CAFEAN 2:
Updated Analysis of the Carbon Footprint of the Economic Activity of Norway

XIO Sustainability Analytics

For:
Norwegian Environment Agency
M-2876|2024
NOVEMBER 2024

Report produced by Kajwan Rasul, Edgar Hertwich, Konstantin Stadler, and Richad Wood (XIO Sustainability A/S) for the Norwegian Environment Agency.

The aim of this report is to (1) summarise the key learnings from all parts of the *Carbon Footprint of the Economic Activity of Norway* (CaFEAN) project, (2) explain how these learnings may be used for policy inputs, (3) provide an overview of the CaFEAN model, and (4) highlight limitations of the model and outline potential improvements and expansions of the model.

Table of Contents

Chapter 1: Summary of CaFEAN

1.1. Introduction

In February 2023, the Norwegian Environment Agency published the report *Klimagassutslipp globalt som følge av økonomisk aktivitet i Norge – Vurdering av metoder og behov*[1]. The report aimed to identify which scientific methods could best provide an understanding of the carbon footprint of the Norwegian economy. Concluding that environmentally extended input-output modelling (EEIO) would be the most effective method to provide a national overview of Norway's consumption-based (CB) emissions (i.e., carbon footprint), the report recommended conducting an initial analysis. The initial analysis should showcase the kind of insights the method could provide and identify future improvements. As a result, the *Carbon Footprint of the Economic Activity of Norway* (CaFEAN) project was initiated.

Consumption-based accounts
and its relations to territorial emissions

Territorial emissions are reported as part of the UN Framework Convention on Climate Change obligations. Together with emissions from residents abroad (e.g., emissions due to the use of marine and airline bunker fuels in international travel), territorial emissions make up the "production-based emission" accounts.

The consumption-based emissions accounts are obtained from adjusting the production-based accounts by including emissions embodied in imports and excluding emissions embodied in exports.

Thus different from the territorial emissions, which only show the emissions occurring within Norway, the consumption-based accounts show the emissions happening due to Norwegian consumption of goods and services, irrespective of whether the emissions occur in Norway or abroad.

The CaFEAN project was finalised in November 2023 and a report[2] was published in January 2024. For the project, a coupled model (henceforth referred to as the CaFEAN model) was developed, which guaranteed that the results were consistent with the official statistics published by Statistics Norway (SSB). The original model estimated Norway's CB greenhouse gas (GHG) emissions to be 70.2 Mt CO_2-eq in 2020. However, the analysis has now been updated and the estimates have changed for all the years 2012-2020, and data for 2021 has been added.

In May 2024, a follow-up project, CaFEAN 2, was initiated. The aim of CaFEAN 2 is to provide:

1. Improved and updated estimates for the CB emissions of Norway using updated data in the CaFEAN model.

[1] https://www.miljodirektoratet.no/publikasjoner/2023/februar-2023/klimagassutslipp-globalt-som-folge-av-okonomisk-aktivitet-i-norge/
[2] https://www.miljodirektoratet.no/publikasjoner/2024/januar-2024/cafean-carbon-footprint-of-the-economic-activity-of-norway/

2. A tool to better understand the observed changes in the CB emissions of specific sectors.
3. A tool to gain deeper insight into the CB emissions of Norwegian households by integrating SSB's recently published consumer expenditure surveys with the CaFEAN model.

The purpose of this chapter is to give a summary of the work done in CaFEAN 2.

1.2. Updated CaFEAN model

1.2.1. Summary of main results

1.2.1.1. The emissions accounts of Norway in 2021

The results of the calculation of the Norwegian consumption-based emissions accounts are provided in Figure 1 for the year 2021. In addition to the 64.7 Mt CO_2-eq in the production account, 71.2 Mt CO_2-eq is embodied in imports, and -59.0 Mt of GHG in CO_2-eq is embodied in exports[3]. This results in a consumption-based account, or carbon footprint of Norway in 2021 of 76.9 Mt GHG CO_2-eq. Note that the production account and footprint include direct household emissions of 5.1 Mt CO_2-eq, such as those from private car use (fuel combustion).

Most emissions embodied in imports are due to carbon dioxide emissions (77 %), with methane having the second largest contribution (20 %) (see Figure 2). Of note is that Norwegian production has very low levels of methane and N_2O (8 % and 3 % of the total production account). The import and hence footprint results show higher levels (17 % and 5 % of the total footprint account for CH_4 and N_2O respectively). Both sets of results are below global averages. Methane is responsible for about 18 % of global greenhouse gas emissions when land-use, land-use change and forestry (LULUCF) is included, or about 20-21 % when LULUCF is excluded (it is excluded in this study)[4].

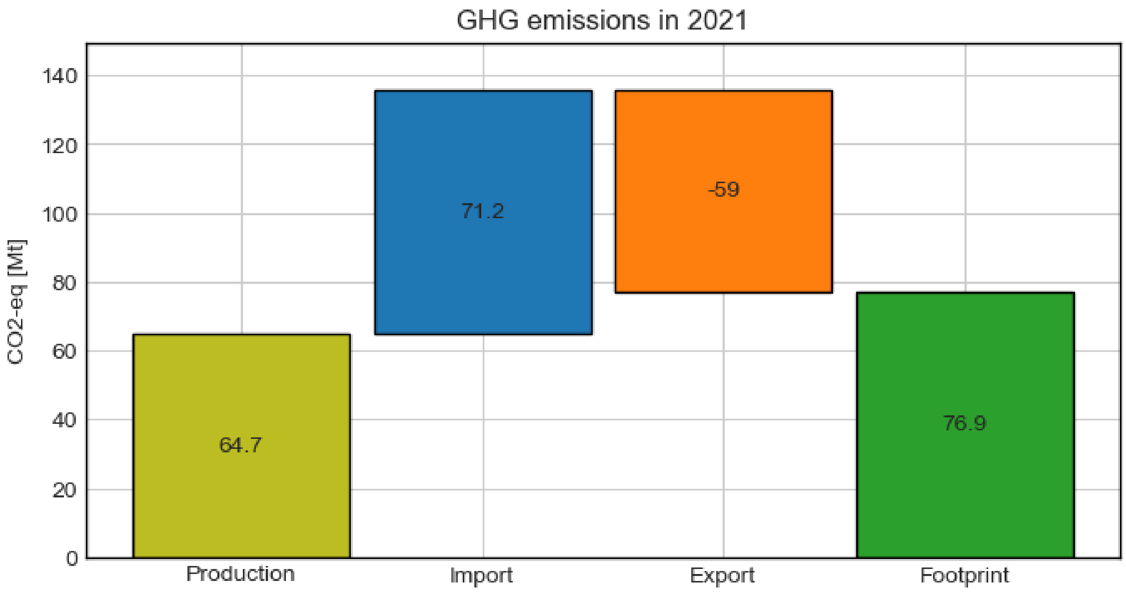


Figure 1: Greenhouse gas emissions embodied in imports and exports, and resultant consumption-based emissions (footprint) of Norwegian Economic Activity.

[3] It should be noted that the emissions embodied in exported products do not include the emissions of non-combusted energy products. For example, the emissions from the Norwegian *production* of oil and gas for export are included in the export emissions accounts, whereas the emissions from the combustion of these emissions outside of Norway are not included.
[4] https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SPM.pdf

Part of the reason for why Norway has relatively low CH_4 and N_2O emissions is due to the lack of methane emissions associated with coal mining or coal seam gas fracking. The oil and gas sector also has tighter emission controls on fugitives released in oil and gas mining than other countries such as Russia, which have significant sources of methane from that sector. The Norwegian footprint account is affected by these international practices, however, due to the use of foreign produced goods and services which embody the more significant methane releases overseas.

1.2.1.2. Trends in the Norwegian emissions accounts

Overall greenhouse gas emissions from Norwegian Economic Activity are lower in 2021 than 2012 (see Figure 3). These results are consistent for all four measures of production-based; emissions embodied in imports; emissions embodied in exports[5]; and consumption-based (footprint). From 2012 to 2021, the consumption-based emission account decreased by 18.5 Mt CO_2-eq (-20 %).

Of note is a 10 % increase in production-based emission account in 2015, coinciding with a 14 % drop in emissions embodied in imports for the same year. The main source of this increase in the production-based account can be attributed to a 6.3 Mt increase in emissions due to water transport by residents abroad. SSB identify this value as being highly uncertain (see footnotes in SSB Emission Accounts). In the following year emissions decrease across all accounts.

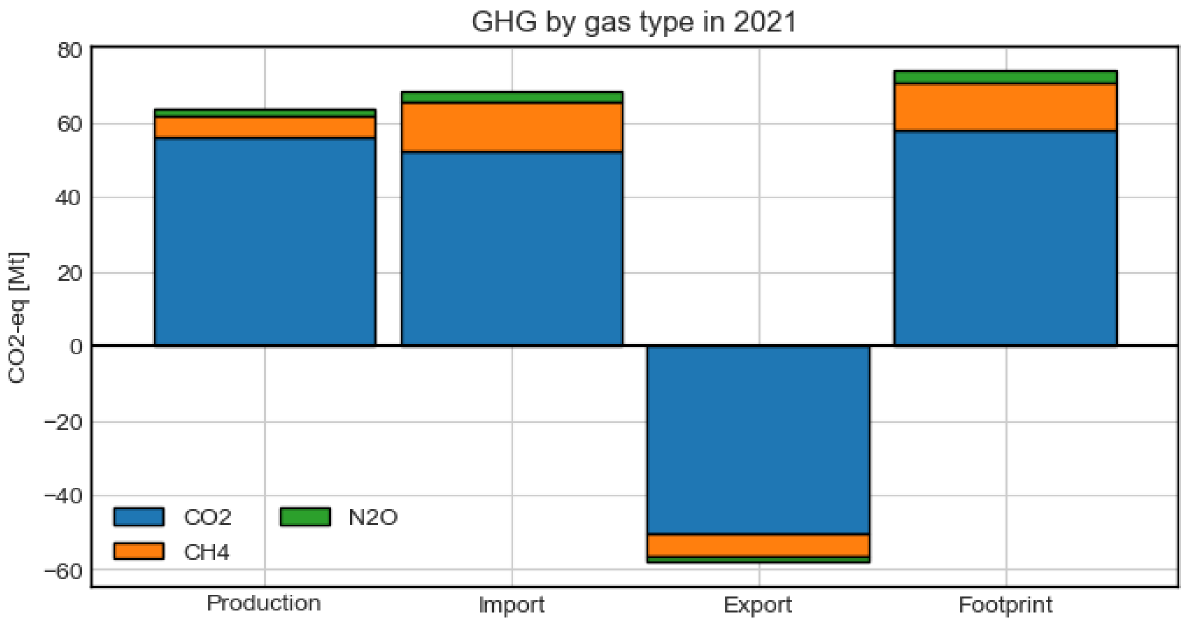


Figure 2: Emissions embodied in imports and exports, and resultant consumption-based emissions (footprint) of Norwegian Economic Activity, by greenhouse gas.

[5] It should be noted that the emissions embodied in exported products do not include the emissions of non-combusted energy products. For example, the emissions from the Norwegian production of oil and gas for export are included, whereas the emissions from the combustion of these emissions outside of Norway are not included.

Emissions embodied in exports and production-based emissions drop 12 % primarily due to a large decrease (4.6 Mt and 7.3 Mt, respectively) in emissions from water transport services. In the meanwhile, emissions embodied in imports and the consumption-based accounts both drop 6 %. A strong drop in emission accounts is also evident for 2019 to 2020. A drop in the order of 6-15 Mt CO_2-eq is evident for all measures and corresponds to the initial lockdown (and slowdown in economic activity, particularly transport) of the coronavirus pandemic.

Prior to the pandemic, production-based emissions were 3 % higher than in 2012. From 2020 to 2021, emissions increased again between 5 to 14 % for all accounts, apart from the production-based account, which decreased 1 %. However, none of the accounts reached 2019 levels. Ongoing lockdown measures in 2021 make it too early to identify whether emissions levels will return to pre-pandemic years.

The breakdown of the Norwegian consumption-based GHG emissions is shown in Figure 4, distinguishing by domestic and foreign sources. The domestic component are the greenhouse gas emissions that are released in Norway that are embodied in goods and services consumed in Norway, whilst the imported component is the emissions released in foreign countries embodied in goods and services that are consumed in Norway.

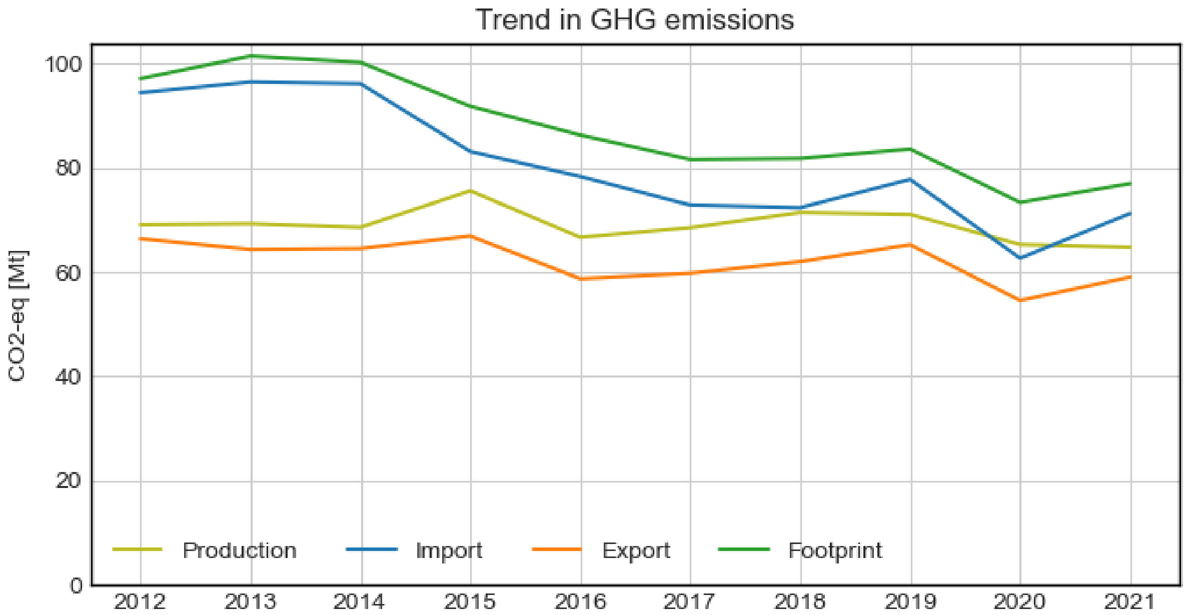


Figure 3: Trends in greenhouse gas emissions: production-based, emissions embodied in imports and exports; and resultant consumption-based emission account of Norwegian Economic Activity, 2012-2021.

The domestic component[6] of the footprint is slowly decreasing, with year-on-year variations less than 10 %. In 2013 and 2015, the difference from previous years were +5 %, while in 2019 and 2021 the differences from previous year were -9 and -10 %, respectively. Emissions from domestic sources declined 18 % from 2012 to 2021. Similarly, emissions embodied in imports have declined 22 % from 2012 to 2021. Prior to 2021, only small year-on-year increases (less than 4 %) occurred in 2013 and 2019. Largest year-on-year decrease (-16 %) and increase (+14 %) happened from 2019 to 2020 and from 2020 to 2021, respectively. These are largely explained by the lockdown measures implemented due to the COVID-19 pandemic.

In the following sections, the sources of the consumption-based account emissions in terms of region and products will be explored.

1.2.1.3. Emissions by final product and origin

The Norwegian consumption-based emissions account (i.e., footprint) can be disaggregated by the final product that is consumed (see Figure 5). These include emissions due to household consumption, government consumption and capital formation. The sector breakdown shown here is the same sector breakdown as the production account (65 NACE sectors aggregated to 17 sectors). However, in these results, we refer to the "final demand" for goods and services from the sector. As such, sectors like agriculture have lower levels of final demand, as many agricultural goods are inputs into food manufacturing which are then consumed in the final demand category *food, beverages & tobacco*.

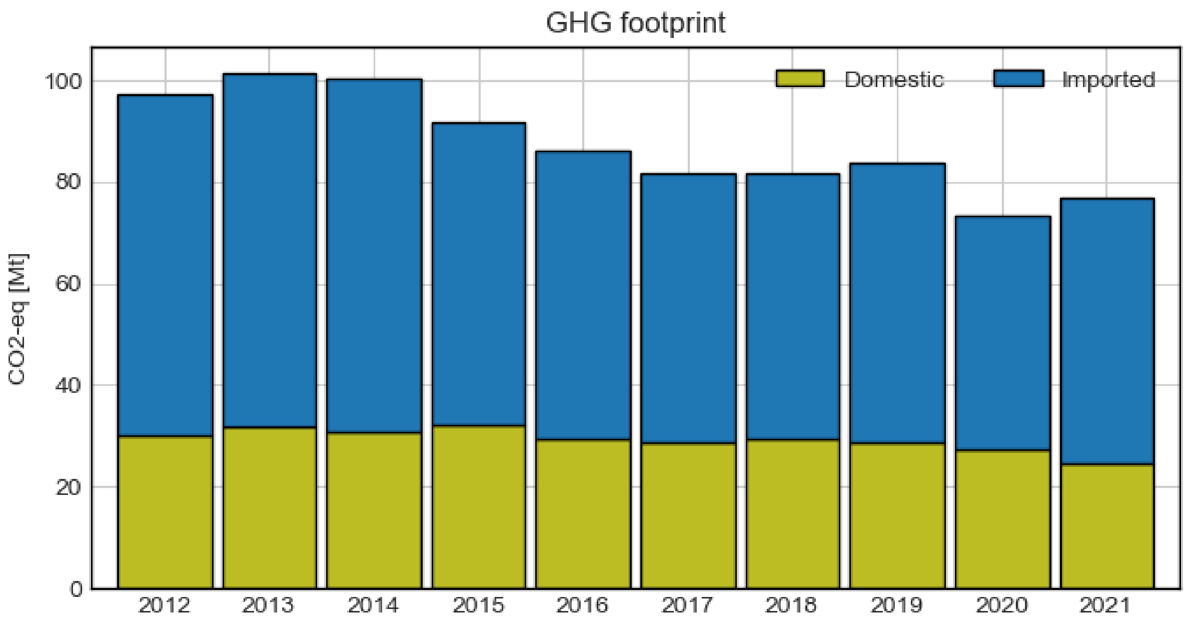


Figure 4: Trends in greenhouse gas footprints broken down into domestic and foreign sources, Mt CO_2-eq, 2012- 2021.

[6] Note that the domestic component here is that part of the production account that is embodied in the consumption of goods and services in Norway, with the remainder of the production account embodied in exports.

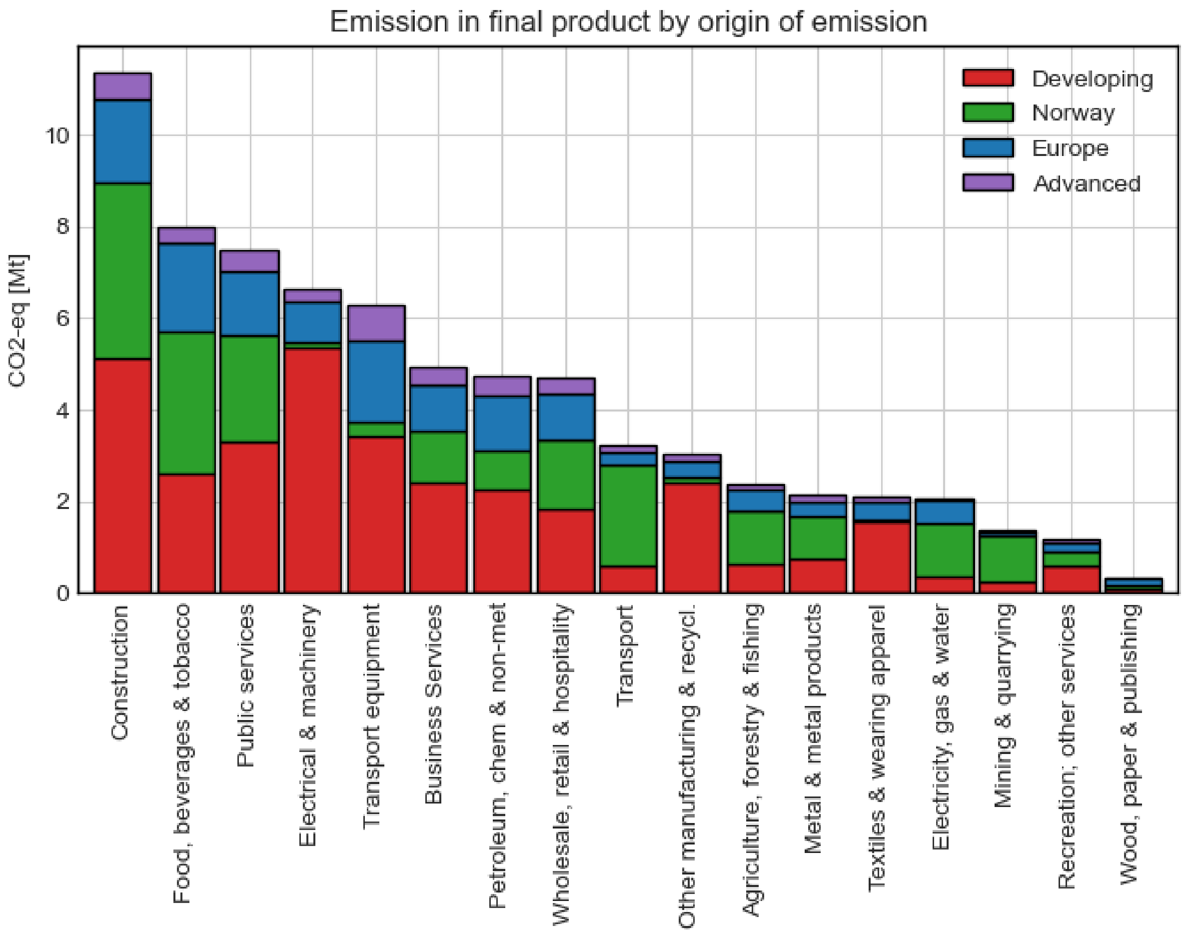


Figure 5: Greenhouse gas emissions embodied in final products in 2021, by origin of emissions, aggregated to 17 sectors, Mt CO_2-eq. These numbers exclude direct emissions by final demand users. The country classification into Advanced and Developing economies can be found in Appendix 5.

