
# ECOLOGICAL FOOTPRINT – RELOADED

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NOHALTEGKEETSROT

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## Abbreviations

| | |
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| EEA | European Environmental Agency |
| EF | Ecological Footprint |
| $EF_C$ | Ecological Footprint of Consumption |
| $EF_E$ | Ecological Footprint of Exports |
| $EF_I$ | Ecological Footprint of Imports |
| $EF_P$ | Ecological Footprint of Production |
| EOD | Earth Overshoot Day |
| FAOstats | Food and Agriculture Organization of the United Nations Statistics |
| GDP | Gross Domestic Product |
| GFN | Global Footprint Network |
| gha | global hectare |
| IEA | International Energy Agency |
| NFA | National Footprint Accounts |
| SER | Service d'Economie Rurale |
| STATEC | National Institute of statistics and economic studies of the Grand Duchy of Luxembourg |
| UN Comtrade | UN Commodity Trade Statistics Database |

## 1 Purpose of the study

In a world of growing climate change and resource constraints, running biocapacity deficits are an increasing economic risk. Yet, those risks barely appear in financial analyses, because natural capital is still incredibly cheap. However, since natural capital is so fundamental for all human activities, inadequate access can make the entire economy lose in value (e.g. a city without a clean drinking water supply will lose in value, even when water itself at the moment is still relatively cheap).

Terms like "climate protection" are often used when talking about the need for change in humanities activities. In reality though, effective climate action is largely about self-protection. The constant overuse of natural resources and the accompanying negative effects on climate and other environmental aspects cannot sustain our growing population. Global Footprint Network has kept track of the national Ecological Footprint and Biocapacity for all countries in the UN statistical data set, including Luxembourg. It shows, that the planet contained in 2016 1.6 global hectares[1] per person of biologically productive space - yet humanity demanded a flow of materials and services that took 2.75 global hectares to regenerate. The difference came from depletion.

For the year 2015, these National Footprint and Biocapacity Accounts documented for Luxembourg a demand that requires 11.5 global hectares per person of biologically productive space (Global Footprint Network 2019). Given that there are only 1.6 global hectares of biologically productive areas in the world, this means that if the global population lived like the inhabitants of Luxembourg, 7.8 Earths would be needed to provide for Luxembourg's demand. Qatar is the only country with a way of living that would, on average, take even more planets (8.8 Earths in their case).

It is not possible to overuse our planet like this forever. This biocapacity deficit of the Luxembourgish economy and the population add up to a growing debt: we are living on the resources of the young generations and those to come. Moreover, the goal is not to only reduce the demand to one planet, but to less than one planet as wild species need their space, too (Wackernagel et al. 2019).

Some may consider that this large demand poses an ethical challenge. At the very least, it points to a substantial economic risk. Given increasing ecological overshoot, how will Luxembourg be able to operate successfully, given such massive resource dependence? What are its options? Every country investing into its own long-term success makes it also more likely for other countries to succeed - because success of one aligned with our one-planet reality helps others to succeed as well. Also, we can no longer build lasting success with development models at odds with physical reality. This means that recognizing the significance of resource security becomes a positive-sum game.

Answering how many planets it takes if everybody lived like you requires clear and robust ecological accounting. It then can tell us by when in the year the world or a country has used more than what is available in the country or the world. For humanity as a whole, this date is called Earth Overshoot Day. The ecological accounts used for estimating it are provided by Global Footprint Network: they are called National Footprint and Biocapacity Accounts (Global Footprint Network 2019).

[1] Global hectares are biologically productive hectares with world average productivity. The world's surface contains about 12.2 billion biologically productive hectares (the other 48.6 billion hectares are either deserts or ice on land, or deep oceans, all of them with low concentration of biological regeneration). This means that one global hectare contains one 12.2 billionth of the earth's total biological regeneration (or biocapacity).

Ecological footprint accounting is a tool that can help countries succeed in a time of increasing ecological constraint. The accounts simply track all demands that compete for the Earth's biologically productive surfaces. These surfaces harbour biomass renewal which serves: sequestration capacity for $CO_2$ from fossil fuel burning (which is more limited than fossil fuel still underground), production of food, fibre, timber and energy production (from hydropower to biomass), use of freshwater, if it diverts water from other ecosystem uses, etc. Also, some of these productive areas are used to accommodate houses and roads. The sum of these demanded areas is called people's "Ecological Footprint"; the ability of ecosystems to renew biomass is called "biocapacity."

Both biocapacity and ecological footprint can be tracked and compared against each other, based on two simple principles: (1) one can add up all the competing demands on biologically productive surfaces, i.e., the surfaces that contain the planet's biocapacity; (2) by scaling these areas proportional to their biological productivity, they become commensurable. The scaled areas units are called "global hectares." They are biologically productive hectares with world average productivity, as explained in footnote 1.

In 2010, Hild et al. used the method of the Global Footprint Network to analyse the ecological footprint of Luxembourg and identify the main sources that increase it to such a high level. The carbon Footprint, representing the $CO_2$ emissions associated with the use of fossil fuel included in consumed products, accounts for 10.02 gha per person of the total Ecological Footprint of 11.82 gha per person. Furthermore, Hild et al. (2010) also identified fuel tourism and cross-border commuters as factors negatively affecting the Ecological Footprint of Luxembourg. Since this study has been published, several national and international environmental policies have been implemented in Luxembourg. The Institut fir Biologësch Landwirtschaft an Agrarkultur Luxemburg a.s.b.l. (Institute for Organic Agriculture Luxembourg) has been charged with re-calculating the national Ecological Footprint and its biocapacity deficit, and to assess their evolution over time.

This report merely focuses on the underlying metrics behind these statistics: to investigate to what extent Global Footprint Network's National Footprint and Biocapacity Accounts, which are all based on UN-Statistics, accurately reflect the situation of Luxembourg. Having confidence in the metric is a precondition for examining potential implications for Luxembourg, something that will be taken on after this initial investigation.

The overall aims of the study are:

1. To compare the UN data used by Global Footprint Network for producing the National Footprint and Biocapacity Accounts (NFA) of Luxembourg for the year 2016 with available national data: Are there discrepancies in the data sources and how do they impact the NFA of Luxembourg?
2. To calculate the Ecological Footprint and Biocapacity for 2018 using the best data sources identified in 1): How has the Ecological Footprint and Biocapacity evolved over time? What are the factors that most importantly impact the Ecological Footprint of Luxembourg?
3. To highlight the impact of fuel tourism and traffic: What is the impact of fuel tourism and commuters on the Ecological Footprint of Luxembourg?

During the work on this study, the following further research questions arose and have been assessed additionally:

- What impact do political decisions such as increase of renewable energies and promotion of electro-mobility have on the Ecological Footprint of Luxembourg?
- What Footprint does food consumption in Luxembourg have and how far does the reduction of food waste help to decrease the Ecological Footprint of Luxembourg?
- Can the impact of the service industry on the Ecological Footprint be quantified? Could it explain a disproportionally large Luxembourgish Ecological Footprint?

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- What Footprint does food consumption in Luxembourg have and how far does the reduction of food waste help to decrease the EF of Luxembourg?
- Can the impact of the service industry on the EF be quantified? Could it explain a disbalance in the Luxembourgish EF?

## 2 Materials and Methods

### *2.1 Principles of Ecological Footprint Calculation*

The calculation of the Ecological Footprint by Global Footprint Network is an accounting system to track the amount of biologically productive land and water areas that are required by a country to produce the natural resources it consumes and to absorb the emissions it generates, using prevailing technology and management strategies (Wackernagel et al. 2002, Wackernagel et al. 2019). These areas are not necessarily located in the assessed country itself, but could be located anywhere in the world and imported in form of resources to the country (Mancini 2016, Wackernagel & Beyer 2019, EEA 2020).

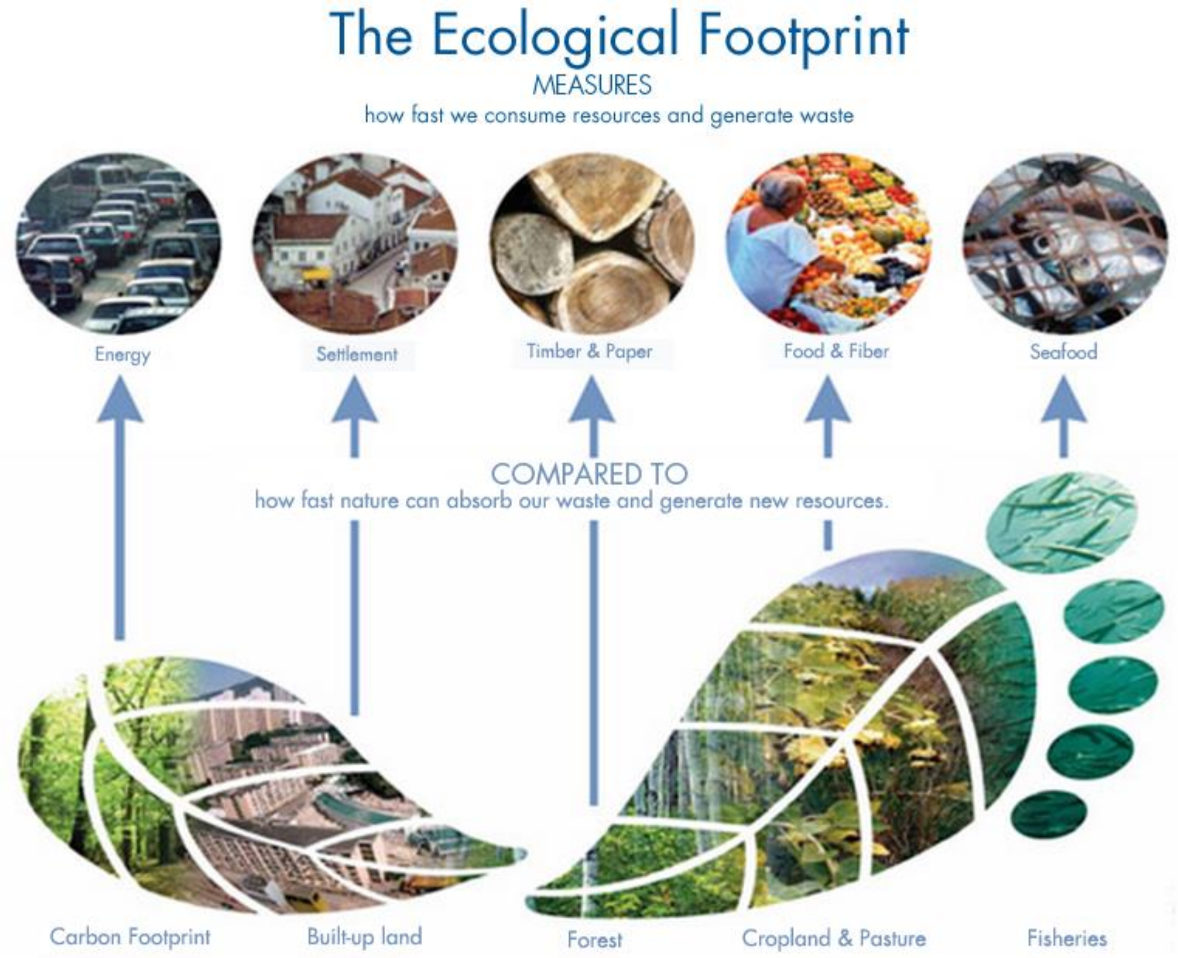


*Figure 1: The ecological footprint tracks the use of six categories of productive surface areas cropland, grazing land, fishing grounds, built-up land, forest area and carbon demand on land. On the supply side, a nation's Biocapacity represents the productivity of its ecological assets (Global Footprint Network 2020d).*

The accounting has two sides: on the one hand, the EFEcological Footprint, the demand that humans place on bioproductive areas and, on the other hand, Biocapacity, the nature's availability to provide the resources and ecosystem services that are annually consumed by humans (Kitzes et al. 2009). The measurement unit of this material balance approach is global hectares (gha), which is the common unit to make the results comparable all over the world. The data from open source data platforms, such as statistics unit of the United Nations' Food and Agriculture Organization (FAOSTAT), United Nations' Commodity Trade Statistics Database (UN Comtrade) or International Energy Agency (IEA), are used to calculate national human consumption and its footprint. Thus, in terms of the EFEcological Footprint calculation, the carbon Footprint portion is one part of a full EFEcological Footprint  analysis where the greenhouse gas (GHG) emissions are translated into global hectares necessary to adsorb these emissions (Kitzes et al. 2009). However, the EFEcological Footprint  is much more than the carbon Footprint.

National Footprint and Biocapacity Accounts use six land use types that are needed to produce the resources consumed: cropland, forest land, grazing land, fishing grounds, built-up land and carbon uptake land.

In 2008, the overall Luxembourgish consumption required 5,549,008 gha, equalling 11.83 gha per person (Hild et al. 2010). In comparison, 898.'796 gha of land contributed to Luxembourg's biocapacity, where water areas are negligible (Hild et al. 2010). According to the glossary of GFNGlobal Footprint Network (GFNGlobal Footprint Network 2020b, see annex Glossary) the five area types for Biocapacity (cropland, forests, grazing land, fishing grounds and built-up land) supporting the six Footprint demand types (cropland Footprint, forest product Footprint, carbon Footprint, grazing land Footprint, fishing grounds Footprint and built-up land Footprint) are the following and related to each other as depicted in Figure 1:

1) ***Cropland****: Cropland is the most bioproductive of all the land-use types and consists of areas used to produce food and fiber for human consumption, feed for livestock, oil crops, and rubber. Due to lack of globally consistent data sets, current cropland Footprint calculations do not yet take into account the extent to which farming techniques or unsustainable agricultural practices may cause long-term degradation of soil. The (1) cropland Footprint includes crop products allocated to livestock and aquaculture feed mixes, and those used for fibers and materials.*
2) ***Forests*** *provide two services: The (2) forest product Footprint, which is calculated based on the amount of lumber, pulp, timber products, and fuel wood consumed by a country on a yearly basis. It also accommodates the (3) carbon Footprint, which represents the carbon dioxide emissions from burning fossil fuels. The carbon Footprint also includes embodied carbon in imported goods. It is represented by the area necessary to sequester these carbon emissions. The carbon Footprint component of the Ecological Footprint is calculated as the amount of forest land needed to absorb these carbon dioxide emissions. Currently, the carbon Footprint is the largest portion of humanity's Footprint.*
3) ***Grazing land****: Grazing land is used to raise livestock for meat, dairy, hide, and wool products. The (4) grazing land Footprint is calculated by comparing the amount of livestock feed available in a country with the amount of feed required for all livestock in that year, with the remainder of feed demand assumed to come from grazing land.*
4) ***Fishing grounds****: The (5) fishing grounds Footprint is calculated based on estimates of the maximum sustainable catch for a variety of fish species. These sustainable catch estimates are converted into an equivalent mass of primary production based on the various species' trophic levels. This estimate of maximum harvestable primary production is then divided amongst the continental shelf areas of the world. Fish caught and used in aquaculture feed mixes are included.*
5) ***Built-up land****: The (6) built-up land Footprint is calculated based on the area of land covered by human infrastructure — transportation, housing, industrial structures, and reservoirs for hydro-power. Built-up land may occupy what would previously have been cropland.*

### 2.2 Advantages of Ecological Footprint calculation

According to the Global Footprint Network, Ecological Footprint accounting provides a biological view of the world: it builds on the insight that the biosphere's power to regenerate has become too small compared to human demand, leading to climate change, biodiversity loss, water scarcity etc. Explaining the challenges from this biological perspective has various advantages:

- This biological approach joins all the human pressures – from water, climate, biodiversity, food, energy, etc. – under one roof. This enables us to solve them all together (rather than one at the cost of another one.). This also helps build the needed bridge between conservation and climate change.
- Ecological Footprint results are understandable. Very few relate to 2°C, ppm, or tons of carbon (or did the number refer to $CO_2$?). But even primary school kids understand number of planets, Earth Overshoot Day, or hectares.
- Perhaps most importantly: In contrast to the 'carbon-only' view, this biological approach makes the company, city or country's economic self-interest clear and obvious. It emphasizes resource security, and the risk to each country for not being prepared. In other words, it helps see climate action as necessary rather than noble. The current climate debate is based on a "noble argument" ("it is our responsibility to humanity and the future"), leading to timid action. In reality, a country's competitiveness and success depends on aggressive climate action, preparing itself for an inevitable carbon-free future, thereby strengthening its own resource security.

### 2.3 Limitations of Ecological Footprint calculation

There are many important limitations, largely based on the specific research question driving the NFA. Accounting provides a description of outcomes. Therefore, it reports on the overall outcomes independent of the causes.

There are six key assumptions behind the methodological that affect the uncertainty of Ecological Footprint accounting EEA (2020):

*1. Annual amounts of biological resources consumed and wastes generated by countries are tracked by national and international organisations.*

*2. The quantity of biological resources appropriated for human use is directly related to the amount of bioproductive land area necessary for their regeneration and for the assimilation of wastes.*

*3. By weighting each area in proportion to its inherent ability to regenerate biomass, the different areas can be expressed in terms of a standardised average productive hectare (a global hectare).*

*4. The overall demand in global hectares can be aggregated by adding all mutually exclusive resource-providing and waste-assimilating areas required to support the demand.*

*5. Aggregated human demand (Ecological Footprint) and nature's supply (Biocapacity) can be directly compared to each other.*

*6. Area demand can exceed area supply.*

In addition to the methodological uncertainties, the EEA (2020) describes the main limitations of the Ecological Footprint and Biocapacity accounting concepts.

*1 Non-ecological aspects of sustainability: having a footprint smaller than the biosphere is a necessary minimum condition for a sustainable society, but it is not sufficient. For instance, the Ecological Footprint does not consider social well-being. In addition, on the resource side, even if the Ecological Footprint is within Biocapacity, poor management can still lead to depletion. A footprint smaller than Biocapacity is merely a necessary condition for making quality improvements replicable and scalable.*

*2. Depletion of non-renewable resources: the footprint does not track the amount of non-renewable resource stocks, such as oil, natural gas, coal or metal deposits. The footprint associated with these materials is based on the regenerative capacity used or compromised by their extraction and, in the case of fossil fuels, the area required to assimilate the wastes they generate.*

*3. Inherently unsustainable activities: activities that are inherently unsustainable, such as the release of heavy metals, radioactive materials and persistent synthetic compounds (e.g. chlordane, polychlorinated biphenyls (PCBs), chlorofluorocarbons (CFCs), polyvinyl chloride (PVC), dioxins, etc.), do not enter directly into footprint calculations. These are activities that need to be phased out independently of their quantity (there is no Biocapacity budget for using them). Where these substances cause a loss of Biocapacity, however, their influence can be seen.*

*4. Ecological degradation: the footprint does not directly measure ecological degradation, such as increased soil salinity from irrigation, which could affect future bioproductivity. However, if degradation leads to reductions in bioproductivity, then this loss is captured when measuring Biocapacity in the future. Moreover, by looking at only the aggregate figure, 'under-exploitation' in one area (e.g. forests) can hide over-exploitation in another area (e.g. fisheries).*

*5. Resilience of ecosystems: footprint accounts do not identify where and in what way the capacity of ecosystems are vulnerable or resilient. The footprint is merely an outcome measure documenting how much of the biosphere is being used compared with how productive it is.*

Several aspects of usage of the environment are not addressed in the National Footprint and Biocapacity Accounts and are often discussed. Kitzes et al. (2009a) sum up the most common questions of Ecological Footprint accounting, amongst others, regarding to water usage, biodiversity, weighting coefficients and conclusions of the calculations. Biodiversity is not explicitly part of Ecological Footprint accounting and does not directly affect human demand. Kitzes et al. (2009a) stated that (1) Ecological Footprint is an indicator of drivers and pressures causing biodiversity loss (2) Ecological Footprint translates the consumption into a specific local land area from which in turn affects biodiversity and (3) humans demand resources that are in direct competition with consumption needs of wild species (Raven and Wackernagel 2020).

