 0.85 | 0.0037 |
| | Barley | 1.00 | 0.85 | 0.0051 |
| | Maize | 1.10 | 0.85 | 0.0086 |
| | Oats | 1.27 | 0.85 | 0.0049 |
| | Rye | 1.17 | 0.85 | 0.0036 |
| | Triticale | 1.25 | 0.85 | 0.0039 |
| | Spelt | 1.56 | 0.85 | 0.0059 |
| | Mix of Fodder Cereals | 1.00 | 0.85 | 0.0051 |
| **2. Pulse** | Peas (Eiweisserbsen) | 1.25 | 0.85 | 0.0235 |
| | Soybeans | 1.00 | 0.85 | 0.0412 |
| | Leguminous Vegetables | 3.87 | 0.16 | 0.0328 |
| **3. Tuber and Root** | Potatoes | 0.47 | 0.13 | 0.0127 |
| | Fodder Beet | 0.37 | 0.15 | 0.0233 |
| | Sugar Beet | 0.53 | 0.15 | 0.0220 |
| **5. Other** | Fruit | NA | 0.17 | 0.0040 |
| | Grass | 0.32 | NA | 0.0198 |
| | Non-Leguminous Vegetables | 0.46 | 0.13 | 0.0230 |
| | Rape | 2.57 | 0.85 | 0.0071 |
| | Silage Corn | 0.05 | 0.32 | 0.0118 |
| | Sunflowers | 2.00 | 0.60 | 0.0150 |
| | Vine | NA | 0.20 | 0.0060 |

## A3.3 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 2020 (FOEN 2020) 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 2020).

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 2020).

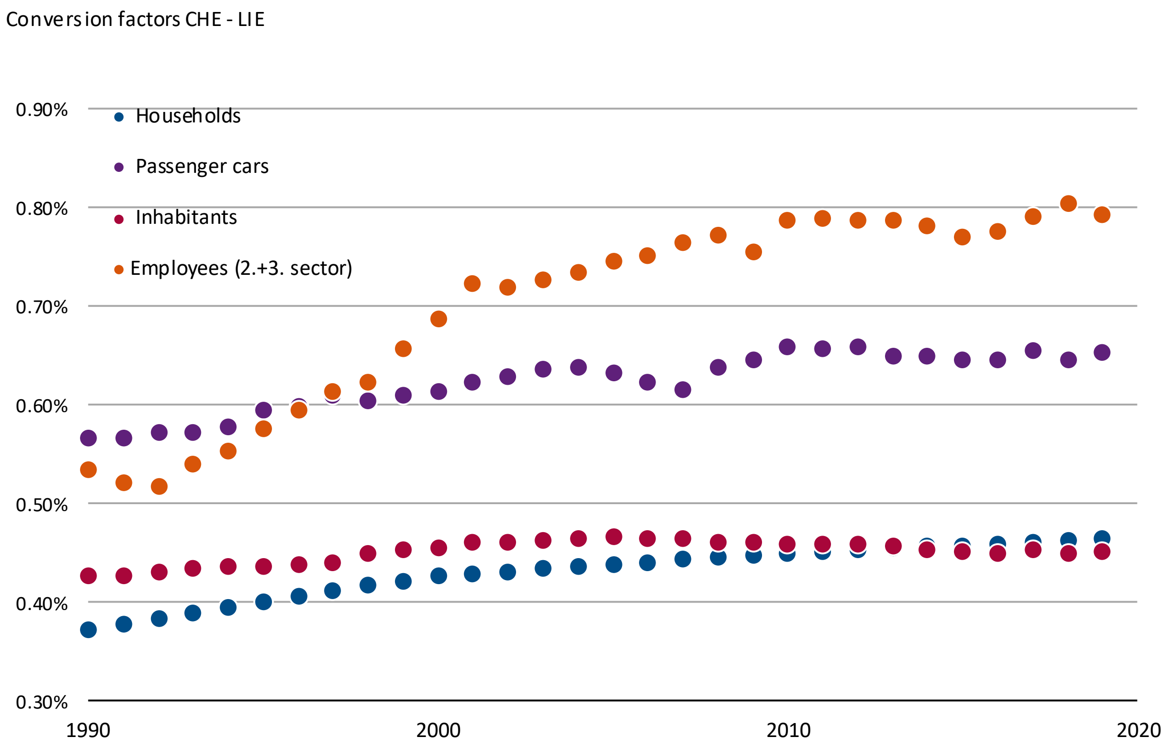



Figure A - 1 Conversion factors used to derive emissions in Liechtenstein from emissions reported in Switzerland's national GHG inventory 2020.

# Annex 4: $CO_2$ reference approach and comparison with sectoral approach, and relevant information on the national energy balance

No supplementary information to the statements given in Chapter 3.2.1 Comparison of Sectoral Approach with Reference Approach.

# Annex 5: Assessment of completeness and (potential) sources and sinks of greenhouse gas emissions and removals excluded

No supplementary information to the statements given in Chapter 1.7 assessment of completeness.