The largest final demand sector is *construction* with 16 % of the total, followed by f*ood, beverages & tobacco* and *public services* with 11 % and 10 % shares, respectively (see Figure 5). It is in stark contrast to the production-based account, where these make up 3.6, 0.8 %, and 0.6 % of the total, respectively. These sectors all rely on emission intensive primary sectors (e.g., agriculture or mining) for their products and services. The public service sector includes public administration, health services, education and social services, and is a significant sector of the Norwegian economy.

Breaking down the greenhouse gas emissions in final products by the region of origin reveals how Norwegian consumption relies on the emissions embodied in global production. Full results at the resolution of the EXIOBASE model are available in the results files (that provide 44 countries and 5 extra rest of world regions) but are aggregated here into three foreign regions – that of Europe (EU and non-EU countries in Europe), other advanced countries, and developing countries (including China). The aggregation key is provided in Appendix 5.

Emissions occurring in developing countries make up the largest share (of the four regions) for 10 out of the 17 final product groups, most notably for *Electrical & machinery* (81 %), *Other manufacturing & recycling* (80 %), and *Textiles & wearing apparel* (75 %). Europe only has the largest share of emissions for *Wood, paper & publishing* (47 %), but has substantial shares of the emissions for *Transport equipment* (28 %) and *Petroleum, chemical, and non-metal products* (26 %). Domestic (Norwegian) emissions are only responsible for more than 50 % of the emissions for 4 products groups, namely *Mining & Quarrying* (73 %), *Transport* (67 %), *Electricity, gas & water* (56 %), and *Agriculture, forestry & fishing* (50 %).

The 20 % decrease in the consumption-based emission account from 2012 to 2021 (see section 1.2.1.2) was primarily due to reduced emissions from *Business Services* (-4.8 Mt CO_2-eq), *Wholesale, retail, and hospitality* (-4.4 Mt CO_2-eq), and *Transport* (-4.4 Mt CO_2-eq). The reductions were primarily in the emission embodied in imports component, rather than domestic component. However, ongoing COVID-19 lockdown measures both in Norway and abroad in 2021 is likely to have had an influence.

1.2.1.4. Emissions by final demand categories

Households (*Final consumption expenditure by households* in the official accounts) are by far the largest category of final demand – both in terms of expenditure (43 %) and consumption-based emissions (50 %) (see Figure 6).

(Gross fixed) Capital formation accounts for 31 % of the total consumption-based emissions (see Figure 6). Note that capital is not endogenized in the input-output tables, so that emissions due to large capital expenditures on e.g., airplanes and railways are not allocated to the goods and services which use the capital in future years. This is to ensure the consistency of the input-output tables with national accounting conventions. The emission footprint from producing transport capital is relatively minor compared to the emissions from its future fuel use, e.g., an airplane emits more during its use phase compared to its construction phase.

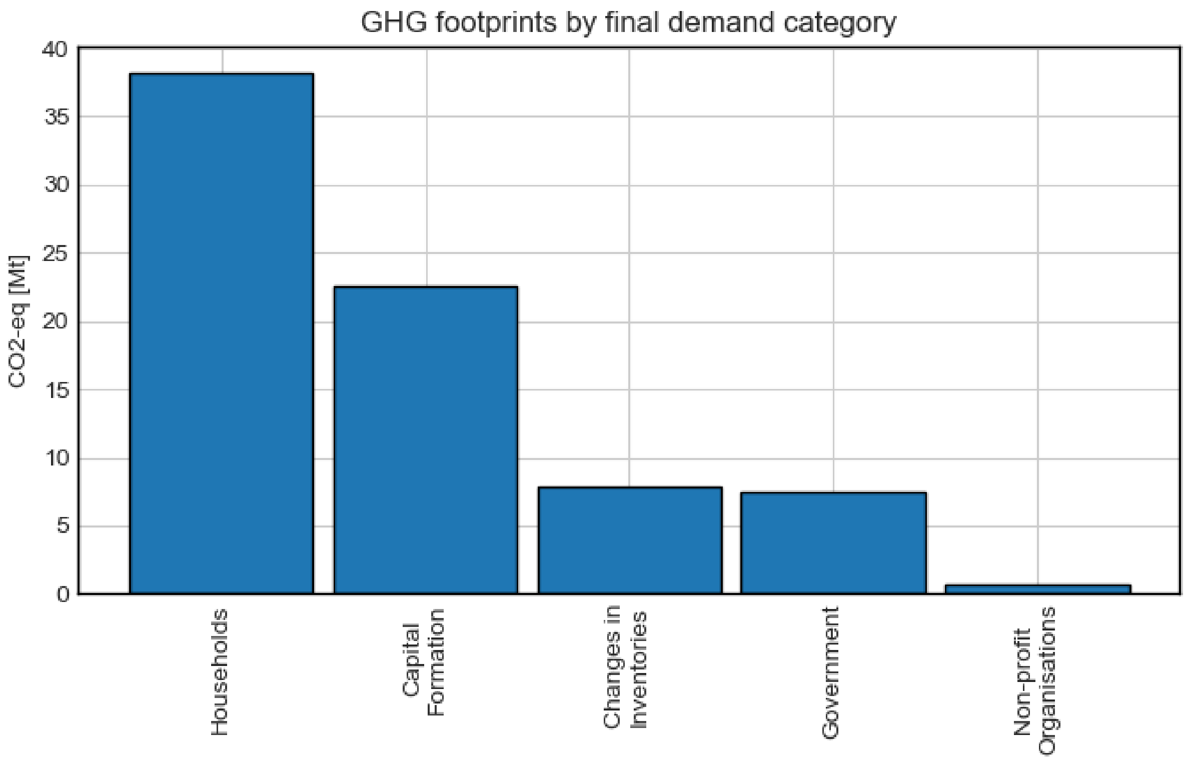


Figure 6: Breakdown of greenhouse gas footprint in Mt CO_2-eq by final demand category, 2021. Households: Final consumption expenditure by households, Capital formation: Gross fixed capital formation, Government: Final consumption expenditure by government, Non-profit Organisations: Final consumption expenditure by non-profit organisations serving households (NPISH). These numbers include direct emissions by final demand users.

Changes in inventories contributes 8 Mt CO_2-eq, a considerable component. In the detailed results, it shows this largely due to construction (incomplete construction projects or components of construction), food products, mining and quarrying, and petroleum products. These results are the addition to inventories of these goods for future years usage, but should be interpreted with caution, as values in the category sometimes are adjusted to balance out any remainder in the balances when constructing the input-output tables.

The largest sources of emissions for household consumption are transport and food consumption. The consumption of food, beverages, and tobacco products accounts for 16 % (6.1 Mt CO_2-eq), with an additional 10 % (3.9 Mt CO_2-eq) and 6 % (2.3 Mt CO_2-eq) from hospitality services and agricultural, forestry & fishing products (see Figure 7). Hospitality services encompasses accommodation and food services, as well as the provision of wholesale and retail services.

In Figure 7, direct emissions by households are presented alongside the goods and services produced in the economy in order to give a complete emission account for households. Nearly 4 Mt CO_2-eq are direct household emissions due to transport (e.g., personal vehicle use – and are only the direct emissions, not the life-cycle emissions of producing fuel or vehicles). An additional 2.3 Mt are due to the purchase of transport equipment (e.g., motor vehicles) and 2.1 Mt CO_2-eq are due to the purchase of transport services (e.g., air transport by airplane or road transport by taxi or bus). Transport equipment emissions include the construction of the equipment, but not the use. Transport services include the production and combustion of the fuels used to provide the services, but only the construction of minor transport equipment (e.g., taxis), but not the construction of major transport equipment such as airplanes, railways etc. The latter are instead reported as gross capital formation (see section further above).

Emissions from petroleum products, chemicals, pharmaceuticals and non-metallic minerals were 3.32 Mt CO_2-eq in the household account. In the Norwegian input-output tables, these sectors are all aggregated into one group. Whilst this excludes the emissions from the combustion of fuels in vehicles owned by households (counted in the direct household emissions), it includes the supply-chain emissions in the provision of those fuels. There are also significant emissions from electrical & machinery products (3.31 Mt CO_2-eq).

Government final consumption expenditure (*Final consumption expenditure by government* in the official accounts) is concentrated on government and public services (including health and education) which have relatively minor emissions intensities (see Figure 8). It should be noted that the provision of public services (rather than the expenditure on the services) is accounted for as an industry in the input-output tables. The government has a dual role in providing public services and paying for them. In the provision of government services, the consumption-based emissions account of government procurement could be calculated, but as an intermediate producer, rather than a component of the national consumption-based emission accounts. Furthermore, government expenditure on fixed capital investments such as railways, hospitals, or tunnels is included in gross fixed capital formation, along with private investments.

The contributions to the consumption-based emissions account of gross fixed capital formation are shown in Figure 9. As expected from earlier results, the dominance of the construction sector is evident, with most construction activity being for capital investment purposes. This sector includes the construction of houses and cabins as well as the construction of infrastructure. It is not possible at the level of the input-output data to break this down further, for example into housing versus other or into public versus private investments. The footprint captures the full supply-chain emissions, including the emissions due to production of steel, cement or wood used in construction, as well as the direct emissions of the sector itself. In the detailed sectoral analysis presented later in this report, a breakdown of upstream emissions in supply chain of the construction sector is provided (see section 1.3).

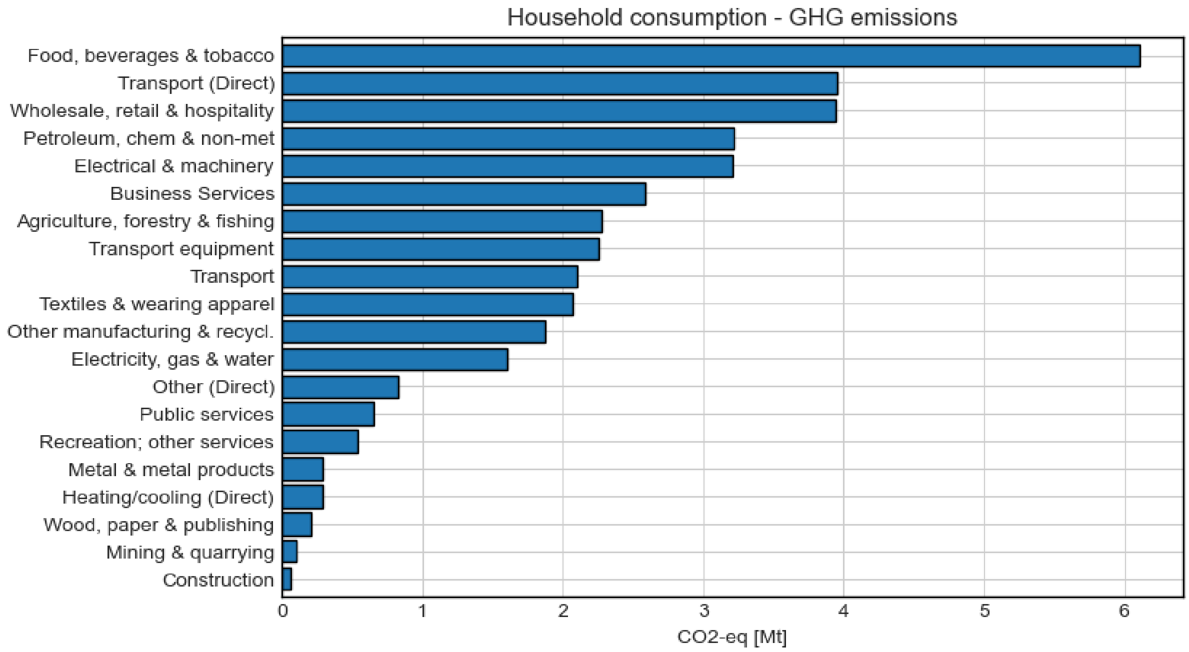


Figure 7: Breakdown of greenhouse gas footprint of household final consumption (*Final consumption expenditure by households* in the official accounts*)* in 2021, by final demand sector in Mt CO_2-eq. Direct emissions are included as three categories and labelled as *(Direct)*.

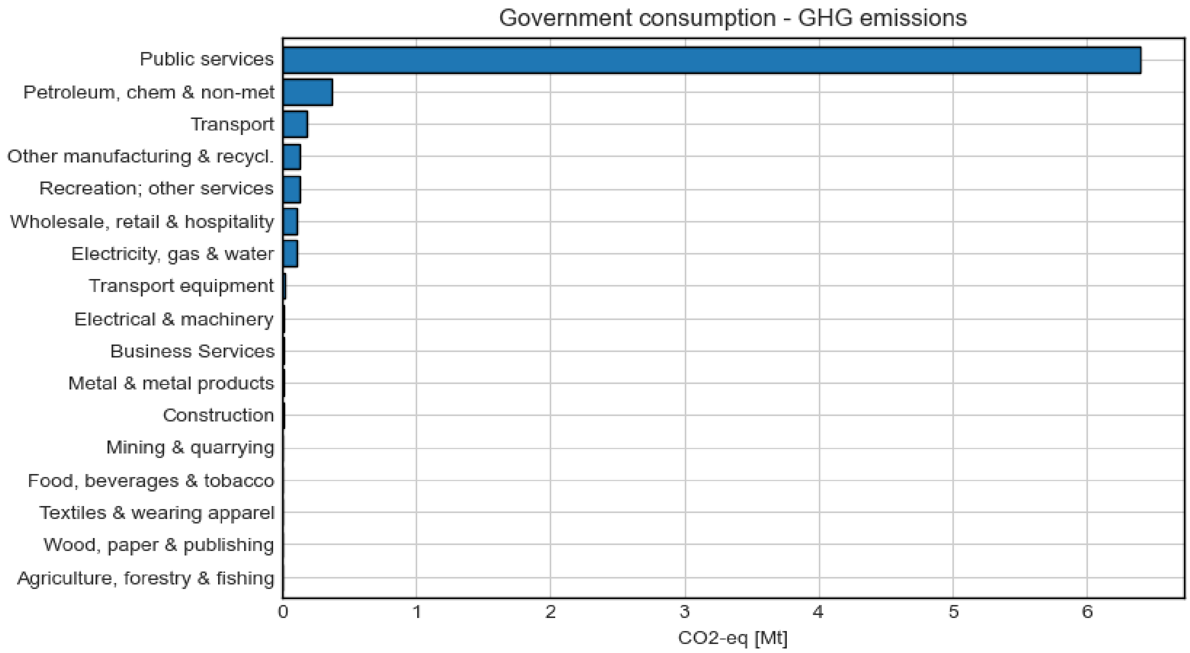


Figure 8: Breakdown of greenhouse gas footprint of government final consumption (*Final consumption expenditure by government* in the official accounts) in 2021, by final demand sector in Mt CO_2-eq.

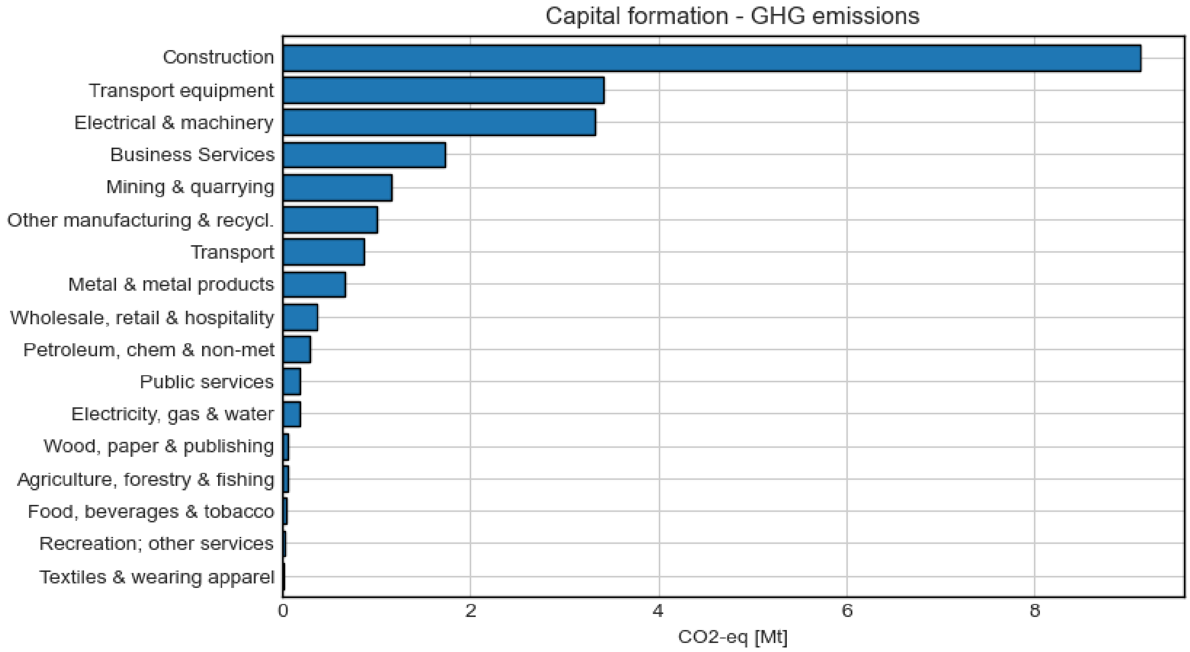


Figure 9: Breakdown of greenhouse gas footprint of capital formation in 2021, by final demand sector in Mt CO_2-eq.

1.2.1.5. Emissions from biomass CO_2

Carbon dioxide emissions due to biomass combustion are presented in Figure 10. Note that these figures should be considered experimental, due to the less advanced accounting conventions around biogenic CO_2. There is potential for under-reporting, but the analysis of the quality of biomass accounts was not a focus of this project and needs to be developed in further work.

Our estimates show that domestic emissions account for roughly 35-40 % of the biomass CO_2 footprint, while foreign sources account for the rest of the footprint. From 2014 to 2019, biomass CO_2 emissions grew steadily, but like the overall non-biogenic emissions, emissions dropped in 2020 due to COVID-19 pandemic. However, in 2021 there was a major rebound with a 26 % increase in emissions, primarily from imported sources. There was a higher rate of growth in biomass CO_2 (up to 2019), particularly in emissions embodied in imports compared to non-biogenic CO_2, and further growth in this metric does warrant a higher level of focus on the issues surrounding the use of biomass and its sustainability.

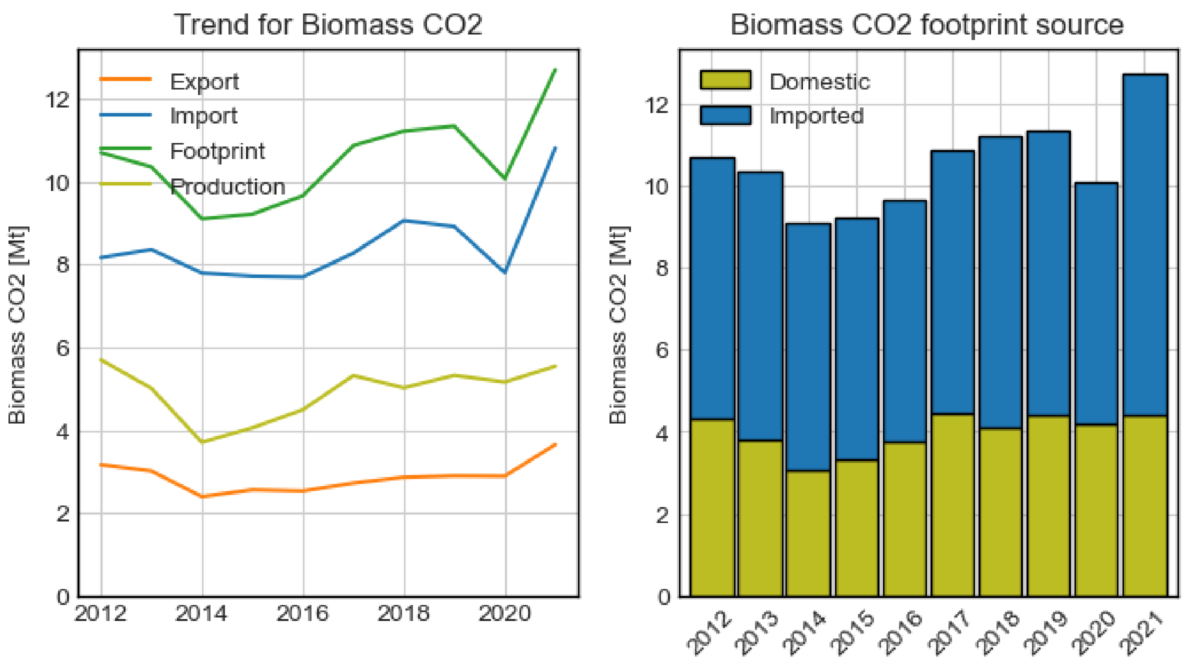


Figure 10: Trends in biomass CO_2: production-based; emissions embodied in imports and exports; and resultant consumption-based emission account of Norwegian Economic Activity, 2012-2021. Right hand side: footprint broken down by domestic versus foreign sources. Note: a portion of emissions embodied in imports will be embodied in exports, and not form part of the Norwegian consumption-based accounts – This explains the differences in the import emissions on the left- and right-hand side.