It is commonly known that Ecological Footprint is simplified view of a very complex system (Kitzes et al 2009b). Ecological Footprint accounts are a descriptor of one particular aspect: how much biologically active area is used compared to how much is regenerated. It is thus of the utmost importance to remember these limitations and constraints of Ecological Footprint when discussing the results, and interpret them with the necessary caution. However, one of the strengths of the model is the well-established methodology, its clear research question, its historical continuity and stability, and the continuous adaption to new findings, data sources and methodology over 20 years leading to improved scientific robustness of the accounts (Kitzes et al. 2009b, Lin et al. 2018, EEA 2020). Further assets of Ecological Footprint accounting are that the indicator is calculated consistently across all countries (using UN data as a neutral, generally accepted data input) and the calculations are updated annually, now covering the period of 1961-2016. The NFAs are descriptive, not normative. They do not provide any conclusions about who should be using what kind of resources and does not provide any suggestions to reduce the Ecological Footprint or even respond to moral and ethical questions (Kitzes et al. 2009a). It is a tool to help to inform about social and political choices (Kitzes et al. 2009a) and can be used to estimate the effects of possible decisions to increase their own resource security.

## *2.4 Methodology*

### 2.4.1 Calculation of National Footprint Accounts

National Footprint and Biocapacity Accounts are primarily based on UN and para-UN data sources including FAOstat, UN Comtrade, IEA (Kitzes et al. 2009b). These data platforms receive the data from national statistical offices that are responsible for the accuracy of provided data. Kitzes et al. (2009b) emphasize that high resolution, accurate data sets are available for many high-income countries. STATEC, the National Institute of statistics and economic studies of the Grand Duchy of Luxembourg is scientifically independent and provides data in neutrality.

The calculation of the Ecological Footprints and Biocapacity of Luxembourg is based on the National Footprint Accounts (NFA) (2019 edition) provided by Global Footprint Network. The NFA calculation is documented in Excel-based workbook with several interconnected sheets. This workbook starts from slightly cleaned input data from FAOSTAT, UN Comtrade and IEA and then calculates the necessary amount of gha to produce the goods and to absorb the wastes in its attempt to estimate countries' footprints. The detailed overview of worksheets for the different footprints is given in "Working Guidebook to the National Footprint and Biocapacity Accounts" (Lin et al. 2019). The different worksheets summarize the footprints of production ($EF_P$), imports ($EF_I$) and exports ($EF_E$) and consumption ($EF_C$), where the $EF_P$ is the footprint that gets affected by the structure of the domestic economy. ($EF_P + EF_I - EF_E = EF_C$).

The first step of the work consisted in the calculation of the EF of Luxembourg for 2016 by using, to the extent possible, national data sources (e.g. STATEC, Service d'Économie Rurale (SER)). Thus, results obtained from national databases have been compared to the Ecological Footprint calculation of Luxembourg for 2016 supplied by Global Footprint Network. By filing up the Excel workbook, it is possible to conclude on the similarity of the data. Except of some differences, mainly arising from more recent data, no notable discrepancies occur using the data from one or another source. As previously discussed by Hild et al. (2010), data is often needed in specific units or in a specific compilation that are not available nationally, especially with regards to the Standard International Trade Classification (SITC) categories. For these commodities, international data was used only. The related data sources for the calculation by IBLA of NFA 2016 and NFA 2018 are presented in the following sections.

According to the Working Guidebook (Lin et al. 2019):

- *ef_carbon* summarizes the carbon Footprint of fossil fuel combustion and electricity trade (for the Standard International Trade Classification (SITC) categories, exports and imports for each good);
- *ef_crop* summarizes the Footprint of cropland embodied in crop products and feed products for livestock and fish;
- *ef_grazing* summarizes the Footprint of pasture and grass embodied in livestock products;
- *ef_fish* summarizes the Footprint of marine and inland water areas embodied in fish and other aquatic products;
- *ef_forest* summarizes the Footprint of forest products Footprint embodied in primary and secondary forest products;
- *ef_build* summarizes the Footprint associated with infrastructure;
- *biocap* reports a country's bioproductive area and Biocapacity in each of the six land use types.

According to the Ecological Footprint Atlas by Global Footprint Network (Ewing et al. 2010), *the Ecological Footprint calculates the combined demand for ecological resources wherever they are located and presents them as the global average area needed to support a specific human activity. This quantity is expressed in units of global hectares, defined as hectares of bioproductive area with world average bioproductivity. By expressing all results in a common unit, Biocapacity and Footprints can be directly compared across land use types and countries. Demand for resource production and waste assimilation are translated into global hectares by dividing the total amount of a resource consumed by the yield per hectare, or dividing the waste emitted by the absorptive capacity per hectare. Yields are calculated based on various international statistics, primarily those from the United Nations Food and Agriculture Organization (FAO ResourceSTAT Statistical Databases). Yields are mutually exclusive: If two crops are grown at the same time on the same hectare, one portion of the hectare is assigned to one crop, and the remainder to the other. This avoids double counting. This follows the same logic as measuring the size of a farm: Each hectare is only counted once, even though it might provide multiple services.*

*The Ecological Footprint, in its most basic form, is calculated by the following equation (Eq. 1):*

$$EF = \frac{D_{Annual}}{Y_{Annual}}$$

*here D is the annual demand of a product and Y is the annual yield of the same product. Yield is expressed in global hectares. Global hectares are estimated with the help of two factors: the yield factors (that compare national average yield per hectare to world average yield in the same land category) and the equivalence factors (which capture the relative productivity among the various land and sea area types).*

*Therefore, the formula of the Ecological Footprint becomes (Eq. 2):*

$$EF = \frac{P}{Y_N} * YF * EQF$$

*where P is the amount of a product harvested or waste emitted (equal to $D_{Annual}$ above), $Y_N$ is the national average yield for P, and YF and EQF are the yield factor and equivalence factor, respectively, for the country and land use type in question. The yield factor is the ratio of national-to world-average yields. It is calculated as the annual availability of usable products and varies by country and year. Equivalence factors translate the area supplied or demanded of a specific land use type (e.g. world average cropland, grazing land, etc.) into units of world average biologically productive area: global hectares and varies by land use type and year.*

*Annual demand for manufactured or derivative products (e.g. flour or wood pulp), is converted into primary product equivalents (e.g. wheat or roundwood) through the use of extraction rates. These quantities of primary product equivalents are then translated into an Ecological Footprint. The Ecological Footprint also embodies the energy required for the manufacturing process.*

*The Ecological Footprint of consumption for a given country measures the Biocapacity demanded by the final consumption of all the residents of the country. This includes their household consumption as well as their collective consumption, such as schools, roads, fire brigades, etc., which serve the household, but may not be directly paid for by the households. In contrast, a country's primary production Ecological Footprint is the sum of the Footprints for all resources harvested and all waste generated within the country's geographical borders. This includes all the area within a country necessary for supporting the actual harvest of primary products (cropland, grazing land, forest land, and fishing grounds), the country's infrastructure and hydropower (built-up land), and the area* *needed to absorb fossil fuel carbon dioxide emissions generated within the country (carbon Footprint). The difference between the production and consumption Footprint is trade, shown by the following equation (Eq. 3):*

$$EF_C = EF_P + EF_I - EF_E$$

*where $EF_C$ is the Ecological Footprint of consumption, $EF_P$ is the Ecological Footprint of production, and $EF_I$ and $EF_E$ are the Footprints of imported and exported commodity flows, respectively.*

*In order to measure the Footprint of imports and exports, one needs to know both the amounts traded as well as the embodied resources (including carbon dioxide emissions) in all categories. The embodied Footprint is measured as the number of global hectares required to make a tonne per year of a given product.*

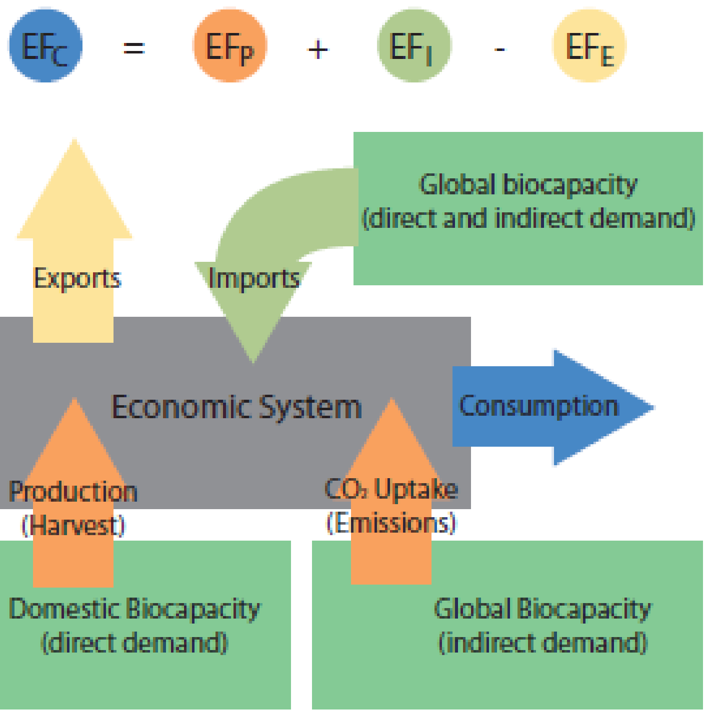


*Figure 2: Calculation of the Ecological Footprint of Consumption (Ewing et al. 2010)*

*The National Footprint Accounts, 2010 Edition track the embodied Ecological Footprint of over 700 categories of traded crop, forest, livestock, and fish products. The embodied carbon dioxide emissions in 625 categories of products is used with trade flows from the United Nation's COMTRADE database (UN Commodity Trade Statistics Database 2007) to calculate the embodied carbon Footprint in traded goods. Throughout the National Footprint Accounts, the embodied Footprint of trade is calculated assuming world average Footprint intensities for all products. Using world-average efficiencies for all traded goods is an overestimate of the Footprint of exports for countries with higher-than-average production efficiency. In turn, it underestimates that country's Footprint of consumption. For countries with below-average transformation efficiencies for secondary products, the opposite is true: An underestimate of the embodied Footprint of exports yields an exaggerated Footprint of consumption. The Footprint intensity of any primary product is by definition the same anywhere in the world since it is expressed in global hectares. However, the embodied Footprint of secondary products will depend on transformation efficiencies ("extraction rates"), and these vary between countries.*

*A national Biocapacity calculation starts with the total amount of bioproductive land available. "Bioproductive" refers to land and water that supports significant photosynthetic activity and accumulation of biomass, ignoring barren areas of low, dispersed productivity. This is not to say that areas such as the Sahara Desert, Antarctica, or Alpine mountaintops do not support life; their production is simply too widespread to be directly harvestable by humans. Biocapacity is an aggregated measure of the amount of land available, weighted by the productivity of that land. It represents the ability of the biosphere to produce crops, livestock (pasture), timber products (forest), and fish, as well as to uptake carbon dioxide in forests. It also includes how much of this regenerative capacity is occupied by infrastructure (built-up land). In short, it measures the ability of available terrestrial and aquatic areas to provide ecological services. A country's Biocapacity for any land use type is calculated as (Eq. 4)*

$$BC = A * YF * EQF$$

*where BC is the Biocapacity, A is the area available for a given land use type, and YF and EQF are the yield factor and equivalence factor, respectively, for the country land use type in question. The yield factor is the ratio of national to world average yields. It is calculated as the annual availability of usable products and varies by country and year. Equivalence factors translate the area supplied or demanded of a specific land use type (e.g. world average cropland, grazing land, etc.) into units of world average biologically productive area (global hectares) and varies by land use type and year.*

To compare the NFA of different countries, political units or the world, the ecological deficit and the number of planets used, are calculated as follows based on the EF and Biocapacity (Eq. 5).

$$ED = EF_C - BC$$

where ED is the ecological deficit (gha), $EF_C$ is the national Footprint of consumption (gha) and BC is the national Biocapacity (gha).

$$planets = \frac{EF_C}{BC_{global}}$$

where $EF_C$ is the national Footprint of consumption (gha) and $BC_{global}$ is the average global Biocapacity (gha).

To highlight the relation between sum of the Footprints or between the Biocapacity and statistical key figures, the Pearson correlation coefficient has been calculated. Assuming independency of the observations, normal distribution of the variables and a linear relation between the variables, the correlation is calculated according to (Eq. 6, Schönwiese 2000):

$$r_{XY} = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

Where $r_{XY}$ is the PEARSON correlation between X and Y, n is the sample size, the $X_i$ and $Y_i$ are a pair of random variables, $\bar{X}$ and $\bar{Y}$ are the means of X and Y.

First, the calculation of the NFA of Luxembourg by Global Footprint Network for the year 2016 (Global Footprint Network 2016) was checked in terms of the data used. The accounting carried out by Global Footprint Network uses international databases. In the study at hand, the dataset for the NFA consisting of ~5.400 data points for 2016 was checked to see if better and more accurate data were available in national databases (IBLA 2016). National data were obtained from the National Institute of statistics and economic studies STATEC and the Service d'Economie Rural (SER). The NFA for 2016 was recalculated based on these national datasets and compared to the accounting by Global Footprint Network (see chapter 3.2). In a second step, the NFA calculation was performed for 2018 based on the same available dataset (IBLA 218). The year 2018 was chosen for the calculation of the newest NFA of Luxembourg as almost all national statistics for that year were available when the project started at the end of 2019. Whenever the data for 2018 was not yet available, the data from 2017 was used. The different Footprints for cropland, forest land, grazing land, fishing grounds as well as the carbon Footprint are depicted in time series from 1961-2018 to show their development and fluctuations over the years and correlations between the factors are evaluated.

### 2.4.2 Consideration of specific Footprints

It was of special interest to identify some of the factors that play an important role for the Luxembourgish Ecological Footprint. A few aspects are being highlighted that are peculiarities of Luxembourg: Traffic and fuel consumption, and cross border commuters.

Fuel consumption and traffic Footprint: The impact of fuel tourism and the high number of commuters from abroad, which is commonly seen as one of the most important factors increasing the EF, is examined using national Luxembourgish studies. The consumption of fuel by cross-border commuters and transit traffic is mainly assessed based on energy consumption data by STATEC (2020) and traffic data by Ewringmann (2016). Energy consumption in GWh (Table 14) and travelled vehicle kilometers (vkm, Table 15) have been translated into related amounts of energy and $CO_{2e}$ using the key metrics shown in Table 1. These million t of $CO_2$ can be converted into global hectares (gha) using the Footprint intensity of carbon (Table 2).

*Table 1: Conversion factors fuel consumption (GWh) into gha for petrol, car diesel, truck diesel and kerosene (*Schmied & Knörr 2011; **UBA 2019).*

| | $kWh\ l^{-1}$ | $kg\ CO_2\ l^{-1}$ | $kg\ CO_2\ 100\ km^{-1}$ |
|---|---|---|---|
| *petrol* | 8.67[2] | 2.37[3] | 23.3 |
| *car diesel* | 9.79[2] | 2.65[3] | 20.8 |
| *truck diesel* | 10.04* | 2.65* | |
| *kerosene* | 11.9** | 3.15** | |

The main conversion factors are listed in the NFA 2019 edition, *cnst_carbon* (Global Footprint Network 2019):

*Table 2: Conversion factors according to NFA 2019 edition, cnst_carbon (Global Footprint Network 2019).*

| *Name* | *Unit* | *Value* |
|---|---|---|
| *C to $CO_2$ Ratio* | $[t\ C\ (t\ CO_2)^{-1}]$ | 0,27 |
| *Carbon Sequestration Factor* | $[t\ C\ wha^{-1}\ yr^{-1}]$ | 0,73 |
| *Ocean Uptake Fraction* | [-] | 0,301 |
| *National Electricity Carbon Intensity* | $[Mt\ CO_2\ (GWh)^{-1}]$ | 8,30E-05 |
| *Regional Electricity Carbon Intensity* | $[Mt\ CO_2\ (GWh)^{-1}]$ | 2,91E-04 |
| *World Primary Energy Carbon Intensity* | $[t\ CO_2\ GJ^{-1}]$ | 5,61E-02 |
| *Total Primary Energy Supply* | [PJ] | 154,493 |
| *Footprint Intensity of Carbon* | $[gha\ (t\ CO_2\ (yr^{-1}))^{-1}]$ | 0,334 |

[2] https://www.energie-gedanken.ch/umrechnungsfaktoren/, Accessed 20.05.2020
[3] https://www.helmholtz.de/erde_und_umwelt/wie-viel-co2-steckt-in-einem-liter-benzin/, Accessed 20.05.2020

Cross-border commuters Footprint: To evaluate the impact of cross-border commuters on the Luxembourgish EF, the household final consumption expenditures (HFCE) of Luxembourg and the study by Mathä et al. (2012) on the expenditures of cross-border commuters in Luxembourg for different categories of consumption have been put in relation to each other (Table 3). HFCE on the territory in 2010 have been 14,713 Million € compared to 20,004 Million € in 2018 (STATEC 2020). The percentage HFCE by non-residents on the territory made up about 23.3 % of total HFCE in 2010. Cross-border commuters working in Luxembourg contribute, according to Mathä et al. (2012) with 1,315 Mill. € to HFCE, equalling 8.9 % of total HFCE.

Mathä et al. (2012) investigated the product-related, cross-border consumer behaviour. The household survey among cross-border commuters from Belgium, Germany and France included the following product categories: fuel, alcohol, tobacco, food, clothing, automotive, furniture expenses. In 2010. 9.300 € per commuter, which is 17 % of the gross income, have been spend in Luxembourg. In total, commuters spend about 9 % of HFCE on the territory (accommodation, electricity, water, gas etc. not included). The expenditures of the cross-border commuters for the different HFCE categories are related to the HFCE on the territory for the corresponding categories. The percentage in 2010 is used to calculate the portion of cross-border commuters on the Ecological Footprint for these categories (Table 18).

*Table 3: Household final consumption expenditures (HFCE) in 2010 and 2018 (STATEC 2020). HFCE by commuters on the territory according to Mathä et al. (2012).*

| | *2010* Mill. € | $HFCE_{terr}$ (%) | *1,000 persons* | *2018* Mill. € | $HFCE_{terr}$ (%) | *1,000 persons* |
|---|---|---|---|---|---|---|
| *HFCE on the territory* | 14712.6 | | | 20003.5 | | |
| *HFCE by non-residents on the territory* | 3424.5 | 23.3 | | 3997.6 | 20.0 | |
| *HFCE by commuters on the territory* | 1315.2 | 8.9 | | | | |
| *HFCE by residents abroad* | 1088.7 | 7.4 | | 1271.1 | 6.1 | |
| *Inhabitants* | | | 502.1 | | | 602.0 |
| *Employees* | | | 340.6 | | | 427.4 |
| *Cross-border commuters* | | | 151.9 | | | 186.0 |

Food Footprint: The assessment of the Food Footprint is based on the NFA 2018 for Luxembourg. The ecological footprints of the imports, exports and production of the different food products are compiled from the carbon Footprint, the cropland Footprint and the grazing land Footprint. The overall food Footprint of consumption is calculated using Equation 3: $EF_E = EF_I + EF_P - EF_E$.