# Annex 6: Additional information to be considered as part of the NIR submission (where relevant) or other useful reference information

## A6.1 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 7: Supplementary information to the uncertainty analysis

## A7.1 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:

$$U_{\%,EF} = \sqrt{\sum_i (Em_{\%,i} * U_{\%,EF,i})^2} \qquad (1)$$ error propagation for emission factors

$$U_{\%,AD} = \sqrt{\sum_i (Em_{\%,i} * U_{\%,AD,i})^2} \qquad (2)$$ 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 - 5.

Table A - 5 Aggregation with Gaussian error propagation for the four relevant key categories.

| **1A3b $CO_2$** | (Sub)Categories | | **Aggr. Uncertainties** |
|---|---|---|---|
| | *gasoline* | *diesel* | *total/implied* |
| $U_{\%}$ Emissions | 10.0% | 15.0% | **9.2%** |
| $U_{\%}$ Activity Data | 10.0% | 15.0% | **9.2%** |
| $U_{\%}$ Emission Factor | 0.1% | 0.1% | **0.1%** |
| **1A3b $CH_4$** | (Sub)Categories | | **Aggr. Uncertainties** |
| | *gasoline* | *diesel* | *total/implied* |
| $U_{\%}$ Emissions | 60.0% | 60.0% | **46.0%** |
| $U_{\%}$ Activity Data | 10.0% | 15.0% | **8.3%** |
| $U_{\%}$ Emission Factor | 59.2% | 58.1% | **45.2%** |
| **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 | 5.1% | 5.1% | **4.1%** |
| $U_{\%}$ Activity Data | 5.0% | 5.0% | **4.0%** |
| $U_{\%}$ Emission Factor | 0.9% | 0.9% | **0.7%** |

## A7.2 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 - 6 Derivation of EF uncertainties from the relevant processes/pools in sector 4.

| Cate-gory | 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 | -0.42 | 1.00 | 2.7 | | | 46.7 | |
| 4A2 | total | 0.06 | 1.00 | 17.2 | | | 46.7 | |
| 4B1 | organic soil | -0.72 | 1.00 | 6.9 | 30.0 | 30.8 | 23.0 | |
| | total | -0.72 | 1.00 | 6.9 | | | 23.0 | |
| 4B2 | organic soil | -0.32 | 0.43 | 26.9 | 30.0 | 40.3 | 23.0 | 0.149 |
| | mineral soil | -0.27 | 0.36 | 26.9 | | | 50.0 | 0.137 |
| | total | -0.59 | 0.79 | 26.9 | | | 34.0 | 0.202 |
| 4C1 | organic soil | -0.09 | 0.77 | 6.0 | 30.0 | 30.6 | 23.0 | 0.035 |
| | mineral soil | 0.02 | 0.20 | 6.0 | | | 50.0 | 0.012 |
| | total | -0.07 | 0.98 | 6.0 | | | 55.0 | 0.037 |
| 4C2 | organic soil | -0.16 | 0.12 | 13.6 | 30.0 | 32.9 | 23.0 | 0.063 |
| | mineral soil | 0.33 | 0.25 | 13.6 | | | 50.0 | 0.164 |
| | living biom. | -0.84 | 0.63 | 13.6 | | | 40.3 | 0.338 |
| | total | -0.67 | 0.88 | 13.6 | | | 57.0 | 0.380 |
| 4D1 | total | 0.00 | 1.00 | 10.5 | | | 50.0 | |
| 4D2 | mineral soil | -0.35 | 0.28 | 40.9 | | | 50.0 | 0.176 |
| | living biom. | -0.76 | 0.61 | 40.9 | | | 40.3 | 0.307 |
| | total | -1.12 | 0.90 | 40.9 | | | 31.8 | 0.354 |
| 4E1 | mineral soil | -0.05 | 0.63 | 6.5 | | | 50.0 | 0.026 |
| | living biom. | -0.03 | 0.37 | 6.5 | | | 40.3 | 0.012 |
| | total | -0.08 | 1.00 | 6.5 | | | 34.9 | 0.029 |
| 4E2 | mineral soil | -1.14 | 0.57 | 19.4 | | | 50.0 | 0.569 |
| | living biom. | -0.85 | 0.43 | 19.4 | | | 40.3 | 0.342 |
| | total | -1.99 | 1.00 | 19.4 | | | 33.4 | 0.664 |
| 4F2 | mineral soil | -1.40 | 0.39 | 40.9 | | | 50.0 | 0.702 |
| | living biom. | -0.93 | 0.49 | 40.9 | | | 40.3 | 0.373 |
| | total | -2.33 | 0.87 | 40.9 | | | 34.1 | 0.795 |
| 4G | total | -0.05 | 1.00 | 50.0 | | | 57.0 | |

(1) related to total area (sum of organic and mineral soils) in 2018 (OE 2020).