1.2.2. Description of data improvements

One reason for updating the CaFEAN analyses was to add 2021 data by including the latest Norwegian input-output table (IOT). Another reason was that EXIOBASE (the model on which the import emissions are based on), underwent a major update from version 3.8.2 to 3.9. Two parts of the EXIOBASE v. 3.9 update are essential for the CaFEAN model.

First, EXIOBASE is now based on the recently published supply and use tables (SUTs) made available as part of the European Union's FIGARO model[7]. FIGARO provides SUTs in a consistent and harmonized format for the years 2010-2022. EXIOBASE v. 3.8.2 and earlier versions relied on national SUTs that were harmonised manually. These were only available for one or a few years for each region between 2007 and 2015, while data for the other years were inter- or extrapolate based on national aggregates. The adaptation of the FIGARO SUTs means EXIOBASE now better captures the structural changes that may have occurred in the global economy, especially in the years after 2015. A structural change can both be large sudden or small gradual changes to production recipes, supply chains, or consumption patterns. A large sudden change occurred in 2020 due to the COVID-19 pandemic. Lockdowns and safety measures were put in place, that restricted either or both producers and consumers (e.g., sudden lockdowns could have caused physical retail stores and their supply chains to experience a sharp drop in production, which would lead to reduced energy use and associated emissions). Smaller gradual changes could be the increased role of *Internet of Things* in goods and appliances, which may increase the energy demand (e.g., configurable lightbulbs controllable by a phone). Simple extrapolations based on national aggregate statistics are unlikely to capture these changes and their impacts in detail.

Second, the energy accounts that provide the foundation for the emissions accounts have been updated, both in terms of the underlying data and the procedure used to construct these accounts. The result is less reliance on now-casting procedures (predictive estimates based on national aggregates for the current period) and more realistic emission accounts.

A comparison of the results of the original and updated CaFEAN model clearly shows major changes[8]. First, the total CB emissions, and EEII, of the Norwegian economy are higher than previously estimated in all years from 2012 to 2021 (See Figure 8 in Appendix 1). In 2020, the CB emissions were 72.6 Mt CO_2-eq as compared to 70.2 Mt CO_2-eq in the original report (See Figure 5 in Appendix 1). In the original report, EEII was lower than production-based emissions from year 2017 onward, while in the update, this is only true for 2020. The effect of COVID-19 on the economy is also clearer in the update, as the EEII dropped more significantly in 2020.

Second, structural changes are clearly observed in the results. Notably, the aggregated sectors *Electrical & Machinery* and *Business Services* are now responsible for a larger share of the footprint (See Figure 17 in Appendix 1). However, the *Construction* sector, which still has the highest footprint, also increased in absolute terms. The changes are more notable when only looking at the EEII results (See Figure 19 in Appendix 1). The *Electrical & Machinery* sector increased from approximately 8 to 12 Mt CO_2-eq, while the *Petrochemical* sector decreases from 16 to 12 Mt CO_2-eq with the updated model. Additional structural changes are observed when ranking the sectors with the most significant footprint changes from 2012 to 2020 (See Table 5 in Appendix 1).

---

[7] https://ec.europa.eu/eurostat/web/esa-supply-use-input-tables/information-data#figaro

[8] In appendix 1, all plots from the original report that are impacted by the update are shown.

1.3. Understanding sectoral footprints

For CaFEAN 2, a tool was developed to conduct a more in-depth analysis of individual sectors of the Norwegian economy. The tool does two things. First, for each good or service delivered to final demand, it determines the contribution of each sector in its supply chain to Norway's CB emissions of purchases of this good or service, distinguishing between domestic emissions and emissions embodied in imports. This allows one to investigate where in the supply chain emissions occur. Second, it calculates the change in emission intensity (Mt CO_2-eq per MNOK) of the emitting sectors over a given time interval. For the domestic sectors, that is the direct emission intensity of the sector (i.e., production based), while for the import sectors, it is the emission intensity of the EEII. It calculates the changes of intensities in both current and constant prices, identifying the effects of price and volume changes in the emitting sectors. Details on the methodology and the produced results, as well as a guide on how to interpret the results, are provided in Appendix 2. Below, two sectors are chosen to showcase the tool.

Construction, that is, the purchase of buildings and infrastructure*,* has the largest footprint[9]. Table 1 provides the estimates on the five largest sources of emissions in its supply chain in 2021 and how these have changed since 2012. In 2021, the footprint of the *Construction* sector was estimated to be 11 Mt CO_2-eq, which is a 0.2 Mt increase since 2012. The most notable change is the 120 % increase in emissions from imported *Electrical equipment*, rising to 2.40 Mt CO_2-eq in 2021. It is now responsible for 21 % of the total footprint of the *Construction* sector and the largest source of emission for the sector. The percentage increase in constant price stressor reveals that an increasing emission intensity (emission per unit) of the imported goods contributed to this rise. However, the more-than-doubling in footprint also suggests a change in production recipes, i.e. that more electrical equipment was used in construction than before, because a 37 % increase in the constant price stressor cannot explain a 120% increase of the footprint alone. The second-largest source of emissions is domestic *Construction and construction* works, which contributed 1.81 Mt CO_2-eq to the footprint of *Construction* in 2021. Its constant price emission intensity has increased 127 %, while its current price emission intensity has decreased 33 %. This implies that the sector has become more emission intensive, but prices are rising faster. The main sources of emissions for the footprint of *Construction* are emissions embodied in imports.

The second example sector is *Business services* which includes information, communication, financial, and other professional services. The *Business services* sector has the largest absolute change in its footprint between 2012-2021. Table 2 provides the estimates on the five largest sources of emissions in its supply chain in 2021 and changes since then. The footprint of the *Business services* sector nearly halved, dropping from 9.6 Mt CO_2-eq in 2012 to 4.9 Mt CO_2-eq in 2021. The main sources of emissions were all from imports. All of these sectors have reduced their emissions intensity both in current and constant prices since 2012, with the exception of the *Electrical equipment* sector, where both have increased. The *Computer programming, consultancy and related services; information services* sector has the largest share of the *Business services* sector footprint with 9 %. Despite a roughly 50 % decrease in both its current and constant price stressors, its footprint has increased by 205 % to 0.44 Mt CO_2-eq in 2021.

[9] Note: when footprint of a specific sector is mentioned, it is referred to the footprint of the goods or services that the specific sector delivers to final demand, and not the footprint of the sector as an intermediate sector.

This implies that the increase in emissions is due to increased imports, both in terms of monetary expenditure and volume of goods/services.

These two sectors were chosen to demonstrate the type of analysis the tool enables. Currently, the analysis is done at the aggregate 17-sector level for the sectors delivering the final goods and services but can be done at the full 64-sector level (these are provided in the results). Furthermore, one could do the analysis for specific greenhouse gasses (e.g., CO_2 or CH4), or only analyse the footprint of certain final demand categories (e.g., household consumption, government expenditures, capital formation). These analyses would provide further insights into the sources of the emissions and how they have changed over time. However, there are caveats one should be aware of when interpreting these results (see Appendix 2 for more information).

Sector **Construction**	Footprint in 2021 **11 Mt CO_2-eq**		Change since 2012 **+0.2 Mt CO_2-eq**	
Source sector	**Footprint [Mt CO_2-eq] (change since 2012)**	**Share of total footprint (change in shares)**	**Change in current price stressor since 2012**	**Change in constant price stressor since 2012**
Electrical equipment *(import)*	2.40 (+120 %)	21 % (+11 %)	+4.2 %	+37 %
Constructions and construction works *(domestic)*	1.81 (+9 %)	16 % (+1 %)	-33 %	+127 %
Other non-metallic mineral products *(import)*	0.92 (+37 %)	8 % (+2 %)	-40 %	-12 %
Basic pharmaceutical products and pharmaceutical preparations[10] *(import)*	0.77 (+8 %)	7 % (0.4 %)	-36 %	-9 %
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials *(import)*	0.61 (-59 %)	5 % (-8 %)	-76 %	-61 %

Table 1: Detailed breakdown of the 5 largest emission sources for the footprint of the final goods delivered from the Construction sector. Brackets at the end of source sector names states whether it is an import or domestic sector the emission originates from.

[10] The sector includes *Coke and refined petroleum products*, *Chemicals and chemical products*, and *Basic pharmaceutical products and pharmaceutical preparations* as these sectors are aggregated in the Norwegian input-output tables.

Sector **Business services**	Footprint in 2021 **4.9 Mt CO_2-eq**		Change since 2012 **-4.7 Mt CO_2-eq**	
Source sector	**Footprint [Mt CO_2-eq] (change since 2012)**	**Share of total footprint (change in shares)**	**Change in current price stressor since 2012**	**Change in constant price stressor since 2012**
Computer programming, consultancy and related services; information services *(import)*	0.44 (+205 %)	9.0 % (+ 7.5 %)	-57 %	-48 %
Computer, electronic and optical products *(import)*	0.38 (-54 %)	7.7 % (-0.9 %)	-60 %	-48 %
Furniture; other manufactured goods *(import)*	0.36 (-68 %)	7.4 % (-4.4 %)	-50 %	-35 %
Electrical equipment *(import)*	0.33 (+37 %)	6.7 % (+4.2 %)	+4.2 %	+37 %
Basic pharmaceutical products and pharmaceutical preparations[10] *(import)*	0.25 (-50 %)	5.1 % (-0.1 %)	-36 %	-9 %

Table 2: Detailed breakdown of the 5 largest sources for the footprint of the final goods delivered from the Business services sector. Brackets at the end of source sector names states whether it is an import or domestic sector the emission originates from.

1.4. Household footprints

The household consumer expenditure surveys enable a further breakdown of the household consumption and its footprint in the CaFEAN model. The products can be disaggregated from the 64-sector IO classification to the COICOP classification, level 2 to 4 depending on the survey. More interesting is however the breakdown of the household consumption into different socioeconomic groups, such as household type, centrality of municipality, or income quartile of household. A detailed description of the methodology, the results, and an overview of caveats for how to interpret the results are provided in Appendix 3. It should be noted that the analysis below uses the CaFEAN model results for 2021 (latest year available), but the consumer surveys for 2022 (only year available). Hence the analysis allocates the CB emissions accounts from 2021 to consumer groups assuming the exact same expenditure shares in 2021 as reported by the consumer surveys from 2022.

Three of the tables from SSB's consumer expenditure have been integrated into the CaFEAN model. Below we highlight three sets of results, namely the household footprint per person for types of households (e.g., living alone, couples with no children) and level of centrality of household, as well as the household footprint per household for different income quartiles. The income quartile footprint is only per household due to data not being available for the average number of people living in each income quartile household. In the per person results (Table 3 and 4) children are counted as persons on equal terms as adults.

Whether results on per person or household level is most relevant or useful for policy guidance, depends on the type of mitigation policies that is considered. On one hand, the household results are better suited for guiding mitigation policies based on economic incentives (tariffs, taxes etc.), as these affect the household as a single economic unit. On the other hand, the per person results are more relevant for guiding mitigation policies based on allowances (e.g., carbon credits), as they can ensure equal rights to each person. Although, the latter raises the question of at what age, should a child be allocated the same allowance as an adult. It should be stressed, that the results should be used for monitoring and guiding policy prioritization and not to set specific tax levels or allowances due to limitations on the data and methodology (see Appendix 3 for more details).

One crucial limitation of the methodology is that environmental impacts are distributed according to how much money is spent rather than what is bought. An example is the purchase of a car. If person A purchases a car at double the price of person B, person A will also be allocated double the amount of the car sector footprint. Even if person A's car is more environmentally friendly than person B's. This is essential when interpreting the footprint results of households from different income quartiles (see Table 5). Furthermore, one needs to acknowledge the potential difference in average number of persons in each household across the different income quartiles. For the centrality results, it is important to interpret the results with care when you look at the consumption of goods and services that typically might be more expensive in central places than in less central places, such as housing.

As expected, the household type expenditure survey footprint results show how households with children have the lowest *per person* emissions (see Table 3). This makes sense, since a child's consumption naturally is much lower than that of an adult. If we consider emissions *per household* instead, these households have the highest emissions. The per person consumption based emissions of people living alone are however also higher than the per person emissions of the household type *Couples with no children*, indicating that households with more than one person are sharing emissions associated with transportation (e.g., driving a car), heating a home, cooking a meal, and more, and hereby reducing the total per person. *Transport* is the largest source of CB emissions for all household types, followed by *Food and non-alcoholic beverages*.

The centrality expenditure survey footprint results show that the most and second most central municipalities have the highest per person footprints. However, they have distinct consumption patterns, so their per person footprint for each product group differs. The most central municipalities have the highest footprint on 6 out of 13 product groups, while the second most central municipalities have the highest footprint on 3 of them. Despite having the lowest per person CB emissions, the least and second least central municipalities have the highest footprint on *Transport* and *Food and non-alcoholic beverages*, which are the product groups with the highest CB emissions. For these two product groups, the most central municipalities are however on almost the same level. The underlying numbers reveals that the most central municipalities have higher emissions from transport services (public transport, taxis etc.), while the least and second least municipalities have higher direct transport emissions, i.e., personal vehicle use. Emissions from *Restaurants and accommodation services*, which are significantly higher for the more central municipalities, should also be considered in combination with the emission from *Food and non-alcoholic beverages*, as these often serve the same consumer need. In that case, the most central municipalities emit notably more than the least and second least central municipalities (0.21 tons CO_2-eq per person).

The most central municipalities have particularly low spending on furnishing and household maintenance compared to the other municipalities, something potentially connected to house ownership and type of housing (e.g., houses rather than apartments) in urban areas. The per person footprint on food seems to follow a U-shape, where the most central, second least and least central municipalities have almost the same footprint (1.38-1.39 tons CO_2-eq per-person), and the municipalities in between have lower footprints (1.23-1.31 tons CO_2-eq per-person). Spending on *Health* is significantly lower for the least and second least central municipalities (0.06 tons CO_2-eq per person) than for the rest (greater than 0.22 tons CO_2-eq per person). There is almost no difference across municipalities when it comes to CB emissions from *Insurance and financial services* (0.4 Mt CO_2-eq per person). It should be noted that the results reflect household purchases, not the consumption of government-provided services such as public education or health care, which explains why no emissions are reported for *Education services*.

The income quartile survey results show that the highest income quartile households are responsible of more than twice the emissions of the lowest income quartile households (see Table 5). In general, footprints are higher for higher income quartile households, although there are a couple of exceptions. Second income quartile households have a larger footprint from *Health* products and services than the third income quartile, and almost as large as the highest income quartile. Similarly, the lowest income quartile households have a larger footprint from *information and communication* products and services compared to the second income quartile. It is however important to reiterate that the methodology does **not** consider differences in product quality (e.g., durability, sustainability, or efficiency) within each product category used in the input-output model, as mentioned above. Thus, the numbers instead show which sectors that the households in different income quartiles spend their money on, and the CB emissions embodied in the products and services of these sectors.

Tons CO_2-eq per person	Living alone	Mother or father with children, youngest child 0-19 years	Couples with no children	Couples with children, youngest child 0-6 years	Couples with children, youngest child 7-19 years	Other households
Transport	2.71	1.34	2.40	1.21	1.55	1.65
Food and non-alcoholic beverages	1.68	1.06	1.48	1.00	1.18	1.26
Furnishings, household equipment and routine household maintenance	1.55	0.68	1.21	0.76	0.91	0.85
Housing, water, electricity, gas and other fuels	1.19	0.55	0.78	0.40	0.45	0.62
Recreation, sport and culture	0.70	0.34	0.61	0.32	0.44	0.41
Clothing and footwear	0.69	0.21	0.60	0.26	0.39	0.34
Restaurants and accommodation services	0.49	0.24	0.33	0.19	0.25	0.27
Information and communication	0.46	0.20	0.26	0.15	0.20	0.20
Health	0.22	0.20	0.36	0.13	0.12	0.40
Alcoholic beverages, tobacco and narcotics	0.33	0.16	0.28	0.10	0.15	0.27
Personal care, social protection and miscellaneous goods and services	0.08	0.12	0.07	0.26	0.07	0.05
Insurance and financial services	0.06	0.03	0.05	0.03	0.03	0.04
Education services	0.00	0.00	0.00	0.00	0.00	0.00
Total	10.16	5.15	8.43	4.82	5.75	6.37

Table 3: Consumption-based emissions in tons CO_2-eq per person in 2021 by different household types. Note: children are counted as persons on equal terms as adults. Other households include couples or lone parent with children more than 18 years old and households with two or more one-person families.

Tons CO_2-eq per person	Most central	Second most central	Above medium central	Medium central	Least and second least central
Transport	1.97	1.78	1.85	2.01	2.04
Food and non-alcoholic beverages	1.38	1.31	1.23	1.27	1.39
Furnishings, household equipment and routine household maintenance	0.84	1.18	1.07	1.04	1.06
Housing, water, electricity, gas and other fuels	0.81	0.73	0.64	0.60	0.58
Recreation, sport and culture	0.44	0.54	0.52	0.47	0.44
Clothing and footwear	0.58	0.45	0.44	0.38	0.42
Restaurants and accommodation services	0.43	0.31	0.30	0.24	0.22
Information and communication	0.30	0.26	0.23	0.23	0.25
Health	0.22	0.30	0.27	0.25	0.06
Alcoholic beverages, tobacco and narcotics	0.26	0.23	0.22	0.20	0.20
Personal care, social protection and miscellaneous goods and services	0.13	0.12	0.09	0.09	0.08
Insurance and financial services	0.04	0.04	0.04	0.04	0.04
Education services	0.00	0.00	0.00	0.00	0.00
Total	7.38	7.26	6.90	6.83	6.77

Table 4: Consumption-based emissions in tons CO_2-eq per person in 2021 by municipality centrality index. Note: children are counted as one person.

Tons CO2-eq per household	Highest income quartile	Third income quartile	Second income quartile	Lowest income quartile
Transport	5.98	4.63	3.58	2.14
Food and non-alcoholic beverages	3.69	3.14	2.57	1.81
Furnishings, household equipment and routine household maintenance	3.34	2.49	1.76	1.42
Housing, water, electricity, gas and other fuels	1.83	1.54	1.32	1.16
Recreation, sport and culture	1.64	1.23	0.84	0.53
Clothing and footwear	1.44	1.04	0.81	0.62
Restaurants and accommodation services	1.04	0.69	0.48	0.41
Information and communication	0.64	0.54	0.49	0.51
Health	0.64	0.45	0.63	0.32
Alcoholic beverages, tobacco and narcotics	0.65	0.59	0.39	0.28
Personal care, social protection and miscellaneous goods and services	0.30	0.27	0.20	0.12
Insurance and financial services	0.22	0.11	0.02	0.01
Education services	0.00	0.00	0.00	0.00
Total	21.43	16.72	13.10	9.32

Table 5: Consumption-based emissions in tons CO_2-eq per household in 2021 by household income quartile.

Chapter 2: Policy inputs

The CaFEAN report shows how the Norwegian economy relies heavily on imports and these tend to have high emissions associated with them. Most of Norway's trade partners (direct or indirect through supply chains) have, like Norway, signed the 2015 UNFCCC Paris Agreement. If the agreement is to be upheld, mitigation measures need to be implemented to reduce global greenhouse gas emissions in the coming decades. Measures which are likely to impact industries and consumers in Norway. Even though Norway has sovereignty over its domestic greenhouse gas mitigation policies, the Norwegian economy is exposed to mitigation policies in other countries due to trade of emission intensive goods and services, as shown in the CaFEAN report. This exposure is especially pertinent now that companies are increasingly obliged to report their Scope 3 emissions. Hence, monitoring how greenhouse gas emissions are embodied in imports and exports is becoming more relevant.

The CaFEAN model provides a tool for monitoring the consumption-based emissions accounts of Norwegian consumption, the emissions intensity of Norwegian production when including the emissions embodied in imported products, as well as the emission embodied in imported goods and services directly by Norwegian final consumers (See section 4.3 for emissions in exports). The methodology (i.e., environmentally extended input-output modelling) adopted is the most viable method for estimating the consumption-based emissions accounts of an economy, as well as monitoring its progress towards reducing the emissions. In comparison to other methodologies (e.g., life cycle assessment) it is particularly suitable for tracking changes over time and evaluate progress towards specific targets in a consistent and complete[11] framework.