The NFA, however, does not provide any possibility for modelling directly the impacts of political measures and frameworks. Therefore, national studies need to be considered in order to evaluate the impact of environmental and energy politics: the data from these studies is used to calculate and assess their prospective effects on the EF. Additionally, he reduction potential is assessed for the following issues:

- increase of renewable energies and electro mobility according to the National Climate Action Plan 2021-2030 (NECP; MEAT & MECDD 2020)

- impact of service employee's workplaces (Maas et al. 2012, Ministère du Travail 2017, STATEC 2020) and data centres and

- reduction of household and food wastes (Schaeler et al. 2019). Many of these approaches are also discussed in various environmental action plans.

The related studies and key parameters are described in the particular sections of Chapter 3.

### *2.5 Characteristics of the Grand-Duchy of Luxembourg*

The surface of the Grand-Duchy of Luxembourg is 2586km², of which 52.6% (131,384 ha) are agricultural land (Service d'Economie Rurale, 2016). Of these 131,384 ha, 47.8% (62,798 ha) are arable land and 50.9% (66,923 ha) grassland (Service d'Economie Rurale, 2016). The population of the Grand-Duchy of Luxembourg has seen a drastic increase over the last decade from 493,500 in 2008 to 613,894 in 2018 (STATEC 2020) and is expected to reach 938,416 by 2050 (Eurostat, 2017). The active population of Luxembourg was 280,235 in 2018 and an additional 196,808 cross border commuters worked in Luxembourg, making up over 40% of the total workforce in Luxembourg (STATEC 2020).

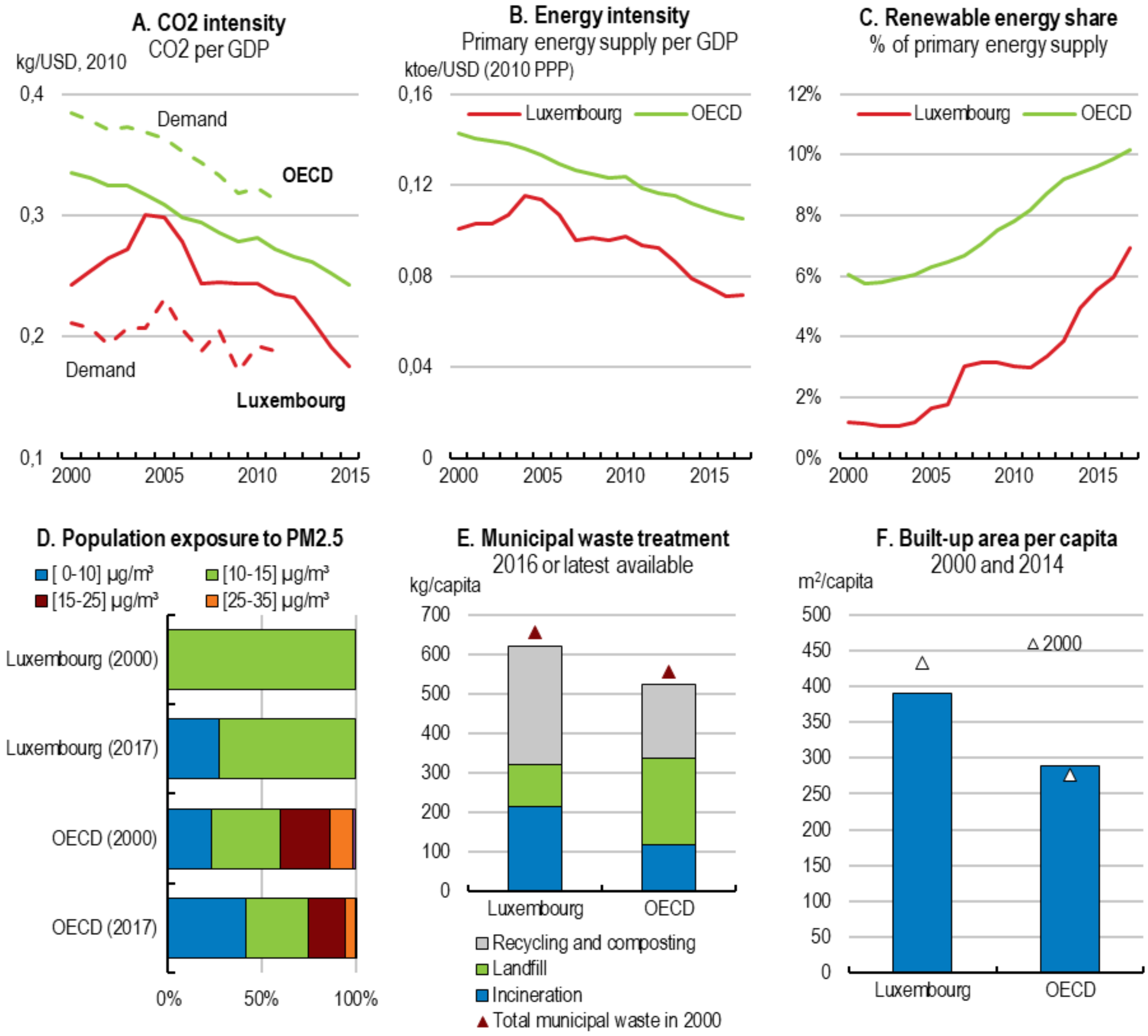


*Figure 3: Green growth indicators: Luxembourg (OECD 2019). A. CO2 intensity measured as CO2 per Gross Domestic Product (GDP), B. Energy intensity as primary energy supply per GDP, C. Renewable energy share in % of primary energy supply, D. Population exposure to particulate matter <2.5 µm, E. Municipal waste treatment in 2016 or latest available, F. Built-up area per capita in 2000 and 2014.*

From an economic point of view, Luxembourg is one of the wealthiest countries in Europe with a Gross Domestic Product (GDP) of 58.9 billion euros in 2018 (OECD 2019). According to the OECD

(2019), the increase of 2.6 % of the GDP in 2018 is mainly due to expansion of the private consumption. The economic strength of Luxembourg is the tertiary sector since, services represent 87.7 % of the value-added shares. Luxembourg as a small country is very important at the European scale: many finance, insurance or other business institutions have their head offices situated in Luxembourg benefiting from advantageous taxes, the good connectivity with other countries and a dynamic environment. Therefore, a lot of commuters find their job in Luxembourg and the national population is continuously growing. Luxembourg mainly relies on imports of items to fulfil the national consumption need. Even though trading partners of Luxembourg are mainly European countries (89 % of the goods are exported to European countries and 84 % of services); there is a need to implement a more circular economy for ecological and sustainable purposes (OECD 2019).

While the total energy supply per capita was 6.3 tonnes of oil equivalent (toe) in 2017 which exceed by far, 4.1 toe for the OECD average, renewable energy in Luxembourg amounts to 6.9 % in 2017 (10.2 % on average in the OECD). They conclude that the government's objective should be to lower the actual energy consumption per capita and to produce and import more renewable energy, thus, reducing the 14.6 t of $C0_2$ emissions per capita from fossil fuels (2016) (9 t of $C0_2$ emissions per capita from fossil fuels in the OECD).

However, Luxembourg has already diminished the energy and $CO_2$ intensity of production in the past years, as shown in Figure 1, panels A and B, partially through an increase in the share of renewable energy in the national energy mix. The $CO_2$ emissions per GDP have drastically been reduced since 2010 which is related to lower primary energy supply per GDP. While the EFc of Luxembourg is the second highest in an international comparison, the energy intensity of economic income is below OECD average. However, Luxembourg's performances remain under the OECD averages. The renewable energy supply is still lower as the OECD average despite a significant progression in the recent years (see panel C in Figure 1). In 2017, 73 % of the population is exposed to air pollution, in particular small particle emissions (> 10 $\mu g\ m^{-3}$), a larger proportion than the OECD average (58.7 %) (Panel D in Figure 1). The principal explaining factor is the share of emission created by road traffic. Within the economic survey of Luxembourg, the OECD suggest that new policies on $CO_2$ emissions are necessary and, that improvements have to be done to facilitate the public transport as well as, to develop the electric mobility in particular for private car drivers. The total municipal waste (0.6 t per capita) is also higher than the OECD average of 0.5 t (Panel_E in Figure 1), although about half is already recycled; a third is incinerated.

# 3 Results

## *3.1 Data References & Comparison of availability of National Data and accessible Global Data*

### 3.1.1 Carbon Footprint

*The carbon Footprint represents the area of forest land required to sequester anthropogenic carbon dioxide emissions* (NFA 2019). Several parameters such as the emissions from fossil fuels and other energy sources and, the embodied emissions resulting from the consumption, production and transport of goods provide the carbon Footprint. They are recorded in Table 4. The total amount of carbon dioxide is converted into global hectares according to the calculation method of the NFA 2019.

Emissions from fossil fuels, emissions from gas flaring and sources other than fossil fuels and, emissions from international transport bunker fuels are described in the Luxembourg's National Inventory Report 1990-2018 (see Table 4), submitted to the European Environment Agency. Concerning the international trade in electricity, amounts of produced and traded electricity for 2018 come from the national statistics portal STATEC, subsection Energy, Energy outlook, 'Energy balance by type of energy products 2000-2018' (see Table 4). National data sources have been utilized, except for the '*carbon_efi_efe*' worksheet, for which data comes from the UN Commodity Trade Statistics Database – Annual International Trade Statistics by Country, Luxembourg 2018 (see Table 4) since, national statistical databases for traded items are not available. This worksheet could not be exactly updated due to the use of different classification codes between the source of the data (UN Commodity Trade Statistics Database) and the Excel file provided by the Global Footprint Network.

*Table 4 Data sources used for the calculation of the carbon footprint*

| Data | Worksheet | Data source(s) | **Data year** |
|---|---|---|---|
| Emissions from fossil fuels | fossil_efp | Luxembourg's National Inventory Report 1990-2018 https://environnement.public.lu/fr/loft/air/inventaires-emissions/inventaire-ges.html (accessed 07.2020) | 2018 |
| International trade quantities by community | carbon_efi_efe | UN Commodity Trade Statistics Database https://trendeconomy.com/data (accessed 05.2020) | 2018 |
| Emissions from gas flaring and sources other than fossil fuels | other_co2_efp | Luxembourg's National Inventory Report 1990-2018. https://environnement.public.lu/fr/loft/air/inventaires-emissions/inventaire-ges.html (accessed 07.2020) | 2018 |
| Emissions from International Transport Bunker Fuels | Int_transport | Luxembourg's National Inventory Report 1990-2018. https://environnement.public.lu/fr/loft/air/inventaires-emissions/inventaire-ges.html (accessed 07.2020) | 2018 |
| International trade in electricity | electricity_trade | STATEC Energy https://statistiques.public.lu (accessed 01.2020) | 2018 |

### 3.1.2 Cropland Footprint

*The cropland Footprint reflects the amount of land necessary to grow all crops consumed by humans and livestock, including agricultural products, market animal feed, and cropped grasses used as* *livestock feed* (NFA 2019). Data source for the production and area, as well as for imports and exports are shown in Table 5.

*Table 5 Data sources used for the calculation of the cropland footprint*

| Data | Worksheet | Data source(s) | Data year |
|---|---|---|---|
| Production (tonnes $yr^{-1}$) and area (ha) | crop_efp | STATEC Agriculture<br>https://statistiques.public.lu (accessed 02.2020)<br><br>Rapport d'activité 2018, Le Gouvernement du Grand Duché du Luxembourg, Ministère de l'Agriculture, de la Viticulture et du Développement Durable, février 2019<br>https://gouvernement.lu/fr/publications/rapport-activite/minist-agriculture-viticulture-protection-consommateurs/magri/2018-rapport-activites-ma.html<br>(accessed 11.2019) | 2018 |
| Imports and exports (1000 t $yr^{-1}$) | crop_efi_efe | FAO Trade databases<br>http://www.fao.org/faostat/ (accessed 02.2020) | 2017 |

In order to have a consistent picture, the cropland Footprint is calculated with data from 2017 for both worksheets "Production and area" and "Imports and exports". The *'crop_efp'* worksheet has been compiled with different 2017 data sets from STATEC: 'Quantities produced of main crops and fodder production (in tonnes) 1960-2018', 'Production of vegetables 2007-2019', and 'Fruit production 2007-2019'. No national data source provides the traded items quantities necessary to fulfil the 'crop_efi_efe' worksheet; therefore, the most recent data from the FAO Trade databases, i.e. from 2017, was used.

### 3.1.3 Grazing Land Footprint

*The grazing land footprint assesses demand for grazing land to feed livestock and the embodied demand for grazing land in traded goods* (NFA 2019). Table 6 shows the different datasets that required updates using more recent data: products used as animal feed, production quantities of livestock products, animal heads in stock, animals' weight, as well as traded livestock.

The portal STATEC Agriculture is the main source for the production data of the 'market_feed_supply' worksheet, for the productions of crops and fodder, meat, dairy products (eggs, milk), and honey. Some missing data, for crop and animal productions as well as fisheries, come from the FAO Production and Fisheries databases (see Table 6). Quantities of traded products used as animal feed all come from the FAO databases. The feed amount for each item has been found in the FAO New Food Balances databases. No recent data neither for the production of oils and seedcakes, nor for the feed amount of these items could be found. In order to respect data coherence, used data for this worksheet are from 2017.

The worksheet 'prod_stat_livestock_n', integrating the "Production quantities of livestock products", has been compiled with data from 2018, extrapolated from the annual report for 2018 of the Ministry of Agriculture, Viticulture and Rural development (see Table 4).Stock of animals and slaughtered weight in '*resourcesat_livestock_n*' and '*cnst_grazing*', where data of 2018 are available, have been derived from the national statistics portal STATEC. The FAO Trade database for 2017 has been used to complete the imports and exports of livestock.

*Table 6: Data sources used for the calculation of the grazing footprint*

| Data | Worksheet | Data source(s) | Data year |
|---|---|---|---|
| Products used as animal feed | *market_feed_supply* | STATEC Agriculture<br>https://statistiques.public.lu (accessed 05.2020)<br><br>FAO Production and Trade databases<br>http://www.fao.org/faostat/ (accessed 05.2020)<br><br>FAO FishStatJ Fisheries Statistical Database<br>http://www.fao.org/fishery/statistics/software/fishstatj (accessed 02.2020) | 2017 |
| Production quantities of livestock products (tonnes year$^{-1}$) | *prodstat_livestock_n* | Rapport d'activité 2018, Le Gouvernement du Grand Duché du Luxembourg, Ministère de l'Agriculture, de la Viticulture et du Développement Durable, février 2019<br>https://gouvernement.lu/fr/publications/rapport-activite/minist-agriculture-viticulture-protection-consommateurs/magri/2018-rapport-activites-ma.html<br>(accessed 11.2019) | 2018 |
| Number of animals in stock (heads or 1000 heads) | *resourcesat_livestock_n* | STATEC Agriculture<br>https://statistiques.public.lu (accessed 11.2019)<br><br>Rapport d'activité 2018, Le Gouvernement du Grand Duché du Luxembourg, Ministère de l'Agriculture, de la Viticulture et du Développement Durable, février 2019<br>https://gouvernement.lu/fr/publications/rapport-activite/minist-agriculture-viticulture-protection-consommateurs/magri/2018-rapport-activites-ma.html<br>(accessed 11.2019) | 2018 |
| Animal weights (tonnes head$^{-1}$) | *cnst_grazing* | STATEC Agriculture<br>https://statistiques.public.lu (accessed 05.2020) | 2018 |
| Imports and exports of livestock (1000 tonnes year$^{-1}$) | *livestock_efi_efe* | FAO Trade Statistical Databases<br>http://www.fao.org/faostat/ (accessed 02.2020) | 2017 |

### 3.1.4 Fishing Grounds Footprint

*The Fishing Grounds Footprint represents the demands of fisheries on aquatic ecosystems as the equivalent surface area required to sustainably support a country's catch* (NFA 2019). Luxembourg is a landlocked country with no access to the sea or ocean. No commercial fishing activities are conducted in the country; it relies only on imports of fisheries. These data can be found on the FAO Fisheries database (see Table 7), only for 2017.

*Table 7 Data sources used for the calculation of the fishing grounds footprint*

| Data | Worksheet | Data source(s) | Data year |
|---|---|---|---|
| Imports and exports (tonnes year$^{-1}$) | *fish_efi_efe* | FAO FishStatJ Fisheries Statistical Database<br>http://www.fao.org/fishery/statistics/software/fishstatj<br>(accessed 02.2020) | 2017 |

### 3.1.5 Forest Products Footprint

*The Forest Products Footprint represents the area of world average forest land needed to supply wood for fuel, construction, and paper* (NFA 2019).

As indicated in Table 8, the production data of forest products comes from the national statistics portal STATEC, 'Forest production (in m³) 1970-2018', using data of 2018, as well as from the FAO Forestry statistical database (year 2018) to complete missing items. The worksheet '*forest_efi_efe*' has only been compiled with date from the FAO databases for 2018 (see Table 8).

*Table 8 Data sources used for the calculation of the forest products footprint*

| Data | Worksheet | Data source(s) | **Data year** |
|---|---|---|---|
| Production (tonnes, $m^{-3}$ or $m^{-3}$ roundwood equivalent) | *forest_efp* | STATEC Agriculture<br>https://statistiques.public.lu (accessed 02.2020)<br><br>FAO Forestry Statistical Databases<br>http://www.fao.org/faostat/ (accessed 02.2020) | 2018 |
| Imports and exports (1000 t $yr^{-1}$) | *forest_efi_efe* | FAO Forestry Statistical Databases<br>http://www.fao.org/faostat/ (accessed 02.2020) | 2018 |

### 3.1.6 Build-up Land Footprint

*The built-up land Footprint represents bioproductive land that has been physically occupied by human activities* (NFA 2019). No direct update is necessary for this parameter since the infrastructure area indicated in the '*infrastructure_efp*' worksheet is used from the worksheet '*bioproductive area'* (Table 9). The infrastructure area is multiplied with the crops yield factor, the equivalence factor and the inter-temporal yield factor (Eq. 2, Table 12) to calculate the built-up land Footprint.

### 3.1.7 Biocapacity

*Biocapacity refers to the amount of biologically productive land and water areas available within the boundaries of a given country. Biocapacity is calculated for each of the five major land use types: cropland, grazing land, fishing grounds (marine and inland waters), forest, and built-up land* (NFA 2019).

Both national and worldwide databases were utilized to update the surface area within the '*bioproductive_area'* worksheet (see Table 9). The Biocapacity has been calculated with data from 2018. Cropland, Grazing lands and Total area surface areas come from STATEC, while Fishing Grounds and Forest Land derive from the FOA databases.

*Table 9 Data sources used for the calculation of the Biocapacity*

| Data | Worksheet | Data source(s) | **Data year** |
|---|---|---|---|
| Land areas of cropland, grazing land, forest, other wooded land, inland waters, and build-up land | *bioproductive_area* | STATEC Agriculture<br>https://statistiques.public.lu (accessed 02.2020)<br><br>FAO ResourceSTAT Statistical Database<br>http://www.fao.org/faostat/ (accessed 01.2020) | 2018 |

## *3.2 Results of Ecological Footprint Calculation*

Results of the comparison of the use of worldwide databases (GFN 2016) and the implementation of national data sources (IBLA 2016) are visible in Table 10 and Figure 4 and detailed results are available in Appendix A.1, A.2 and A.3. The differences between the results are small, the EF of consumption ($EF_c$) amounts to 7,433,853 gha for Global Footprint Network 2016 instead of 7,471,455 gha for (IBLA 2016), resulting in a difference of 0.07 gha $capita^{-1}$.

