REVISITING THE ECOLOGICAL FOOTPRINT

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EXECUTIVE SUMMARY

The ecological footprint was developed by the Global Footprint Network as a global indicator of natural resource use. While the GFN publishes the ecological footprint of countries on an annual basis, the CSDD asked the Institute for Organic Agriculture (IBLA) to produce a revised ecological footprint estimate based on more detailed data for Luxembourg. IBLA published an updated ecological footprint for Luxembourg based on 2018 data in a 2020 report. This current report represents a further update of the 2018 ecological footprint. In particular, this report investigates six anomalies that were identified by the CSDD when assessing the underlying data. The seven anomalies include: aviation and trucking (1), iron/steel (2), chemicals (3), non-ferrous or aluminium industry (4), minerals/cement/glass (5), rubber (6), wood production and forestry (7).

The anomalies in the carbon footprint arise, because the GHG emissions due to production or transformation seem to be in some cases falsely allocated to Luxembourg, as a result of the underlying data structure and emission factors that relate to larger product classes and do not take into account product transformation within Luxembourg. These data issues affect the overall figures due to the small size of Luxembourg relative to its import and export streams. This report consulted other reliable and robust data sources, notably the life cycle inventory, ecoinvent, to investigate these anomalies.

With the refined calculations performed in this report, the total carbon footprint is reduced from 17.0 to 15.7 Mt CO2 emissions (or 5.66 to 5.23 million gha). The land needed for forest products changed from 831,000 gha to 387,000 gha. With these two adjustments, the ecological footprint is reduced from **7.63** to **6.75 million gha** or from 12.67 to 11.22 gha per capita. Given Luxembourg's biocapacity of 1.32 gha/capita, the biocapacity deficit is **9.90 gha/cap** (from 11.34 gha/cap in the previous report).

The previous report estimated the ecological footprint of Luxembourg at 7.77 "planets" per year, which we estimate at 6.88. This figure refers to the number of planets needed if every citizen in the world had the same consumption pattern as Luxembourg. From this new footprint result the overshoot day can be calculated, dividing 365 by this number of planets. The overshoot day was very stable in the past years: February 14 (IBLA (2018) for 2016), February 15 (Global Footprint Network (2017) for 2016), and February 16 (IBLA (2020) for 2018). Adjusting figures for imports and exports in detail (i.e. by using product-specific embodied energy factors instead of a single generic value) shows that Luxembourg exports more embodied energy and carbon than previously calculated. The new overshoot day is found to be **February 22**, extending the previous 2018 estimate by six days.

ACRONYMS AND UNITS

GFN	Global footprint network
GHG	Greenhouse gas
OECD	Organisation for Economic Co-operation and Development
IBLA	Institute for Organic Agriculture Luxembourg
LIST	Luxembourg Institute of Science and Technology

Table 1. Units used in this report, and conversion factors between them, for 2018. Interpretation: 1 t CO_2 = 0.334 gha, 1 Earth = 4.88 t CO_2/cap, 7.8 Earths = 23 Mt CO_2.

		1 of …			
		t CO_2/cap	gha/cap	Earth	Mt CO_2
is…	t CO_2/cap	1	2.99	4.88	1.65495
	gha/cap	0.334	1	1.63	0.55
	Earth	0.205	0.61	1	0.34
	Mt CO_2	0.604245	1.81	2.95	1

*This value is the resident population on July 1st 2018 divided by 1 million, conversion factors in light blue are therefore only valid for Luxembourg in 2018.

Table 2. Equivalence factors for the various land types and for carbon sequestration (carbon uptake land is assimilated to forest land), in productivity-weighted global hectares per (world) hectare.

Land type	Equivalence factor (gha/wha)
Crop land	2.51
Grazing land	0.46
Forest land	1.29
Fishing grounds (marine, inland)	0.37
Built-up land (or infrastructure)	2.51
Carbon	1.29

1 INTRODUCTION

1.1 Motivation

The concept of "ecological footprint" was developed by the Global Footprint Network as a global indicator of natural resource use, specifically measuring the *demand* and *supply* of nature. The demand side encompasses the various consumption items of a given population, be it fuels, housing, food products, clothing… while the supply side is an assessment of a nation's biocapacity.[1] The biocapacity items include: cropland, grazing land, fishing grounds (marine and inland waters), forest, and built-up land. Carbon sequestration capacity is added as an extra category as "carbon uptake land". Demand (consumption-based) and supply (resources[2]) are then aggregated into a single score in global hectares, which serves as an estimate of the biocapacity deficit or reserve of a given country or area.

In 2010, a first estimate of Luxembourg's Ecological Footprint was performed by the Luxembourg Research Centre for Environmental Technologies (Hild et al. 2010). In 2019, the Institute for Organic Agriculture Luxembourg (IBLA) was mandated by the CSDD with the recalculation of the national Ecological Footprint (EF) and its biocapacity deficit and assess their evolution over time, using data for the years 2016 and 2018.

When rightly interpreted, the EF method provides a lot of information on the relative footprint of a country's consumption relative to available resources and renewable capacity. The use of set coefficients (such as how much CO_2 a global hectare can sequestrate, how many global hectares are available on Earth) makes it possible to aggregate various environmental impacts, such as direct land occupation or greenhouse gas emissions to a single score, in turn easy to compare across countries. There has been a fair share of criticism towards the EF method[3], as best represented in Rees and Wackernagel (2013).

In this report, we revisit the issues that make calculation of Luxembourg's EF so difficult: border effects and statistical errors arising from the high share of imports or exports in certain sectors compared to within-country production and consumption. The report thus complements the EF method.

1.2 Revisiting the 2020 EF report

The Ecological Footprint report of 2020 used Luxembourg's 2020 National Inventory Report (with data for 2018) as the starting point, along with information on imports and exports from STATEC. As with most top-down consumption-based estimation methods, a difficulty arose in constructing a consumption-based carbon footprint from territorial accounting sources. For example, fuel consumption by trucking companies serving demand outside of Luxembourg needs to be subtracted from the total fuel consumption in Luxembourg, in order to obtain the portion of

[1] From https://www.footprintnetwork.org/our-work/ecological-footprint/
[2] Carbon footprint is not literally a resource but is assimilated as one in the form of "carbon uptake capacity"
[3] A dedicated page is even available on the Global Footprint Network website: https://www.footprintnetwork.org/our-work/ecological-footprint/limitations-and-criticisms/

consumption that can be allocated to Luxembourg. The carbon footprint is one component of the EF, and it is this component, on which the current report focuses. In the case of Luxembourg, the carbon footprint has an outsize contribution to the overall EF.

While the Global Footprint Network calculates the EF of all countries annually, performing a detailed analysis of Luxembourg is of particular interest and importance, due to several particularities that arise in the case of Luxembourg: fuel tourism, cross-border commuting, and a high dependence on imports and exports. These aspects are not covered by the EF guidelines. Therefore, an *ad hoc* methodology had to be developed for the Luxembourgish case, relying on value assumptions, for example, to what degree is the *country* responsible for freight that merely passes through, for the sole purpose of inexpensive refueling? And what is meant by "country"? Residents only? Or everyone receiving a wage from a Luxembourg company? How should imports and exports be treated, when consumption is shared among residents and commuters?

An in-depth assessment of the data sources and actual figures of the IBLA 2020 EF report led to the identification of seven anomalies which the CSDD aimed to better understand and evaluate:

- **Air transport (1)**. The footprint allocated to air transport in Luxembourg seems disproportionate in comparison with neighbouring countries, namely 0.65 planet, compared with about 0.1 in Belgium, Germany or France. Energy embodied in imported and exported products should account for energy used for their transportation, including cargo freight. To avoid double-counting, cargo freight would normally be excluded for goods that are not ultimately consumed in Luxembourg.
- **Industry (2 to 5)**. The embedded energy of products should always increase along their value chain (from raw materials, to transformation, to semi-finished and finished products). Imported goods that are transformed in Luxembourg should therefore be re-exported with a higher embodied energy, but this was not the case in the dataset of the 2020 EF report for all the product categories, including:
    a. Iron and steel **(2)**
    b. Chemicals **(3)**
    c. Non-ferrous metals **(4)**
    d. Mineral, cement, glass **(5)**
    e. Rubber (6)
- **Forests (7)**. Two different data sources of wood imports and exports were used when estimating the required forest land and the CO_2 emissions from fossil fuel combustion for wood production.

The CSDD mandated the Luxembourg Institute of Science and Technology (LIST) to assess these anomalies, to provide clarifications and, where possible, additional data sources for estimating Luxembourg's carbon footprint.

The method and results shown in this report are an alternative assessment to the original Ecological Footprint as defined by the Global Footprint Network. In that sense, the present exercise addresses some of the difficulties of applying the more general EF framework to the Luxembourg context.

2 ADDRESSING THE 7 IDENTIFIED QUESTIONS

2.1 Air transport

Identified question: the annual number of planets corresponding to the aviation sector is found to be equal to 601582 gha, i.e. **0.61 planet**[4] which is surprisingly high compared with neighbour countries, where this value is closer to 0.1 planet. How can such high data for Luxembourg be explained?

Section 3.4 in 2020 report:

> *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_2e for aviation, equalling 601,582 gha. The slight differences between these three data sources cannot be explained.*

Explanation: the basis value for the aviation sector calculation is the amount of kerosene consumed over year 2018 in Luxembourg. Several values have been collected, as displayed in Table 3, showing slight variations.

The 2020 report indicates that "slight differences (…) cannot be explained". There is at least one detail that may have caused a slight deviation in reported values: over the 616.0 ktoe of kerosene indicated as imported in 2018, 1.5 was used for storage, and 614.5 was actually consumed as aviation fuel. It should be noted that international aviation fuel includes both kerosene and 10% of the aviation gasoline consumed in Luxembourg (MECDD 2020, p.186). For comparison, aviation gasoline just exceeds 8 TJ/year, for a grand total of 25729 TJ/year. Using the IPCC emission factors (GHG Protocol 2017), this amount of 25729 TJ/year translates into **1.80 Mt CO_2 eq./year**. The National Inventory accounts for this value as "International Bunkers – Aviation".