2.1. Consumption-based emissions monitoring

In the CaFEAN report, it was shown that a large share of emissions contributing to Norway's footprint occurs in developing countries, especially for products of the sectors *Electrical & machinery, Textiles & wearing apparel* and *Other manufacturing & recycling* (See Figure 22 in Appendix 1). The CaFEAN model by itself cannot ascertain whether Norway's climate policy leads to *carbon leakage*, i.e. whether companies outsource energy intensive production to more lightly regulated jurisdictions. It can, however, be used to identify sectors that are shifting the emission intensive parts of their supply chains abroad to countries with dirtier energy mixes or more resource-intensive production. Such a shift could occur for various reasons and was certainly a result of the great unbundling of supply chains that happened in the first two decades of this century. Such a development, even if not caused by domestic policy, would be relevant for policy considerations, because it would render climate policy ineffectual. The detailed sectoral footprint analysis in CaFEAN 2 further identifies changes in the emissions of imported goods, both in volume and emissions intensity (i.e., constant and current price emissions intensities). Furthermore, the model can compare emission intensities of domestic and imported goods.

The current Norwegian government has decided to increase its Climate Investment Fund, which aims to invest in renewable energy in developing countries[12]. In this context, the CaFEAN model

[11] Complete in terms of including all impacts along the full supply chain of the products and services considered.
[12] https://www.regjeringen.no/en/aktuelt/target-to-double-climate-finance-exceeded-for-second-year-in-a-row/id3048346/

may be used as a guide for the Norwegian government, as well as other Norwegian companies/funds, on where to invest in green solutions to reduce the CB emissions of the Norwegian economy.

2.2. Relevance for EU policies

In Norway, the European Union, and in other major trading partners of Norway, several greenhouse gas emissions reducing policies are considered or already implemented. These include policies such as the EU's *Emission Trading System* (ETS) or the *Carbon Border Adjustment Mechanism* (CBAM). As such, these policies will also influence the Norwegian economy through trade relations.

The ETS covers only a subsection of economic sectors, specifically the energy-intensive industry sectors and electricity/heat generation sectors[13]. A similar ETS mechanism is now being implemented for transport and buildings. The CaFEAN model can be used to estimate how large a share of the total footprint these sectors are responsible for, and analyse how allowances to emit are traded between sectors and countries in the EU. It can calculate the share of a product's cost that are related to ETS payments. As the cap (limit) for the total emissions decreases, the CaFEAN model can also monitor the emission reductions and how they affect the Norwegian economy and its trade patterns. Furthermore, the model can be used to compare (changes in) the emission intensity of specific goods imported from the EU versus other countries. It can identify which portion of emissions embodied in imports is affected by the CBAM. Thus, it can be used to monitor the impacts of CBAM over time, as these are unfolding. Using the consumer expenditure survey footprint analysis made in CaFEAN 2 can also estimate the impact these regulations will have on Norwegian households. There is the argument that less well-off households are disproportionately affected by climate policy. The just transition would require that such impacts be compensated. CaFEAN 2 can be used to investigate this question and suggest a level of compensation to offset the impact of climate policy on the economy of lower-income households.

In June 2024, the Norwegian government adopted EU's *Corporate Sustainability Reporting Directive* (CSRD), which requires all large companies to report their environmental and social impacts, including their greenhouse gas emissions. The regulation states that 'the undertaking may consider Commission Recommendation (EU) 2021/2279 on the use of the Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisations.' The EC JRC has developed two sets of Environmental Footprint (EF) methods, one for products (PEF) and one for organizations (OEF)[14]. For both, sector specific Category Rules (PEFCR and OEFCR) are made to ensure comparability and consistency within sectors. As of today, there is only one set of category rules made available, which is an OEFCR for the Copper industry made by the International Copper Association[15]. These two methods are both based on a life-cycle assessment (LCA) framework, requiring companies to report 16 different types of environmental impacts.

For the CaFEAN project, environmentally extended input-output (EEIO) analysis was chosen over LCA as the preferred method. Even though both are methods used to evaluate the

[13] https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/scope-eu-emissions-trading-system_en
[14] https://green-business.ec.europa.eu/environmental-footprint-methods_en
[15] https://internationalcopper.org/resource/copperoefsr/

environmental impacts of goods and services, they differ significantly in approach. LCA uses a process engineering bottom-up approach which tries to estimate the impact of each process in the supply chain of a product. Conversely, EEIO uses an economic top-down approach, where total impacts are allocated to industries based on global, international, and/or national statistics[16]. The methods therefore have different benefits/drawbacks and are used to answer different types of research questions. EEIO is especially more suited to analyse the role of trade and trends of environmental impacts over multiple years, in a consistent and comparable manner. In research, these methods are increasingly being used in combination, to harvest the benefits of both. EEIO can be particularly useful in reducing the data demand of an LCA (at a potential reduction in precision), and thereby reduce costs for companies' corporate sustainability reports[17]. At this point, the LCA approach is not feasible for most businesses. Environmentally extended input-output tables hence offer an available and attractive basis for comparison. It should also be noted that the directive[18], in Section 5.2, opens up for reporting sector averages when considering the value chain, which is exactly what CaFEAN provides. EXIOBASE, on which the CaFEAN model is based, estimates all 16 types of environmental impacts as required by the EF method, as the only MRIO (See section 4.2 on how to include additional environmental impacts).

The EU has also recently published their own EEIO model, FIGARO. The model is used to analyse "... the socio-economic and environmental effects of globalisation in the European Union"[19]. It is also the model which provides the basis for the EU RME model, which is used to estimate raw material consumption and thereby provide input to circular economy policies[20]. Similarly, the CaFEAN model can be coupled to other datasets to provide more detail on specific sectors (See section 4.4).

---

[16] See preliminary report "*Klimagassutslipp globalt som følge av økonomisk aktivitet i Norge – Vurdering av metoder og behov*" for a detailed comparison of the two methods.
[17] This is known as Hybrid LCA.
[18] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=OJ:L_202302772
[19] https://ec.europa.eu/eurostat/web/products-statistical-working-papers/-/ks-tc-19-002
[20] https://ec.europa.eu/eurostat/documents/1798247/6874172/Documentation+of+the+EU+RME+model/

Chapter 3: The CaFEAN model

3.1. Overview

The core CaFEAN model relies on datasets published by SSB and the global environmentally extended MRIO database, EXIOBASE. It uses the datasets from SSB to model the trade of goods within Norway including its imports, exports, and domestic greenhouse gas emissions. EXIOBASE is used to estimate the emissions embodied in the imports and the origin of these imports. Exchange rates from EUROSTAT are also used to convert EXIOBASE's monetary flows from euros to Norwegian kroner. In CaFEAN 2, more datasets from SSB are integrated into the model to further analyse the data. These are consumer expenditure surveys, household and population statistics, and deflators. Figure 1 shows a simplified sketch of how the datasets are used in combination.

Documentation for the core CaFEAN model is provided in the original CaFEAN report, while the two extensions developed in CaFEAN 2 are documented in the appendices of this report. Additionally, the code repository contains documentation on how to reproduce the results, including a description of the steps involved in the developed procedures.

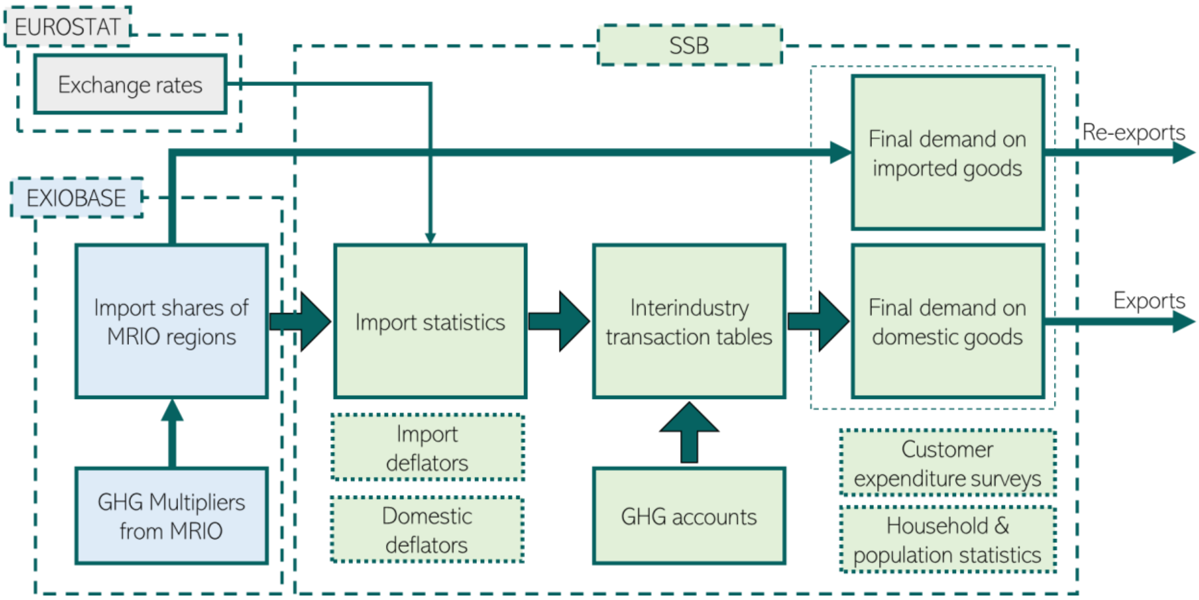


Figure 11: Diagrammatic of the coupled model approach. The figure is an updated version of Figure 3 in the CaFEAN report, which now includes the additional SSB datasets with are used in CaFEAN 2 (dashed boxes). Most of the model is based on official Norwegian statistics, while EXIOBASE provides the emission intensity of imported products.

The updated CaFEAN model produces the following results:

1. The underlying data and the figures presented in the CaFEAN report.
2. Detailed sectoral analysis results for all sectors.
3. Household footprints disaggregated by consumer expenditure surveys.
4. Cleaned intermediate datasets and results that can be used for further analysis.

IO analysis by default produces many results. The purpose of the CaFEAN report was to focus on aggregate results and major trends. However, a deeper dive into the results could provide additional insights.

3.2. Maintenance and updates

Ideally, the CaFEAN model should be updated whenever any one of the underlying datasets are revised. This ensures the results reflect the most accurate and up-to-date picture of Norway's CB emissions. This is particularly important as the underlying datasets may be retroactively updated, with past data corrected or methodological changes applied across the entire time series. More recent results enhance the policy relevance of the CaFEAN model.

The three data sources of the model are SSB, EXIOBASE, and EUROSTAT. SSB publishes new datasets annually for all statistics used in the CaFEAN model, apart from the household consumption expenditure surveys. As of 2024, EXIOBASE will also move towards annual updates. Exchange rates from EUROSTAT, updated annually, can also be substituted with rates from other sources. Updated SSB data will capture structural changes and trend shifts, while updated EXIOBASE data will reflect changes in global supply chains impacting the Norwegian economy.

Input-output tables are always published with at least a year delay, depending on the country and institution. SSB publishes their tables with approximately 2 years delay, i.e., tables for 2022 are published in 2024. EXIOBASE has a larger time lag, as it relies on national statistics from multiple regions, which are then reconciled with other datasets. The latest update of EXIOBASE with a shift to the FIGARO tables reduces this time lag to 4 years for most countries in the model. To partially compensate for the 2-year delay, EXIOBASE estimates recent IO tables using national aggregates and proxy datasets, i.e. now-casting. Thus, EXIOBASE can provide tables for current years. These now-casted tables however come with some limitation and miss any structural changes in the economy which is not reflected in the aggregate statistics. Despite this limitation of EXIOBASE, it is still worthwhile updating the results when SSB publishes new datasets, as these capture all changes in the domestic part of the consumption-based emissions, as well as changes in the domestic import structure of the emissions embodied in imports. In years where there are major disruptions (e.g., pandemic, war) to supply chains that the Norwegian economy relies on, one could publish the results for the now-casted EXIOBASE years as preliminary. In normal years however, the results are most likely to be accurate enough to track and monitor the consumption-based emission account of the Norwegian economy.

Assuming SSB and EXIOBASE do not alter their data formats (i.e., new naming conventions, extra dimensions, increased sector resolution etc.), updating the CaFEAN model for a new year is straightforward. The main steps are[21]:

1. Download/clone the code repository from GitHub.
2. Download the data from SSB, EXIOBASE, and EUROSTAT and place it in the correct folders in the code repository.
3. Install the required software (Python and relevant packages)
4. Change the config.py to include the new year(s).
5. Run the Python scripts.

However, if the data format changes, both auxiliary data and code must be updated accordingly. In terms of updating the code, it should be limited to the config.py file. The file contains all configurable options for running the code and anticipates some potential future changes.

[21] A more detailed guide is provided in the GitHub repository.

Updating auxiliary data should be straightforward, requiring only adjustment to reflect changes in the raw data (e.g., sector name changes).

A full integration of the CaFEAN model into the data pipelines of SSB and/or Miljødirektoratet is also possible. Such integration would make it possible to update the model and its results automatically. The effort required depends on the chosen solution, the level of automation and robustness needed, and the systems it will integrate with.

Chapter 4: Model caveats & potential improvements

4.1. Caveats in input-output analysis

EEIO analysis relies on key assumptions that are essential for accurate interpretation of the results.

First, environmental impacts are distributed according to how much money is spent rather than what is bought. An example is the purchase of a car. If person A purchases a car at double the price of person B, person A will also be allocated double the amount of the car sector footprint. Even if person A's car is more environmentally friendly than person B's. This rule applies to all products within each IO sector. This assumption is especially important when interpreting the household survey footprint analysis.

Second, the analysis is based on yearly country aggregate numbers, and one should be careful to interpret these at a higher level of detail. An example is the emission intensity of electricity consumption. The emission intensity of, price of, and demand for electricity can vary significantly throughout the year and across regions. However, the CaFEAN model assumes that all sectors across Norway consume electricity based on a uniform yearly average, with emission intensities calculated accordingly. Therefore, caution is advised when applying these emission intensities to daily electricity prices, as they may not be representative.

Third, publishing input-output tables takes time because they rely on detailed economic data from many sources. The data is not always immediately available, so there can be a delay of a year or more. To estimate the most recent years, now-casting based on aggregate economic data is used. However, these estimates may not capture sudden changes in the economy. As a result, newly published data may affect model results for previous years. An example is the EXIOBASE update from version 3.8.2 to 3.9 shown in CaFEAN 2.

Fourth, MRIO models are based on several different datasets, that rarely agree on the same numbers. As a result, extensive reconciliation and balancing are required to produce the best possible estimates. Therefore, these estimates may not always align with national statistics. In the coupled approach used to build the CaFEAN model, the numbers are however consistent with all the official Norwegian national statistics used in the analysis.

The documentation for the household survey footprint analysis and detailed sector analysis includes a list of caveats specific to each type of analysis.

4.2. Environmental impacts beyond greenhouse gas emissions

The CaFEAN model is currently made only to estimate the CB emissions of the Norwegian economy. However, the model can be expanded easily to cover a wide range of environmental impacts, including land use, water use, biodiversity, material, and energy footprints, among others.

In the current setup, Norwegian statistics/impact data would need to be added to the model, like the domestic emissions datasets currently is. The effort required to integrate domestic impacts depends on the availability and format of the data. A temporary workaround could be to use EXIOBASE estimates for Norway until domestic data is available.

Expanding the model to include additional environmental impacts would offer a more comprehensive view of the Norwegian economy's environmental footprint. This would allow for cross-analysis of different impacts, helping to identify trade-offs or problem shifting (e.g., increased biofuel demand may reduce climate impacts but increase biodiversity impacts).

4.3. Emissions in exports

Norway is one of the world's largest exporters of oil and gas. In the emissions embodied in exports (which is not included in the CB emissions accounts of Norway), the emissions from production of Norwegian oil and gas products for exports are included. However, most emissions from oil and gas occurs when the products are used (i.e., combusted). As the use occurs in the importing country, these emissions are not included in the 'emissions embodied in exports' nor in any of the other Norwegian emissions accounts. Instead, emissions due to the use of oil and gas are allocated to the territorial accounts of the importing country. The CaFEAN report estimated such potential emissions from Norwegian exported oil and gas in 2020 at around 507 Mt CO_2, nearly ten times the emission embodied in exports (See last part of Section 5.5 in the CaFEAN report).

There are various methods to estimate these emissions, their location and economic use, though none of these methods are well-established as the preferred method in the literature. The primary challenge lies in determining how to allocate the responsibility. Therefore, specific decisions must be made before these estimates can be calculated.

4.4. Coupling to other detailed datasets

Norwegian IO tables are provided at a 64-sector resolution[22] and are partially limited by the Statistics Law from being more detailed[23]. However, additional datasets can be integrated with the CaFEAN model to offer more detailed sector information. For example, the EU RME model expands the FIGARO tables (including the Norwegian IO table) 64 to 182 sectors, improving the modelling and understanding of raw material flows and circular economy potential of raw materials[24]. Similarly, the Food and Agriculture Biomass Input-Output (FABIO) model could provide deeper insights into biomass supply and usage. This would be particularly useful for monitoring the land use and biodiversity impacts of the Norwegian economy.

[22] In reality, it is a 62-sector resolution as the petrochemical sectors are aggregated.
[23] https://www.ssb.no/arbeid-og-lonn/artikler-og-publikasjoner/ny-statistikklov-og-detaljniva-i-tabeller
[24] https://ec.europa.eu/eurostat/documents/1798247/6874172/Documentation+of+the+EU+RME+model/

Appendices

Appendix 1

Extra figures

Updated version of the figures from the CaFEAN report. Original Figure number is kept making it easier to reference the original report.

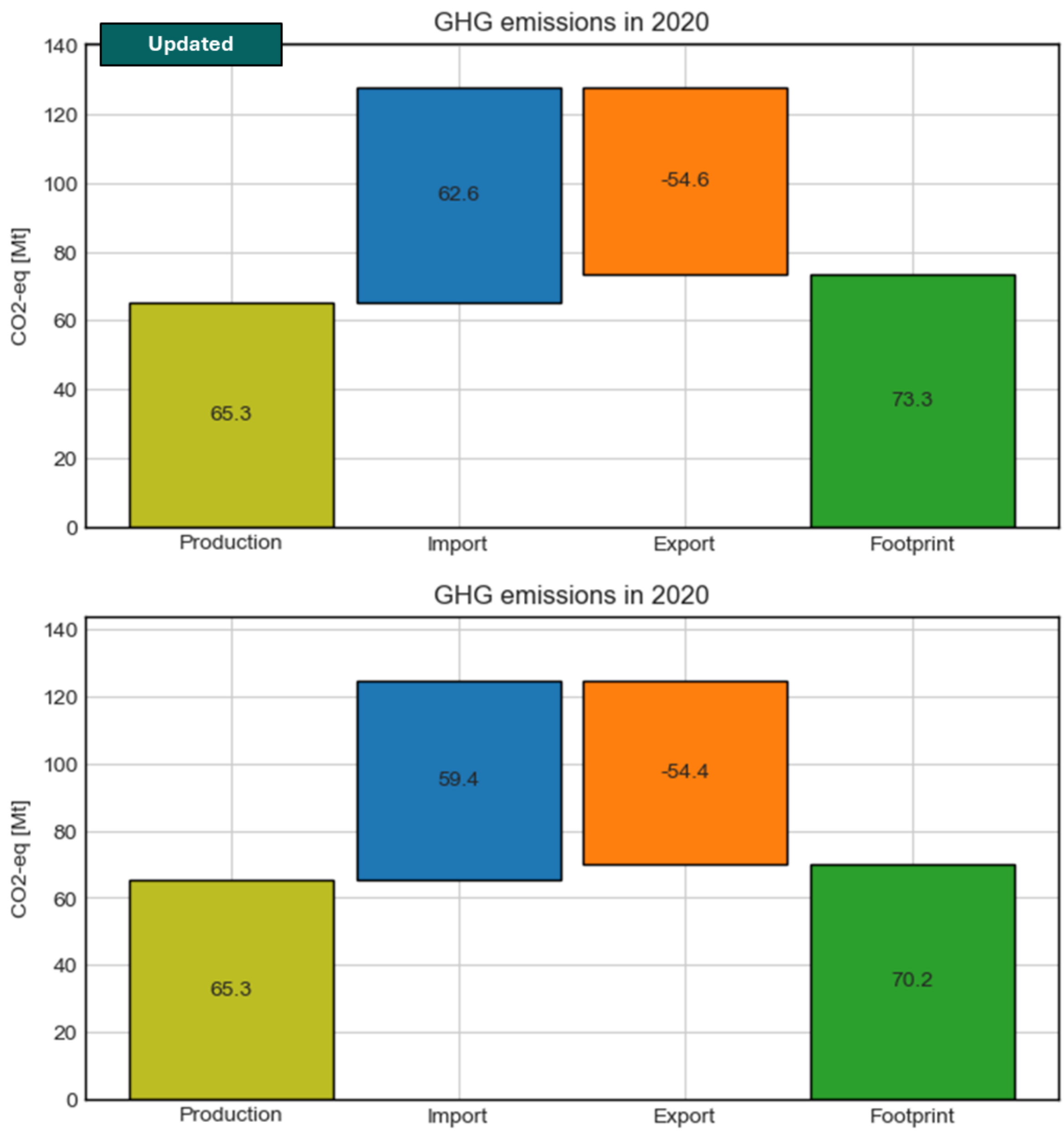
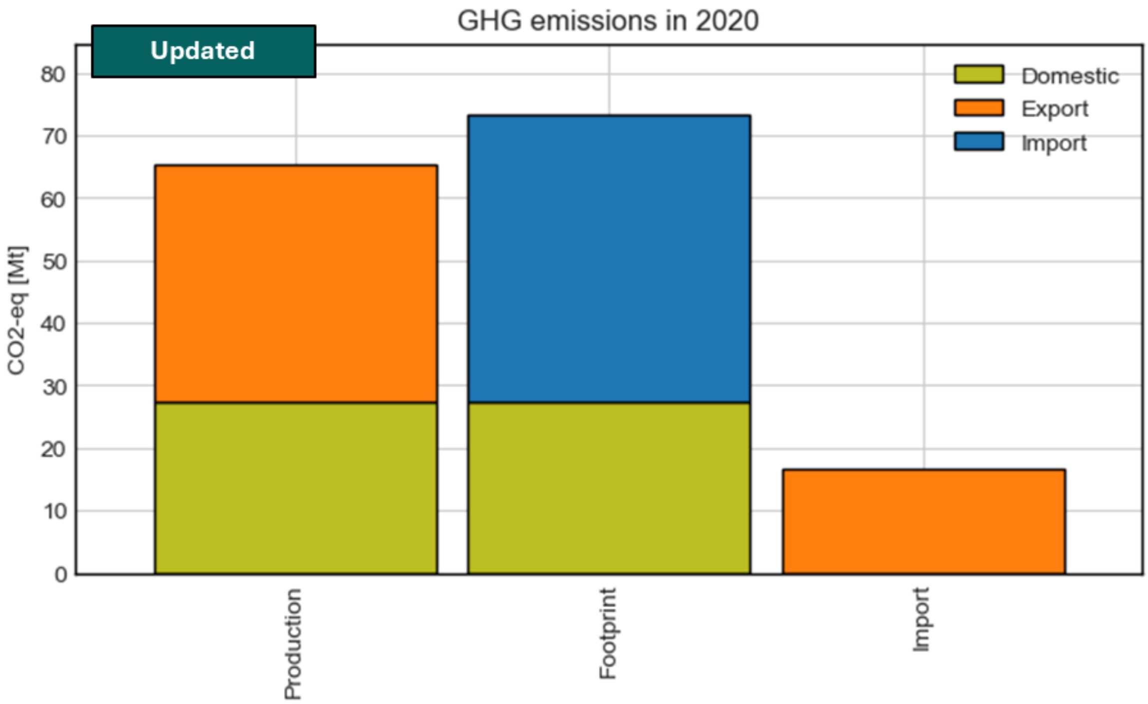


Figure 5 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).