*Table 10: Comparison of the EF of Consumption $EF_C$ for 2008 (Hild et al. 2010), 2016 (Global Footprint Network 2016), 2016 and 2018 (both IBLA). Calculated $EF_c$ 2018 using part or entire dataset from 2017 are indicated by "*".*

| [gha] | Hild et al. EFC 2008 | GFN EFC 2016 | IBLA EFC 2016 | IBLA EFC 2018 |
|---|---|---|---|---|
| Crop | 392,832 | 511,979 | 516,457 | 604,722* |
| Grazing | 82,907 | 364,418 | 366,071 | 343,469* |
| Forest Products | 220,024 | 652,177 | 652,177 | 830,507 |
| Fish | 28,886 | 85,510 | 85,482 | 79,109* |
| Built-up Land | 118,934 | 47,037 | 96.455 | 105,521 |
| Carbon | 4,700,273 | 5,772,731 | 5,754,803 | 5,878,194 |
| Total | 5,549,008 | 7,433,853 | 7,471,445 | 7,841,451 |
| [gha capita-1] | Hild et al. EFC 2008 | GFN EFC 2016 | IBLA EFC 2016 | IBLA EFC 2018 |
| Crop | 0.84 | 0.89 | 0.90 | 1.00* |
| Grazing | 0.18 | 0.63 | 0.64 | 0.57* |
| Forest Forest Products | 0.47 | 1.13 | 1.13 | 1.38 |
| Fish | 0.06 | 0.15 | 0.15 | 0.13* |
| Built-up Land | 0.27 | 0.08 | 0.17 | 0.17 |
| Carbon | 10.02 | 10.03 | 10.00 | 9.76 |
| Total | 11.82 | 12.91 | 12.98 | 13.03 |
| Biocapacity Deficit | 10.22 | 11.67 | 11.63 | 11.7 |
| Planet Earths | | 7.92 | 7.96 | 7.99 |

If the world's population was living under identical socio-economic conditions, and experienced the same production and consumption patterns as a resident of Luxembourg the number of planets demanded is calculated to be 7.99 in 2018 corresponding to a total of 7,841.451 gha and 13.03 gha per capita (Table 8). The Ecological Footprint calculations by Global Footprint Network and IBLA are nearly identical for the year 2016: 12.91 gha capita$^{-1}$ (Global Footprint Network 2016) and 12.98 gha capita$^{-1}$ (IBLA 2016). According to Global Footprint Network, in the last decade (between 2008-2018), the per person demand in Luxembourg has increased by 1.45 global hectares per person. The number of planets increased, because there is currently less biocapacity per person than back in 2008. Meanwhile the population of Luxembourg has augmented by approximately 29 % in this period.

The global biocapacity per capita was 1.63 gha in 2016. Luxembourg with a biocapacity of only 1.32 gha has a lower capacity to provide the needed resources or to absorb the man-made waste. The global Ecological Footprint in 2016 was 2.75 gha capita$^{-1}$ (Table 11). While this Ecological Footprint still exceeds the global biocapacity, the biocapacity deficit is much smaller than that of Luxembourg as an individual country (ED 2016 = 11.63 gha capita$^{-1}$; ED 2018 = 11.70 gha capita$^{-1}$). This is also much higher than the ED of the EU27 + UK 2016. In other words: while the global population needs 1.69 planets for its resources and absorb its wastes and emissions, Luxembourg needs close to 8 planets (7.96 planets in 2016 and 7.99 planets in 2018) (Table 11).

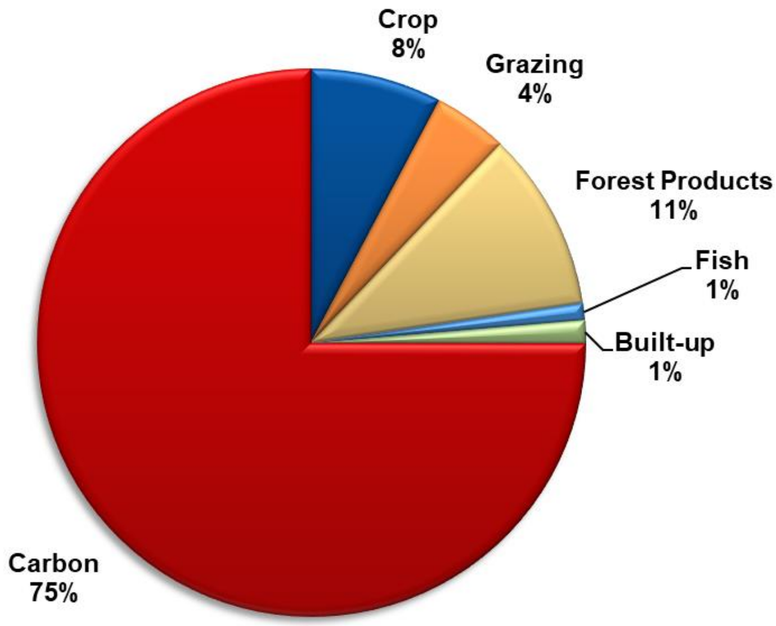


*Figure 4: Ecological Footprint of Consumption by a land use type 2018 (NFA 2018).*

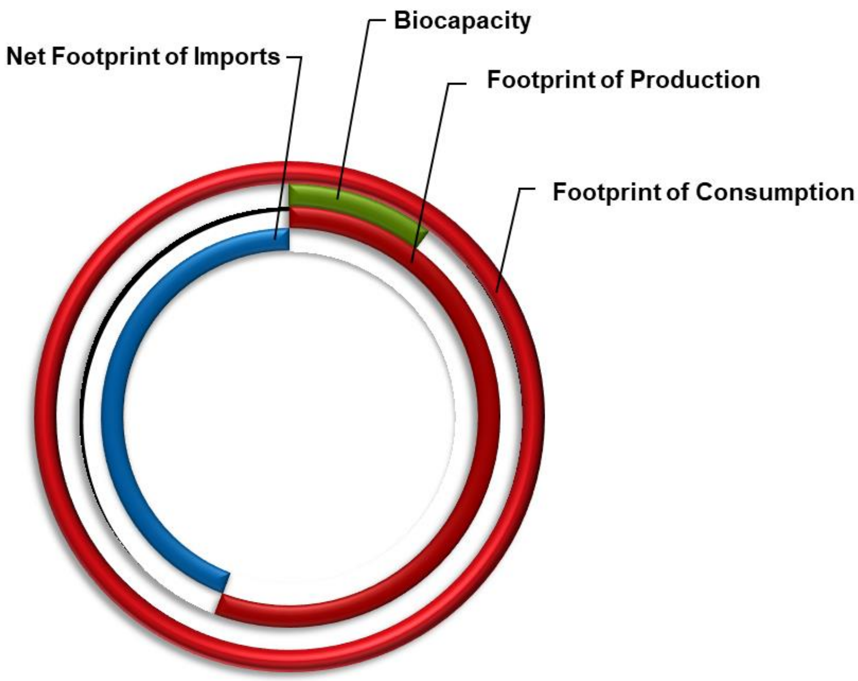


*Figure 5: Ecological Footprint and Biocapacity 2018 (NFA 2018).*

Comparing IBLA 2016 and IBLA 2018: the $EF_c$ in gha per capita is equal with 12.98 in 2016 to 13.03 in 2018. However, 370,006 gha more were consumed in 2018 compared to 2016. Thus, as the population of Luxembourg has increased over this time period, the total gha has naturally increased as well. The ecological Footprint of consumption by the land use types as well as the Ecological Footprint and Biocapacity for 2018 are depicted in Figures 4 and 5.

*Table 11: Comparison of the Ecological Footprint and Biocapacity (gha capita$^{-1}$) of the World, the EU 27 + UK and Luxembourg in 2016 and Luxembourg 2018. (World 2016 and EU 27+UK 2016: EEA, 2020; Luxembourg 2016 and 2018: own calculation)*

| *Ecological Footprint & Biocapacity* | *World 2016*[2] | *EU 27 + UK 2016*[1] | *Luxembourg 2016* | *Luxembourg 2018* |
|---|---|---|---|---|
| *Carbon Footprint* | 1.65 | 2.76 | 10.00 | 9.76 |
| *Built-up Footprint* | 0.06 | 0.11 | 0.17 | 0.17 |
| *Fish Footprint* | 0.09 | 0.14 | 0.15 | 0.13 |
| *Forest Products Footprint* | 0.27 | 0.55 | 1.13 | 1.38 |
| *Grazing Footprint* | 0.14 | 0.23 | 0.64 | 0.57 |
| *Crops Footprint* | 0.53 | 0.8 | 0.90 | 1.00 |
| *Total Ecological Footprint* | 2.75 | 4.59 | 12.98 | 13.03 |
| *Total Biocapacity* | 1.63 | 2.06 | 1.35 | 1.33 |

The results and evaluation of the Ecological Footprint of land type (crop, grazing, forest products, fish, built-up land and carbon) as well as the calculation of the biocapacity are presented in detail in the following sections.

### 3.2.1 Cropland Footprint

In 2018, the cropland Footprint counts for 8 % of the total Ecological Footprint of consumption in Luxembourg. It represents 604,722 gha namely, 1.00 gha person$^{-1}$ as shown in Figure 1 below. Looking at the time trends of cropland Footprint (see Figure 6), the cropland Footprint globally tends to decrease over time, even though fluctuations are visible. The last decade shows a decrease of the cropland Footprint which had re-increased from the 90's to 2010. Main changes of the cropland Footprint are related to the annual fluctuations of produced and imported amounts of crops for human food and animal feed. The calculation of the cropland Footprint is based on the crops imported for human consumption, and animal feed and on the production of crops and legumes in Luxembourg. Besides the cropland Footprint, figure 6 shows the time series of the total production of cereals in Luxembourg. Comparing the Luxembourgish animal production 2018 with 2010, milk production increased by 38 %, egg production by 30 % and the number of pigs by 13 % and cattle by 8%.

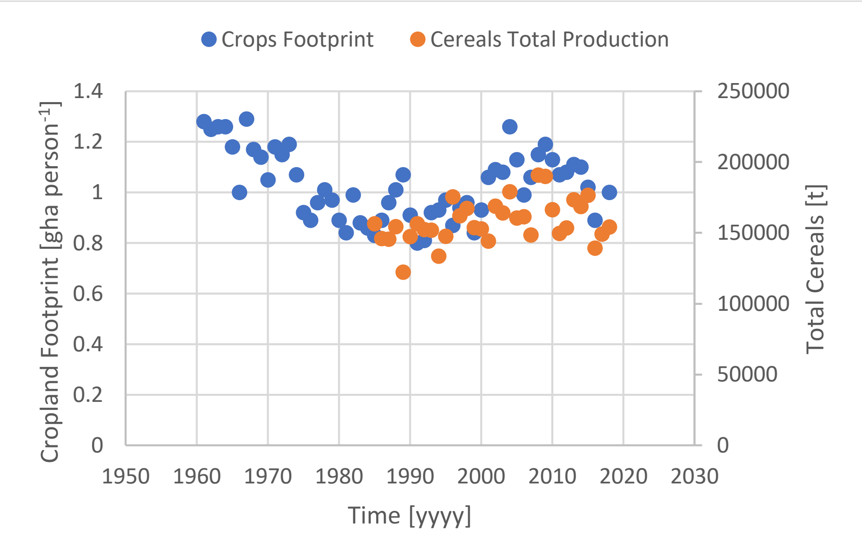


*Figure 6: Time trends of Cropland Footprint (Global Footprint Network 2019, own calculation for 2016 and 2018) and total production of cereals in Luxembourg (STATEC 2020).*

### 3.2.2 Grazing Land Footprint

With an $EF_C$ of 343,469 gha, that means 0.57 gha person$^{-1}$, grazing land Footprint accounts for 5 % of the total EF. Due to the low contribution in the total EF, grazing land Footprint is correlated by 0.23 with total EF. Nevertheless, Figure 7 shows an increase of grazing land Footprint in time with fluctuations. Since 2010, it can be observed that the grazing land Footprint decreases. The more livestock and food of animal origin is produced, the higher the feed demand. This demand is provided by the crop and the grazing land Footprint. Luxembourg has a surplus production of dairy and a self-sufficiency for livestock of 107 % for cattle and 63 % for pigs (STATEC 2020). For dairy products and eggs, a 74,987 gha are exported and account for the carbon Footprint. The footprints of food production and the demand of foodstuff (in global hectares) are described in detail in Table 20. The grazing land Footprint by the Global Footprint Network in 2008 (364,758 gha) and in 2016 (364,418 gha) and by IBLA in 2018 (343,469 gha) is in the same order of magnitude. But in the same time, Luxembourg's population raised from 483,800 inhabitants in 2008 to 602,000 inhabitants in 2018, leading to the effect that the grazing footprint per capita decreases.

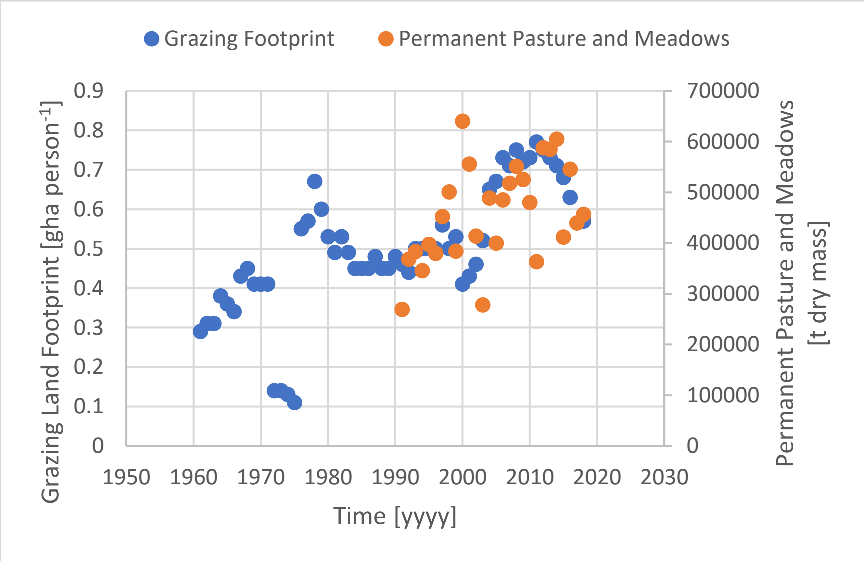


*Figure 7: Time trends of Grazing Land Footprint (Global Footprint Network 2019, own calculation for 2016 and 2018)[4]*

### 3.2.3 Fishing Grounds Footprint

The fishing grounds Footprint is generally increasing in time (see Figure 8), since Luxembourg relies only on fisheries imports as the population is augmenting the demand increases too. However, the fishing grounds Footprint represents only 1 % of the total EF. Fishing grounds Footprint accounts for 79,109 gha of the total EF, i.e. 0.13 gha person$^{-1}$.

[4] Please be aware that if figures of Hild et al. (2010) were considered the description of trends in the report is not always appropriate.

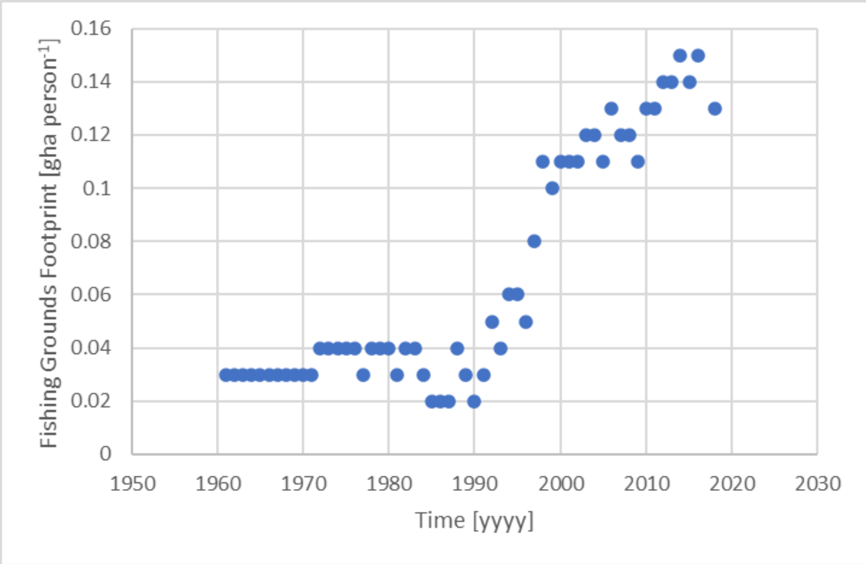


*Figure 8: Time trends of Fishing Grounds Footprint (Global Footprint Network 2019, own calculation for 2016 and 2018)*

### 3.2.4 Forest products Footprint

The forest products Footprint, accounting for 830,507 gha that means 1.38 gha person$^{-1}$, represents 11 % of the total EF. There is no clear relation between forest products Footprint and total Footprint. As can be seen in Figure 9, the Footprint increases over time. While a decrease in the production of forest products could be observed in Luxembourg over the past couple of years, the imports have augmented between 2016 and 2018, thus increasing the EF again.

The visual comparison of the forest product Footprint with the Luxembourgish production of hardwood and softwood also shows great fluctuations (Figure 9). These fluctuations in production, as well as in imports and exports of wood and of wood-based products (e.g. wood fuel, wood pulp, printing and writing paper, STATEC 2020, data not shown) lead to an increase in the forest products Footprint until approx. 2001 and the subsequent very variable consumption.

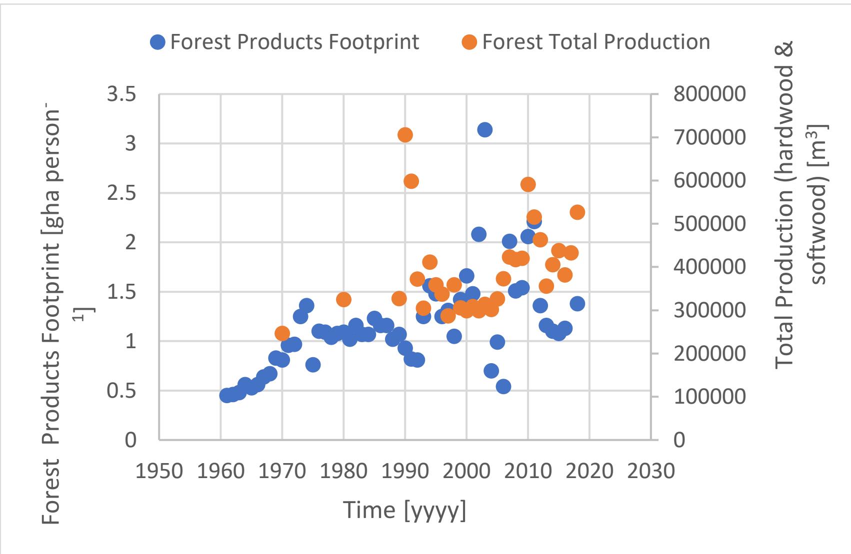


*Figure 9: Time trends of Forest Products Footprint (Global Footprint Network 2019, own calculation for 2016 and 2018)[1] and total production of hardwood and softwood in Luxembourg (STATEC 2020).*

### 3.2.5 Built-up land Footprint

The built-up land Footprint is characterised by a continuous decrease in time (see Figure 10). In 2018, it accounts for 0.13 gha person$^{-1}$, corresponding to 79,109 gha. It has a small effect on the total Ecological Footprint, where it counts only for 1 %. However, the built up Footprint is higher in 2018 due to the Yield Factor (YF, for additional explanation please refer to the Glossary) which has increased from 1.04 in 2016 to 1.14 in 2018 and is, in the methodology of NFA, equalled to the YF of cropland (NFA 2019).