Table 3. Values for kerosene consumption.

Source	Year	Value	Unit	URL
Eurostat	2018	614.5 7147 25729	ktoe GWh TJ	https://ec.europa.eu/eurostat/databrowser/view/NRG_BAL_SD__custom_1573090/default/table?lang=en
STATEC	2018	618.2 7190 25880	ktoe GWh TJ	https://statistiques.public.lu/stat/TableViewer/tableViewHTML.aspx?ReportId=12774&IF_Language=fra&MainTheme=1&FldrName=4&RFPath=51
National Inventory Report	2018	598.3 7164 25790	kt GWh TJ	https://unfccc.int/documents/228020 page 247

[4] Meaning that 0.65 planet would be needed to absorb CO2 emissions from flights if every citizen in the world used airplanes as Luxembourg does.

Once energy consumption values are clarified and validated, the next step is to verify allocations, namely **between freight and passenger transportation**. Such a split can help explaining the difference between the footprint of aviation in Luxembourg and in neighbouring countries.

Various statistical sources provide freight and passengers values for air travel, either in energy use, greenhouse gas emissions, or performance (i.e. in tonnes-km or passenger-km), but the most consistent data was found in the OECD database. Figure 1 shows a breakdown of aviation carbon dioxide emissions by type (passenger or freight) and geographical scope (domestic or international). Compared to neighbouring countries, **the specificity of Luxembourg as a logistic hub appears clearly**: **as much as 80% of aviation emissions are due to freight**, while the remaining 20% (about 0.20 Mt) are attributed to passengers.

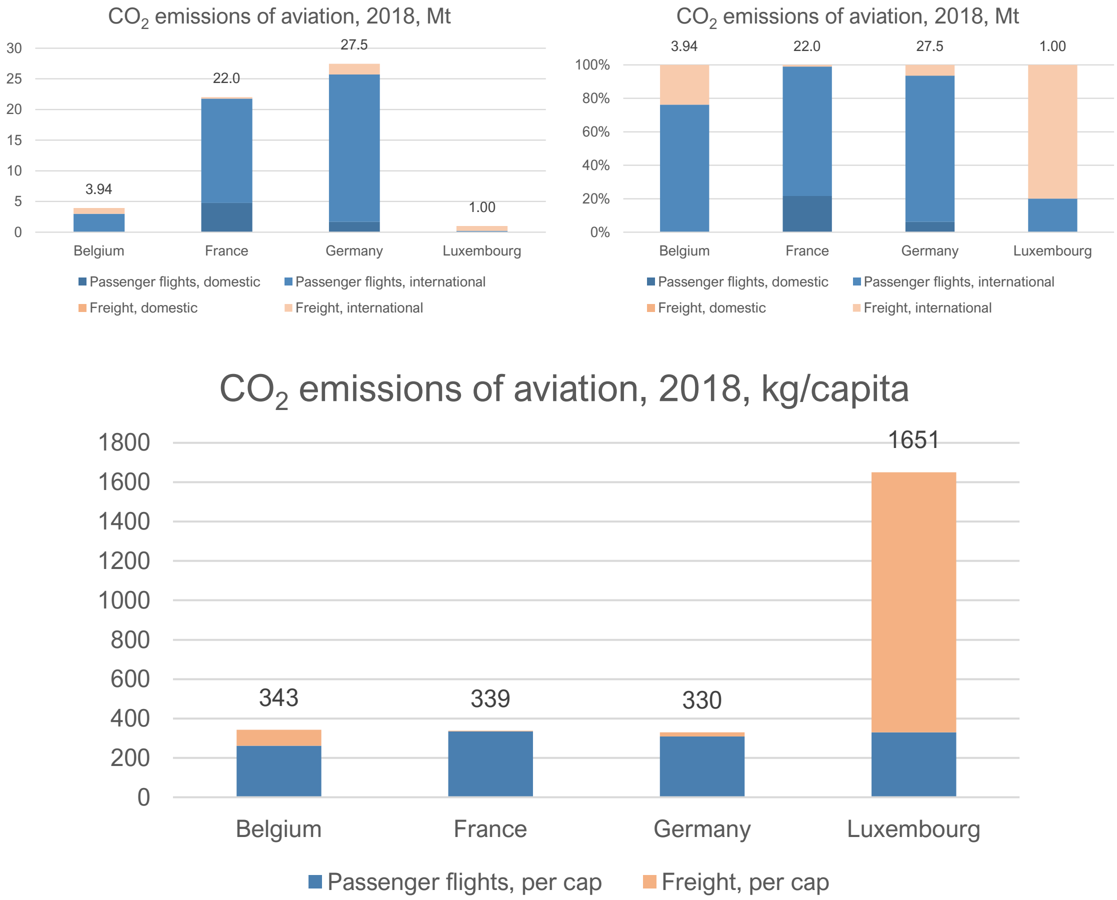

Figure 1. CO_2 emissions of aviation, by type and geographical scope, in 2018.
***Left**: absolute values, **right**: relative contributions, **bottom**: per-capita emissions. Source: OECD Statistics.*

For the 602605 inhabitants in Luxembourg (as of January 2018), 0.20 Mt CO_2 would therefore represent about 332 kg CO_2 per capita, or 0.07 planets, sensibly the same amount as the flying emissions of Belgians, French or German citizens. Note that the OECD reports CO_2 only, but non-GHG emissions from aviation are negligible.

The total of 1.00 Mt CO_2 eq. reported by the OECD is however significantly lower than the amount of emissions that can be inferred from kerosene consumption, 1.80 Mt CO_2. The origin of the former value could not be traced, as the National Inventory 2020 (for year 2018) is rather clear that no split is made between domestic and international flight as information is missing (Figure

2) –this issue is identified as a planned improvement. Alternatively, the System of Environmental-Economic Accounting (SEEA) approach provides values of 0.22 Mt CO_2 and 1.24 Mt CO_2 for passenger flights and air freight, respectively, extending the UNFCCC approach by adding the emissions allocated to residents abroad, and non-residents on the territory. The sum (1.46 Mt) however, still does not amount to 1.80.

Table 10-10– Planned improvements

GHG source & sink category	Planned improvements
International Bunkers - Aviation	Analyse LTO data per aircraft type from Eurostat for Luxembourg in order to optimize split between International Bunkers – Aviation and 1A3a – Domestic aviation.

Figure 2. Excerpt from the NIR indicating that no split is made between "International Bunkers – Aviation" and "Domestic aviation" categories.

Table 4. Summary of carbon dioxide emissions from the various sources collected (mind the unit).

Source	Year	Passenger	Freight	Total	Unit
eu-calc (PRIMES model)	2020	0.04	1.24	**1.28**	Mt CO_2 eq.
OECD (UNFCCC approach)	2018	0.20	0.80	**1.00**	Mt CO_2
OECD (SEEA approach)	2018	0.22	1.02	**1.24**	Mt CO_2
NIR 2020	2018			**1.80**	Mt CO_2 eq.

The IBLA (2020) report ultimately used data from STATEC to determine kerosene consumption of 601582 gha, which amounts to 1801000 t CO_2 per year (Table 5). In this report, we include emissions from passenger travel only of 200000 t CO_2 per year, leaving out emissions from air freight, since these are accounted for in the embodied emissions of the goods consumed in Luxembourg. Passenger flights represent a carbon footprint of 66,700 gha, while freight accounts for 266,000 gha.

Table 5 Carbon dioxide emissions from aviation in 2018. The passenger and freight values for "2020 Report" have been recalculated from the split in "This Report", in italics.

	2020 Report		**This Report**	
	t CO2/year	**gha**	**t CO2/year**	**gha**
Aviation (total)	1801000	601582	997587	333194
Aviation for passenger transport			199777	66726
Aviation for freight transport			797810	266469

The carbon footprint calculation should be made on a final consumption basis to avoid double-counting; there would indeed be a risk of accounting for transportation emissions both in "transport" and "final consumption" (via embodied energy). Following such an approach, freight emissions are therefore always attributed to the final products and not accounted for in the footprint, as they belong to intermediate consumption. As such, emissions from energy used in freight are already embodied in products, either when they are sold to another sector of the economy, or to the final demand (households and government).

Consistently with the STATEC-reported value, the OECD passenger/freight split can be reallocated to the total of 1.80 Mt CO_2, which yields the value of 361 kt CO2/year for passengers only, i.e. 120500 gha. To align on the GFN methodology we however retain the total of 333194 gha for the recalculation.

2.2 Industry

Identified anomaly: The embodied energy content of inputs and outputs of some products manufactured in Luxembourg raised seemed incoherent. In particular, manufacturing of to-be-exported products requires about 0.68 planet, but emissions embodied in exports amount to 0.55 for chemicals, 0.24 for steel products, 0.02 for tyres, and a net negative balance of 0.28 planet for non-ferrous metals.

Explanation: In the 2020 Footprint report update, imported and exported products are inventoried on a physical basis. Greenhouse gases embodied in industrial items had been estimated based on the embodied energy of each item category, itself calculated from total weight imported/exported/produced. For example, all rubber products are given a 91 GJ/t factor for embodied energy. Then an average carbon intensity is applied to estimate the corresponding fossil CO_2 emissions of imports and exports. These factors are constant and set to 56.1 kg CO_2/GJ and 56.7 kg CO_2/GJ, which seems to match the emission factor used in IPCC reports[5], and of Dutch natural gas (lower heating value) (Dröge, Peek et al. 2016), respectively. The reason for using different factors is unknown. Furthermore, this assumption is quite strict as, in reality, the energy mix of industrial process includes other energy carriers, which can range from hard coal (94.6 kg CO_2/GJ), to electricity (15–200 kg CO_2/GJ), to diesel (74.1 kg CO_2/GJ).