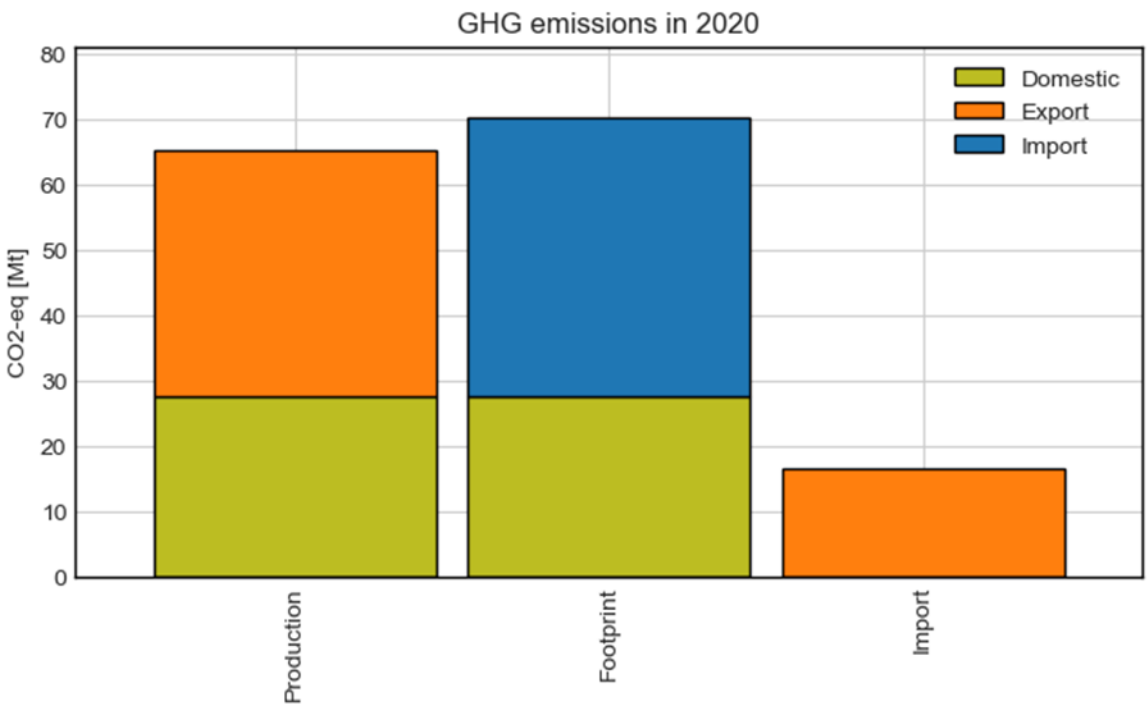


Figure 6 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).

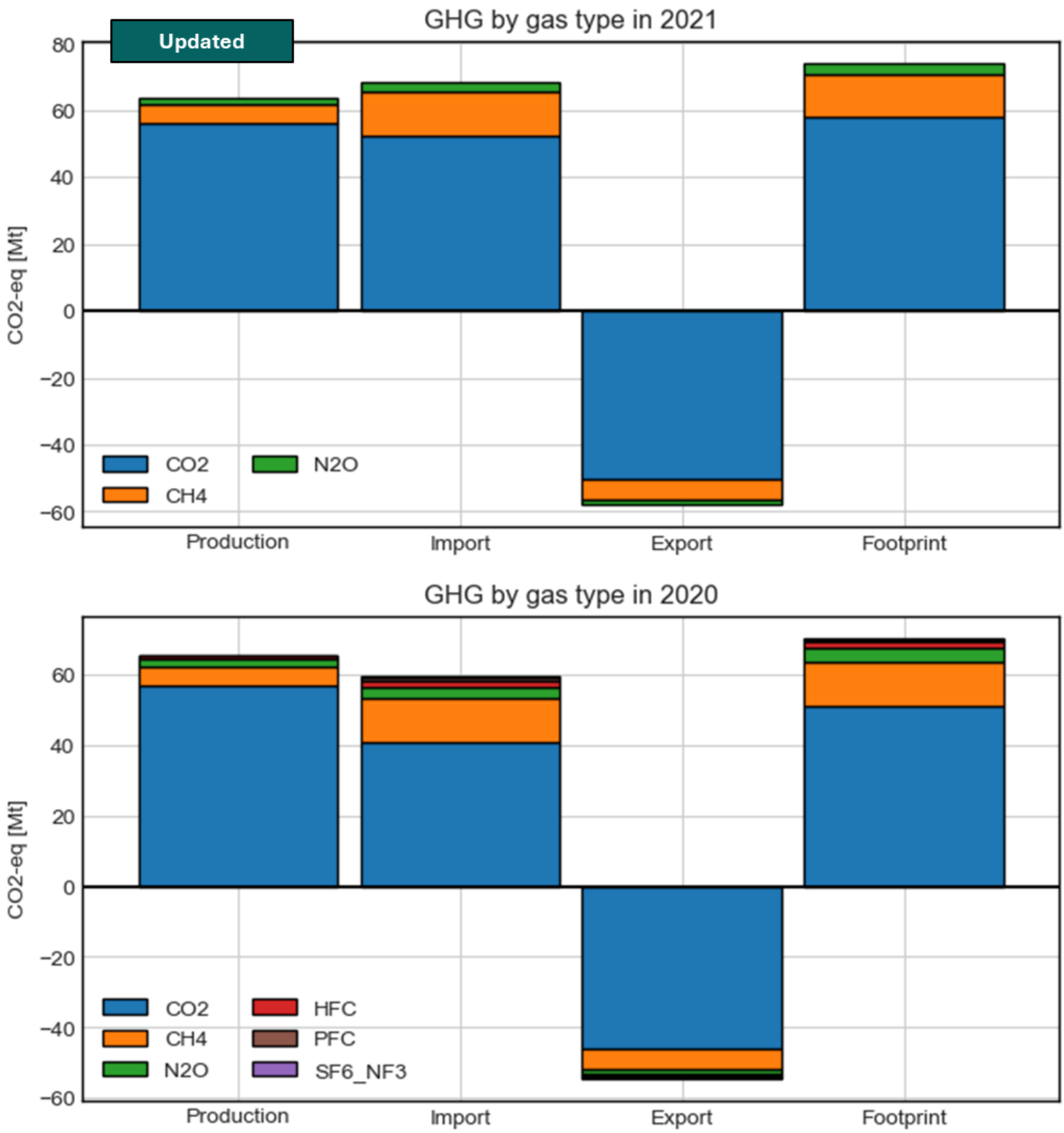
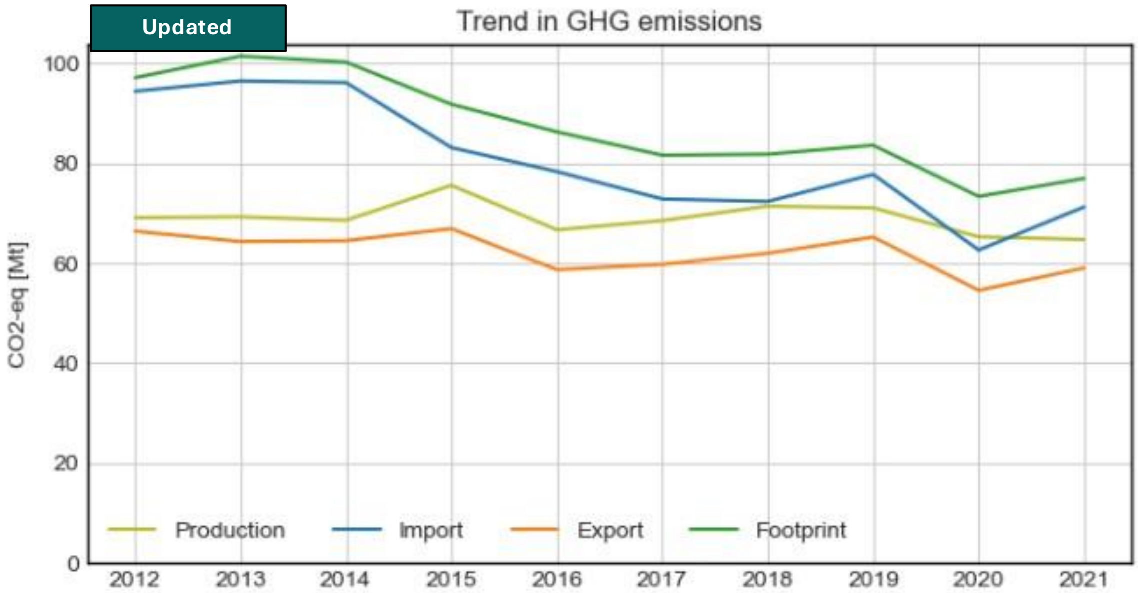


Figure 7 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).



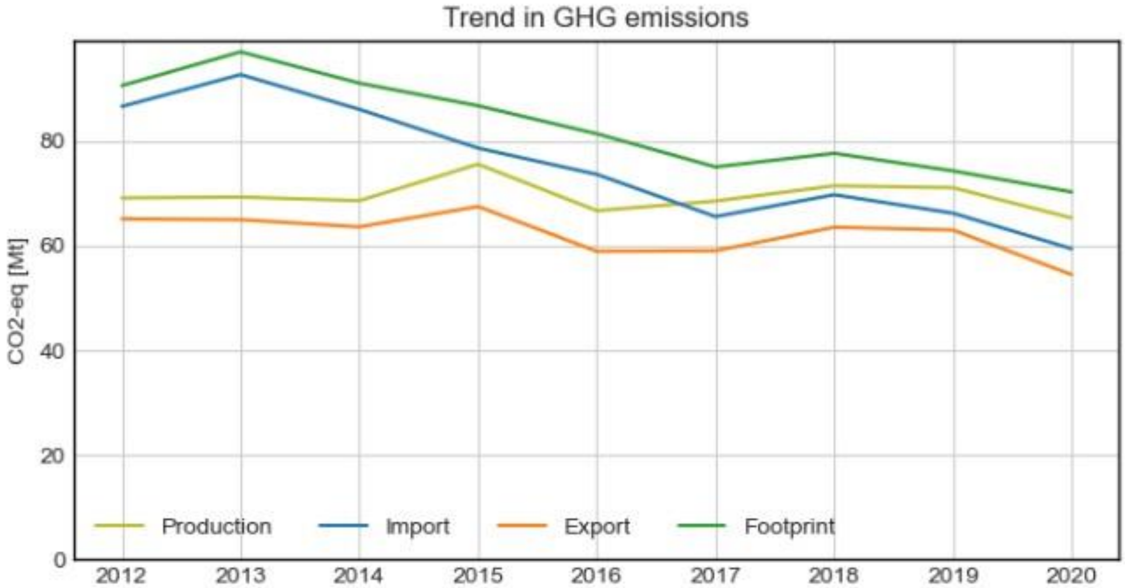


Figure 8 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).

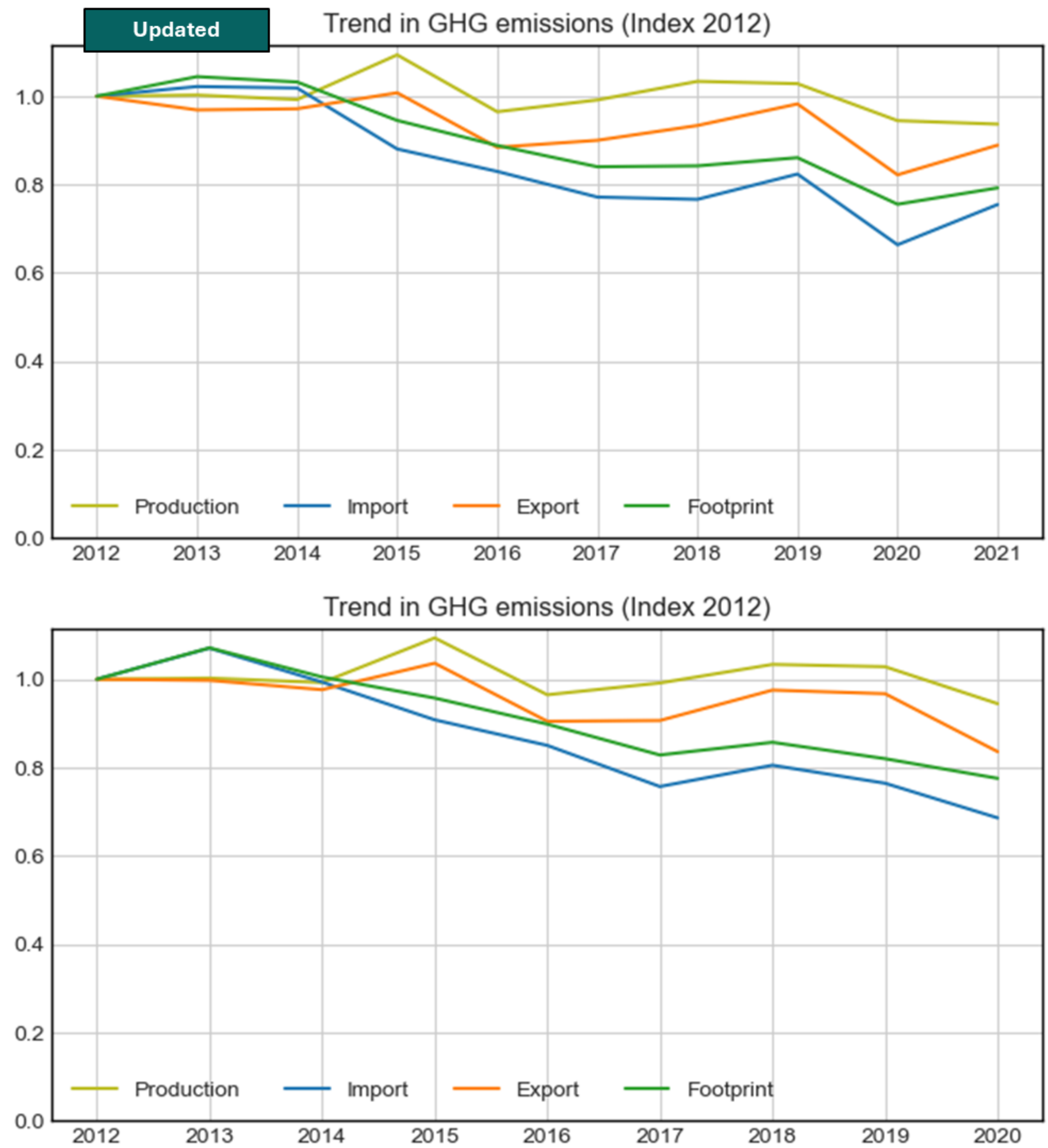
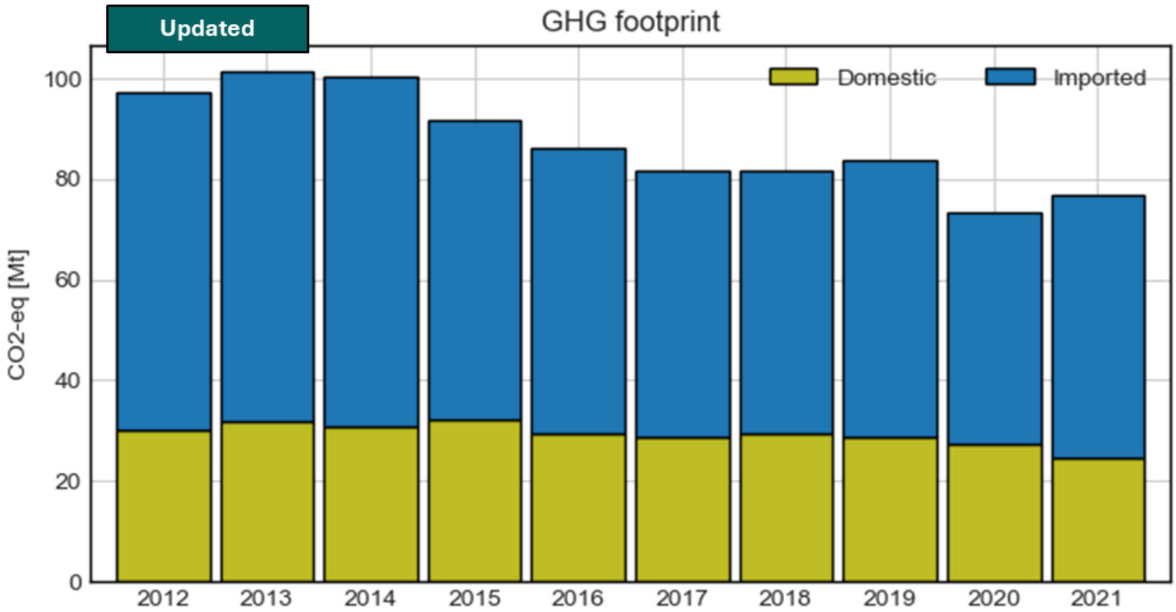


Figure 9 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).



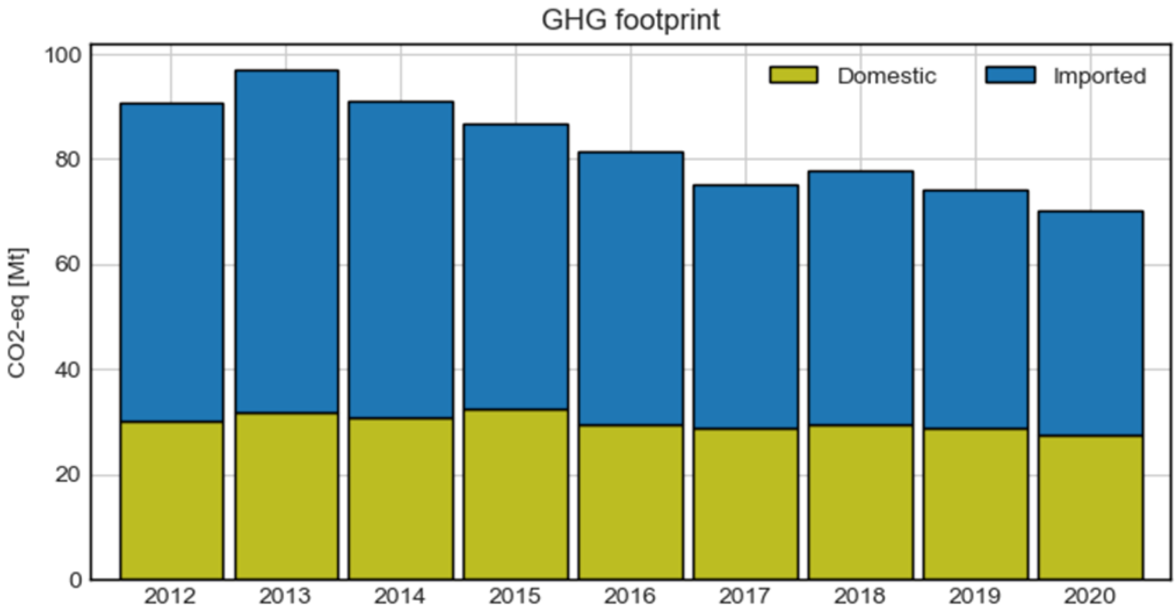


Figure 10 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).