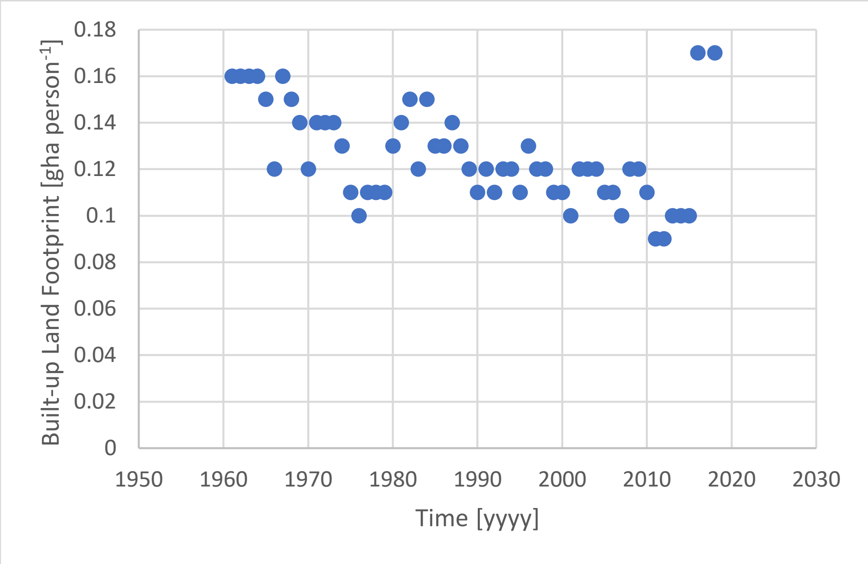


*Figure 10 Time trends of Built-up Land Footprint (Global Footprint Network 2019,, own calculation for 2016 and 2018)*[1]

### 3.2.6 Carbon Footprint

The carbon Footprint amounts to 9.27 gha person$^{-1}$ being 5,578,640 gha in total. It makes up 79 % of the total Ecological Footprint. Figure 11 shows the fluctuations of the carbon Footprint over time. Over the past 10-15 years a steady decrease can be observed.

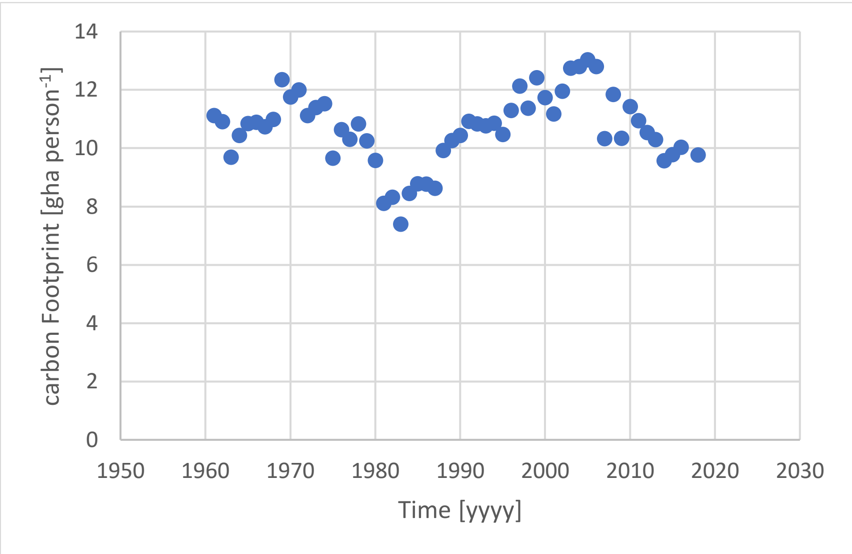


*Figure 11: Time trends of carbon Footprint (Global Footprint Network 2019, own calculation for 2016 and 2018)*

### 3.2.7 Total Footprint

Since 1961, the Ecological Footprint of Luxembourg in gha capita$^{-1}$ variations, with a tendency to decrease since 2003 (Figure 8). In Luxembourg, from 1961 until 2018, the highest correlation of 0.93 is calculated between the yearly Ecological Footprint and the carbon Footprint. Moreover, the carbon Footprint makes up 79 % of the total Luxembourgish Footprint during this period, compared to the humanity's carbon Footprint on total Ecological Footprint of 54% (2010). The increasing demand for gha in Luxembourg as well as the gha capita$^{-1}$ exceeded the advances and adoption of new, more environmentally friendly and less energy intensive technologies for produced goods until 2003. Since 2003, the $EF_C$ is decreasing, and it is mostly due to the reduction of the carbon Footprint.

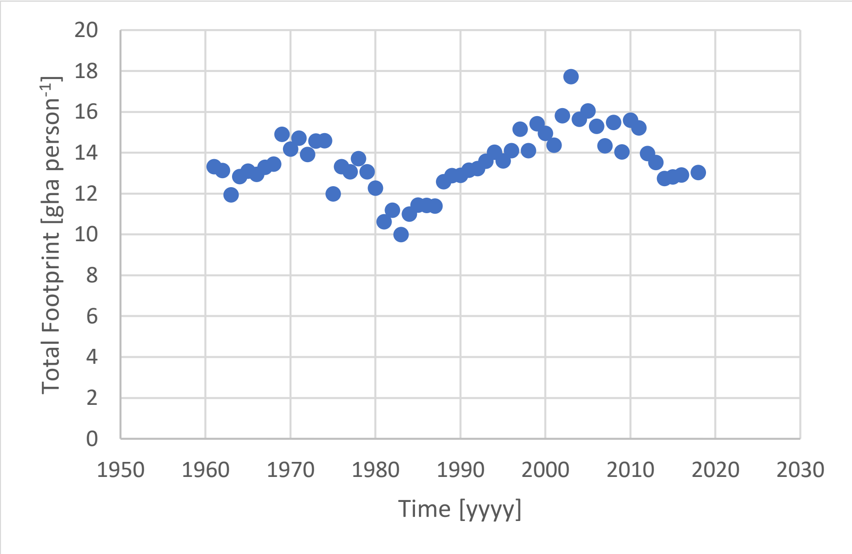


*Figure 12: Development of Total Footprint from 1961-2018 (Global Footprint Network 2019, own calculation for 2016 and 2018)*

### 3.2.8 Biocapacity

In 2018, the Biocapacity accounts for 1.33 gha capita$^{-1}$, being 801.758 gha in total, while the world average is 1.63 gha capita$^{-1}$. The development of the total Biocapacity in time is visible in Figure 13. It shows that Biocapacity, the amount of biologically productive land and water areas available in Luxembourg, keep decreasing over time. A strong correlation, over time, is observable between the evolution of the Luxembourgish population and the total Biocapacity per capita (r = 0.85). In comparison to Germany (233.1 person km$^{-2}$ and a Biocapacity of 1.62 gha capita$^{-1}$ in 2016), Luxembourg only had a Biocapacity of 1.24 gha capita$^{-1}$ (GFN 2020c) even though the population density (225.1 person km$^{-2}$) was similar (Eurostat 2020a).

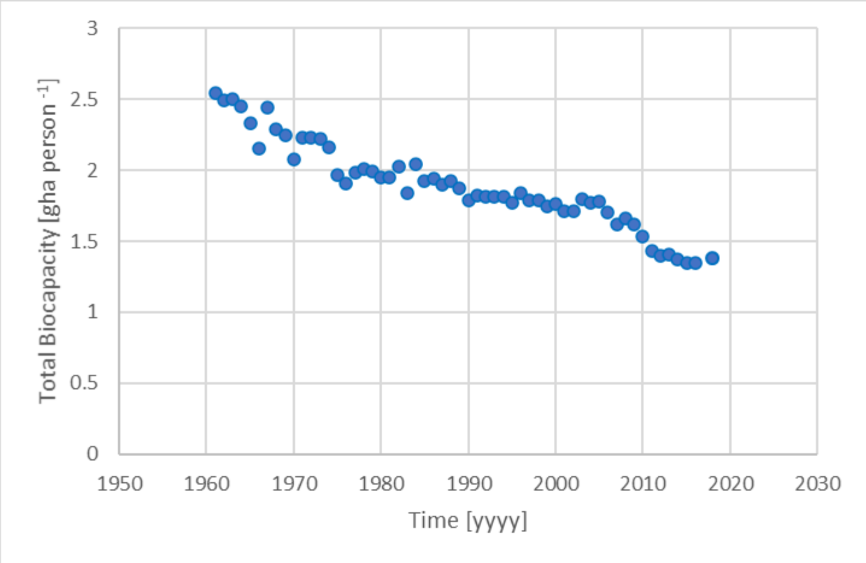


*Figure 13: Development of Total Biocapacity from 1961-2018 (Global Footprint Network 2019, own calculation for 2016 and 2018)*

Large divergences in the areas allocated to the different land cover types are observable according to the source of the data (Table 12). In Global Footprint Network 2016, the data are provided by CORINE Land Cover 2000, while the data for e.g. IBLA 2016 and IBLA 2018 are compiled from global and national databases (Chapter 3.1). While a relatively small discrepancy can be observed between the total land cover from these different sources of data, the largest divergence is within the land cover types *crop land* and *grazing land* (Table 12), which is due to the yield factor, which is given for a land use type within the country for the calculated year.

Land cover areas provided by Hild et al. (2010) are based on cropland and grazing land statistics by the Ministry of Agriculture/SER (CORINE 2006 projections) and match the most recent areas used by IBLA (2016, 2018), based on the statistics by the Ministry of Agriculture (2018) and STATEC (2020). The use of national data in the IBLA 2016 EF calculation resulted in a higher yield factor (YF) for *crop land* compared to the Global Footprint Network 2016 calculation. This rather sizable difference in the YF, however, offsets the impact of the larger crop land cover in the GNF 2016 calculation, such that the difference in the Biocapacity between the two calculations is not as pronounced as would be expected. The Biocapacity is 1.24 gha capita$^{-1}$ for GNF 2016 and 1.35 gha capita$^{-1}$ under IBLA 2016. The Biocapacity from both calculations show a decrease compared to 2008 with a Biocapacity of 1.91 gha per person (see Hild et al. 2010). The biocapacity per person slightly declines in the IBLA 2018 calculation (1.33 gha capita$^{-1}$).

*Table 12: Results of the calculation of the Biocapacity according to different sources: Hild et al. (2010), Global Footprint Network 2019 (NFA 2016), IBLA 2016 and IBLA 2018 (own calculation).*

| *Land Cover (Hild et al. 2010), 2008* | *Area [ha]* | *YF [wha ha-1]* | *EQF [gha wha-1]* | *Biocapacity [gha capita-1]* |
|---|---|---|---|---|
| *Crop Land* | 61,159 | 1.95 | 2.64 | 0.67 |
| *Grazing Land* | 79,373 | 2.38 | 0.50 | 0.20 |
| *Inland Fishing Grounds* | 1,016 | 1.00 | 0.40 | 0,00 |
| *Forest Land* | 93,617 | 2.93 | 1.33 | 0.78 |
| *Infrastructure* | 24,089 | 1.95 | 2.64 | 0.26 |
| ***Total*** | 259,254 | | | 1.91 |
| *Land Cover (GFN 2019) 2016* | *Area [ha]* | *YF [wha ha-1]* | *EQF [gha wha-1]* | *Biocapacity [gha capita-1]* |
| *Crop Land* | 105,225 | 0.63 | 2.50 | 0.29 |
| *Grazing Land* | 37,703 | 2.38 | 0.46 | 0.07 |
| *Inland Fishing Grounds* | 1,039 | 1.00 | 0.37 | 0.00 |
| *Forest Land* | 94,121 | 3.80 | 1.28 | 0.80 |
| *Infrastructure* | 29,839 | 0.63 | 2.50 | 0.08 |
| ***Total*** | 267,928 | | | 1.24 |
| *Land Cover (IBLA 2016) 2016* | *Area [ha]* | *YF [wha ha-1]* | *EQF [gha wha-1]* | *Biocapacity [gha capita-1]* |
| *Crop Land* | 63,536 | 1.04 | 2.50 | 0.30 |
| *Grazing Land* | 67.115 | 2.38 | 0.46 | 0.14 |
| *Inland Fishing Grounds* | 1,016 | 1.00 | 0.37 | 0.00 |
| *Forest Land* | 91,037 | 3.80 | 1.28 | 0.78 |
| *Infrastructure* | 37.156 | 1.04 | 2.5 | 0.12 |
| ***Total*** | 259,860 | | | 1.35 |
| *Land Cover (IBLA 2018) 2018* | *Area [ha]* | *YF [wha ha-1]* | *EQF [gha wha-1]* | *Biocapacity [gha capita-1]* |
| *Crop Land* | 63,997 | 1.14 | 2.50 | 0.32 |
| *Grazing Land* | 67,607 | 2.38 | 0.46 | 0.14 |
| *Inland Fishing Grounds* | 1,016 | 1.00 | 0.37 | 0.00 |
| *Forest Land* | 90,340 | 3.80 | 1.28 | 0.75 |
| *Infrastructure* | 36,900 | 1.14 | 2.50 | 0.13 |
| ***Total*** | 259,860 | | | 1.33 |

*Table 13:: Comparison of the Ecological Footprint and Biocapacity of Germany, France, Belgium and Luxembourg in 2016 (Germany, France, Belgium: Global Footprint Network; Luxembourg 2016: own calculation).*

| *Ecological Footprint & Biocapacity* | *Germany* | *France* | *Belgium* | *Luxembourg* |
|---|---|---|---|---|
| *Carbon Footprint* | 3.19 | 2.65 | 3.91 | 10.00 |
| *Built-up Footprint* | 0.13 | 0.13 | 0.14 | 0.17 |
| *Fish Footprint* | 0.05 | 0.21 | 0.12 | 0.15 |
| *Forest Products Footprint* | 0.5 | 0.51 | 0.55 | 1.13 |
| *Grazing Footprint* | 0.19 | 0.24 | 0.37 | 0.64 |
| *Crops Footprint* | 0.78 | 0.71 | 1.15 | 0.90 |
| *Total Ecological Footprint* | 4.84 | 4.45 | 6.25 | 12.98 |
| *Total Biocapacity* | 1.62 | 2.38 | 0.79 | 1.35 |

## *3.3 Fuel tourism & traffic Footprint by cars*

6.3 billion vehicle kilometres (vkm) by cars and 1.1 billion vkm by trucks and busses have been travelled in Luxembourg in 2012 (Ewringmann 2016). Of these vehicle kilometres, 4.8 billion vkm $yr^{-1}$ have been travelled by inhabitants (by car) and 1.2 billion by cross-border commuters within Luxembourg. Fuel tourism accounted for 0.35 billion vkm $yr^{-1}$, which is mainly driving to the fuel station in Luxembourg directly at the frontiers and going back. Thus, this additional amount of vkm represent only a small share of the total vkm $yr^{-1}$ of Luxembourg (4.8 %). However, the trans-border workforce also regularly fills up their cars in Luxembourg. For trucks, only 18 % of 1.1 billion vkm $yr^{-1}$ by trucks are travelled by national trucks. Furthermore, with a population of 537,000 people in 2012, the average person travelled ca. 8950 vkm (Allegrezza 2012). In that same year 155,607 people were commuters to Luxembourg from neighbouring countries; they travelled on average 7,710 vkm within Luxembourg (Allegrezza 2012). It is therefore unsurprising that Luxembourg ranked 4$^{th}$ highest place in Europe in the "Hours spent in road congestion annually" in 2017[5], especially as the Luxembourgish population and the workforce commuting to Luxembourg increases annually (STATEC 2020).

### 3.3.1 Fuel tourism Footprint

In 2012 according to STATEC (2020) 20,588 GWh were used by non-resident borderers (transporter, bus, cross-border workers and tourists), which is 68.5 % of the total amount of transport oil fuel consumption. This high share of exported fuel by cars and trucks is taken into account in Luxembourg's carbon Footprint as it is sold in Luxembourg and increases the Luxembourgish GDP. In the following, the authors talk about fuel exports in terms of fuel bought in Luxembourg by people not living in Luxembourg (e.g. trans-border workforce, people living and working in the Greater Region but buying their fuel in Luxembourg in so called fuel tourism, and international truck traffic), and is thus not consumed by inhabitants of Luxembourg.

[5] https://ec.europa.eu/transport/facts-fundings/scoreboard/compare/energy-union-innovation/road-congestion_en#2017

*Table 14: Energy consumption in Luxembourg (GWh) (STATEC, 2020).*

| *Year* | | *2016* | *2018* |
|---|---|---|---|
| *Total* | | 47309 | 51386 |
| *Industry* | | 8203 | 7693 |
| *Transport* | | 28305 | 31750 |
| | *Road: non-resident borderers* | 16721 | 18968 |
| | *Road: Households* | 2417 | 2456 |
| | *Air* | 6370 | 7190 |
| *Services* | | 4826 | 5697 |
| *Households* | | 6426 | 6154 |
| *Agriculture* | | 75 | 92 |

In 2016, the transport oil fuel consumption for non-resident borderers was 16,721 GWh of 28,305 GWh in total (59 %; STATEC 2020, Table 14). Petrol has a share of 16 %, car diesel of 13 % and truck diesel of 71 % (Ewringmann 2016). Petrol consumption is 2,675 GWh equalling 244,263 gha (conversion factors see Table 1), car diesel consumption is 2,174 GWh equalling 196,524 gha and truck diesel is 11,872 GWh equalling 1,0733,23 gha[6]. Adding up these fuel exports, it is 1,514,109 gha and makes up 27.8 % of the carbon Footprint in 2016. In 2018 an amount of 18,968 GWh of fuel has been sold to non-residents, which is 1,717,579 gha and 29.2 % of the carbon Footprint in 2018 (Table 15).

*Table 15: Fuel consumption of non-residents Footprint.*

| | *GWh* | *vkm (in bill.)* | *gha* | *% carbon Footprint* | *gha capita$^{-1}$* |
|---|---|---|---|---|---|
| *fuel consumption of non-residents (2016)* | 16,721 | | 1,514,109 | 27.8 | 2.63 |
| *fuel consumption of non-residents (2018)* | 18,968 | | 1,717,579 | 29.2 | 2.85 |

Not accounting these exported fuel gha to Luxembourg in 2018, the number of planets needed to support the lifestyle of the Luxembourgish population would decline by 1.75 planets, being a reduction of 2.85 gha capita$^{-1}$. However, a majority of the fuel exported is consumed by the transborder workforce, so in a way consumed on Luxembourgish territory (1.2 billion vkm yr$^{-1}$ travelled by commuters within Luxembourg). 0.35 billion vkm yr$^{-1}$ arise from cars travelling to Luxembourg only to refuel, equalling 25,486 gha (0.04 gha capita$^{-1}$). The Footprint of foreign trucks is 470,539 gha or 0.78 gha capita$^{-1}$, but it cannot clearly be differentiated if these trucks deliver goods to Luxembourg or it is mainly transit transport.

### *3.4 Kerosene Consumption*

According to STATEC (2020) the energy consumption in 2018 was 7189.5 GWh. Following the calculation for petrol and diesel consumption, the kerosene consumption equals 635,636 gha or 1.06 gha capita$^{-1}$. Using the data from Eurostat (2020) for the kerosene consumption in 2018, 597,000 t kerosene have been used, equalling 628,104 gha. The National Inventory Report 2018, used for NFA 2018 (please refer to Table 4), includes 1.8 kt $CO_2$e for aviation, equalling 601,582 gha. The slight differences between these three data sources cannot be explained.