The ecoinvent 3.7 database (Wernet, Bauer et al. 2016) has been used as background data for products' life cycle inventories matching the sector categories. In those cases where sectors provided a range of different products with significantly different embodied GHG content (e.g. "Alcohols, phenols, phenol alcohols, glycerine), we take the average of the value for different products in this sector. Regarding "Rubber tyres & tubes for vehicles aircraft", it was decided to model a "car tyre" (Piotrowska et al. 2019) as no suitable match was found in ecoinvent. The whole classification and concordance with ecoinvent can be found in Annex, in Table 15.

As ecoinvent can provide both cumulated energy demand and greenhouse gas results per product, we can compare both embodied energy and embodied carbon to the values in the 2020 report. Two caveats apply here: (1) cumulated energy demand is calculated as the aggregate of all fossil fuel carriers (as MJ), which includes fossil fuels used as feedstocks but not combusted at any life cycle stage; (2) non-energy greenhouse gas emissions cannot be inferred from embodied energy (examples: the calcination process in producing cement or clay bricks emits CO_2 directly).

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[5] See for example https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-ii.pdf

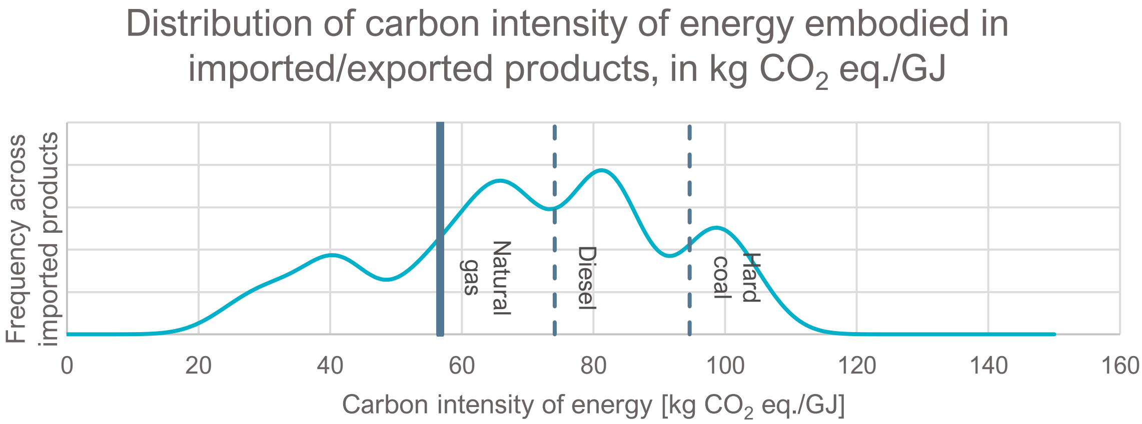

Figure 3. Distribution of revised carbon intensities across the product classification. Natural gas (in solid orange, 56.7 kg CO_2 eq./GJ) was used as the unique factor in the original dataset, which tended to underestimate both imports and exports' embodied GHG emissions.

Finally, accounting for imports of waste streams to be recycled involves a modelling choice. The output of the treatment activities providing these products in ecoinvent has negative mass outflows to maintain the mass balance of the activity. Hence, embodied GHG of these products are found to be negative. In addition, a negative sign could be maintained to consider the environmental benefit of reusing. However, in this case, we have decided to set these values to zero and not include them in our balance.

2.2.1Iron and steel

In 2018, Luxembourg imported 2.3 Mt and exported 0.12 Mt of iron and steel scrap. Most of the material imported was used to manufacture steel products (blooms, billets, plates…) for a total of 2.4 Mt exported, while 0.79 Mt of these products were also imported in the same period. Embedded CO2 emissions are calculated from embodied energy estimates for each product; in the case of iron and steel scrap, this embodied energy was originally estimated at 25 GJ/t (or MJ/kg). Interestingly, the same factor was attributed to semi-finished products (namely: blooms, billets, slabs, wire rods, angles, plates, and wire) which were exported. All in all, 67% of exported products were not attributed any additional energy (and emissions) after being processed in Luxembourg as the embodied energy factor was identical before and after transformation (25 GJ/t) even though energy was invested into these products, in Luxembourg. **First remark: the factor for exported products should be strictly higher than that of imported materials used for their production.**

Most (if not all) of iron and steel processed in Luxembourg are from recycled material. According to the "cut-off" approach commonly used in life cycle assessment, the embodied energy of recycled products should not include that of their first lifecycle, as this has already been attributed to a previous final user. **Second remark: the embodied energy factor for imported iron & steel products (25 GJ/t) seems too high, by one or two orders of magnitude, considering that the only activities associated with scrap (the main share of imported ferrous metals) are collection, sorting, and transportation.**

Given the two remarks, the embedded CO2 of iron and steel products has been recalculated considering:

- Product-specific embodied energy factors,
- Product-specific embodied CO_2 factors (following the protocol described in the introduction of this section) as energy carriers vary from activity to activity,
- The condition that embodied energy only increases along a product's value chain, up until its end use, after which it is considered zero again (and restarts with end-of-life treatment).

After matching each product category with a process from the ecoinvent database (see details in Annex, section 5.1), we estimate the total embodied CO_2 emissions of imports at 0.47 Mt CO_2 eq., and of exports at 0.93 Mt CO_2 eq. This is a drastic reduction from the estimate of the 2020 report, given due to the difference in embodied energy factors.

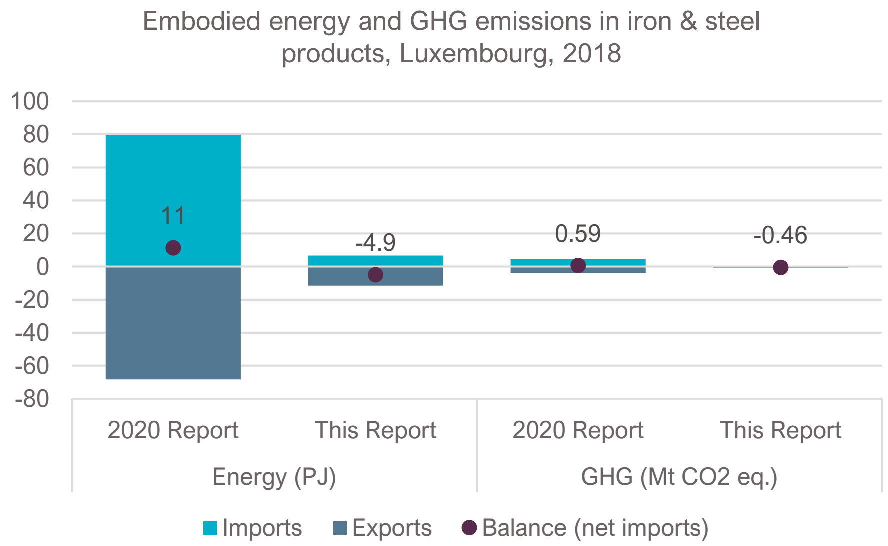

Figure 4. Embodied energy (PJ) and GHG emissions (Mt CO2 eq., CO2 only for IBLA data) of imported and exported iron and steel products, Luxembourg, 2018.

As shown in Table 6, the difference between carbon emission estimates of IBLA and this report is relatively high. The net imports of 0.59 Mt CO_2 eq. correspond to 197,000 gha.

Table 6. Detail of iron and steel products imported and exported, with their embodied energy, and embodied carbon estimates, before and after readjustment.

			Quantity		Factors				Embodied energy				Embodied CO2 (2020 Report) or GHG (This Report)			
			Imports	Exports	Embodied energy factor (2020 Report)	Embodied energy factor (This Report)	Embodied GHG emission factor (2020 Report)	Embodied GHG emission factor (This Report)	Imports (2020 Report)	Exports (This Report)	Imports (2020 Report)	Exports (This Report)	Imports (2020 Report)	Exports (This Report)	Imports (2020 Report)	Exports (This Report)
Sector	Product	SITC-1 code	kt	kt	GJ/t	GJ/t	t CO2 eq./t	t CO2 eq./t	TJ	TJ	TJ	TJ	kt CO2 eq.	kt CO2 eq.	kt CO2 eq.	kt CO2 eq.
iron scrap steel products	Iron & steel scrap	2820	2264	122	25.3	0.5	0.03	0.03	57274	3086	1158	62	3212	175	77	4
	Other ferro alloys	6715	35	0	50.0	33.7	1.91	2.71	1760	0	1186	0	99	0	95	0
	Blooms, billets, slabs, etc. Of iron or steel	6725	75	2	25.3	3.5	0.20	0.36	1909	41	262	6	107	2	27	1
	Wire rod of iron or steel	6731	121	1	25.3	3.9	0.22	0.38	3049	23	468	3	171	1	46	0
	Angles etc. Of iron or steel, 80 mm or more	6734	29	1463	25.3	3.5	0.20	0.36	740	37011	102	5081	42	2100	11	527
	Plates etc of iron or steel uncoated under 3	6743	275	10	25.3	6.0	0.34	0.36	6958	246	1649	58	390	14	99	4
	Oth. Coated iron or steel plates etc under 3	6748	233	775	32.0	7.6	0.43	0.45	7462	24792	1775	5898	419	1407	105	349
	Iron & steel wire	6770	21	123	25.3	3.9	0.22	0.38	539	3103	83	476	30	176	8	47
Total			3054	2494					79691	68301	6682	11585	4469	3876	469	931
Balance										*-11390*		*4903*		*-594*		*463*

2.2.2Chemicals

"Chemicals" actually include several product categories: chemical substances for the industry (alcohols, phenols, glycerine, gases, condensation products, preparations, …), textile, plastic articles, colouring agents, and cleansing products. The balance of energy and greenhouse gases for this category is shown in Figure 5. Both are positive, meaning that Luxembourg imports more than it exports: a main reason is that chemicals are products used in other industries, and get re-exported as part of products not part of the "Chemicals" category.