# Annex 8: Supplementary information the QA/QC system

## A8.1 Checklists for QC activities

- Checklist for project manager (PM), project manager assistant (PMA), staff member climate unit (SC), sectoral experts (SE)
- Checklist for national inventory compiler (NIC)
- Checklist for NIR authors (NA)

Table A - 7 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 NIR authors, NIC national inventory compiler, PM project manager, PMA project manager assistant, 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, HS Heike Summer, JB Jürgen Beckbissinger, MSM Markus Sommerhalder, SH Stefan Hassler.

| **Quality Control System for Climate Reporting Liechtenstein Submission 2021** | | **Respon-sible** | **Date** | **Visa** |
|---|---|---|---|---|
| **Checklist for sectoral experts and NIR 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 | 04.11.2020 | JB, HS |
| | INFRAS-internal checks, comparison with methods chosen | NA | 09.11.2020 | BES |
| 2. Check for transcription errors in data input and reference | plausibility check of the basic input data for Solvent and Ind calculation | SE | 11.11.2020 | JB |
| | plausibility check of the basic input data from the LWA | SE | 18.11.2020 | JB |
| | check input Data for SF6 Emission calculation | SE | 25.11.2020 | JB |
| | check stationary Energy | NA | 02.12.2020 | BES |
| | check IPPU | NA | 09.12.2020 | BES |
| | check Waste | NA | 05.12.2020 | MSM |
| | Agriculture: Plausibility check of data in background tables Acontec. Issues identified and discussed with Acontec | SE | 11.12.2020 | FEW, JB |
| 3. Check that emissions are calculated correctly | Ongoing checks of the calculated emissions in all sectors | SE | 25.11.2020 | JB |
| | Clarification of data/figures | PM | 16.12.2020 | BES |
| | INFRAS-internal control: Plausibility checks, "Delta-Analysis" combined with KCA, INFRAS-internal control of time series | NA | 17.12.2020 | BES, FEW |
| | INFRAS-internal checks during generation of tables/figure in Chapter. 2 Trends (independant control by second person BES) | SE | 10.12.2020 | FEW |

| **Quality Control System for Climate Reporting Liechtenstein Submission 2021** | | **Respon-sible** | **Date** | **Visa** |
|---|---|---|---|---|
| 4. Check that parameter and emission units are correctly recorded and that appropriate conversion factors are used | check energy-activity-data (reference approach) | SE | 04.11.2020 | JB |
| | check energy-activity-data (reference approach) | NA | 09.12.2020 | BES |
| | check Energy | SE | 04.11.2020 | JB |
| | check Energy | NA | 14.12.2020 | BES |
| | check IPPU | SE | 04.11.2020 | JB |
| | check IPPU | NA | 10.12.2020 | BES |
| | check Agriculture | SE | 05.11.2020 | JB |
| | check Agriculture | NA | 11.12.2020 | FEW |
| | check LULUCF | SE | 06.11.2020 | JB |
| | check LULUCF | NA | 23.11.2020 | BRI |
| | check Waste | SE | 07.11.2020 | JB |
| | check Waste | NA | 05.12.2020 | MSM |
| | check KP-LULUCF | SE | 07.01.2021 | HS |
| | check KP-LULUCF | NA | 22.12.2021 | BRI |
| 5. Check the integrity of database files | integrity checked | SE | 18.11.2020 | JB |
| 6. Check for consistency in data between source categories | check general data consistency | SE | 18.11.2020 | JB |
| | check Energy (stationary) | NA | 09.12.2020 | BES |
| | check Energy (mobile) | NA | 10.12.2020 | BES |
| | check IPPU | NA | 11.12.2020 | BES |
| | check Agriculture | NA | 08.01.2021 | FEW |
| | check LULUCF | NA | 08.01.2021 | BRI |
| | check Waste | NA | 15.01.2021 | MSM |
| | check KP-LULUCF | NA | 07.01.2021 | BRI |
| 7. Check that the movement of inventory data among processing steps is correct | Processing checked | NIC | 11.12.2020 | HS |
| | Data transfer from the land-use statistics to the LULUCF tables and clarification of comprehensive questions with JB | SE | 06.11.2020 | HS |
| | check Agriculture | SE | 11.11.2020 | JB |
| | plausibility check / control of overall emissions from agriculture in CO2 equivalents, in total and for the source categories for all years | SE | 11.11.2020 | JB |
| | check LULUCF | SE | 12.12.2020 | HS |
| 8. Check that uncertainties in emissions and removals are estimated or calculated correctly | check Energy | NA | 08.01.2021 | FEW |
| | check IPPU | NA | 08.01.2021 | FEW |
| | check Agriculture | NA | 15.01.2021 | FEW |
| | check Waste | NA | 25.01.2021 | MSM, FEW |
| | check (KP-)LULUCF | SE | 08.01.2021 | BRI |
| 9. Check time series consistency | check for temporal consistency in time series input data for each category. | NIC | 20.01.2021 | HS |
| | check in the algorithm/method used for calculations throughout the time series. | NIC | 20.01.2021 | HS |
| | check methodological and data changes resulting in recalculations. | NA | 11.12.2020 | BES |
| | check that the effects of mitigation activities have been appropriately reflected in time series calculations. | NIC | 20.01.2021 | HS |