[6] To simplify matters, it was assumed that 14 % of the energy (GWh) from fossil fuels comes from petrol and 84 % from diesel. The share of ethanol (petrol B5 5 % ethanol and diesel B7 7 % ethanol) has been neglected as growing the raw material for the ethanol production in turn leads to the consumption of global hectares.

### *3.4 Electric power Footprint*

In 2018, 6,627 GWh of electricity have been consumed in Luxembourg, being about 13 % of the total energy consumption (2018; STATEC). In 2018 about half of the electric power was used by industries, in particular for steal production (40 % of the electricity), while 33 % are consumed by the service sector and circa 15 % by private households (MEAT & MECDD 2020).

From the 466 GWh of electric power produced in Luxembourg (2018; STATEC), 75 %, representing 345 GWh (Table 13), are already coming from renewable energy sources (ILR 2020). Indeed, the country does not dispose of fossil energy sources, therefore the domestic electric power is mostly produced by a hydropower station, wind turbines, solar panels and biogas obtained from biomass. Nevertheless, the electricity needs exceed by far the current national production potential meaning, that Luxembourg is mostly reliant on energy imports from other countries, such as Germany, France or Belgium (STATEC 2018). However, the share of renewable energy of the trading partners are not as high as in Luxembourg since, Germany still produces electricity from coal plants and France from nuclear power plants. That's why, in 2017, 8.1 % of the total consumed electricity came from renewable energy sources (MEAT & MECDD 2020). Regarding to the total energy needs, 6.4 % are covered by renewable energy sources (MEAT & MECDD 2020).

National engagements in the "National Energy and Climate Plan 2021-2030" (NECP; MEAT & MECDD 2020) have been established as a result of the Paris agreement in 2015. The main goals are a reduction of the GHG emissions by 55 % (excepted EU Emission Trade) compared to 2005, a reduction of 40-44 % of the energy consumption compared to 2007 and an increase of renewable energy up to 25 % compared to 8.1 in 2018 (MEAT & MECDD 2020). Main drivers of action concern the renovation of buildings and the construction of low energy ones, the improvement of the energy efficiency in the industry sector and for SME, introduce new policies to regulate the traffic and fuel tourism and, to develop the electro mobility. But these goals might be ambitious and prove difficult to reach by 2030. For electricity for example, improvements depend highly on the evolution of the situation in the neighbouring countries. The challenge is not easy for Luxembourg where the population is still growing, resulting in an increase of the energy needs. Due to energy security issues, it is not probable to expect that Luxembourg turns its electricity production to 100 % renewable even though the national production capacity is expected to rise up. It would reinforce the dependency on imports. Luxembourg aims to favour a better cooperation at a national and regional scale for the development of flexibility measures, such as demand side response and storage (MEAT & MECDD 2020).

### *3.5 Electro mobility*

The increase in the energy efficiency of Luxembourgish transport is to be achieved primarily by reducing traffic, by expanding public transport and by promoting electromobility in cars and transport. This is intended to reduce the dependency on oil imports. According to the NECP 2021-2030, the share of electromobility is aimed to achieve 49 % in 2030. To face the upcoming demand for charging stations for electric vehicles, Luxembourg had already installed 280 public charging stations by end of 2018 and plans to install more to reach 800 by 2020.

*Table 16: Electro mobility Footprint*

| | *vkm (in Bill.)* | *$CO_{2e}$ (t)* | *gha* | *% carbon Footprint* | *gha $capita^{-1}$* |
|---|---|---|---|---|---|
| *vkm car total* | 6.3 | 1,582,751 | 528,304 | 9.5 | 0.88 |
| *vkm combustion engine* | 3.63 | 775,058 | 258,869 | 4.6 | 0.43 |
| *vkm electro mobility* | 3.63 | 168,587 | 56,343 | 0.9 | 0.09 |

Taking the aims of the NECP, 3.63 billion vkm of the 6.3 billion vkm travelled by cars in 2012 reported by Ewringmann (2016) will be travelled by electric cars in 2030[7]. An electric car has a mean electricity consumption of 16 kWh per 100 km (not including production of the car or the battery) (Agora 2019). The $CO_2$ emissions of the electricity mix imported to Luxembourg is given in the NFA by the national electricity carbon intensity of electricity imports (2.91·10-4 Mt $CO_2$ $GWh^{-1}$, see Table 1). The electricity demand for 49 % electro mobility add up to 168,587 t $CO_2$ or 56,343 gha (Table 16). These same 3.63 billion vkm travelled by conventional cars with combustion engine (23 % benzine, 77 % diesel, see subsection 6.2.1) would emit 775,058 t $CO_2$, equalling to 258,869 gha. Thus, 202,526 gha could be saved when the goal of 49 % electro mobility is achieved, which corresponds to 0.34 gha $capita^{-1}$.

### *3.5 Cross-border Commuters*

In total, commuters spend about 9 % of HFCE on the territory (Table 3). Through their daily travel to work, commuters to not have additional expenses for transport costs (time and money) for the purchase of goods (Mathä et al. 2012). The expenditures of cross-border commuters for the different product categories are shown in Table 17. The proportions on HFCE by cross-border commuters for the different categories in 2010 are assumed to be the same in 2018. The $EF_C$ for the product categories is calculated for durables, vehicles, tobacco, alcoholic beverages and clothes by comparing the $EF_I$, $EF_P$ and $EF_E$. For the proportionate food Footprint, please refer to food consumption Footprint (Table 20). Those product categories where no data is given in the NFA 2018, the GHG emissions were used instead.

Most of the money of cross-border commuters spent on the Luxembourgish territory is for fuel, food and vehicles. Three product categories with the highest consumption of gha, however, are fuel (311,609 gha), food (253,108 gha) and travelling by plane (49,513 gha). In total, a consumption of 680,946 gha on the Luxembourgish territory is calculated for cross-border commuters, thus is responsible for 1.13 gha per Luxembourgish resident capita of the total Luxembourgish EF of 13.03 gha $capita^{-1}$.

[7] An extrapolation of the traffic data from 2012 to 2018 due to the development of the population and employment figures was not carried out.

*Table 17: Footprint of cross-border commuters. Expenditures according to Mathä et al. (2012), Household Final Consumption (HFCE) according to STATEC (2020) and Ecological Footprint (own calculation).*

| | *2010* | | | | *2018* | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Exp.* (€ commuter$^{-1}$)* | *$Exp._{total}$ (Mill. €)* | *HFCE** (Mill €)* | *$HFCE_{C,Com}$ (%)* | *$EF_I$ (gha)* | *$EF_E$ (gha)* | *$EF_C$ (gha)* | *GHG (gha)* | *$EF_{C,Com}$ (gha)* |
| *Durables (TV, computer,...)* | 468 | 71.1 | 962 | 7% | 33559 | 10174 | 23385 | - | 1728 |
| *Vehicles* | 1256 | 190.8 | 846 | 23% | 197753 | 84551 | 113202 | 63686 | 39891 |
| *Fuel* | 2460 | 373.7 | - | - | - | - | - | - | 311609 |
| *Tobacco* | 563 | 85.5 | 929.2 | 9% | 32159 | 12195 | 19964 | - | 1837 |
| *Alcoholic beverages* | 230 | 34.9 | 316 | 11% | 56144 | 18786 | 37358 | - | 4130 |
| *Food at/outside home* | 2498 | 280.9 | 1356.7 | 21% | - | - | 1222379 | - | 253108 |
| *Public transport* | 66 | 10.0 | 127.6 | 8% | - | - | - | 101536 | 7978 |
| *Culture and leisure* | 55 | 8.4 | 236.5 | 4% | - | - | - | 6908 | 299 |
| *Education* | 46 | 7.0 | 75.1 | 9% | - | - | - | 25879 | 2948 |
| *Travelling, train or plane tickets* | 463 | 70.3 | 191.1 | 37% | - | - | - | 133818 | 49513 |
| *maintenance and repair of vehicles* | 132 | 20.1 | - | - | - | - | - | 7463 | 1716 |
| *health* | 169 | 25.7 | 279.5 | 9% | - | - | - | 9317 | 1048 |
| *clothes and shoes* | 765 | 116.2 | 779.1 | 15% | 44115 | 9659 | 34456 | - | 5139 |
| *Other expenditures* | 136 | 20.7 | - | - | - | - | - | - | - |
| *Sum* | 9317 | 1315.2 | 14712.6 | 9% | | | | | 680946 |

### *3.6 Service employees Footprint*

The service sector of Luxembourg is very developed and is an important source of work in the country. It represents 87.7 % of the value-added shares of the country (OECD 2019). Alone, the financial sector produces 28 % of the GDP while aggregating 10 % of the employment. Combined a total of 16 % of the employees in Luxembourg (67,603 jobs) are working in the 'Information and Communication' sector (19,076.25) and the 'Finance and Insurance' sector (48,526.25) (2018; STATEC 2020).

The service industry has a huge impact on the Luxembourg economy and on the use of energy. According to STATEC (2020, Table 14), the service industry consumes as much electricity as the households. The impact of the service sector leads to a negative bias when it comes to comparing

Luxembourg to its neighbouring countries: These exports of tertiary activities consist of producing intangible goods and information, but these kinds of products, which are mainly exported, are not included in the calculation of the Ecological Footprint (similar to tourism) as they cannot be quantified (e.g. in form of tons). But the workplaces need energy and therefore produce $CO_2$ emissions. Ideally these intangible goods from the service industry could be embedded in the calculation as 'exports' thus, balancing with the emitted $CO_2$ from this sector. Moreover, it is not really clear whether employment figures when it comes to accessory services in the financial industry, are reflected in the figures (lawyers, auditors, fiduciary etc.).

To get an idea of all these activities on the carbon Footprint, the emissions of $CO_2$ resulting from the work of an 'office' employee have been estimated for Luxembourg. Embodied $CO_2$ emissions from the daily use of computers, from mailing and other activities on the web as well as, from heating of the buildings and other electrical usage have been taken into account.

According to the study conducted by Maas et al (2012), the electricity needs of an office building accounts for 217 kWh $m^{-2}$ per year. It includes the power used by ventilation and/or heating systems, own data centres, office equipment (computer, printer…) and, if available, cooling machines. Assuming a minimum office surface area of 10 $m^2$ per employee (Ministère du Travail 2017) and 67,603 full time workers in the information and finance sectors, emissions of 0.01 Mt of $CO_2$ per year result from the electricity consumption alone (IBLA calculation). This converts to about 147 GWh of electricity, counting for 2.22 % of Luxembourg's consumption (2018; STATEC). Concerning the energy necessary for heating (electricity excluded), Maas et al (2012) have estimated a consumption of 131 kWh $m^{-2}$ per year. $CO_2$ emissions account for 0.02 Mt of $CO_2$ per year, following the same calculation procedure than previously.

In total, direct emissions from office employees and buildings would amount to 0.03 Mt of $CO_2$ per year. The low contribution in the carbon Footprint would not bring significant change when the service employees Footprint would be reduced. It represents 17,695 gha of the $EF_C$ thus, 0.03 gha $capita^{-1}$ (Table 18).

*Table 18: Service employees Footprint. The energy consumption of workplaces is based on heating energy and electricity needs.*

| | *employees* | *GWh* | *gha* | *% carbon Footprint* | *gha capita$^{-1}$* |
|---|---|---|---|---|---|
| *workplace* | 67,603 | 147 | 17,695 | 0.3 | 0.03 |
| *mail, webbrowser* | 67,603 | 25 | 3,009 | 0.0 | - |

Within the previous calculation, the embodied $CO_2$ emissions of electronic operations such like, sending emails or browse the web, are not included. An extra calculation reveals that about 254 kg $CO_2$ per year are emitted per user. Reading, writing or sending about 20 mails per day over a year equals to the amount of $CO_2$ emitted by 1,000 car kilometres, searching web addresses accounts for 9.9 kg of $CO_2$ per year per user and, surfing the web requires about 365 kWh per year and user (energuide.be). Multiplied by 67,603 workers, another 0.02 Mt $CO_2$ embodied emissions can be considered.

### *3.7 Data centres Footprint*

Luxembourg is known as being the best-connected country in Europe. No fewer than 23 data centres are in operation, representing 46,761 $m^2$ of floor space (LU-CX 2020). A key factor explaining the development of such infrastructures in Luxembourg is that the cost of electricity is one of the lowest in Europe, and the cheapest in western Europe (Eurostat, 2020b). Electricity supply is the most reliable in Europe with Luxembourg having the lowest number of annual power outages (CEER 2014). Data centres have energy intensive needs, since they run 24/7 all year round. A high energy demand is attributed to the primary IT needs and cooling equipment (Castellazzi et al 2017).

*Table 19: Data centres Footprint.*

| | *GWh* | *electricity consumption (%)* | *gha* | *% carbon Footprint* | *gha capita$^{-1}$* |
|---|---|---|---|---|---|
| *data center* | 933 | 14 | 90,635 | 1.5 | 0.15 |
| *data center – renewable energies* | 933 | 14 | 25,860 | 0.4 | 0.04 |

According to the available technical descriptions, data centres in Luxembourg have an estimated total power of altogether 106,460 kW per hour (LU-CX 2020). This represents a yearly consumption of about 933 GWh of electricity, accounting for 14 % of the electricity consumption in Luxembourg in 2018 (Table 19). Electrical energy needs for data centres exceed by far the 466 GWh of power self-produced in Luxembourg. Therefore, it is assumed that imported electricity supplies the data centres. In this case, it has been calculated that data centres contribute to emissions of circa 0.3 Mt $CO_2$ in 2018. That is about 90,635 gha needed to balance these emissions. Energy consumption of the data centres in Luxembourg contribute to 1.5 % of the carbon Ecological Footprint, being 0.15 demanded gha capita$^{-1}$.

### *3.8 Food consumption Footprint*

The Footprints of cropland, grazing land and fishing grounds in 2018 add up to 1,259,737 gha, equalling 2.09 gha capita$^{-1}$ and are mainly used to produced food. Thus, it is of interest what kind of food leads to what demand of global hectares. Table 20 shows the Footprints for the different product categories. Please note, that as the NFA are a top-down approach, the consumption footprint derives from the national imports, exports and production of the different food products. The demand of gha for plant-based food is 496,786 gha or 0.83 gha capita$^{-1}$, for fish 116,496 gha or 0.19 gha capita$^{-1}$ and for food of animal origin 625,639 gha or 1.04 gha capita$^{-1}$. The footprints of fertilizer and energy are distributed to plant-based food and food of animal origin according to their share on $EF_C$. As fish is not produced in considerable amounts in Luxembourg, no fertilizer or energy footprint is added to the fish footprint.

*Table 20: Food consumption Footprint.*

| | | $EF_I$ (gha) | $EF_E$ (gha) | $EF_P$ (gha) | $EF_C$ (gha) |
|---|---|---|---|---|---|
| *plant-based food* | *coffee, tea, spices* | 90,602 | 33,244 | | 57,358 |
| | *sugar, sugar preparations, honey* | 13,590 | 3,028 | | 10,562 |
| | *oils and fats* | 26,668 | 1,351 | | 25,317 |
| | *alcoholic beverages* | 56,144 | 18,786 | | 37,358 |
| | *beverages* | 94,797 | 21,718 | | 73,079 |
| | *vegetable and fruit, juices* | 177,075 | 21,680 | 9,852 | 165,247 |
| | *cereals and cereal preparations* | 232,338 | 188,539 | 64,777 | 108,576 |
| *fish* | *fish, crustaceans, molluscs* | 39,037 | 1,650 | | 37,387 |
| | *fish* | 88,825 | 9,716 | | 79,109 |
| *food of animal origin* | *dairy products and birds' eggs* | 44,078 | 74,987 | 46,057 | 15,148 |
| | *meat and meat preparations* | 265070 | 75,542 | | 189,528 |
| | *living animals* | 4,720 | 15,541 | 144,311 | 133,490 |
| | *fodder cereals* | 89,577 | 86,230 | 93,204 | 96,551 |
| | *feedstuff* | 95,737 | 0 | | 95,737 |
| *fertilizer* | | 33,421 | | | 33,421 |
| *energy* | | | | | 6,684 |
| *total* | | | | | 1,259,737 |

According to section 3.5 Cross-border commuters, the expenditures of cross-border commuters is 21 % of food HFCE and 11 % of alcoholic beverages sold in Luxembourg. This consumption adds up to 257,238 gha and equals 0.43 gha capita$^{-1}$.

### *3.8 Household and food waste Footprint*

In 2018, Luxembourg inhabitants have produced an amount of waste of 610 kg capita$^{-1}$ year$^{-1}$ (Eurostat 2020c). This is at the higher spectrum of waste per capita and per year produced when compared to the neighbouring countries: Germany with 615 kg capita$^{-1}$ year$^{-1}$, France with 527 kg capita$^{-1}$ year$^{-1}$ and Belgium 411 kg capita$^{-1}$ year$^{-1}$.The end-consumer is responsible for a high share of this waste: The 2018 analysis of the residents' household waste in Luxembourg revealed that 193.7 kg of waste (>30 %) were thrown away per capita at the end-consumer stage (Schaeler at al. 2019). This amount is composed by weight of 31.6 % organic waste, 17.9 % paper and cardboard and, 16.7 % plastics. Compared to 2013, the quantity of waste per capita has been reduced by 13.2 %, which represents a reduction of 30 kg capita$^{-1}$ year$^{-1}$. Nevertheless, due to continuous increase of the population from 537,039 inhabitants in 2013 to 602,605 in 2018, the total amount of waste is steady and shows only a slight reduction of 2.7 % within this period. According to Schaeler at al. (2019), the reduction potential that still exists in the residual waste sector amounts to approximately 63.5 % by weight. This reduction is difficult to reach, since it requires an optimized syndicate-wide expansion of the recycling systems.

Looking in more details, small changes in the consumption and recycling behaviour of the inhabitants could already contribute to reduce the Ecological Footprint of household waste. Within the 31.6 % of organic waste, 5.53 % is considered to be avoidable (Schaeler et al. 2019). It equals to about 10.7 kg capita$^{-1}$ year$^{-1}$ which is a total of 6441.4 t year$^{-1}$ country-wide. The necessary Biocapacity to absorb this amount of waste represents 2,693 t $CO_2$ equalling to about 900 gha. The analysis by Schaeler et al. (2019) also showed that coffee capsules in the residual waste add up to 1.6 kg capita$^{-1}$ year$^{-1}$ equalling to approximately 956 t year$^{-1}$ for the whole country.

They amount for about 110 t $year^{-1}$ of plastic and aluminium, where the rest of the waste is coffee grounds. Assuming that the amount of packaging material is equally distributed between both components meaning, 55 t aluminium and 55 t plastic, the estimated Ecological Footprint sizes 0.2 gha for aluminium and 0.1 gha for plastic. This total of 0.3 gha could be reduced by two-thirds, by replacing aluminium and plastic capsules by biodegradable ones, and by organizing a special collect of the conventional capsules in order to re-utilise or recycle them.

At a general scale, reducing the amount of organic waste by 5 % means, that 5 % less food is consumed and imported. By cutting down the imports by 5 % for all food items (e.g. fish, vegetables, fruits, food preparations, oils and coffee), the impact on the Ecological Footprint is estimated to be at least 62,987 gha. This represents 0.1 gha $capita^{-1}$ that could be saved.