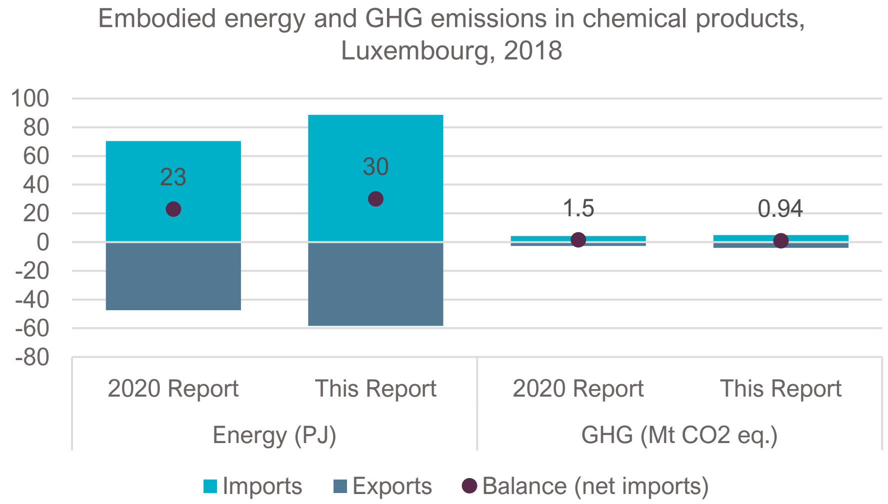

Figure 5. Embodied energy (PJ) and GHG emissions (Mt CO2 eq., CO2 only for IBLA data) of imported and exported chemical products, Luxembourg, 2018.

The detail for each product category is shown in Table 7. Variations in embodied energy factors can be significant for certain products, with decreases of 88% for perfumery and cosmetics, 69% for printing inks, or increases of 130% for gases, or 285% for textiles. However, the energy and greenhouse gas footprints of the entire "Chemicals" category are found to be relatively close to their original values, with 89 and 58 PJ imported and exported (originally 70 and 47 PJ), as well as 4.9 and 4.0 Mt CO_2 eq. imported and exported (originally 4.2 and 2.7 Mt).

Table 7. Detail of chemical products imported and exported, with their embodied energy, and embodied carbon estimates, before and after readjustment.

			Quantity		Factors				Embodied energy				Embodied CO2 (2020 Report) or GHG (This Report)			
Sector	Product	SITC-1 code	Imports kt	Exports kt	Embodied energy factor (2020 Report) GJ/t	Embodied energy factor (This Report) GJ/t	Embodied GHG emission factor (2020 Report) t CO2 eq./t	Embodied GHG emission factor (This Report) t CO2 eq./t	Imports (2020 Report) TJ	Exports (This Report) TJ	Imports (2020 Report) TJ	Exports (This Report) TJ	Imports (2020 Report) kt CO2 eq.	Exports (This Report) kt CO2 eq.	Imports (2020 Report) kt CO2 eq.	Exports (This Report) kt CO2 eq.
chemicals	Alcohols,phenols,phenol alcohols,glycerine	5122	21	0	88	64	3.7	2.7	1827	18	1338	13	102	1	56	1
	Oxygen,nitrogen,hydrogen,rare gases	5131	184	0	40	92	5.2	3.1	7362	7	16968	17	413	0	564	1
	Prods of condensation, polycond. & polyadditi	5811	395	208	80	118	6.7	6.5	31626	16657	46790	24643	1774	945	2564	1350
	Chemical products and preparations,nes	5999	295	19	50	25	1.4	2.0	14754	954	7356	476	827	54	577	37
	other chemicals	5100 - 5200	0	0	40	25	1.4	2.0	0	0	0	0	226	10	0	0
textile fabrics	Coated or impregnated textile fabrics & prod.	6554	10	51	70	270	15	26	695	3555	2678	13703	39	202	263	1345
plastic articles	Articles of artif.plastic materials,n.e.s.	8930	77	145	80.5	62	3.5	2.5	6202	11646	4799	9011	348	661	192	360
colors	Colouring materials,nes	5331	59	77	40	70	4.0	5.7	2378	3075	4190	5418	133	175	341	441
	Printing inks	5332	3.4	21	200	62	3.5	4.5	688	4137	212	1275	39	235	16	94
	Prepared paints, enamels, lacquers, etc.	5333	36	3.2	70	70	4.0	5.7	2517	227	2534	229	141	13	206	19
cleansing products	Perfumery & cosmetics,dentifrices etc.	5530	14	53	100	12	0.7	2.4	1359	5300	162	632	76	301	33	129
	Surface acting agents and washing preparation	5542	24	47	40	64	3.6	4.1	952	1888	1517	3009	53	107	97	192
Total			1118	624					70361	47466	88545	58426	4172	2703	4908	3969
Balance												*-30119*		*-1469*		*-940*

2.2.3Non-ferrous metals

In the case of Luxembourg, the “Non-ferrous metals” comprises non-ferrous metal scrap, and both unwrought and worked aluminium and aluminium alloys. For this sector, the original IBLA assumptions are more consistent with our current assumptions (namely for embodied energy factors), and results are relatively similar. The main feedstock in Luxembourg smelters is scrap aluminium (as shown by the imports figures), so all aluminium production was assumed to use 100% scrap, both for cast and wrought products. Figure 6 shows net exports of embodied energy and GHG emissions, with a net balance of 0.5–14.0 PJ and 0.81–0.04 Mt CO_2 eq. exported in total for this sector. Original and recalculated values are in high disagreement, with a factor 20 reduction, because of the original assumption that aluminium production was primary only (from alumina).

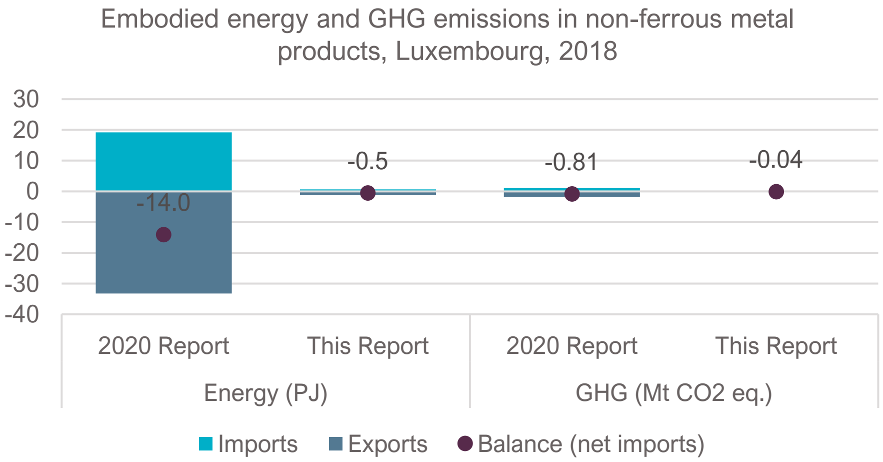

Figure 6. Embodied energy (PJ) and GHG emissions (Mt CO_2 eq., CO_2 only for IBLA data) of imported and exported iron and steel products, Luxembourg, 2018.

As shown in Table 8, carbon embodied in imports and exports, from both estimates (last four columns), are in line for the three products. The net exported carbon (0.04 Mt CO_2 eq.) amounts to 14211 gha, or 0.04 planets as of 2018. This category does not lead to significant balance changes in comparison to the earlier estimate.

Table 8. Detail of non-ferrous metal products imported and exported, with their embodied energy, and embodied carbon estimates, before and after readjustment.

			Quantity			Factors				Embodied energy				Embodied CO2 (2020 Report) or GHG (This Report)			
Sector	Product	SITC-1 code	Imports kt	Exports kt		Embodied energy factor (2020 Report) GJ/t	Embodied energy factor (This Report) GJ/t	Embodied GHG emission factor (2020 Report) t CO2 eq./t	Embodied GHG emission factor (This Report) t CO2 eq./t	Imports (2020 Report) TJ	Exports (This Report) TJ	Imports (2020 Report) TJ	Exports (This Report) TJ	Imports (2020 Report) kt CO2 eq.	Exports (This Report) kt CO2 eq.	Imports (2020 Report) kt CO2 eq.	Exports (This Report) kt CO2 eq.
non ferrous scrap	Non ferrous metal scrap	2840	183	13	10.0	0.3	0.02	0.02	1833	130	59	4	103	7	3	0	183
non ferrous products	Aluminium and aluminium alloys, unwrought	6841	62	119	194.0	7.6	0.43	0.61	12080	23063	472	901	677	1309	38	72	62
	Aluminium and aluminium alloys, worked	6842	23	44	225.5	7.1	0.40	0.52	5297	10032	168	317	297	569	12	23	23
Total			269	176					19209	33225	698	1222	1077	1885	53	96	269
Balance										14015		524		808		43	

2.2.4Sand, slag, cement, glass

This category includes most non-metallic bulk materials, under three subcategories: sand and slag, cement and bricks, and glass. The first subcategory, sand and slag, is by far the main import in weight with a total of 3.6 Mt of materials imported (the next highest material import in weight is iron and steel scrap with 2.3 Mt). Although massive in volume, these materials do not have very high embodied energy or greenhouse gases, and the whole category represents a total of 360 kt CO_2 eq.

It is to be noted that non-energy CO_2 emissions are high for cement, which undergoes a process of calcination during its manufacture, which directly emits CO_2 regardless of the process' energy intensity. For this material, we accounted for the energy embodied in cement (4.1 MJ/t, vs. 9.2 MJ/t originally) and added the share of CO_2 due to calcination, giving a final factor of 88 kg CO_2 eq./kg cement (instead of 51 kg CO_2 eq./kg originally).