| **Quality Control System for Climate Reporting Liechtenstein Submission 2021** | | **Respon-sible** | **Date** | **Visa** |
|---|---|---|---|---|
| 10. Check completeness | Completeness check for all sectors | SE | 25.11.2020 | JB |
| | Completeness check for all sectors | NA | 20.01.2021 | 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 | 11.12.2020 | HS, JB, FEW, BES, ANE, MSM, BRI |
| | Check value of implied emission factors across time series. | NIC | 20.01.2021 | HS |
| | Check if there are any unusual and unexplained trends noticed for activity data or other parameters across the time series. | NIC/SE | 11.12.2020 | HS, JB, FEW, BES, ANE, MSM, BRI |
| 12. Review of internal documentation | Internal OE check of documentation; Clarification of open questions with SE | PM/PMA | 12.12.2020 | HS |
| **Further activities** | **Procedure** ***(description of checks that were carried out)*** | **Respon-sibles** | **Date** | **Visa** |
| 13. Compare estimates for key catgories to previous estimates | check of KCA previous/latest key categories | SE | 13.12.2020 | FEW, ANE |
| 14. Compare CRF tables with previous year | check Energy | NA | 02.12.2020 | BES |
| | check IPPU | NA | 03.12.2020 | BES |
| | check Agriculture | NA | 11.12.2020 | FEW |
| | check Waste | NA | 04.12.2020 | MSM |
| | check LULUCF | NA | 23.11.2020 | BRI |
| | check KP-LULUCF | NA | 08.01.2021 | 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/PMA | 6.11.2020 | HS |
| | check: Energy (stationary) | NA | 17.12.2020 | BES |
| | check: Solvents | NA | 05.12.2020 | BES |
| | Clarification of comprehensive questions in different sectors with SE | PM/NA | 10.12.2020 | HS |
| | Two independent checks of Energy (mobile) | SE | 05.12.2020 | BES |
| | check waste | NA | 15.01.2021 | MSM |
| | check Agriculture | SE | 11.12.2020 | FEW |
| | check LULUCF | SE | 13.01.2020 | 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 | 17.12.2020 | BES |
| 17. Check correctness of KCA, comparison with previous results | Plausibility checks of KCA | PM | 06.01.2021 | HS |
| | cross-check within KCA with/without LULUCF 1990 and 2014: Emissions correct, thresholds correct. Comparison with KCA of Submission Apr 2016. Plausibility checks of KCA | NA | 03.12.2020 | FEW, ANE |
| 18. Check correctness of uncertainty analysis, comparison with previous results | internal plausibility checks for all sectors | NA | 06.12.2020 | FEW |
| | internal plausibility checks for KP-LULUCF | NA | 21.01.2021 | BRI |

| **Quality Control System for Climate Reporting Liechtenstein Submission 2021** | | **Respon-sible** | **Date** | **Visa** |
|---|---|---|---|---|
| 19. Check of transcription errors CRF --> NIR (numbers, tables, figures) | INFRAS internal plausibility checks | NA | 07.01.2021 | BES |
| | check waste | NA | 21.01.2021 | MSM |
| | INFRAS-internal control. Comparison of data in CRF tables and NIR. 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 NIR and adjusts the text correspondingly. These working steps are afterwards checked by another collaborator of INFRAS. | NA | 08.01.2021 | BES, FEW |
| 20. Check AD in NIR and CRF and compare data with reference data sources | check waste | NA | 21.01.2021 | MSM |
| 21. Check for complete and correct references in NIR | INFRAS-internal checks | NA | 20.01.2021 | BES |
| 22. Check for correctness, completeness, transparency and quality of NIR | Proofread of complete draft NIR | NA | 20.01.2021 | BES |
| | final proofread Executive Summary, feedback to HS | NFP | 03.04.2021 | SH |
| | final proofread inventory/NIR, feedback and discussion with HS | QM | 04.04.2021 | SH |
| | final proofread inventory/NIR, discussion with JH and JB | PM | 1.04.2021 | BES |
| | final proofread inventory/NIR, feedback to HS | SE | 6.04.2021 | HE |
| | Internal OE discussions on the inventory/NIR draft with AG, SB, HE and HS | PM/PMA | 9.04.2021 | HS |
| | Feedback from OE internal discussions | PM/PMA | 9.04.2021 | HS |
| | Final proofreading inventory/NIR | PM/PMA | 9.04.2021 | HS |
| 23. Check for completeness of submission documents | Final check and Submission | PM/NIC NFP | 9.04.2021 | SH, HS |
| 24. Archiving activities | Archiving: INFRAS, Meteotest, save internally all data individually. NIR 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 | 9.04.2021 | BES, BRI |
| | Internal Review of documents submitted in April 2019; all relevant documents archived | NIC | 9.04.2021 | HS |

## A8.2 Checklists for QA activities (internal review)

Table A - 8 Checklists for QA activity internal review.