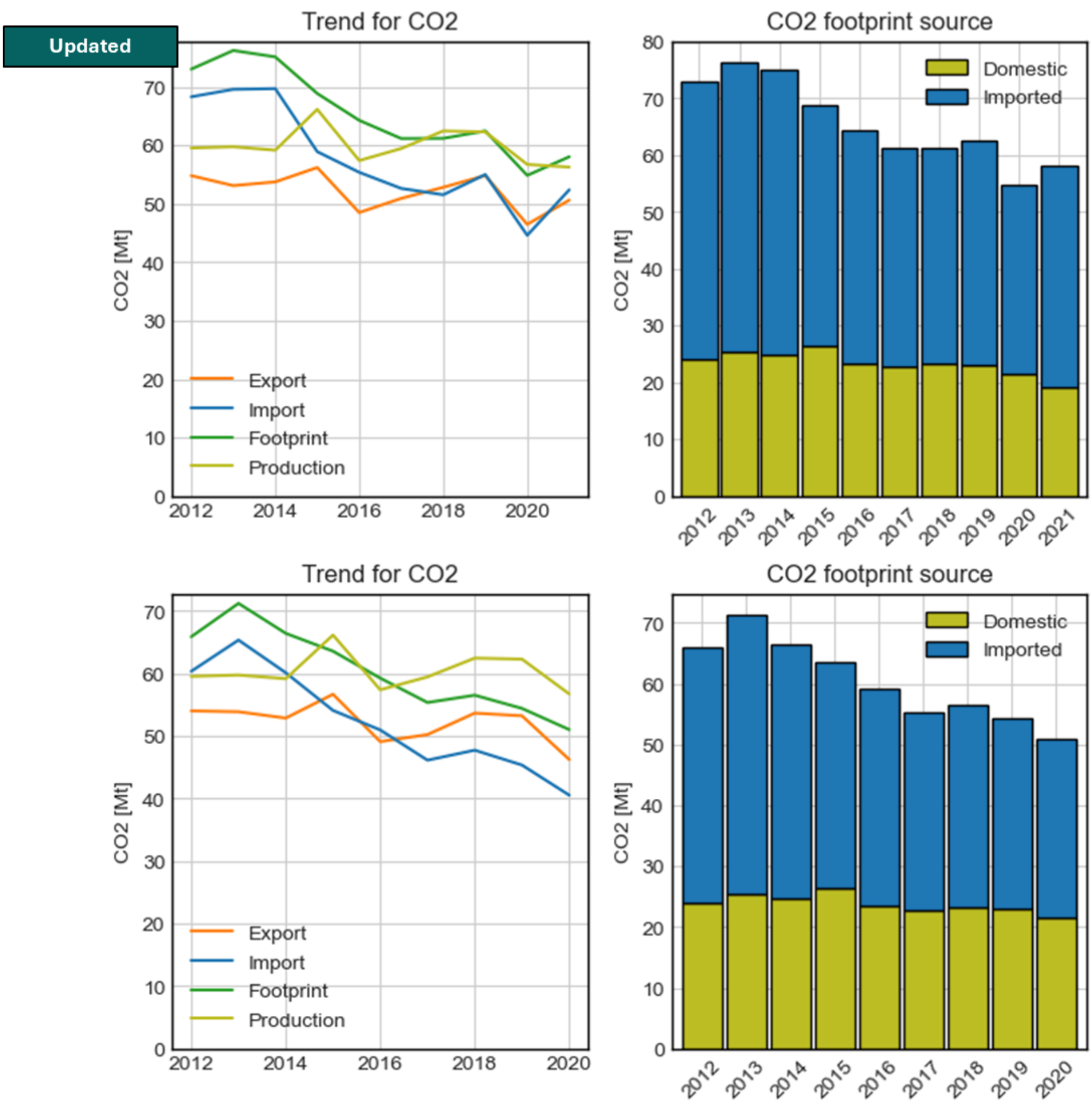


Figure 11 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).

Updated

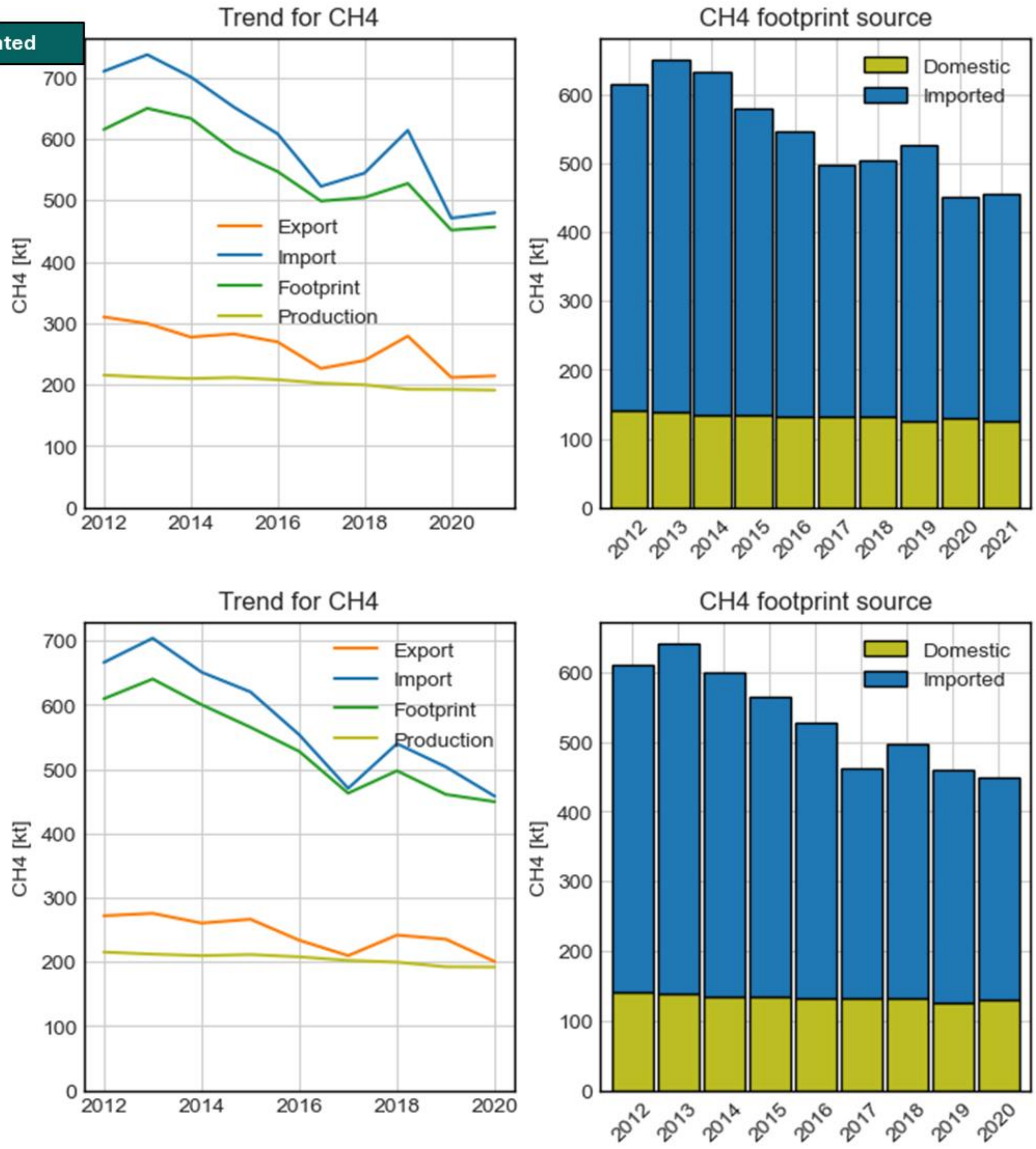


Figure 12 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).

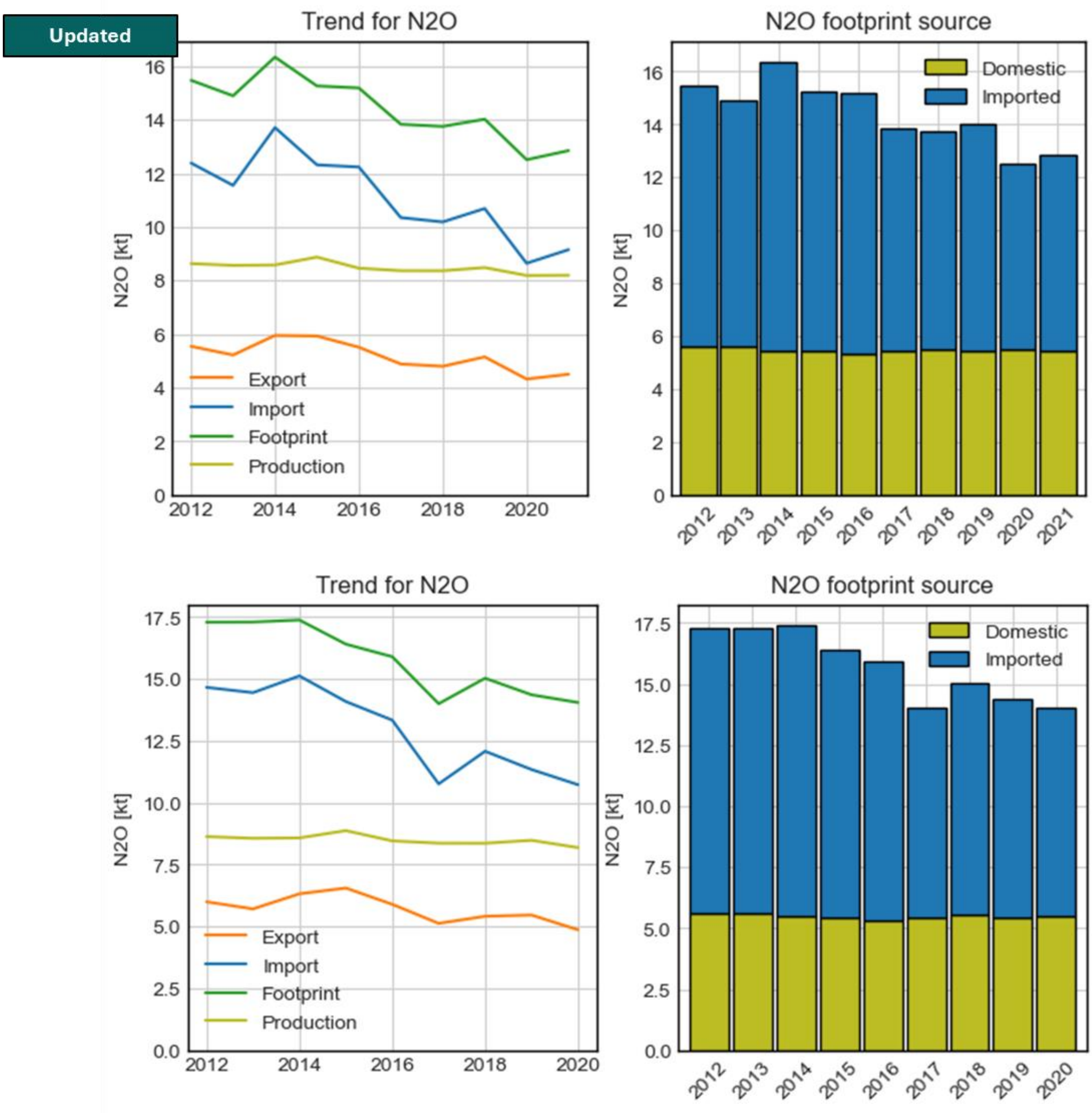
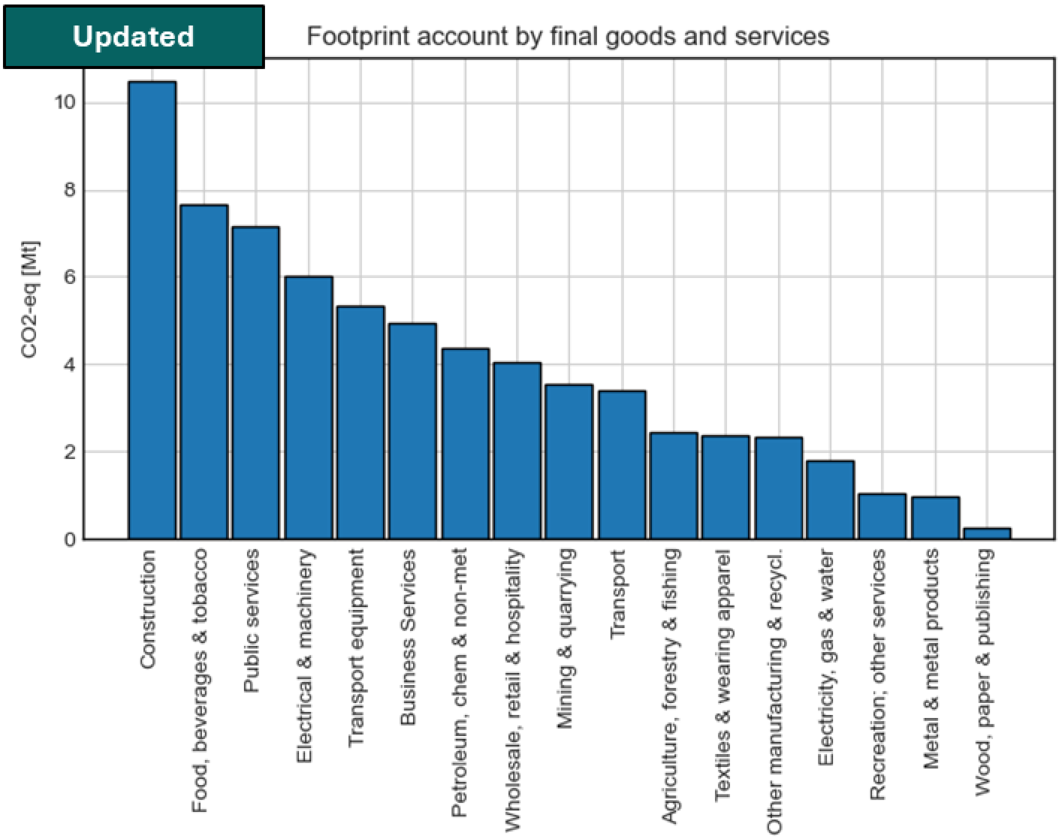


Figure 13 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).



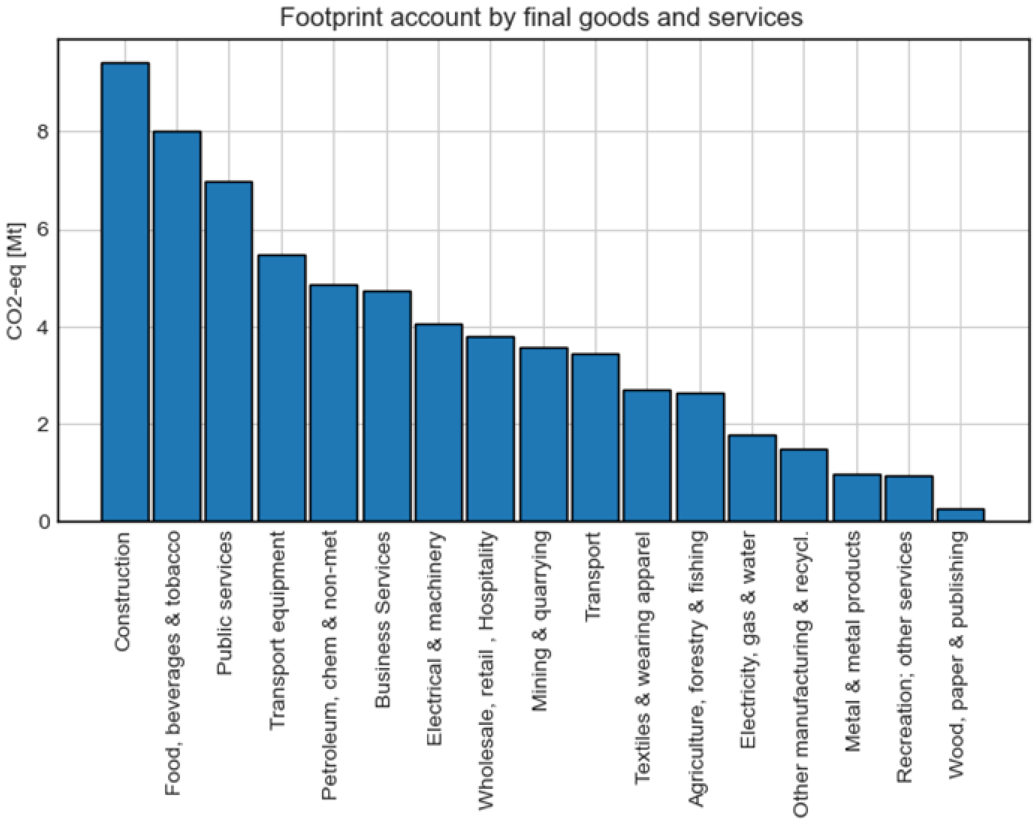
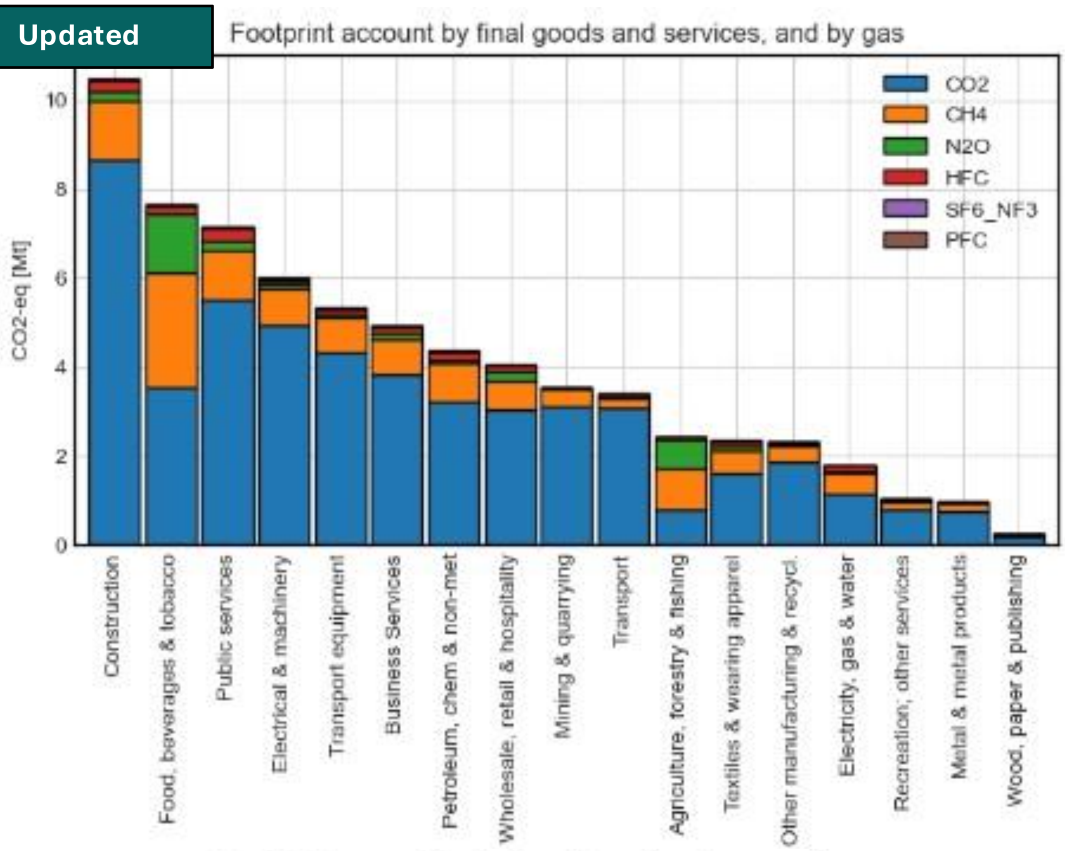


Figure 16 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).