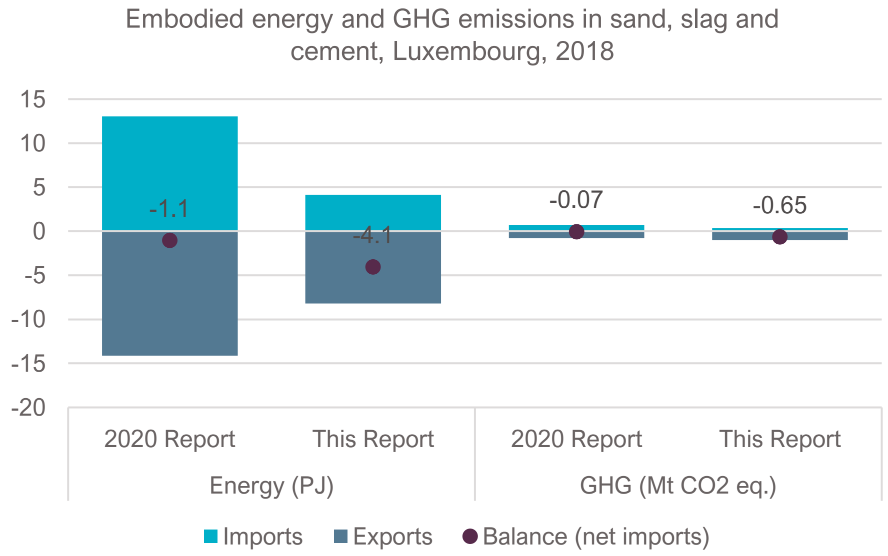

Figure 7. Embodied energy (PJ) and GHG emissions (Mt CO2 eq., CO2 only for IBLA data) of imported and exported sand, slag, and cement and glass products, Luxembourg, 2018.

Estimates in embodied energy vary between IBLA's and this report's calculations, but CO_2 emissions align, due to the inclusion of calcination emissions for cement products. As shown in Table 9, discrepancies in embodied CO_2 are the highest for sand and slag products, specifically from waste (according to the cut-off approach of life cycle assessment, we assumed that the products' first lifecycle's impacts have already been attributed to the first user) and cement. The net exports of 0.65 Mt CO_2 eq. correspond to 0.22 planets as of 2018.

Table 9. Detail of sand, slag, cement and glass products imported and exported, with their embodied energy, and embodied carbon estimates, before and after readjustment.

			Quantity		Factors				Embodied energy				Embodied CO2 (2020 Report) or GHG (This Report)			
		SITC-1	Imports	Exports	Embodied energy factor (2020 Report)	Embodied energy factor (This Report)	Embodied GHG emission factor (2020 Report)	Embodied GHG emission factor (This Report)	Imports (2020 Report)	Exports (This Report)	Imports (2020 Report)	Exports (This Report)	Imports (2020 Report)	Exports (This Report)	Imports (2020 Report)	Exports (This Report)
Sector	Product	code	kt	kt	GJ/t	GJ/t	t CO2 eq./t	t CO2 eq./t	TJ	TJ	TJ	TJ	kt CO2 eq.	kt CO2 eq.	kt CO2 eq.	kt CO2 eq.
sand, slag…	Sand excluding metal bearing sand	2733	1638	37	0.1	0.2	0.01	0.01	136	3	280	6	8	0	19	0
	Slag,dross,scalings & similar waste,nes	2766	762	166	10.0	0.2	0.01	0.01	7623	1662	130	28	428	94	9	2
	Minerals crude,nes	2769	1161	3	2.0	0.2	0.01	0.01	2323	5	198	0	130	0	13	0
cement and bricks	Cement	6612	108	622	9.2	4.1	0.23	0.88	988	5699	442	2547	55	323	95	546
	Refractory bricks & other ref.construction ma	6623	150	23	3.0	13.8	0.78	0.88	451	69	2074	318	25	4	133	20
	Non refractory ceramic bricks,tiles,pipes etc	6624	106	6	3.0	2.5	0.14	0.24	317	18	264	15	18	1	26	1
glass	Glass in the mass,rods & tubes,waste glass	6641	16	32	23.5	0.3	0.01	0.03	385	758	4	8	22	43	0	1
	Glass in rectangles surface ground or polishe	6644	48	277	15.0	13.3	0.75	1.09	718	4156	635	3677	40	236	52	302
	Safety glass,toughened or laminated	6647	8	116	15.0	13.8	0.78	1.16	113	1739	103	1596	6	99	9	134
Total			3997	1282					13054	14109	4131	8197	732	801	356	1007
Balance										*1055*		*4066*		*68*		*652*

As non-energy CO_2 emissions are accounted for, the significant exports of cement contribute to net GHG exports being largely negative – but only energy-related carbon emissions are accounted for in the emissions inventory. The 2020 Report only accounts for energy-related emissions across all categories, **therefore we choose to remain with the 2020 Report values for the total carbon emissions' account.**

2.2.5Rubber

Raw rubber materials imported to Luxembourg include natural (108 kt) and synthetic (60 kt) gums and substitutes, exports thereof represent roughly half of the imports (56 and 23 kt respectively). Semi-finished products ("materials of rubber") are also traded, with 25 and 4.7 kt imported and exported annually. As for rubber finished products, they mostly consist in tyres, for road vehicles and aircraft, 42 kt are imported, 140 kt are exported. The main industry in this sector is Goodyear, located in Colmar-Berg.

The previous report used a fixed 91 GJ/t embodied energy factor, but finer estimates (using the ecoinvent database) show lower factors for rubber materials (72–79 GJ/t), and higher for finished products (111–120 GJ/t). As tyre products are not available in the ecoinvent database, we modelled a tyre manufacturing process to estimate embodied energy and GHG. All in all, while energy and GHG emissions embedded in imports and exports roughly balanced each other, recalculations show that more energy and emissions is exported (as value is added in Luxembourg). To confirm the modelling, the review by Dong, Zhao et al. (2021) has been used to derive the 120 GJ/t and 4.94 kg CO_2 /kg tire factors.

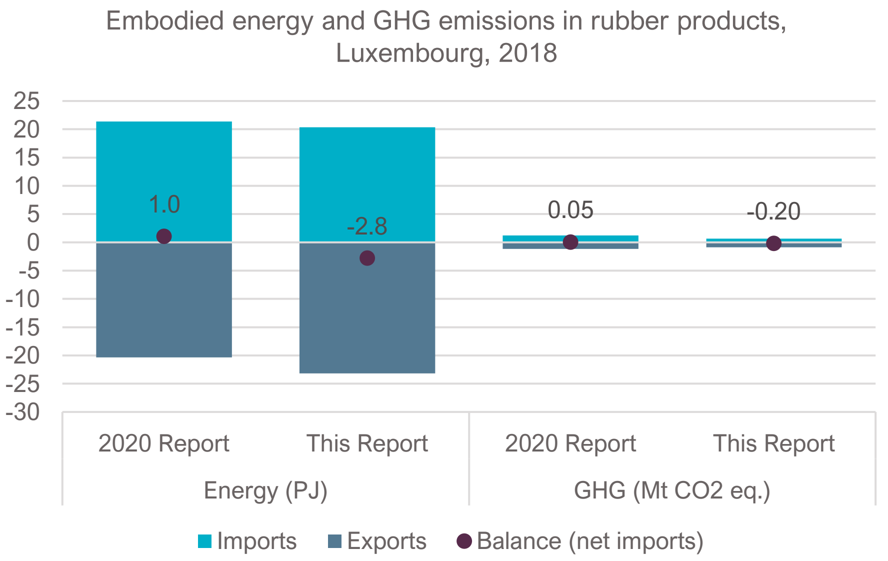

Figure 8. Embodied energy (PJ) and GHG emissions (Mt CO2 eq., CO2 only for IBLA data) of imported and exported rubber products, Luxembourg, 2018.

All adjustments considered, Luxembourg would become a net exporter of GHG embodied in rubber products with 645 kt CO_2 eq. annually (from 45 kt CO2 eq. of net imports originally). Balance details are shown in Table 10.

Table 10. Detail of rubber products imported and exported, with their embodied energy, and embodied carbon estimates, before and after readjustment.

			Quantity		Factors				Embodied energy				Embodied CO2 (2020 Report) or GHG (This Report)			
Sector	Product	SITC-1 code	Imports kt	Exports kt	Embodied energy factor (2020 Report) GJ/t	Embodied energy factor (This Report) GJ/t	Embodied GHG emission factor (2020 Report) t CO2 eq./t	Embodied GHG emission factor (This Report) t CO2 eq./t	Imports (2020 Report) TJ	Exports (This Report) TJ	Imports (2020 Report) TJ	Exports (This Report) TJ	Imports (2020 Report) kt CO2 eq.	Exports (This Report) kt CO2 eq.	Imports (2020 Report) kt CO2 eq.	Exports (This Report) kt CO2 eq.
rubber	Natural rubber and similar natural gums	2311	108	56	91	72	4.1	1.9	9846	5085	7788	4022	552	289	201	104
	Synthetic rubber and rubber substitutes	2312	60	23	91	79	4.5	2.4	5455	2119	4747	1844	306	120	145	56
rubber manufactured	Materials of rubber	6210	25	5	91	111	6.3	4.6	2289	430	2790	524	128	24	115	22
	Rubber tyres & tubes for vehicles and aircraf	6291	42	140	91	120	6.8	4.9	3801	12712	5012	16763	213	721	206	690
Total			235	224					21391	20346	20337	23153	1200	1155	667	872
Balance										*-1045*		*2816*		*-45*		*204*

2.2.6Wood and wood products

Luxembourg is a net importer of sawnwood (43 kt), and a net exporter of manufactured wood products (fibreboards: 80 kt). Luxembourg also imports paper waste and old paper (72 kt). Based on more refined data from ecoinvent, the embodied energy factors in this report are lower than in the previous report, in particular for paper waste and fibreboards (Table 11). The result is that with the new estimates, Luxembourg becomes a net exporter of embodied CO_2 emissions (29 kt CO_2) versus the previous report's estimate of net imports of 185 kt CO_2.

Table 11 Detail of wood products imported and exported, with their embodied energy, and embodied carbon estimates, before and after readjustment.