## 4. Discussion & Conclusions

National Footprint and Biocapacity Accounts are based on various UN and para-UN data sources including FAOstat, UN Comtrade and IEA (Kitzes et al. 2009b). These data platforms receive the data from national statistical offices that are responsible for the accuracy of provided data. Kitzes et al. (2009b) emphasize that high resolution, accurate data sets are available for many high-income countries. STATEC, the National Institute of statistics and economic studies of the Grand Duchy of Luxembourg is scientifically independent and provides data in neutrality. The comparison between nationally available data for 2016 and the data from the UN data sources, used by Global Footprint Network for the calculation of the 2016 Ecological Footprint, revealed that more up-to-date data was available for the year 2016 in the national data sources. This led to small differences in the Ecological Footprint calculations for the year 2016: Using national data, we calculated an overall Luxembourgish demand in 2016 of 12.98 gha capita$^{-1}$ whereas Global Footprint Network calculated 12.91 gha capita$^{-1}$. The Global Footprint Network calculation was published in April 2019, whereas the last our calculation was performed MONTH 2020. As the data needs to first be collected and revised at the national level before it is reported to the international statistics bodies (either at European or global level) there is an important time lag before current data is available at the international level and are often available earlier through the national statistics offices (in our case the STATEC). Thus, the updated data for 2016 that has been used by IBLA might not all have been available when Global Footprint Network did the accounting in 2019. Nevertheless, the discrepancies in the data only lead to minor differences in the results of the Ecological Footprint for Luxembourg. It can therefore be concluded, that confidence can be placed in the metric and these results can be used to further investigate the potential implications for Luxembourg. It should be mentioned that some data is often needed in specific units or in a specific compilation that are not available nationally, especially with regards to the Standard International Trade Classification (SITC) categories. This was also previously discussed by Hild et al. (2010). For these commodities, no data comparison could be made and only UN and para-UN data were used.

As the National Footprint Accounting 2016 by IBLA and Global Footprint Network did not differ substantially, the Luxembourgish Ecological Footprint and Biocapacity have been calculated for 2018 using the same data basis. However, it needs to be noted, that not all data was available, not even at national level, for the year 2018. Where not, data from 2017 was used instead. This lag in data availability is also why Global Footprint Network is always a couple of years behind in the calculation of National Footprint and Biocapacity Accounts (and they also provide now-casting for estimates of more recent years). Thus, when they eventually will have the data available in international databases and will recalculate the NFA for Luxembourg, small differences in the results can be expected. Nonetheless, these small differences are not as important as the bigger picture they paint: Luxembourg has a much bigger resource demand than its biocapacity can provide; and this demand has not shown any considerable decrease over the past decades. For 2018, the demand of 13.03 gha capita$^{-1}$ was even higher than for 2016. Not surprisingly, the number of planets, that would be needed, if everyone lived like residents of Luxembourg has also increased from 7.96 in 2016 (calculations by IBLA) to 7.99 in 2018. In 2008, a decade ago, Global Footprint Network calculated that 8.86 planets would be needed (Global Footprint Network 2019). Even though several national and international environmental policies have been implemented in between, they do not seem to have had a positive effect on the National Footprint. A basic quantitative condition for global sustainability is that humanity uses substantively less than one planet. Luxembourg is using about eight planets and therefore it is not replicable. It runs a big ecological deficit which could become a risk in a world of persistent and growing overshoot.

The global biocapacity per capita was 1.63 gha in 2016. Luxembourg with a Biocapacity of only 1.33 gha has a lower capacity per person than the world to provide the needed resources or to absorb human-made waste. This coupled with a large resource demand, leads to a huge biocapacity deficit of 11.7 gha capita$^{-1}$. The missing Biocapacity is mainly bought from lower-income regions and "loaned" from future generations. Not all countries can be biocapacity debtors for long, but vice-versa, Footprint accounts do not demand all countries to be self-sufficient in resources (Wackernagel and Lin 2019). Nevertheless, the biocapacity deficit of Luxembourg is massive, and the reasoning of Wackernagel and Lin (2019) should not be used as an excuse to not take drastic action to reduce the Ecological Footprint of Luxembourg. The European Environmental Agency (EEA 2020) states countries with an ecological deficit can meet their demands in three ways: (1) over-exploitation of their own stocks of ecological capital, e.g. through overfishing; (2) import of products leading to exploitation of the biocapacity of other nations; or (3) exploitation of the global commons, in particular by releasing carbon dioxide ($CO_2$) emissions into the atmosphere from fossil fuel burning, land use change and the production and consumption processes.

"Luxembourg is part of the Greater Region and due to its economic openness should not to be considered alone but in the European context", is the Luxembourgish fundamental attitude. In case of Luxembourg with close to 200.000 commuters in relation with 600.000 inhabitants and a mainly exporting economy of which the main part is services which are corrected for export-load on energy, the GFN concept might come to its limits and needs to be looked at in differentiated terms. However, the approach of the Global Footprint Network is to see each individual country like a farm. If a country, like Luxembourg, runs an ecological deficit, it is the farm Luxembourg that runs the deficit. Perhaps that country may have enough financial advantage to compensate this deficit for the moment (as is the case at the moment with Luxembourg, being one of the wealthiest in the Europe (OECD 2019)), however, the world as a whole is running a deficit, too. Thus, the import of products leading to the overexploitation of the Biocapacity of other nations (2) and the exploitations of the global commons (3) will soon no longer be an option (not that they should be at the present).

In order to identify and better understand where action is most relevant and efficient, factors that most importantly impact the Ecological Footprint of Luxembourg were studied. Out of the different Footprints assessed (carbon Footprint, cropland Footprint, grazing land Footprint, fishing grounds Footprint, forest products Footprint and build-up land Footprint) the carbon Footprint was by far the largest and with the highest impact on the overall Ecological Footprint of Luxembourg (it explains 79 % of the total Ecological Footprint of Luxembourg). Thus, improvements in this parameter will have the most significant effect on the overall Ecological Footprint of Luxembourg. This was already observed since 2003: a steady decline in the overall Ecological Footprint of Luxembourg could be observed, which mainly coincides with a steady decrease in the carbon Footprint. The main factors impacting on the carbon Footprint are fossil fuel combustion, electricity import and trade (Lin et al. 2019). A more in-depth look was therefore taken at these sectors.

The "Transport" and "Energy" sectors, both assigned to the carbon Footprint in the NFA, have immense potential for reducing the Ecological Footprint. Luxembourg has already diminished the energy and $CO_2$ intensity of production in the past years, partially through an increase in the share of renewable energy in the national energy mix. The $CO_2$ emissions per GDP have drastically been reduced since 2010 which is related to lower primary energy supply per GDP (OECD 2019). These efforts are also reflected in the decline in the carbon Footprint over the past two decades. However, Luxembourg's performances remain under the OECD averages. The renewable energy supply is also still lower as the OECD average despite a significant progression in the recent years (OECD 2019). In order to meet climate protection goals, such as those from the Paris Agreement, and the further reduce the carbon Footprint and in turn the Ecological Footprint of Luxembourg, further important efforts need to be made. This is currently being taken into account by the "National Energy and Climate Plan 2021-2030" (MEAT & MECDD 2020) that requires a drastic reduction of energy consumption in all sectors, the development of renewable energies and, hence, to reduce Luxembourg's dependency on energy imports. Even if about 75 % of the electric power production in the country is renewable, Luxembourg remains highly dependent on the electricity production from fossil resources or nuclear power from neighbouring countries: 93 % of its electricity demand is currently imported (2018; STATEC). With the share of renewable energy of the trading partners not as high as in Luxembourg, an important part of the electricity's impact on the Ecological Footprint of Luxembourg is inevitable yet. We calculated, that in order to reach the goal of 25 % renewable energy from the NECP for 2030 (assuming the same electricity demand), the electricity sector needs to reach 33.6 % renewable power by 2030, instead of the 8.1 % in 2017. This means that of the imported electricity, 28.4 % need to come from renewable energy sources, equalling a 10-times increase in renewable energy imports compared to the 2017 levels. This highlights again our dependency on the efforts of our trading partners to increase the renewable energy share in the products; without important changes in their production method and the availability of electricity from renewable energy sources, Luxembourg is unable to do much to reduce its electricity related carbon Footprint.

The future expansion of information and communication technologies will have an even higher need for data centres and will inevitably lead to higher electrical energy consumption and related $CO_2$ emissions. The 23 data centres currently in operation have an electricity demand of 933 GWh and already represent 14 % of the national electricity consumption (LU-CX 2020). With further expansion of data centres, the carbon Footprint owed to electrical power use is expected to explode. New low consumption technologies for buildings and electronic systems are necessary to be explored. Luxembourg could reduce the electricity trade Footprint by producing more electricity using renewable energy sources and importing more from renewable sources. Assuming that Luxembourg could already produce the necessary 933 GWh of electricity to power the current 23 data centres using renewable energy sources, the Ecological Footprint would be reduced to 25,860 gha instead of 90,635 gha. This objective is, however, hard to achieve, as it means that the production would need to be more than doubled. Additionally, the prices for electricity would rise as renewable energy sources are still more expensive, which in turn would decrease the attractiveness of Luxembourg as location for data centres. One could argue, that fewer data centres on the territory would solve some of Luxembourg's environmental issues and automatically reduce the Ecological Footprint; however, these data centres are still needed and their ecological footprint will still affect the global Ecological Footprint. So, their impact would only be transferred to a different country and no overall global net improvement in sustainability is achieved. Likewise, the loss of the data centres would lead to other, hard to predict repercussions to e.g. the Luxembourgish economy. Some refunding in the industry sector, the highest electricity consumer with nearly 50 % of the Luxembourgish demand, has to be considered, as well as renovation of private households; the latter already being an important objective in the current NECP. Such changes, however, are complex dilemmas: on the one hand, a greening of the economic activities and, on another hand, social aids and subsidies to avoid social discrimination in the application of, for example, new construction rules (such as imposing the use of renewable energies in new buildings) need to be brought into line.

The consumption of fossil fuels by the transport sector of 31750 GWh is responsible for 44.5 % of the carbon Footprint of Luxembourg, equalling 4.28 gha $capita^{-1}$. Kerosene, i.e. air travel, alone is responsible for 1.06 gha capita$^{-1}$ in 2018. In 2012, a total of 7.4 billion vkm were travelled on the Luxembourgish territory by car, bus and truck. Assuming that this number has not decreased over the years (which is very unlikely with a growing population), the impact on the gha capita$^{-1}$ is 1.94. Knowing that in 2018 over 40 % of the workforce in Luxembourg is made up of cross border commuters from the Greater Region, a large portion of the vkm are travelled by non-residents. Furthermore, due to the lower taxes in Luxembourg on fuels, these are cheaper than in the neighbouring countries, resulting in the phenomenon of so-called fuel tourism: people travelling to Luxembourg to simply fuel up their vehicles. It is often discussed, that these two peculiarities of Luxembourg can distort the Ecological Footprint. Hild et al. (2010) also came to the conclusion, that fuel tourism and cross-border commuters were factors that augment the Ecological Footprint of Luxembourg. Thus, to clarify the magnitude of the impact of fuel tourism and of cross-border commuters, in general, their share on the Luxembourgish Ecological Footprint have been evaluated. In 2018, fuel tourism made up 2.85 gha capita$^{-1}$ and cross-border commuters contributed with 1.13 gha capita$^{-1}$ to the Luxembourgish Ecological Footprint. To avoid double counting, fuel sold to cross-border commuters and the corresponding impact of 0.52 gha capita$^{-1}$ needs to deducted from one of the two footprints before adding them together. Thus, ca. 3.5 gha capita$^{-1}$ of the 9.27 gha capita$^{-1}$ of the carbon Footprint (ca. 37 %) are a direct result from these two factors. It would be naïve to condemn the cheap prices of the fuel in Luxembourg; the fuel would still be bought, maybe not in Luxembourg, but in the Greater Region. At the moment, for trucks with a 1,000-l tank and using the diesel price from July 2020, a maximum detour to Luxembourg of 242 km from France, 135 km from Germany and 317 km from Belgium would still be worthwhile.

Not selling the fuel in Luxembourg would improve the national carbon Footprint of Luxembourg, but not the Footprint of the Greater Region or Europe. Same as with the data centres, the fuel is still needed for transport. Increasing the tax in Luxembourg, thus making the fuel no longer cheaper than in neighbouring countries will again only shift the ecological impact but not increase the net global sustainability. Furthermore, the ramifications for the economy and society are difficult to predict. In order to ensue real change, the vkm per person (resident or cross-border commuter) need to be reduced and alternative transport options made more available. The latter the Luxembourgish government aims to achieve through the expansion of public transport system and the promotion of electro-mobility in cars and transport.

The NECP aims to achieve 49 % electro-mobility by 2030. Through this measure 0.34 gha capita$^{-1}$ could be saved. However, switching to electro-mobility only makes sense, if the electricity used is obtained from renewable energy sources. This would then result in possible savings of 0.42 gha capita$^{-1}$. Nevertheless, as we have seen before, increasing the share of renewable energy in our electricity products is highly dependent on what changes are implemented by our trading partners. Furthermore, an increase in electromobility will also increase our overall electricity demand and further increase our dependency on electricity imports. Thus, the expected effect on the EF of Luxembourg might not be a straight forward net positive effect. The result of most studies is (e.g. Romare & Dahllöf 2017, BMU 2019) that electric cars have a clear climate advantage over vehicles with internal combustion engines. However, these comparisons and the calculated savings potential are heavily dependent on which categories of cars (small cars, mid-range cars, upper class) are compared with each other. The production of batteries for electric cars in particular is a key point: it is very energy-intensive and weighs up a large part of the emissions saved during operation. The production of traction current also has a major impact on emissions. The reduction of $CO_2$ emissions in countries with a high proportion of renewable energies for traction current is significantly higher than in Luxembourg with currently only around 7 % renewable energies. The longer electric vehicles are operated, the less the production is important. After a journey of 150,000 km with a mixed driving profile, the total emissions of an electric vehicle are approx. 24 % below those of petrol engines and 16 % below those of diesel vehicles (Agora 2019). Further developments that reduce emissions, especially in production technology and by promoting renewable energies, increase the climate advantage of electro-mobility.

Since the service sector in Luxembourg is very developed and an important source of work, yet only produces intangible goods and information, it is not directly captured in the Ecological Footprint calculations. The study at hand aimed to evaluate the impact of the service sector in the Ecological Footprint in order to see if this could explain a disbalance in the Luxembourgish Ecological Footprint: ideally intangible goods from this sector could be embedded in the calculations as "exports" in order counterbalance the Ecological Footprint of production from the sector. Therefore, the carbon Footprint of an office employee was estimated. Our calculation, however, showed that the global hectares for the employees' workplaces (regarding to energy needs) and seemed to play a minor role for Ecological Footprint of Luxembourg (0.3 % of the carbon Footprint). But, accompanying services of the financial and service industry such as lawyers, auditors, fiduciary are not considered in this approach. Moreover, STATEC (2020) indicates the service industry consumes as much electricity as the households. The overall impact of the service sector leads to a negative bias when it comes to comparing Luxembourg to its neighbouring countries:

Finally, the last factors assessed for their impact on the Ecological Footprint of Luxembourg were food consumption, and household and food waste. The food consumption Footprint was calculated for plant-based food, fish and food of animal origin. A total of 1,259,737 gha or 2.09 gha capita$^{-1}$ are needed to cover the demand of food purchased on the territory of Luxembourg; 0.42 gha capita$^{-1}$ can attributed to the cross-border commuters. There are of course also other non-residents that do their grocery shopping in Luxembourg as one or the other product is cheaper here than in their country of resident. However, as the same is true for residents of Luxembourg that go to Germany, France or Belgium to do their weekly shopping, it might be assumed, that the EF in this case balances each other out. The Footprint of food consumption in 2008 was calculated to be 1.49 gha capita$^{-1}$, whereof cross-border commuters accounted for 131,337 gha (0.27 gha capita$^{-1}$) (Hild et al. 2010). Overall, the food Footprint is responsible for a substantial part of the Ecological Footprint of Luxembourg (ca. 16 %) and reducing this Footprint can help improve the sustainability of Luxembourg. The consumption of food of fish and animal origin (meat, eggs, dairy products) together makes up 58.9 % of the Luxembourgish food Footprint (c.f. Poore and Nemecek 2018), thus a reduction in their consumption is an easy way to reduce the corresponding Footprint. Luxembourg has a very high meat consumption rate (80.07 kg year$^{-1}$ capita$^{-1}$ in 2017, (FAOSTAT 2020)). As excessive meat consumption is also often linked to a rise in non-communicable diseases, the effort to improve the Ecological Footprint of Luxembourg can also have positive effects on the health of the population (e.g. Willett et al. 2019).

A second approach to reduce the Footprint of food is to reduce food waste. Around 1/3 of all produced food end up as waste; 42 % of these 33 % wasted food is thrown away at the end-consumer stage (Antigaspi 2020). On top of this, a large portion of household waste still consists of organic waste (33.6 %), even though national efforts exist to collect organic waste separately for "recycling": e.g. to produce compost or energy in biogas plants. The study by Schaeler et al (2019) stated there is a saving potential of 5 % corresponding to a reduction in consumption footprint of at least 0.1 gha capita$^{-1}$. When less food is wasted, less food needs to be produced or imported to provide the necessary calories to feed the population. Moreover, the imports of global hectares could decrease over proportionally if local production is not reduced or even increased.

The approaches presented here to reduce the Ecological Footprint are only a small insight into the possible reduction potential. The calculations presented here, in particular for Luxembourg's energy consumption, show that measures, on the one hand, can lead to a reduction in the Ecological Footprint and, on the other hand, might also lead to an increase in resource consumption that in turn increases the footprint (e.g. electromobility or wood pellet heating systems (not shown separately)). For the same reason, the reduction potentials calculated cannot be simply summed to evaluate the effect from implementing several approaches together. Overall, it needs to be noted that each of these calculations is subject to a large number of uncertainties, which not least relates to the compilation of meaningful comparative data and figures. As such, the reduction potentials calculated are therefore not an absolute science and should be more seen as giving an order of magnitude and scope what is possible to achieve through the implementation of certain changes and efforts. Each of these approaches presented here is backed by one or more national studies, some of which are very complex, that shed light on the current situation and possible future scenarios for Luxembourg, and the results can therefore be used to identify some linchpins to incur change. Nevertheless, only a few scenarios and approaches were calculated and discussed here; they provide possible starting points for reducing the Ecological Footprint of Luxembourg. It should, however, not be forgotten that several other options and approaches exist. For example, a reduction of 0.1 planets could be achieved by reducing the volume of traffic by establishing satellite offices at the borders, increasing the use of car sharing or the use of public transport, and promoting “work from home” (i.e. fewer trips to work).

Especially the latter was shown to work better than expected during the recent lockdown during the COVID-19 pandemic. According to a recent survey by the STATEC (2020), around 70 % of employees were working from home during the lockdown and the experience was in the context of COVID-19 lockdown rated as a positive experience by 55 % of the participants and neutral by 30 % of the participants. Even before the pandemic around 20 % of employees were able to work at least for part of their work hours from home. A higher number of hours spent working from home corresponded to a decrease in job satisfaction whereas 1-15h spent working from home showed an increase in job satisfaction (STATEC 2020). As such, enabling work from home for 1-2 days per week for a large portion of the workforce in Luxembourg (knowing that this is not possible for all employees in all sectors) might entail two benefits: increased worker satisfaction and reduced $CO_2$ emissions with a corresponding reduction the carbon Footprint of Luxembourg.

Overall, the Ecological Footprint is a tool to communicate the impact of resource consumption on the environment to the general public in a visual language. For Luxembourg, the Ecological Footprint shows in an impressive way the overuse of available resources and points out that mainly the use of energies (fossil fuels and electricity) accounting for 7.02 gha capita$^{-1}$ leads to this disastrous picture. Therefore, the main addressee of the National Footprint and Biocapacity accounts are the representatives of politics and economy who must ensure that Luxembourg is developed into a sustainable, independent and self-sufficient economy. Nonetheless, the food Footprint, accounting for 2.08 gha capita$^{-1}$, shows that every single person may contribute to a more sustainable society by rethinking and changing their own consumption and lifestyle habits.