Updated



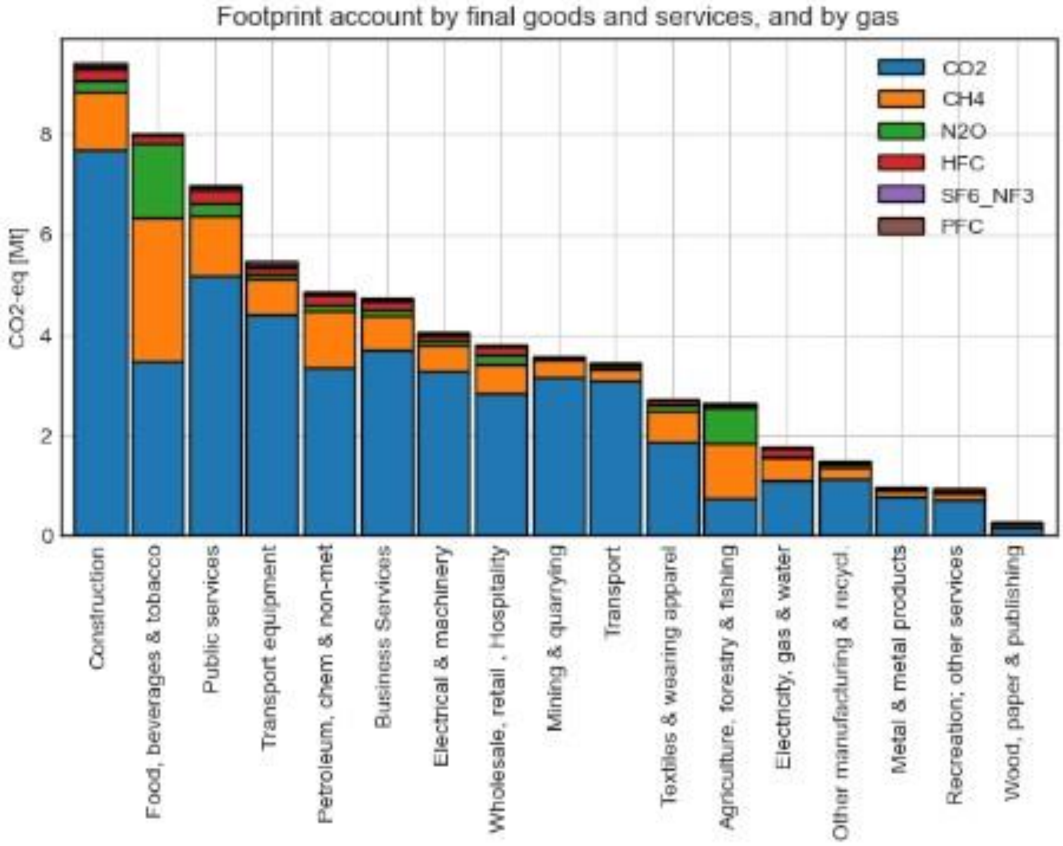
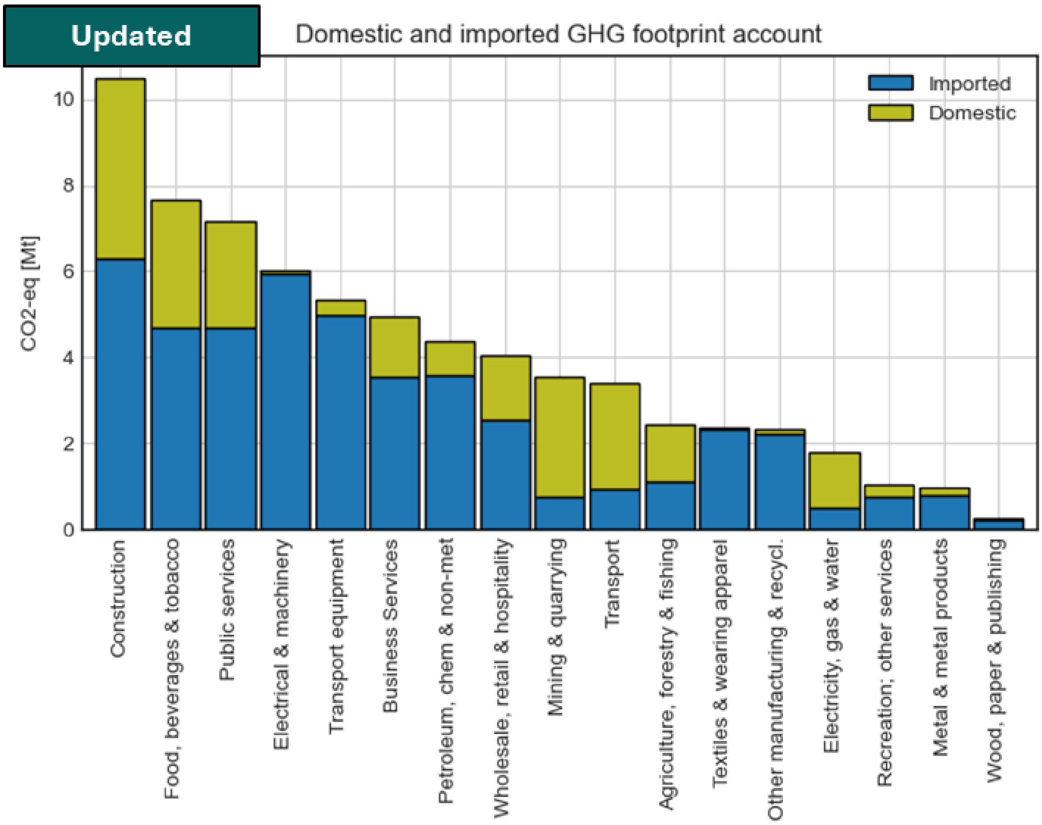


Figure 17 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).



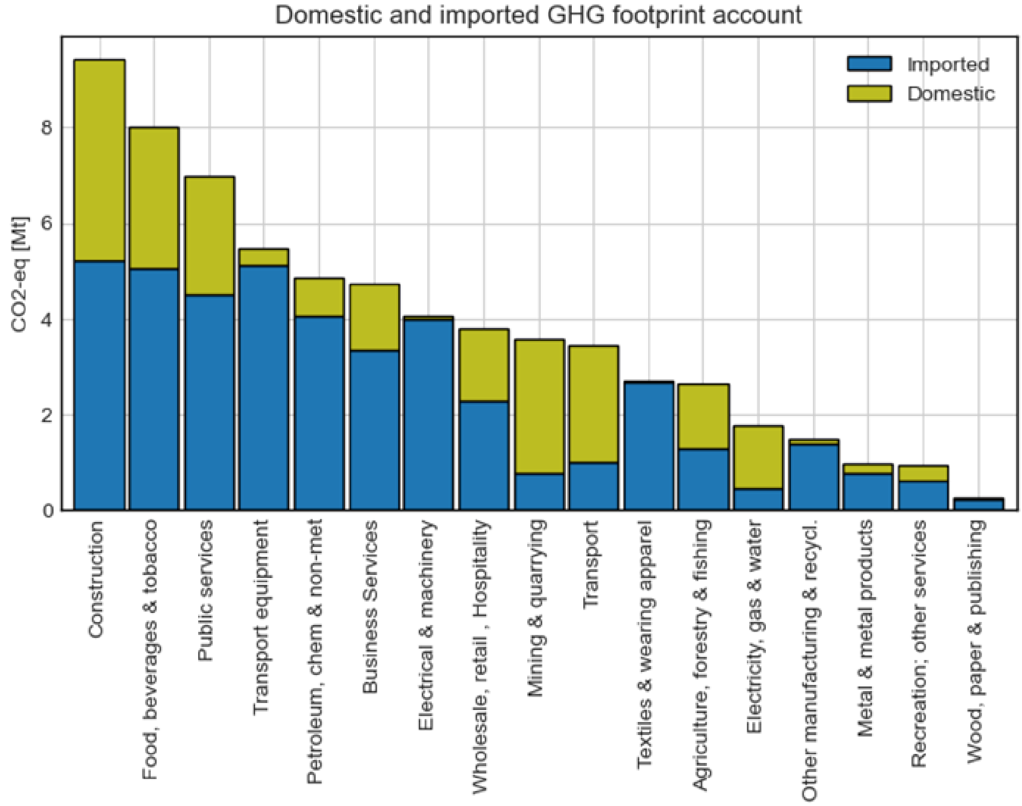
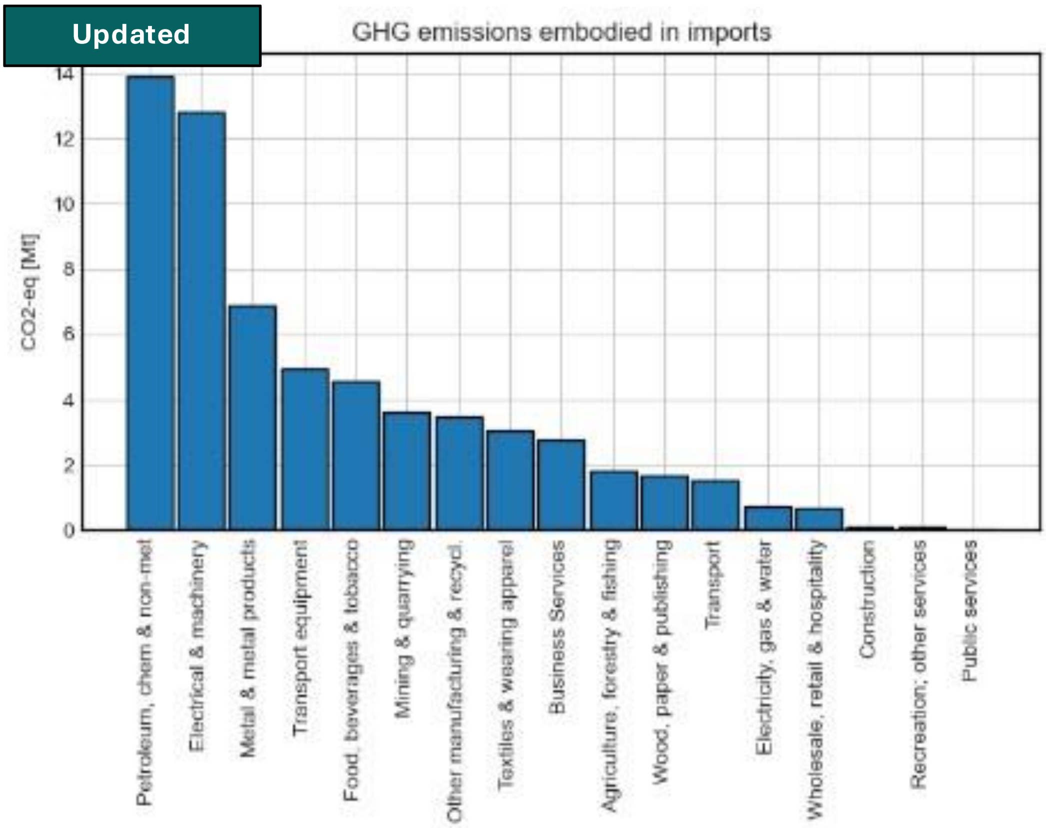


Figure 18 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).

Updated



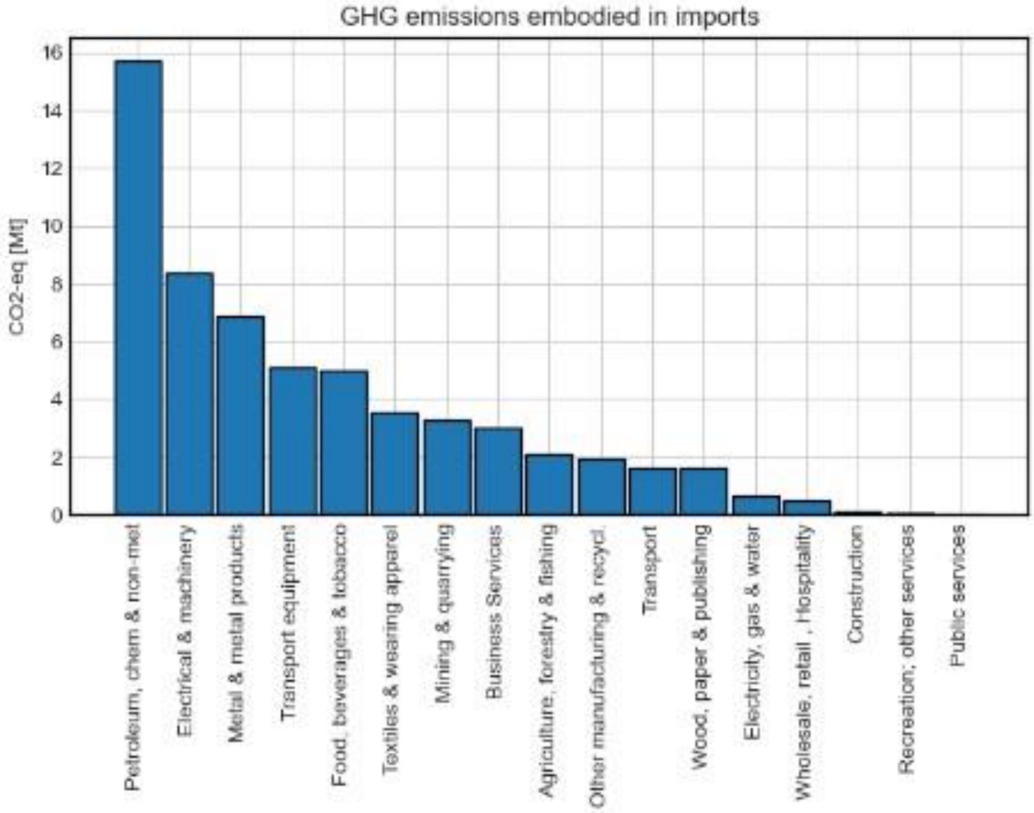
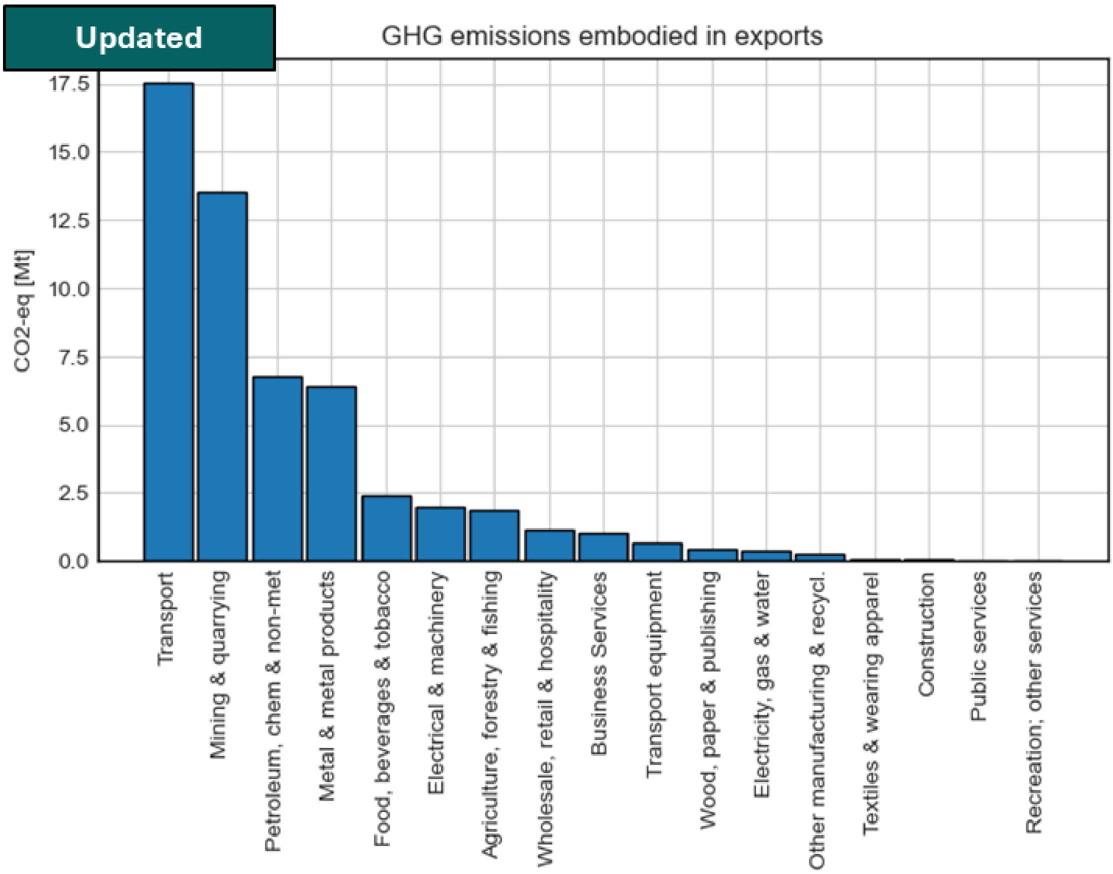


Figure 19 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).



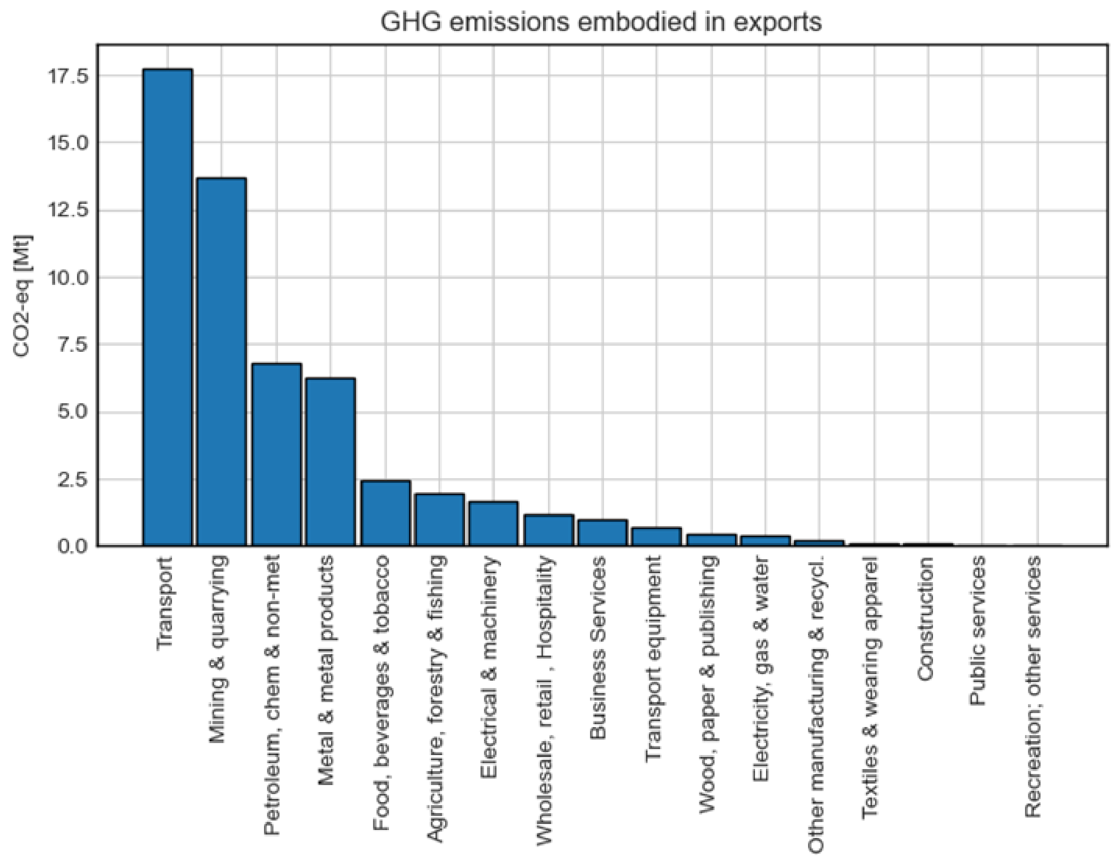
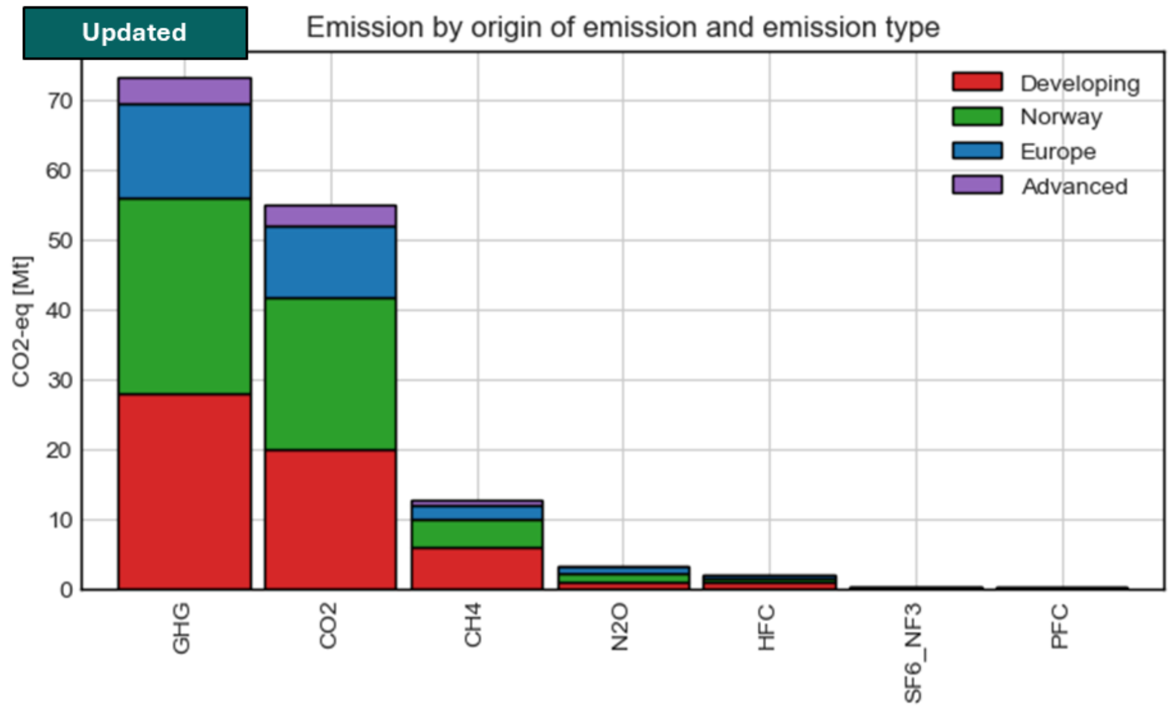


Figure 20 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).