			Quantity		Factors				Embodied energy				Embodied CO2 (2020 Report) or GHG (This Report)			
		SITC-1	Imports	Exports	Embodied energy factor (2020 Report)	Embodied energy factor (This Report)	Embodied GHG emission factor (2020 Report)	Embodied GHG emission factor (This Report)	Imports (2020 Report)	Exports (This Report)	Imports (2020 Report)	Exports (This Report)	Imports (2020 Report)	Exports (This Report)	Imports (2020 Report)	Exports (This Report)
Sector	Product	code	kt	kt	GJ/t	GJ/t	t CO2 eq./t	t CO2 eq./t	TJ	TJ	TJ	TJ	kt CO2 eq.	kt CO2 eq.	kt CO2 eq.	kt CO2 eq.
wood and pulps	Sawlogs and veneer logs conifer	2422	323	280	7.4	3.60	0.20	0.31	2392	2074	1164	1009	134	118	101	88
	Paper waste and old paper	2511	1	73	28.2	0.00	0.00	0.00	35	2061	0	0	2	117	0	0
wood manufacture, paper	Fibreboards & buildg brds of pulp or veg fibr	6416	14	94	24.78	17.07	0.97	0.96	337	2322	232	1600	19	132	0	0
	Paper and paperboard in rolls or sheets nes	6419	191	163	24.8	23.61	1.34	1.21	4735	4039	4508	3846	266	229	13	90
Total			529	610					7499	10496	5904	6455	421	596	114	178
Balance												*550*		*175*		*63*

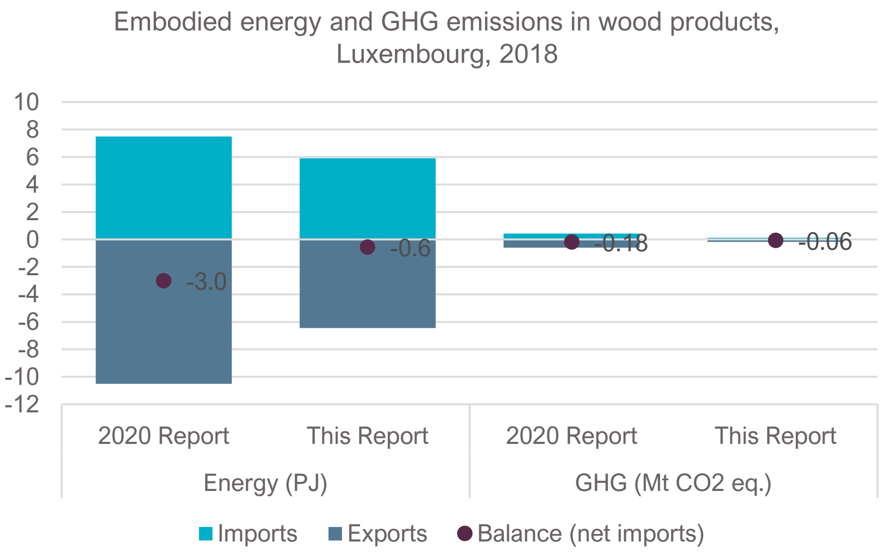

Figure 9 Embodied energy (PJ) and GHG emissions (Mt CO2 eq., CO2 only for IBLA data) of imported and exported wood products, Luxembourg, 2018

A summary table of net GHG emissions for the product categories described in section 2.2 is in the Annex.

2.3 Imported energy: a note

Question: The total imported energy (electricity, natural gas, oil, and other fossil fuels) is assigned to LU consumption, even though a portion of it is used for the production of goods that are ultimately exported, e.g. steel. The EF is thus inflated, if the portion of imported energy used by the industrial sector for exported products is not subtracted. Sector-specific information of energy imports is not publicly available.

Explanation: This question ceases to be an issue, since in the previous sections, we corrected the embodied energy factors (GJ/ton) of the exported products. As explained above, the embodied energy factors in the previous report were the same for a more finished product (e.g. tires) as for the input (e.g. rubber), which cannot be the case, since energy is required to transform rubber into tires. With the corrected factors, we already subtract energy imported for manufacturing products that are ultimately exported, since the higher embodied energy of the finished product that is exported contains the energy used in Luxembourg to make the product. The remainder of the "energy imports" category, that includes energy used by households, services, and industry can thus correctly be attributed to energy used for products that are ultimately consumed in Luxembourg. The "energy imports" category can thus remain unchanged given the correction of the embodied energy factors detailed in section 2.2.

2.4 Forest land needed: Wood and wood products

Identified question: In the previous report, two different data sources were used to estimate the required forest area for wood production (data from FAO) and to estimate CO_2 emissions from fossil fuel combustion during wood product manufacturing (data from UN COMTRADE). The CO_2 emissions part is addressed in section 2.2.6 in this report. In this report we use a single source for consistency – UN COMTRADE.

Explanation: Data on wood product imports and exports are needed to calculate the area of forest land needed as well as the CO_2 emissions from fossil fuel combustion during wood product manufacturing. In the 2020 EF report, data from FAO were used for the former and data from UN COMTRADE were used for the latter. FAO and UN COMTRADE data tend to be more accurate for larger countries, since measurement error in imported or exported volumes is low enough to not materially affect the estimates. In a small country like Luxembourg, the measurement error is large enough to affect the results.

We have recalculated the forest land necessary for timber production in Luxembourg .

Wood production in Luxembourg required 338,700 global hectare (gha) of forest land, and this estimate remains unchanged from the previous report. Whereas the previous report used FAO data to calculate forest land needed for imports and exports and UN COMTRADE data to calculate CO_2 emissions from fossil fuel combustion during wood product manufacturing, we use a single source (UN COMTRADE) in the current report. While the two data sources generally overlap, measurement error in imports and exports is amplified in small countries, and UN COMTRADE data appear more in line with what is known about Luxembourg timber production, imports, and exports. UN COMTRADE imported and exported timber volume in m^3 are 7% and 37% higher than the equivalent categories in FAO data. Given that Luxembourg is in fact a net exporter of timber products due in large part to the activities of Kronospan, UN COMTRADE data appears to be more accurate.

Using UN COMTRADE data necessitates converting the kg of wood products contained in the UN COMTRADE data into a volume of wood, to which a yield factor is applied to determine the required forest land. While the 2020 report assumed a single density of about 600 kg/m^3 for all wood categories, we used more refined densities ranging from 500 to 700 kg/m^3, depending on the type of wood product based on discussion with wood industry representatives. We estimate net imports of 48,500 gha, while the previous report estimated net imports of 491,600 gha (Table 12). With the forest land required for wood production, the total forest land required amounts to 387,200 gha instead of 830,300 gha.

Table 12 Forest area required and yield factors for wood production, imports, exports

Variable	2020 Report (IBLA) using FAO data	This Report using UN COMTRADE data, refined density factors
Density (kg/m^3)		
Wood fuel	600	700
Industrial roundwood	600	500 (conifer) 700 (non-conifer)
Sawnwood	600	500 (conifer) 700 (non-conifer)
Veneer sheets	600	600
Plywood	600	600
Imports (gha)	1,202,900	1,541,400
Exports (gha)	711,300	1,492,900
Net imports (gha)	491,600	48,500
Production (gha)	338,700	338,700
Total forest land required (net imports + production) (gha)	830,300	387,200

3 OVERALL RESULT – A COMPARISON OF CARBON AND TOTAL ECOLOGICAL FOOTPRINTS

3.1 Conclusions

With the exception of forest land needed for wood and wood products, all of our changes are in the carbon footprint category of the ecological footprint. The emissions in t CO2/year and global hectare equivalents for each of the categories discussed in section 2.2. are presented in Table 13. While the previous report estimated CO_2 emissions of 3.33 Mt CO_2 eq. for these seven sectors, we find negative CO_2 emissions of 0.352 Mt CO_2. The total carbon footprint is thus reduced from 17.0 to 15.7 Mt CO_2 emissions (or 5.66 to 5.23 million gha). The sector contributions and the net emissions are presented graphically in Figure 10.

Table 13 Net CO2 Emissions from production and net imports for the carbon footprint portion of the ecological footprint

	Net emissions (production + imports - exports)			
	2020 Report		This report	
	kt CO_2 eq	1000 gha	kt CO_2 eq	1000 gha
Aviation	1801	602	1801	602
Iron and steel	594	198	-463	-155
Chemicals	1470	491	940	314
Non-ferrous metals	-808	-270	-42.5	-14
Mineral, cement, glass	-68.5	-22.9	-69	-23
Rubber	45.2	15.1	-204	-68.1
Wood	186	62.1	-29.3	-9.8
Subtotal	3220	1075	1934	646
Other sectors	13734	4587	13734	4587
Total carbon footprint	16953	5662	15668	5233

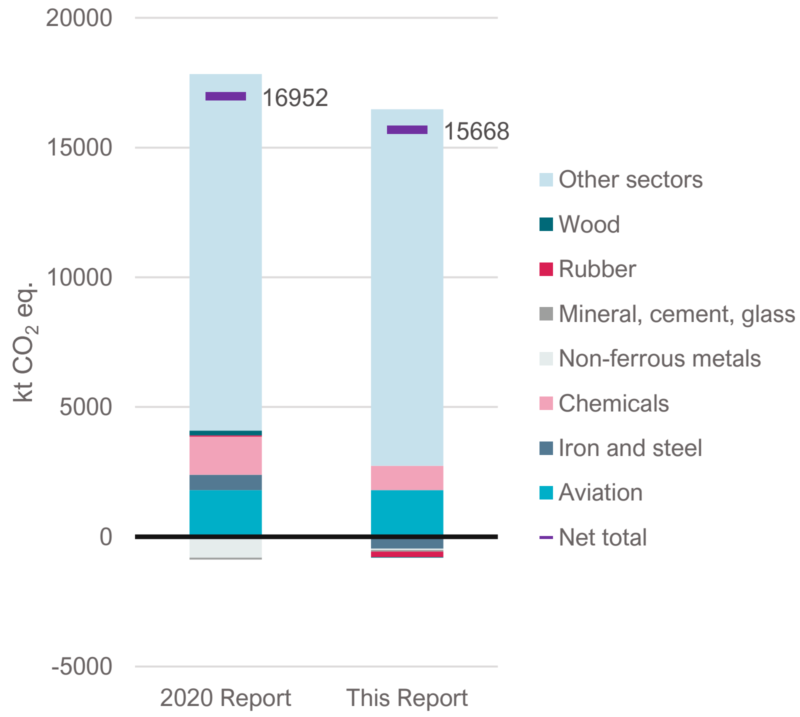

Figure 10. Comparison of sectoral carbon footprint, after trade adjustments. Carbon-intensive sectors in which Luxembourg is a net exporter appear as negative series.