**Liechtenstein's National Inventory Report**
**Review form for internal review of NIR submission 2021**

| | |
|---|---|
| Reviewer | **Heike Summer (HS)** |
| Institution | Office of Environment |
| phone | +423 236 61 96 |
| e-mail | heike.summer@llv.li |
| Chapter(s) reviewed | all |

| | |
|---|---|
| NIR authors | Bettina Schaeppi (BES) |
| Institution | INFRAS |
| phone | +41 44 205 95 47 |
| e-mail | bettina.schaeppi@infras.ch |

| | |
|---|---|
| **Reviewer's comments (yellow) and answers of authors (green)** | |
| Update CRF data in the inventory report and perform completeness checks. Consider comments in the document. | |
| CRF data and completeness were checked in the NIR. All comments in the document were addressed. | |
| **Reviewers comments performed** | |
| Date / Signum | 01.04.2021 / HS |

| | |
|---|---|
| **Taken note of review** | |
| Date / Signum | 12.04.2021 / BES |

**If necessary: Additional comments of reviewer (yellow) and author's answers (green)**

| |
|---|
| none |
| |
| |

| | |
|---|---|
| | |
| Datum / Signum | 14.04.2021 / HS |

**Liechtenstein's National Inventory Report**
**Review form for internal review of NIR submission 2021**

| | |
|---|---|
| Reviewer | **Stefan Hassler (SH)** |
| Institution | Office of Environment |
| phone | +423 236 61 97 |
| e-mail | stefan.hassler@llv.li |
| Chapter(s) reviewed | ES, chp. 1 |

| | |
|---|---|
| NIR 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 | 06.04.2021 / SH |

| | |
|---|---|
| **Taken note of review** | |
| Date / Signum | 12.04.2021 / BES |

**If necessary: Additional comments of reviewer (yellow) and author's answers (green)**

none

| | |
|---|---|
| Datum / Signum | 14.04.2021 / SH |

## A8.3 Inventory development plan submission 2020

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 Report (NIR). It is updated regularly based on the recommendations of the expert review teams of the UNFCCC (ERT). The last recommendations are FCCC/ARR/2006/LIE, FCCC/ARR/2008/LIE, FCCC/ARR/2009/LIE, FCCC/ARR/2010/LIE, FCCC/ARR/2011/LIE, FCCC/ARR/2012/LIE, FCCC/ARR/2013/LIE, FCCC/ARR/2014/LIE,FCCC/ARR/2016/LIE and FCCC/ARR/2018/LIE resulting from the Centralized Reviews in 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2016 and 2018. Liechtenstein's inventory submission 2019 has not been reviewed.

For the preparation of Liechtenstein's inventory submission 2021 only preliminary findings of the expert review for submission 2020 were available. Therefore, only some of the findings were addressed in the IDP of submission 2021 as shown in the table below. Further improvements of the inventory will be planned for submission 2022 based on the final recommendations and encouragements from the centralized review of 2020.

Liechtenstein prioritizes the implementation of planned improvements based on the results of the key category analysis (see chp. 1.5) 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 summarizes the recommendations and planned improvements and illustrates the implementation status of those. A description of the headers is provided here:

**IDP No.**

The first column indicates the internal number of each point of Liechtenstein's IDP.

**Recommendations/Planned improvement**

The recommendations of the ERT or planned improvements are described in detail in the second column.

**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 2013/59 means paragraph 59 of the report on the inventory submitted in 2013, FCCC/ARR/2013/LIE.

**Status**

The status provides information about the state of development of each specific point (“not yet implemented” or “will not be implemented”).

**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 A - 9 Inventory development plan for Liechtenstein's greenhouse gas inventory 2021.