The lockdown due to the COVID-19 pandemic showed that world leaders are not afraid to take drastic measures when absolutely necessary. This naturally had several negative effects on the economy: the global economy crashed dramatically and the total extent of the global economic consequences is not yet foreseeable. It is not certain if or when Luxembourg, Europe and the world will return to their economic performances before the crisis. From an environmental point of view, however, this lockdown also had positive consequences with regard to emissions and the ecological footprint. As a result, while Earth Overshoot Day in 2019 occurred on July 29th, COVIDinduced reduction in demand led to Earth Overshoot Day 2020 being pushed back by over three weeks to August 22nd . This special situation demonstrates that reducing consumption is possible in a short timeframe. However, as Global Footprint Network stated in its press release for Earth Overshoot Day 2020: we need to choose our future by design not by disaster.

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## Glossary

This glossary (here in excerpts) to explain relevant terms used to assess the Ecological Footprint of a country is provided by the Global Footprint Network Glossary (2020b) and is accessible on https://www.footprintnetwork.org/resources/glossary/.

*Biocapacity or biological capacity*: The capacity of ecosystems to regenerate what people demand from those surfaces. Life, including human life, competes for space. The Biocapacity of a particular surface represents its ability to renew what people demand. Biocapacity is therefore the ecosystems' capacity to produce biological materials used by people and to absorb waste material generated by humans, under current management schemes and extraction technologies. Biocapacity can change from year to year due to climate, management, and also what portions are considered useful inputs to the human economy. In the National Footprint and Biocapacity Accounts, the Biocapacity of an area is calculated by multiplying the actual physical area by the yield factor and the appropriate equivalence factor. Biocapacity is usually expressed in global hectares.

*biological capacity per capita*: There were ~ 12.2 billion hectares of biologically productive land and water on Earth in 2019. Dividing by the number of people alive in that year (7.7 billion) gives 1.6 global hectares per person. This area also needs to accommodate the wild species that compete for the same biological material and spaces as humans.

*biologically productive land and water*: The land and water (both marine and inland waters) area that supports significant photosynthetic activity and the accumulation of biomass used by humans. Non-productive areas as well as marginal areas with patchy vegetation are not included. Biomass that is not of use to humans is also not included. The total biologically productive area on land and water in 2019 was approximately 12.2 billion hectares.

*carbon Footprint:* The carbon Footprint measures $CO_2$ emissions associated with fossil fuel use. In Ecological Footprint accounts, these amounts are converted into biologically productive areas necessary for absorbing this $CO_2$. The carbon Footprint is added to the Ecological Footprint because it is a competing use of bioproductive space, since increasing $CO_2$ concentrations in the atmosphere is considered to represent a build-up of ecological debt. Some carbon Footprint assessments express results in tonnes released per year, without translating this amount into area needed to sequester it.

*Consumption*: Use of goods or of services. The term consumption has two different meanings, depending on context. As commonly used in regard to the Footprint, it refers to the use of goods or services. A consumed good or service embodies all the resources, including energy, necessary to provide it to the consumer. In full life-cycle accounting, everything used along the production chain is taken into account, including any losses along the way. For example, consumed food includes not only the plant or animal matter people eat or waste in the household, but also that lost during processing or harvest, as well as all the energy used to grow, harvest, process and transport the food.

As used in Input-Output analysis, consumption has a strict technical meaning. Two types of consumption are distinguished: intermediate and final. According to (economic) System of National Accounts terminology, intermediate consumption refers to the use of goods and services by a business in providing goods and services to other businesses. Final consumption refers to non-productive use of goods and services by households, the government, the capital sector, and foreign entities.

*consumption components (or consumption categories):* Ecological Footprint analyses can allocate total Footprint among consumption components, typically Food, Shelter, Mobility, Goods, and Services—often with further resolution into sub-components. Consistent categorization across studies allows for comparison of the Footprint of individual consumption components across regions, and the relative contribution of each category to the region's overall Footprint. To avoid double counting, it is important to make sure that consumables are allocated to only one component or sub-component. For example, a refrigerator might be included in either the food, goods, or shelter component, but only in one.

*Consumption Land Use Matrix:* Starting with data from the National Footprint and Biocapacity Accounts, a Consumption Land Use Matrix allocates the six major Footprint land uses (shown in column headings) allocated to the five basic consumption components (row headings). For additional resolution, each consumption component can be disaggregated further. These matrices are often used as a starting point for sub-national (e.g. state, county, city) Footprint assessments. In this case, national data for each cell is scaled up or down depending on the unique consumption patterns in that sub-national region compared to the national average.

*conversion factor:* A generic term for factors which are used to translate a material flow expressed within one measurement system into another one. For example, a combination of two conversion factors - “yield factors” and “equivalence factors”- translates hectares into global hectares. The extraction rate conversion factor translates a secondary product into primary product equivalents.

*derived product:* The product resulting from the processing of a primary product. For example, wood pulp, a secondary product, is a derived product of roundwood. Similarly, paper is a derived product of wood pulp.

*double counting:* In order not to exaggerate human demand on nature, Footprint Accounting avoids double counting, or counting the same Footprint area more than once. Double counting errors may arise in several ways. For example, when adding the Ecological Footprints in a production chain (e.g., wheat farm, flour mill, and bakery), the study must count the cropland for growing wheat only once to avoid double counting. Similar, but smaller, errors can arise in analyzing a production chain because the end product is used in produce the raw materials used to make the end product (e.g. steel is used in trucks and earthmoving equipment used to mine the iron or that is made into the steel). Finally, when land serves two purposes (e.g. a farmer harvests a crop of winter wheat and then plants corn to harvest in the fall), it is important not to count the land area twice. Instead, the yield factor is adjusted to reflect the higher bioproductivity of the double-cropped land.

*ecological debt or Biocapacity debt:* The sum of annual ecological deficits. Humanity’s Footprint first exceeded global Biocapacity in the early 1970s, and has done so every year since. By 2019 this annual overshoot had accrued into an ecological debt that exceeded 17 years of the Earth’s total productivity.

*ecological deficit/reserve or Biocapacity deficit/reserve:* The difference between the Biocapacity and Ecological Footprint of a region or country. An ecological deficit occurs when the Footprint of a population exceeds the Biocapacity of the area available to that population. Conversely, an ecological reserve exists when the Biocapacity of a region exceeds its population’s Footprint. If there is a regional or national ecological deficit, it means that the region is importing Biocapacity through trade or liquidating regional ecological assets, or emitting wastes into a global common such as the atmosphere. In contrast to the national scale, the global ecological deficit cannot be compensated for through trade, and is therefore equal to overshoot by definition.

*Ecological Footprint:* A measure of how much area of biologically productive land and water an individual, population or activity requires to produce all the resources it consumes and to absorb the waste it generates, using prevailing technology and resource management practices. The Ecological Footprint is usually measured in global hectares. Because trade is global, an individual or country’s Footprint includes land or sea from all over the world. Without further specification, Ecological Footprint generally refers to the Ecological Footprint of consumption. Ecological Footprint is often referred to in short form as Footprint. “Ecological Footprint” and “Footprint” are proper nouns and thus should always be capitalized.

*Ecological Footprint of consumption (EFC):* The most commonly reported type of Ecological Footprint, it is defined as the area used to support a defined population’s consumption. The consumption Footprint (in gha) includes the area needed to produce the materials consumed and the area needed to absorb the carbon dioxide emissions. The consumption Footprint of a nation is calculated in the National Footprint and Biocapacity Accounts as a nation’s primary production Footprint plus the Footprint of imports minus the Footprint of exports, and is thus, strictly speaking, a Footprint of apparent consumption. The national average of per capita Consumption Footprint is equal to a country’s Consumption Footprint divided by its population.

*Ecological Footprint Standards:* Specified criteria governing methods, data sources and reporting to be used in Footprint studies. Standards were established by the Global Footprint Network Standards Committee, composed of scientists and Footprint practitioners from around the world. The latest ones are from 2009. Standards serve to produce transparent, reliable and mutually comparable results in studies done throughout the Footprint Community. Where Standards are not appropriate, Footprint Guidelines should be consulted. For more information, consult www.footprintstandards.org.

*embodied energy*: Embodied energy is the energy used during a product's entire life cycle in order to manufacture, transport, use and dispose of the product. Footprint studies often use embodied energy when tracking trade of goods.

*equivalence factor:* A productivity-based scaling factor that converts a specific land type (such as cropland or forest) into a universal unit of biologically productive area, a global hectare. For land types (e.g., cropland) with productivity higher than the average productivity of all biologically productive land and water area on Earth, the equivalence factor is greater than 1. Thus, to convert an average hectare of cropland to global hectares, it is multiplied by the cropland equivalence factor of 2.51. Grazing lands, which have lower productivity than cropland, have an equivalence factor of 0.46 (see also yield factor). In a given year, equivalence factors are the same for all countries.

*global hectare (gha):* Global hectares are the accounting unit for the Ecological Footprint and Biocapacity accounts. These productivity-weighted biologically productive hectares allow researchers to report both the Biocapacity of the earth or a region and the demand on Biocapacity (the Ecological Footprint). A global hectare is a biologically productive hectare with world average biological productivity for a given year. Global hectares are needed because different land types have different productivities. A global hectare of, for example, cropland, would occupy a smaller physical area than the much less biologically productive pasture land, as more pasture would be needed to provide the same Biocapacity as one hectare of cropland. Because world productivity varies slightly from year to year, the value of a global hectare may change slightly from year to year.

*overshoot:* Global overshoot occurs when humanity's demand on nature exceeds the biosphere's supply, or regenerative capacity. Such overshoot leads to a depletion of Earth's life supporting natural capital and a buildup of waste. At the global level, ecological deficit and overshoot are the same, since there is no net-import of resources to the planet. Local overshoot occurs when a local ecosystem is exploited more rapidly than it can renew itself.

*yield:* The amount of regenerated primary product, usually reported in tons per year, that humans are able to extract per area unit of biologically productive land or water.

*yield factor:* A factor that accounts for differences between countries in productivity of a given land type. Each country and each year has yield factors for cropland, grazing land, forest, and fisheries. For example, in 2008, German cropland was 2.21 times more productive than world average cropland. (The German cropland yield factor of 2.21, multiplied by the cropland equivalence factor of 2.51 converts German cropland hectares into global hectares: one hectare of cropland is equal to 5.6 gha.

Note that primary product and primary production Footprint are Footprint specific terms. They are not related to, and should not be confused with the ecological concepts of primary production, gross primary productivity (GPP) and net primary productivity (NPP).

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# Appendix

## A.1 National Footprint Accounting 2019 Edition - Luxembourg 2016 by GFN (GFN 2016)

**National Footprint Accounts 2019 Edition - Data Year 2016**

**Luxembourg**

**Ecological Footprint and Biocapacity Totals**

| Demand Type [-] | $EF_{Production}$ [gha] | $EF_{Imports}$ [gha] | $EF_{Exports}$ [gha] | $EF_{Consumption}$ [gha] | Biocapacity [gha] |
|---|---|---|---|---|---|
| Crop | 165.875 | 734.311 | 388.207 | 511.979 | 165.875 |
| Grazing | 41.200 | 396.703 | 73.485 | 364.418 | 41.200 |
| Forest Products | 244.245 | 930.138 | 522.205 | 652.177 | 458.109 |
| Fish | - | 95.224 | 9.714 | 85.510 | 384 |
| Built-up | 47.037 | - | - | 47.037 | 47.037 |
| Carbon | 3.057.004 | 7.468.328 | 4.752.600 | 5.772.731 | - |
| **TOTAL** | **3.555.361** | **9.624.703** | **5.746.212** | **7.433.853** | **712.605** |

**Ecological Footprint and Biocapacity Per Capita**

| Demand Type [-] | $EF_{Production}$ [gha person$^{-1}$] | $EF_{Imports}$ [gha person$^{-1}$] | $EF_{Exports}$ [gha person$^{-1}$] | $EF_{Consumption}$ [gha person$^{-1}$] | Biocapacity [gha person$^{-1}$] |
|---|---|---|---|---|---|
| Crop | 0,29 | 1,28 | 0,67 | 0,89 | 0,29 |
| Grazing | 0,07 | 0,69 | 0,13 | 0,63 | 0,07 |
| Forest Products | 0,42 | 1,62 | 0,91 | 1,13 | 0,80 |
| Fish | 0,00 | 0,17 | 0,02 | 0,15 | 0,00 |
| Built-up | 0,08 | 0,00 | 0,00 | 0,08 | 0,08 |
| Carbon | 5,31 | 12,97 | 8,25 | 10,03 | 0,00 |
| **TOTAL** | **6,18** | **16,72** | **9,98** | **12,91** | **1,24** |

| | | Total | | Per Capita | |
|---|---|---|---|---|---|
| | | Luxembourg | World | Luxembourg | World |
| Available Biocapacity | [gha] | 712.605 | 12.169.283.366 | 1,24 | 1,63 |
| Footprint of Production | [gha] | 3.555.361 | 20.508.908.286 | 6,18 | 2,75 |
| Net Imports | [gha] | 3.878.492 | | 6,74 | |
| Footprint of Consumption | [gha] | 7.433.853 | | 12,91 | |
| ($BC - EF_P$) | [gha] | -2.842.756 | -8.339.624.920 | -4,94 | -1,12 |
| ($BC - EF_C$) | [gha] | -6.721.248 | | -11,67 | |

| Number of planets demanded if world's population lived like residents of Luxembourg | 7,92 |
|---|---|

## A.2 National Footprint Accounting 2019 Edition - Luxembourg 2016 by IBLA

**National Footprint Accounts 2019 Edition - Data Year 2016**

# Luxembourg

**Ecological Footprint and Biocapacity Totals**

| Demand Type [-] | $EF_{Production}$ [gha] | $EF_{Imports}$ [gha] | $EF_{Exports}$ [gha] | $EF_{Consumption}$ [gha] | Biocapacity [gha] |
|---|---|---|---|---|---|
| Crop | 167,642 | 735,312 | 386,497 | 516,457 | 164,936 |
| Grazing | 73,340 | 399,951 | 107,220 | 366,071 | 73,340 |
| Forest Products | 244,245 | 930,138 | 522,205 | 652,177 | 443,098 |
| Fish | - | 95,196 | 9,714 | 85,482 | 375 |
| Built-up | 96,455 | - | - | 96,455 | 96,455 |
| Carbon | 3,057,004 | 7,468,328 | 4,770,529 | 5,754,803 | - |
| **TOTAL** | **3,638,685** | **9,628,925** | **5,796,165** | **7,471,445** | **778,204** |

**Ecological Footprint and Biocapacity Per Capita**

| Demand Type [-] | $EF_{Production}$ [gha person$^{-1}$] | $EF_{Imports}$ [gha person$^{-1}$] | $EF_{Exports}$ [gha person$^{-1}$] | $EF_{Consumption}$ [gha person$^{-1}$] | Biocapacity [gha person$^{-1}$] |
|---|---|---|---|---|---|
| Crop | 0.29 | 1.28 | 0.67 | 0.90 | 0.29 |
| Grazing | 0.13 | 0.69 | 0.19 | 0.64 | 0.13 |
| Forest Products | 0.42 | 1.62 | 0.91 | 1.13 | 0.77 |
| Fish | 0.00 | 0.17 | 0.02 | 0.15 | 0.00 |
| Built-up | 0.17 | 0.00 | 0.00 | 0.17 | 0.17 |
| Carbon | 5.31 | 12.97 | 8.29 | 10.00 | 0.00 |
| **TOTAL** | **6.32** | **16.72** | **10.07** | **12.98** | **1.35** |

| | | Total | | Per Capita | |
|---|---|---|---|---|---|
| | | Luxembourg | World | Luxembourg | World |
| Available Biocapacity | [gha] | 778,204 | 12,169,283,366 | 1.35 | 1.63 |
| Footprint of Production | [gha] | 3,638,685 | 20,508,908,286 | 6.32 | 2.75 |
| Net Imports | [gha] | 3,832,760 | | 6.66 | |
| Footprint of Consumption | [gha] | 7,471,445 | | 12.98 | |
| $(BC - EF_P)$ | [gha] | -2,860,481 | -8,339,624,920 | -4.97 | -1.12 |
| $(BC - EF_C)$ | [gha] | -6,693,241 | | -11.63 | |

| Number of planets demanded if world's population lived like residents of Luxembourg | 7.96 |
|---|---|

## A.3 National Footprint Accounting 2019 Edition - Luxembourg 2018 by IBLA

### National Footprint Accounts 2019 Edition - Data Year 2018

# Luxembourg

**Ecological Footprint and Biocapacity Totals**

| Demand Type [-] | $EF_{Production}$ [gha] | $EF_{Imports}$ [gha] | $EF_{Exports}$ [gha] | $EF_{Consumption}$ [gha] | Biocapacity [gha] |
|---|---|---|---|---|---|
| Crop | 226,166 | 736,212 | 357,655 | 604,722 | 182,541 |
| Grazing | 73,877 | 368,026 | 98,237 | 343,666 | 73,877 |
| Forest Products | 338,706 | 1,203,325 | 711,524 | 830,507 | 439,713 |
| Fish | - | 88,825 | 9,716 | 79,109 | 375 |
| Built-up | 105,251 | - | - | 105,251 | 105,251 |
| Carbon | 3,628,339 | 7,292,681 | 5,042,826 | 5,878,194 | - |
| **TOTAL** | **4,372,340** | **9,689,069** | **6,219,959** | **7,841,451** | **801,758** |

**Ecological Footprint and Biocapacity Per Capita**

| Demand Type [-] | $EF_{Production}$ [gha person$^{-1}$] | $EF_{Imports}$ [gha person$^{-1}$] | $EF_{Exports}$ [gha person$^{-1}$] | $EF_{Consumption}$ [gha person$^{-1}$] | Biocapacity [gha person$^{-1}$] |
|---|---|---|---|---|---|
| Crop | 0.38 | 1.22 | 0.59 | 1.00 | 0.30 |
| Grazing | 0.12 | 0.61 | 0.16 | 0.57 | 0.12 |
| Forest Products | 0.56 | 2.00 | 1.18 | 1.38 | 0.73 |
| Fish | 0.00 | 0.15 | 0.02 | 0.13 | 0.00 |
| Built-up | 0.17 | 0.00 | 0.00 | 0.17 | 0.17 |
| Carbon | 6.03 | 12.11 | 8.38 | 9.76 | 0.00 |
| **TOTAL** | **7.26** | **16.09** | **10.33** | **13.03** | **1.33** |

| | | Total | | Per Capita | |
|---|---|---|---|---|---|
| | | Luxembourg | World | Luxembourg | World |
| Available Biocapacity | [gha] | 801,758 | 12,169,283,366 | 1.33 | 1.63 |
| Footprint of Production | [gha] | 4,372,340 | 20,508,908,286 | 7.26 | 2.75 |
| Net Imports | [gha] | 3,469,111 | | 5.76 | |
| Footprint of Consumption | [gha] | 7,841,451 | | 13.03 | |
| ($BC - EF_P$) | [gha] | -3,570,582 | -8,339,624,920 | -5.93 | -1.12 |
| ($BC - EF_C$) | [gha] | -7,039,693 | | -11.69 | |

| Number of planets demanded if world's population lived like residents of Luxembourg | 7.99 |
|---|---|