The adjusted carbon footprint along with the adjusted land needed for forest products is presented in Table 14. As discussed in section 2.4, the land needed for forest products changed from 831,000 gha to 387,000 gha. With these two adjustments, the ecological footprint is reduced from **7.63** to **6.75 million gha** or from 12.67 to 11.22 gha per capita. Given Luxembourg's biocapacity of 1.32 gha/capita, the biocapacity deficit is **9.90 gha/cap** (from 11.34 gha/cap in the previous report).

Table 14. Total balance of Ecological Footprint components, comparison across the subsequent calculations.

Source		Global Footprint Network	IBLA 2018	IBLA 2020	LIST 2022
Year		2016	2016	2018	2018
Global hectare (gha)	Crop	511979	516457	604722	604722
	Grazing	364418	366071	343469	343469
	Forest Products	652177	652177	830507	387140
	Fish	85510	85482	79109	79109
	Built-up Land	47037	96455	105521	105521
	Carbon	5772731	5754803	5662111	5233000
	Total	7433853	7471445	7625367	6753000
Global hectare per capita (gha/cap)	Crop	0.89	0.9	1.00	1.00
	Grazing	0.63	0.64	0.57	0.57
	Forest Products	1.13	1.13	1.38	0.64
	Fish	0.15	0.15	0.13	0.13
	Built-up Land	0.08	0.17	0.17	0.18
	Carbon	10.03	10	9.41	8.69
	Total	12.91	12.98	12.67	11.22
Biocapacity Deficit (gha/cap)		11.67	11.63	11.34	9.90
Planet Earths		7.92	7.96	**7.77**	**6. 88**

The previous report estimated the ecological footprint of Luxembourg at 7.77 “planets” per year, which we estimate at 6.88. This figure refers to the number of planets needed if every citizen in the world had the same consumption pattern as Luxembourg. From this new footprint result the overshoot day can be calculated, dividing 365 by this number of planets. The overshoot day was very stable in the past years: February 14 (IBLA (2018) for 2016), February 15 (Global Footprint Network (2017) for 2016), and February 16 (IBLA (2020) for 2018). Adjusting imports and exports in detail (i.e. by using product-specific embodied energy factors instead of a single generic value) shows that Luxembourg exports more embodied energy and carbon than previously calculated (Figure 11). The new overshoot day is found to be **February 22**, extending the previous 2018 estimate by six days.

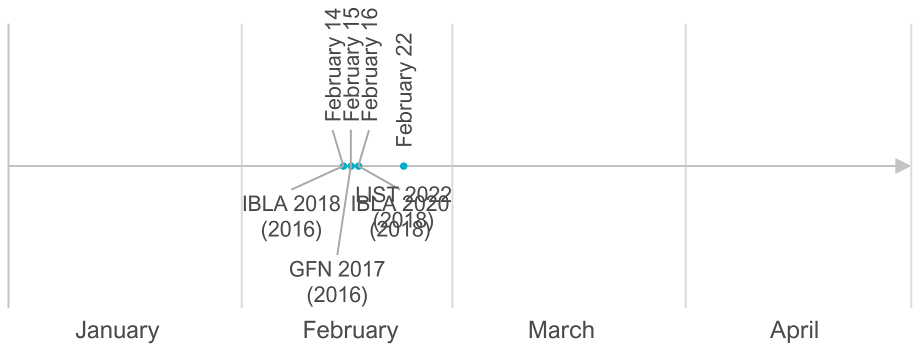

Figure 11 Overshoot Day - Comparison of ecological footprint calculations, labelled as “[Author] [Publication year] ([representative year])”

Thus, while using more refined data reduced Luxembourg’s estimated ecological footprint, Luxembourg remains the country with the second-highest biocapacity deficit and second-earliest overshoot day, preceded only by Qatar on February 10 and followed by Canada, the US, and the UAE on March 13.

The overshoot days of Belgium, Germany, and France are March 26, May 4, and May 11, respectively. This report serves as a reminder that Luxembourg is living beyond its limits in terms of its ecological footprint due in particular to its high carbon footprint. Reducing our carbon footprint requires outright reductions in consumption across all sectors alongside shifts towards low-emissions modes of transportation, heating sources, and electricity production.

3.2 Limitations, further work

In this report, we revisited the issues that make calculation of Luxembourg's EF so difficult: border effects and statistical errors arising from the high share of imports or exports in certain sectors compared to within-country production and consumption. The report thus complements the EF method. While the revised embodied energy and emission factors for the 7 sectors considered and the forest land required can be considered more representative of Luxembourgish reality, several limitations remain. Most of the revised embodied emission factors come from ecoinvent and are representative of production in Europe rather than the specific case of Luxembourg. However, this represents an improvement over the general EF method, which uses global average factors.

Second, small changes yield factors or density factors for wood production can shift the amount of required forest land for Luxembourgish wood consumption quite dramatically. Finally, there is no official data on the split between passenger and freight aviation, and the estimation of fuel consumption by domestically registered vehicles and foreign-registered vehicles rests on several assumptions. The portion of the ecological footprint that comes from road freight remains unaddressed. Further work could help refine Luxembourg's ecological footprint even further and would likely reduce it even further. However, any further refinements in the estimation will likely not change the fact that Luxembourg is one of the top countries in terms of living beyond ecological limits.

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5 ANNEX

5.1 Match between product classification and ecoinvent 3.7 processes

Table 15. Concordance between classification of products imported, exported, and produced, and ecoinvent processes, with a comparison of embodied energy and carbon intensity adjustments. The original carbon intensity of energy was assumed constant, at 56.7 kg CO_2 eq./GJ (natural gas).

Sector	Name	Matching ecoinvent process	Embodied energy (original) [GJ t-1]	Embodied energy (revised) [GJ t-1]	Deviation	Carbon intensity of energy (revised) [kg CO2 eq./GJ]	Deviation
Rubber	Natural rubber and similar natural gums	seal, natural rubber based//[DE] seal production, natural rubber based	91	72.0	-21%	25.8	-54%
	Synthetic rubber and rubber substitutes	synthetic rubber//[RER] synthetic rubber production	91	79.2	-13%	30.6	-46%
Rubber manufactured	Materials of rubber	tube insulation, elastomere//[DE] tube insulation production, elastomere	91	110.9	22%	41.1	-27%
	Rubber tyres & tubes for vehicles and aircraf	Car tyre - Supplementary information in "Car tyre" sheet	91	120.0	32%	41.5	-27%
Iron scrap	Iron & steel scrap	iron scrap, sorted, pressed//[RER] market for iron scrap, sorted, pressed	25	0.5	-98%	66.8	18%
Steel products	Other ferro alloys	ferromanganese, high coal, 74.5% Mn	50	33.7	-33%	80.3	42%
	Blooms, billets, slabs, etc. Of iron or steel	iron scrap, sorted, pressed//[RER] market for iron scrap, sorted, pressed + deep drawing, steel, 10000 kN press, automode//[RER] deep drawing, steel, 10000 kN press, automode	25	3.5	-86%	103.8	83%
	Wire rod of iron or steel	iron scrap, sorted, pressed//[RER] market for iron scrap, sorted, pressed + wire drawing, steel//[RER] wire drawing, steel	25	3.9	-85%	98.3	73%
	Angles etc. Of iron or steel, 80 mm or more	iron scrap, sorted, pressed//[RER] market for iron scrap, sorted, pressed + deep drawing, steel, 10000 kN press, automode//[RER] deep drawing, steel, 10000 kN press, automode	25	3.5	-86%	103.8	83%
	Plates etc of iron or steel uncoated under 3	iron scrap, sorted, pressed//[RER] market for iron scrap, sorted, pressed + sheet rolling, steel//[RER] sheet rolling, steel	25	6.0	-76%	60.3	6%
	Oth. Coated iron or steel plates etc under 3	iron scrap, sorted, pressed//[RER] market for iron scrap, sorted, pressed + sheet rolling, steel//[RER] sheet rolling, steel + powder coat, steel//[RER] powder coating, steel	32	7.6	-76%	59.2	4%
	Iron & steel wire	iron scrap, sorted, pressed//[RER] market for iron scrap, sorted, pressed + wire drawing, steel//[RER] wire drawing, steel	25	3.9	-85%	98.3	73%
Non ferrous scrap	Non ferrous metal scrap	aluminium scrap, new//[RER] market for aluminium scrap, new	10	0.5	-95%	64.4	14%
Non ferrous products	Aluminium and aluminium alloys, unwrought	aluminium, primary, ingot//[IAI Area, EU27 & EFTA] market for aluminium, primary, ingot	194	139	-28%	70.7	25%
	Aluminium and aluminium alloys, worked	aluminium, wrought alloy//[GLO] market for aluminium, wrought alloy	226	168	-26%	83.8	48%