| IDP No. | Identified Issues, e.g. recommendations or planned improvements | Reference | Status | Comment/Reason NIR | Sector |
|---|---|---|---|---|---|
| 14 | Documentation of the use of results of the uncertainty analysis in the improvement of the national inventory. The ERT considers that the explanation could be enhanced by including a discussion of the linkages between the key source, uncertainty analysis and the inventory development plan. This could be achieved with the inclusion of specific references in the inventory development plan where uncertainty and key category analysis have been used to inform a particular priority improvement. | ARR 2018, ID#G.8, PMF 2020, ID#G.7 | Implemented in submission 2021 | The use of results from the KCA and the uncertainty analysis are generally used for prioritizing planned improvements (as described in chapters 1.5 and 1.6, respectively). The description of how the results of the inventory report are used in the improvement of the national inventory was added in Annex A8.3. Where relevant, the link between the IDP and the results of the uncertainty analysis and the KCA is mentioned in the respective entries of the current IDP. | 0 General |
| 15 | Methods: The ERT identified a number of instances where the use of Swiss AD, EFs and methods are not well justified and where transparency could be improved in the explanations of the applicability of Swiss parameters to Liechtenstein (see issues #E.12, I.5, A.11, W.1 and W.8)<br>The ERT encourages the Party to provide further information as specified in the issues listed to support the continued use of Swiss AD, EFs and methods and to consider undertaking further country-specific research to derive AD, EFs and methods reflective of local circumstances as resources allow. | PMF 2020, ID#G.11 | Implemented in submission 2021 | Liechtenstein provides further information as specified in the issues mentioned (see comments to issues #E.12, I.5, A.11, W.1 and W.8) that explain, why the application of Swiss AD, EFs and methods is appropriate for Liechtenstein and is applicable to the national circumstances. Liechtenstein considers undertaking further country-specific research to derive AD, EFs and methods reflective of local circumstances within the available resources. | 0 General |
| 16 | Conduct internal review complemented with systematic external review. | Review 2013 | 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 sufficently assured. The party is continuously trying to improve internal review procedures. | 0 General |
| 17 | Review and strengthen its QC procedures to eliminate errors and improve the accuracy of its emission estimates. | ARR 2013 / 21;81;87;89; Table 3; ARR 2016, ID#G.6 | 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 |
| 18 | Implement additional QC procedures to avoid mistakes or discrepancies between the CRF tables and the NIR. | ARR 2013 / 16c;21;24;35; Table 3, ARR 2018, ID#G.6, PMF 2020, ID#G.5 | 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 |
| 19 | Notation keys: The ERT recommends that the Party update CRF table 9 and NIR Annex 5 to include relevant information on where the emissions from light and heavy duty trucks are accounted for and information justifying the assumption that emissions from other carbon containing fertilisers are insignificant according to paragraph 37(b) of the UNFCCC Annex I inventory reporting guidelines. | PMF 2020, ID#G.9 | Ongoing implementation | Liechtenstein included in the NIR 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).<br>The assumption that emissions from other carbon containing fertilisers are insignificant has been justified in NIR chapter 5.10. | 0 General |
| 20 | Include in the NIR information on how priority is given to the actions listed in decision 15/CMP.1, annex, paragraph 24(a) and (b), in implementing commitments under Article 3, paragraph 14, of the Kyoto Protocol. Information in the NIR on minimization of adverse impacts. | ARR 2018, ID#G.1, PMF 2020, ID#G.1 | will not be implemented | Liechtenstein is of the view that the explanation to the ERT was of the best available knowledge. Liechtenstein can't influence the actions in Switzerland and because of the customs treaty. Therefore, this issue will remain unresolved for the future. | 0 General |

| IDP No. | Identified Issues, e.g. recommendations or planned improvements | Reference | Status | Comment/Reason NIR | Sector |
|---|---|---|---|---|---|
| 59 | Fuel combustion- reference approach - liquid fuels - CO2: Use the correct notation key "NO" for bitumen and lubricants | PMF 2020. ID#E.5, (ARR 2018 ID#E.14), PMF 2020 ID#E.6 (ARR 2018 ID#E.15) | Implemented in submission 2021 | For lubricants, the fraction of oxidized carbon was set to 1 instead oft NO, since the net carbon emissions are not equal to zero and since. This leads to an automatic calculation of actual CO2 emissions by the CRF reporter that is consistent. | 1 Energy |
| 60 | 1.A.2.e Food processing, beverages and tobacco- Gaseous fuel -CH4: The ERT recommends the Party to provide more information and justification of selection the country specific EF in the next NIR. | PMF 2020, ID#E.13 | Implemented in submission 2021 | An additional reference is provided for the country specific EF in chp.3.2.6.2 - Methodological issues - Emission factors . | 1 Energy |
| 61 | Implement additional QC procedures to avoid mistakes or discrepancies between the CRF tables and the NIR. | ARR 2013 / 21 | 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 |
| 62 | 1.A.3.b.i Cars: Diesel oil - N2O, Gaseous fuel - CH4, Diesel oil - CH4, Gasoline - CO2: The ERT recommends the Party to use latest version 4.1 of HBEFA in selection of emission factors and disaggregate emissions in categories under 1A3b in the next submission. | PMF 2020, ID#E.9, ID#E.10, ID#E.11, ID#E.12 | Ongoing implementation | Liechtenstein updated the emission factors based on the latest version of HBEFA (Version 4.1) for the road transportation model in Submission 2021. This update was given a high priority, since CO2 emissions from the combustion of fuels in Road transportation (1A3b) is a key category regarding both level and trend.<br>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.<br>A more detailed explanation was added in the NIR of submission 2021 on how the data is aggregated under source category 1A3bi – Cars (see chp. 3.2.7.2 - Methodology - Road transportation). In the CRF documentation box information on the notation keys “IE” will be integrated in submission 2022 once the final ARR of the review 2020 is available. | 1 Energy |
| 63 | 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”. | PMF 2020, ID#E.14 | Ongoing implementation | 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.<br>A more detailed explanation was added in the NIR of submission 2021 on how the data is aggregated under source category 1A3bi – Cars (see chp. 3.2.7.2 - Methodology - Road transportation). In the CRF documentation box information on the notation keys “IE” will be integrated in submission 2022 once the final ARR of the review 2020 is available. | 1 Energy |
| 71 | Data for 2G3b were not updated for Submission 2021. | Internal decision | Implemented in submission 2021 | Emission data for 2G3b were updated in Submission 2021. | 2 IPPU |