	Sand excluding metal bearing sand	inert filler//[GLO] sand to generic market for inert filler	0	0.2	106%	67.6	19%
Sand, slag…	Slag,dross,scalings & similar waste,nes	inert filler//[GLO] sand to generic market for inert filler	10	0.2	-98%	67.6	19%
	Minerals crude,nes	inert filler//[GLO] sand to generic market for inert filler	2	0.2	-91%	67.6	19%
	Cement	cement, Portland//[Europe without Switzerland] market for cement, Portland	9	4.1	-55%	214.5	278%
Cement and bricks	Refractory bricks & other ref.construction ma	refractory, fireclay, packed//[DE] refractory production, fireclay, packed	3	13.8	360%	64.1	13%
	Non refractory ceramic bricks,tiles,pipes etc	clay brick//[RER] clay brick production	3	2.5	-17%	97.1	71%
	Glass in the mass,rods & tubes,waste glass	glass cullet, sorted//[RER] market for glass cullet, sorted	24	0.3	-99%	96.5	70%
Glass	Glass in rectangles surface ground or polishe	flat glass, coated//[RER] market for flat glass, coated	15	13.3	-12%	82.1	45%
	Safety glass,toughened or laminated	flat glass, uncoated//[RER] market for flat glass, uncoated + tempering, flat glass//[RER] tempering, flat glass	15	13.8	-8%	83.9	48%
	Alcohols,phenols,phenol alcohols,glycerine	Average of (glycerine | market for glycerine | RER |) & (ethoxylated alcohol (AE3) | market for ethoxylated alcohol (AE3) | RER |) & (phenol | market for phenol | RER |)	88	64.5	-27%	41.6	-27%
	Oxygen,nitrogen,hydrogen,rare gases	Average of (hydrogen, liquid | market for hydrogen, liquid | RER |) & (oxygen, liquid | market for oxygen, liquid | RER |) & (nitrogen, liquid | market for nitrogen, liquid | RER |)	40	92.2	130%	33.3	-41%
Chemicals	Prods of condensation, polycond. & polyadditi	Average of (nylon 6-6 | market for nylon 6-6 | RER |) & (polyurethane, flexible foam | market for polyurethane, flexible foam | RER |) & (polyurethane, rigid foam | market for polyurethane, rigid foam | RER |)	80	118.4	48%	54.8	-3%
	Chemical products and preparations,nes	chemical, inorganic | market for chemicals, inorganic | GLO |	50	24.9	-50%	78.4	38%
	other chemicals	chemical, inorganic | market for chemicals, inorganic | GLO |	40	24.9	-38%	78.4	38%
Textile fabrics	Coated or impregnated textile fabrics & prod.	Average of (textile, jute | market for textile, jute | GLO |) & (textile, kenaf | market for textile, kenaf | GLO |) & (textile, knit cotton | market for textile, knit cotton | GLO | kilogram |) & (textile, non-woven polyester | market for textile, non woven polyester | GLO |) & (textile, non-woven polypropylene | market for textile, non woven polypropylene | GLO |) & (textile, silk | market for textile, silk | GLO |) & (textile, woven cotton | market for textile, woven cotton | GLO |)	70	269.8	285%	98.2	73%
Plastic articles	Articles of artif.plastic materials,n.e.s.	Average of (packaging film, low density polyethylene | packaging film production, low density polyethylene | RER |) & (liquid packaging board container | liquid packaging board container production | RER |)	81	62.3	-23%	40.0	-30%
	Colouring materials,nes	Average of (alkyd paint, white, without solvent, in 60% solution state | market for alkyd paint, white, without solvent, in 60% solution state | RER |) & (alkyd paint, white, without water, in 60% solution state | market for alkyd paint, white, without water, in 60% solution state | RER |)	40	70.5	76%	81.4	43%
Colors	Printing inks	Average of (printing ink, rotogravure, without solvent, in 55% toluene solution state | market for printing ink, rotogravure, without solvent, in 55% toluene solution state | RER |) & (printing ink, offset, without solvent, in 47.5% solution state | market for printing ink, offset, without solvent, in 47.5% solution state | RER |)	200	61.6	-69%	73.8	30%
	Prepared paints, enamels, lacquers, etc.	Average of (alkyd paint, white, without solvent, in 60% solution state | market for alkyd paint, white, without solvent, in 60% solution state | RER |) & (alkyd paint, white, without water, in 60% solution state | market for alkyd paint, white, without water, in 60% solution state | RER |)	70	70.5	1%	81.4	43%
Cleansing products	Perfumery & cosmetics,dentifrices etc.	soap | soap production | RER | kilogram |	100	11.9	-88%	82.8	46%
	Surface acting agents and washing preparation	non-ionic surfactant | market for non-ionic surfactant | GLO |	40	63.7	59%	63.9	13%
Wood and pulps	Sawlogs and veneer logs conifer	sawlog and veneer log, meranti, debarked, measured as solid wood//[RER] market for sawlog and veneer log, meranti, debarked, measured as solid wood	7	3.6	-51%	86.9	53%
	Paper waste and old paper		28	0.0	-100%		-100%
Wood manufacture, paper	Fibreboards & buildg brds of pulp or veg fibr	paper sack//[RER] market for paper sack	25	17.1	-31%	56.2	-1%
	Paper and paperboard in rolls or sheets nes	paper, newsprint// [RER] market for paper, newsprint	25	23.6	-5%	51.4	-9%

5.2 Review of carbon footprint sources

The **consumption-based** carbon footprint adds up GHG emissions occurring anywhere in the world due to **consumption in Luxembourg**. Another kind of footprint is the **production-based or territorial carbon footprint**, which includes GHG emissions occurring within the territory or country, irrespective of whether the goods produced in Luxembourg are also exported.

These sources should be considered more robust than the Ecological Footprint, as they take into account only induced emissions of greenhouse gases, in absolute values, and do not depend on further factors and metrics (such as biocapacity) which may introduce uncertainties. We suggest using GHG emissions for further communication, as it facilitates interpretation and comparison with third-party sources.

5.2.1UNFCCC inventory

Countries regularly report their territorial GHG emissions to the UNFCCC in an annual National Inventory Report. The NIRs constitute the primary source for greenhouse emission accounting at the territorial scale. Luxembourg's 2021 NIR includes data up to the year 2019.

This inventory adopts a production-based (territorial approach).

5.2.2EXIOBASE

EXIOBASE is a database that relies on the compilation of economic input-output tables and environmental accounts for 49 regions in the world, including all individual European Member States (EU27+1) and major economies (USA, China, India, Japan, Australia…). It contains information on domestic economies as well as international trade, EXIOBASE is therefore a tool of choice when calculating emissions (or primary energy, or any sort of environmental indicator) embodied in imports and exports. The data is available for the period 1995-2022 (the authors have applied now-casting models for the last 3 years of the database).

This database can provide both production-based (territorial approach) and consumption-based accounts.

5.2.3Ecoinvent

The ecoinvent database contains information on industrial processes, in physical terms. It is the leading database for life cycle assessment, as it contains all the elements necessary to build life cycle inventories (that is, material, energy, emission, and waste flows for any specific process), which can therefore be used to derived life-cycle environmental factors, namely embodied emissions or energy per kg of a given product. It is used in the present work to derive embodied greenhouse gas emission factors for imports and exports.

This database can provide both production-based (as direct impacts) and consumption-based accounts (as lifecycle impacts) – but primarily at the product (or process) level.

5.2.4EDGAR6.0 database

Another database of air pollutants, with a territorial perspective.

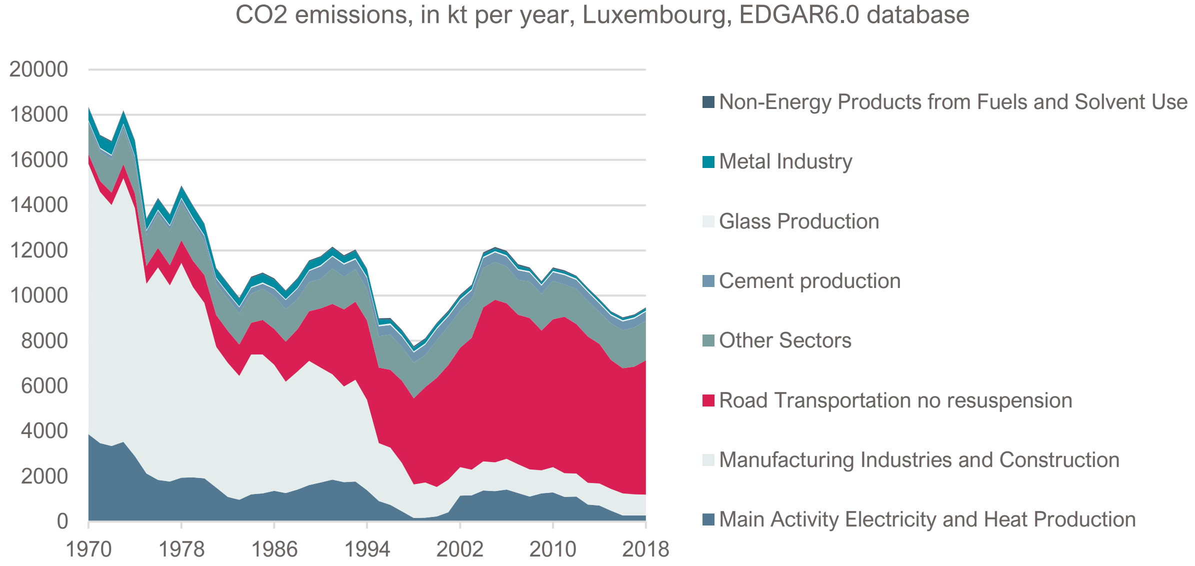

Figure 12. CO2 emissions of Luxembourg, 1970 to 2018, from the EDGAR 6.0 database.

5.3 Summary table of GHG emissions for the products described in Section 2.2

Table 16. Net imported greenhouse gas emissions per product category that has been modified, original and revised (t CO_2eq).

	Imports – Exports (t CO_2 eq.)		Imports – Exports (gha)	
	2020 Report	This Report	2020 Report	This Report
wood products	**-76498**	-42790	-25550	-14292
non-ferrous ore scrap	**95416**	73258	31869	24468
non-ferrous products	**-903435**	-45461	-301747	-15184
stones sand slag	**470652**	470652	157198	157198
cement mineral products	**-229806**	-229806	-76755	-76755
glass ceramics	**-309335**	-309335	-103318	-103318
rubber	**449335**	186025	150078	62132
rubber manufactures	**-404182**	-390253	-134997	-130344
iron ore scrap	**3037097**	73258	1014390	24468
steel products	**-2443460**	-535840	-816116	-178971
chemical products	**2331732**	2371969	778798	792238
colourings	**-109012**	9257	-36410	3092
cleansings	**-278267**	-190918	-92941	-63767
textile manufactures	**-162761**	-1082243	-54362	-361469
plastic products	**-313025**	-168467	-104550	-56268