| IDP No. | Identified Issues, e.g. recommendations or planned improvements | Reference | Status | Comment/Reason NIR | Sector |
|---|---|---|---|---|---|
| 72 | 2.F.1 Refrigeration and air conditioning – HFCs and PFCs<br>The ERT notes the practicality of this approach of borrowing from the Swiss methodology, but considers that the current descriptions in the NIR are not fully representative of the methodology applied by Liechtenstein, and recommends that the Party transparently explain in the NIR how it applies the Swiss methodology to its inventory, in particular why certain gas species that are reported in the Swiss inventory are considered to not occur in Liechtenstein. | PMF 2020, ID#I.3 (ARR 2018, ID#I.4) | Implemented in submission 2021 | The description of the procedure to determine emissions of HFC and PFC was enhanced in chp. 4.7.2.<br>A more detailed description of how the threshold is applied per sub-category is provided in the NIR of submission 2021 in chp. 4.7.2.1. | 2 IPPU |
| 73 | There was an error in the preparation of the data for sectors 2F2 and 2F4 leading to a minor recalculation of the time series 2015-2018. | Internal decision | Planned improvement for 2022 | This error will be corrected in the next submission. | 2 IPPU |
| 97 | 3I: The ERT recommends that Liechtenstein reports "NE" under CO2 emissions from Other Carbon-containing Fertilizers in the next inventory submission, if justifications for the application of the insignificance threshold defined in para. 37(b) of the UNFCCC Annex I inventory reporting guidelines) have been tested and met. | ARR 2018, ID#A.11 | Implemented in submission 2021 | Urea ammonium nitrate (UAN) is used in Switzerland. On average, the share of UAN is <1% of total urea applied in Switzerland. The share of UAN used in Liechtenstein cannot be determined. However, it is very likely <1% as well, and therefore negligible. Liechtenstein will change the notation key from "NO" to "NE" in Submission 2021. Furthermore, the assumption that other carbon-containing fertilizers are insignificant has been justified in chapter 5.10 of the NIR. | 3 Agriculture |
| 98 | 3B(a): Use notation key NO instead of 0.00 | ARR 2018, ID#A.7 | Implemented in submission 2021 | The problems in CRF table 3B(a) have been resolved. | 3 Agriculture |
| 99 | 3B: Improve QC procedures to ensure the consistency of the information provided in the CRF tables. | ARR 2018, ID#A.2, ID#A.5 | Ongoing implementation | Liechtenstein will continue to optimize the consistency of the CRF tables (as far as the CRF reporter allows to alter notation keys). | 3 Agriculture |
| 100 | 3A1: Replace notation keys with numerical data in the additional information table, where appropriate, or justify the use of notation keys in a footnote or the documentation box in CRF table 3.As1. | ARR 2018, ID#A.3 | Planned improvement for 2023 | The notation keys in CRF table 3.As2 are similar to the Swiss CRF, since the methodology is the same. Only exception are the parameters weight and digestibility of feed (not for cattle, but for Swine, Sheep and other animal categories), where Liechtenstein will adjust the notation keys to the Swiss inventory.<br>Liechtenstein has added the additional information in the Annex of the NIR.<br>Furthermore, Liechtenstein will check how the justification of the notation keys could be implemented in the CRF or in the NIR for future submissions. | 3 Agriculture |
| 121 | 4: The ERT recommends that the Party be consistent in the application of Swiss data for reporting and verification purposes and highlight the use of Swiss data from the pre-Alps region prominently at the beginning of the LULUCF chapter, as done in the KP-LULUCF chapter (NIR, chapter 11.3.1.1, p.278), to make this approach more transparent. | ARR 2018, ID#L.15 | Implemented in submission 2021 | Adopted new carbon contents in biomass and soil for 4B and 4C from Swiss model results (NIR 2020). Text inserted in chp. 6.1.1. | 4 LULUCF |

| IDP No. | Identified Issues, e.g. recommendations or planned improvements | Reference | Status | Comment/Reason NIR | Sector |
|---|---|---|---|---|---|
| 122 | 4A: The ERT recommends that Liechtenstein improve the accuracy of emission/removal estimates for deadwood and litter and ensure that estimates are consistent with the UNFCCC Annex I inventory reporting guidelines (para. 4) by, for example, using expansion factors for woody components only and separating non-woody and woody litter. | ARR 2018, ID#L.16 | Implemented in submission 2021 | A new expansion factor for dead wood was derived from results of the 4th Swiss NFI (NIR chp. 6.4.2.2). Emissions/removals from deadwood and litter are now based on results of the Swiss Yasso07-model application (NIR chp. 6.4.2.5). | 4 LULUCF |
| 123 | 4A: The ERT recommends that the Party verifies that the BEFs and wood densities are still accurate for recent years or uses information from more recent Swiss NFIs to estimate BEFs and wood densities. | PMF 2020. ID#L.11 | Implemented in submission 2021 | New BEFs and densities (BCEFs) were derived from Swiss NFI4 as described in NIR chp. 6.4.2.2 | 4 LULUCF |
| 124 | In 4.C1, an inconsistency (approximately 5%) in the carbon stock change of organic soils was detected. | Internal decision | Planned improvement for 2022 | The reason for the inconsistency must be found and corrected. | 4 LULUCF |
| 125 | 4A - 4F: The ERT encourages the Party to include the necessary regular updates in the chapter on “Planned improvements for activity data” (NIR, chapter 6.3.6) to clarify that it is continuously extrapolating or interpolating data and, when available, include new data from the AREA land-use statistics. | ARR 2018, ID#L.12 | Planned improvement for 2023 | New AREA data will probably be available in summer 2022. | 4 LULUCF |
| 144 | 5B: NIR 2019, Table 7-7: The waste amount stated n row "composted centrally" is referring to wet matter (70%), and not to dry matter (30%). This mistakte might affect the calculation of respective GHG emissions. | Internal decision | Implemented in submission 2021 | Correction of error in the submission 2021 | 5 Waste |
| 145 | 5B: Activity data stated in CRF tables are referring to amounts treated in centralised composting plants only. Activity data for backyard composting need to be added. | Internal decision | Implemented in submission 2021 | Correction of error in the submission 2021 | 5 Waste |
| 146 | 5B: Activity data in CRF tables are stating amounts of organic waste composted in centralized plants, only. Activity data for backyard composting are missing. However, greenhouse gas emission estimates are taking into acoount backyard composting. Activity data in CRF tables will be revised in next submission accordingly. | Internal decision | Implemented in submission 2021 | Correction of error in the submission 2021 | 5 Waste |
| 147 | CH4 emission estimation from wastewater sewered to the wastewatertreatment plant from 2014 – 2018 was not complete. | Internal decision | Implemented in submission 2021 | A mistake in the last submission has been corrected. CH4 emission estimation from wastewater sewered to the wastewatertreatment plant from 2014 – 2018 was not complete. This leads to a considerable increase of CH4-emissions for this period. | 5 Waste |
| 148 | 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 Annex I inventory reporting guidelines. | ARR 2018, ID#W.2 | Ongoing implementation | All waste categories aren’t key sources. Therefore, a simplified uncertainty analysis has been carried out.<br>However, NIR submission 2020 CH4 emissions from 5D1 Wastewater Treatement and discharge was a key category. | 5 Waste |
| 149 | 5B: NIR 2019, Table 7-8: The waste amount stated in row "composted backyard" is referring to wet matter (70%), and not to dry matter (30%). This mistakte might affect the calculation of respective GHG emissions. | Internal decision | Planned improvement for 2022 | Correction of error in the next submission 2022 | 5 Waste |

| IDP No. | Identified Issues, e.g. recommendations or planned improvements | Reference | Status | Comment/Reason NIR | Sector |
|---|---|---|---|---|---|
| 150 | 5D: There is a mistake in the time series concerning the activity data of sewage gas losses starting from 2006. | Internal decision | Planned improvement for 2022 | Possibilities for correcting this mistake were analysed in submission 2021 and the mistake will be corrected in the next submission 2022. | 5 Waste |
| 151 | 5C: CO2 emission factor for open buring in the Swiss GHG emission calculation was slightly changed. | Internal decision | Planned improvement for 2022 | The new emission factor is going to be adopted in the next submission. | 5 Waste |
| 162 | Forest Management: The ERT recommends that the Party estimate emissions and removals for litter for the complete time series and report these in its next submission | PMF 2020. ID#KL.6 | Implemented in submission 2021 | Results from the Swiss Yasso07 model was adopted for litter and dead wood | 6 KP-LULUCF |
| 163 | Deforestation: The ERT recommends that the Party correct the error in the deforested area and report the correct numbers in its next (2021) submission. | PMF 2020. ID#KL.5, ID#L.12 | Implemented in submission 2021 | The error was corrected and the documentation of the calculation was improved (NIR Table 11-5) | 6 KP-LULUCF |
| 164 | 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. | ARR 2018, ID#L.12 | Planned improvement for 2023 | New AREA survey data will probably be available in summer 2022. | 6 KP-LULUCF |

# Annex 9: Voluntary supplementary information for article 3 paragraph 3 of the Kyoto Protocol: Kyoto tables

No supplementary information in addition to chp. 11.

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