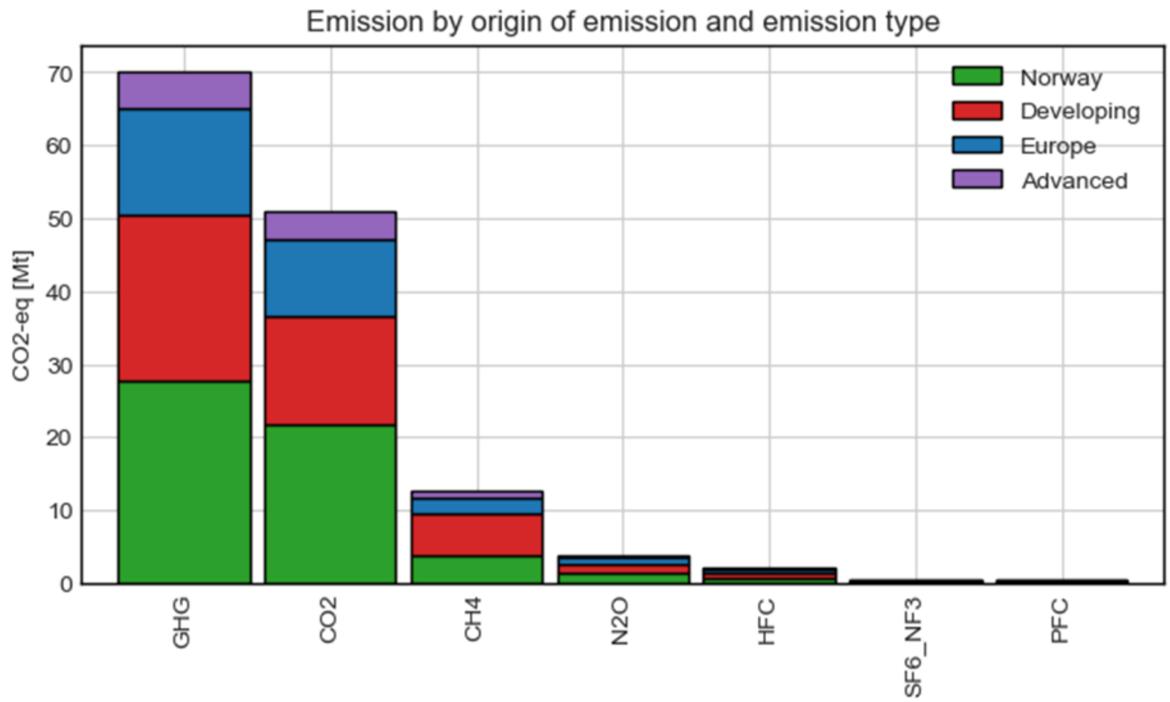
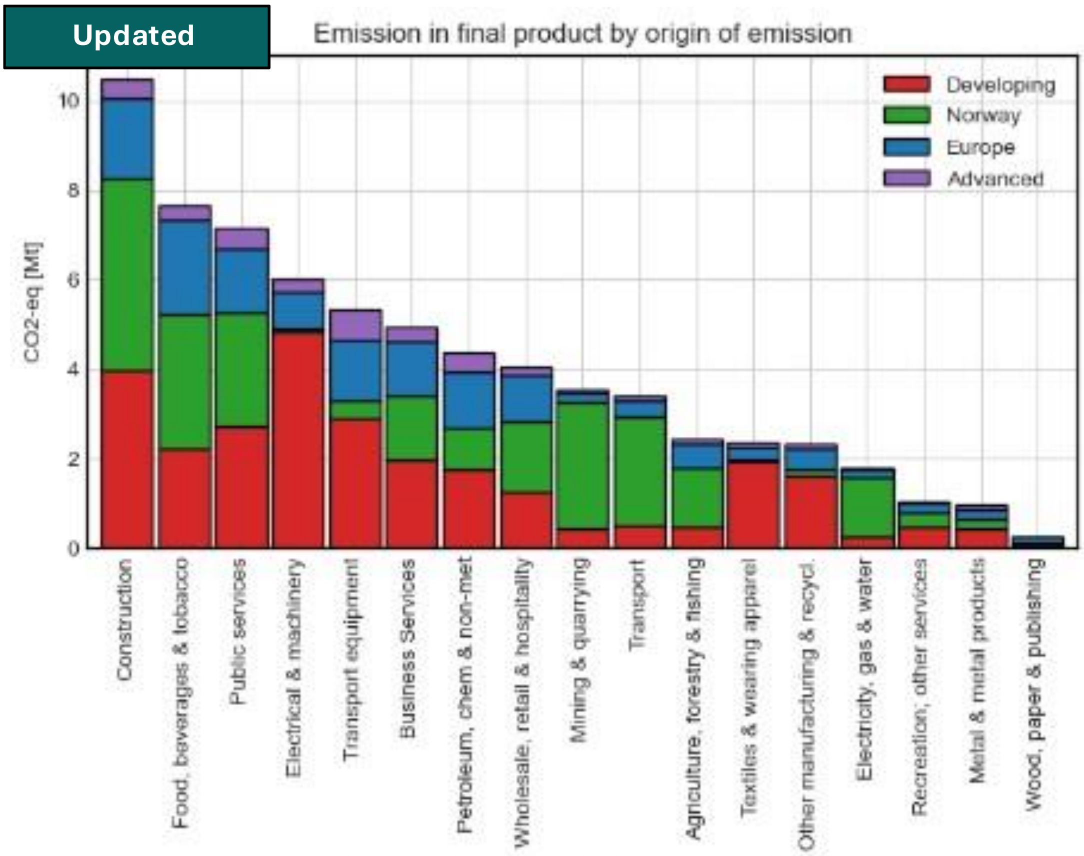


Figure 21 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).



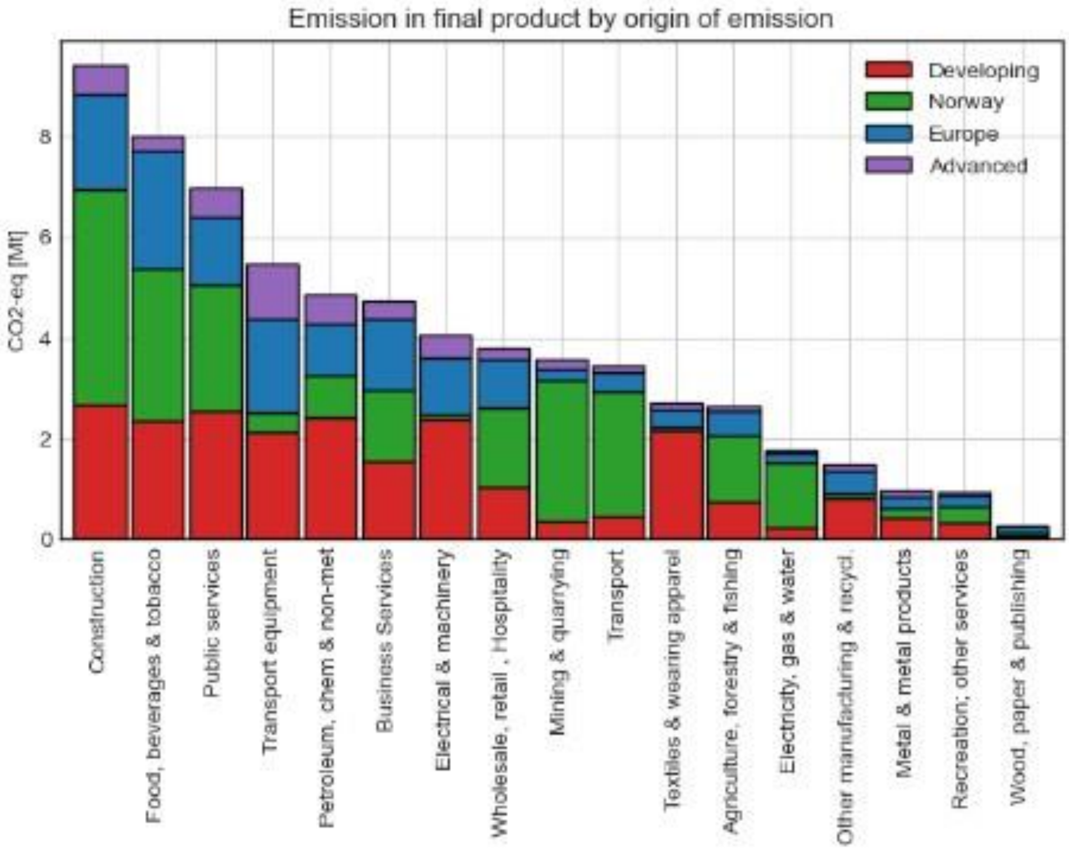
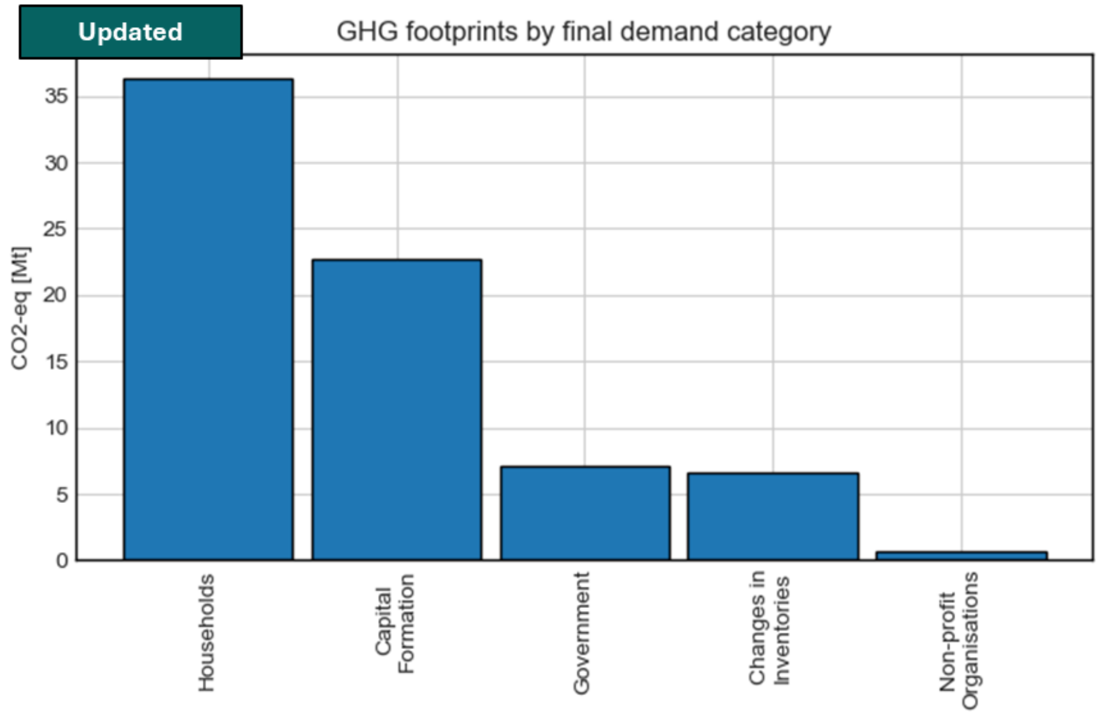


Figure 22 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).



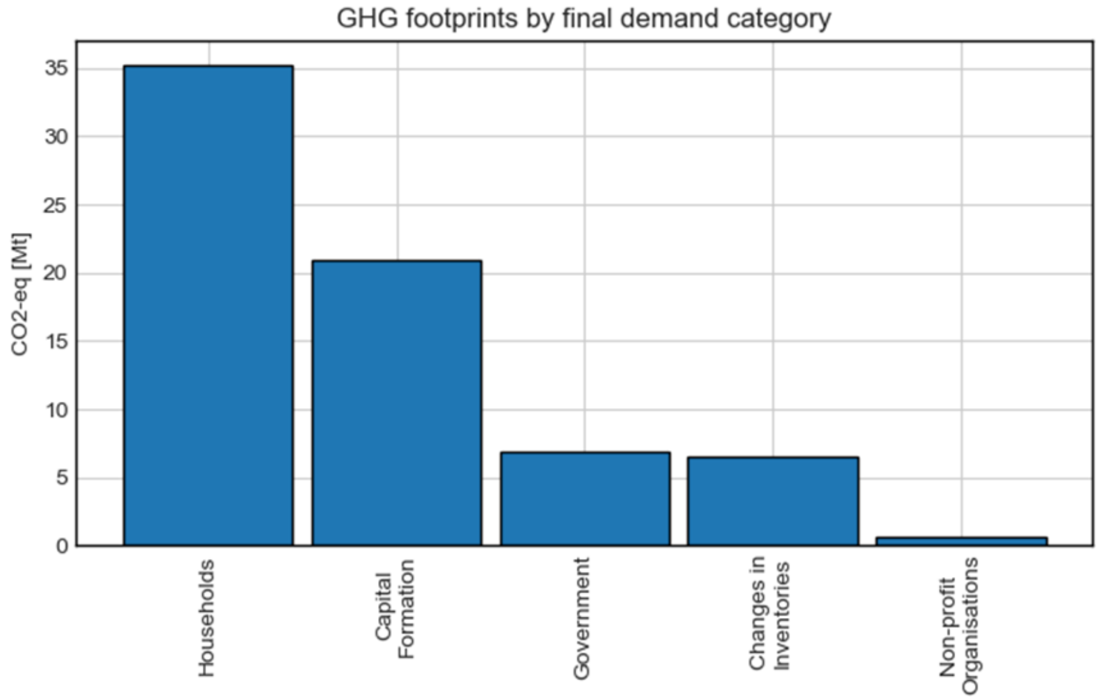
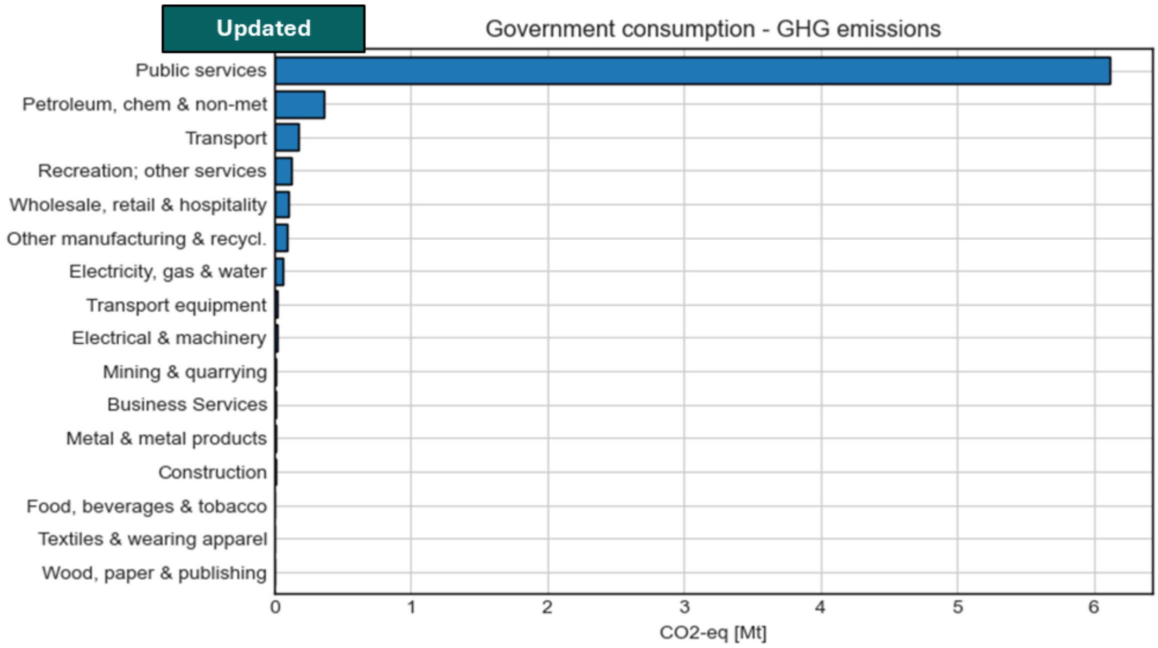


Figure 23 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).



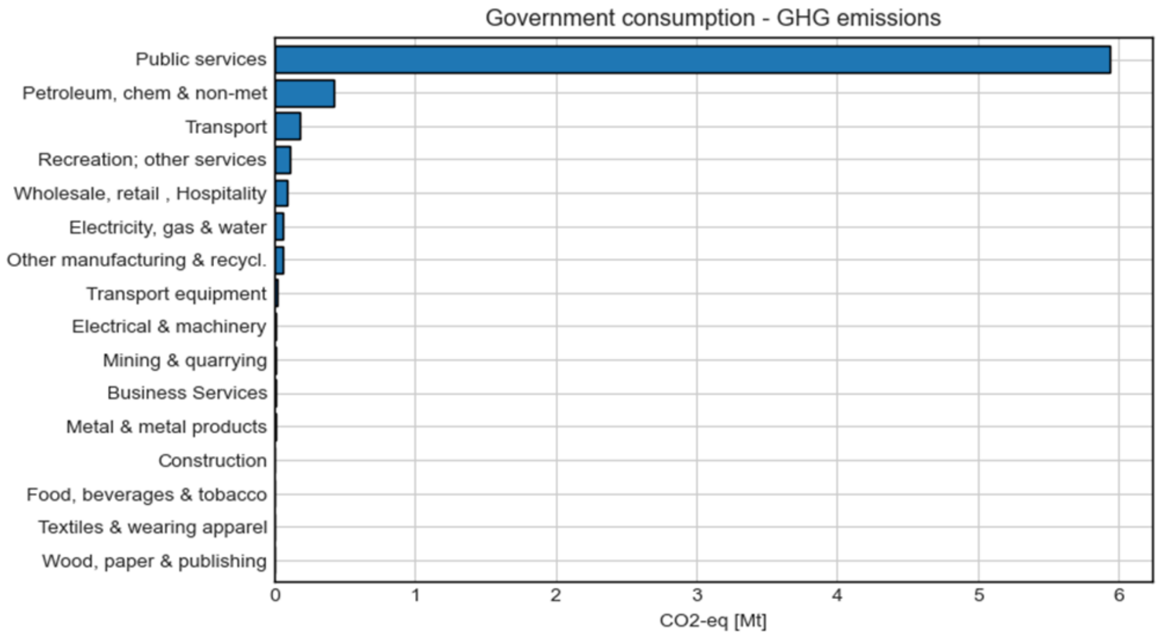
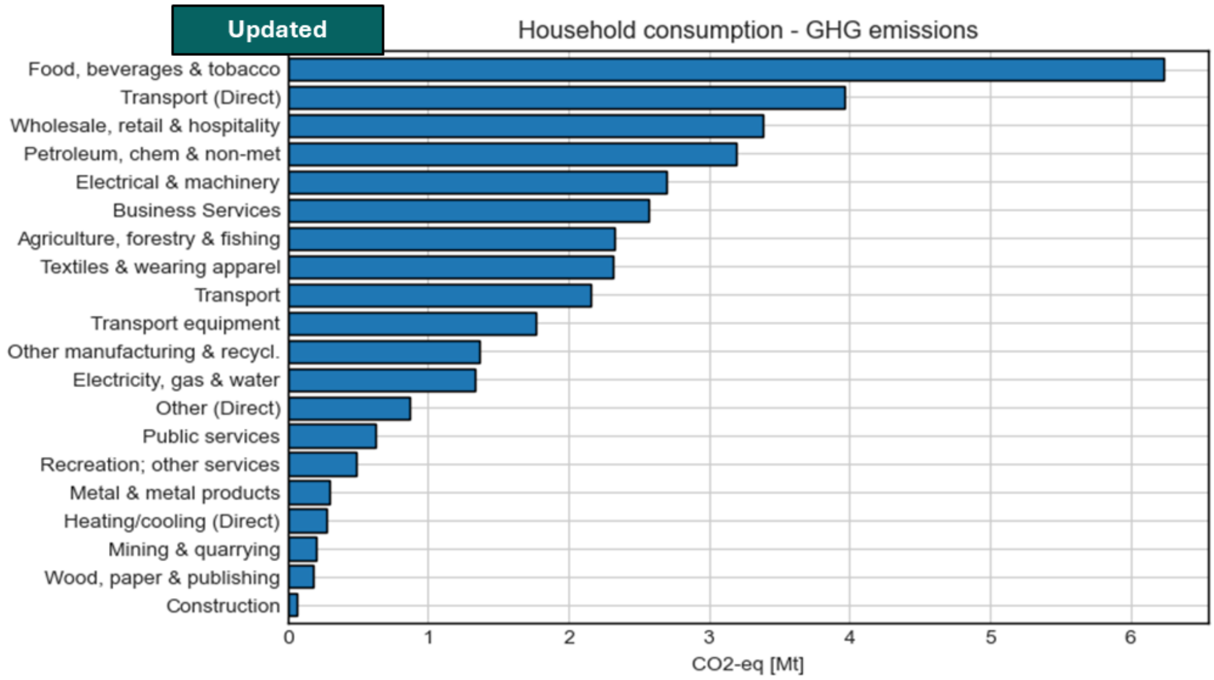


Figure 24 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).



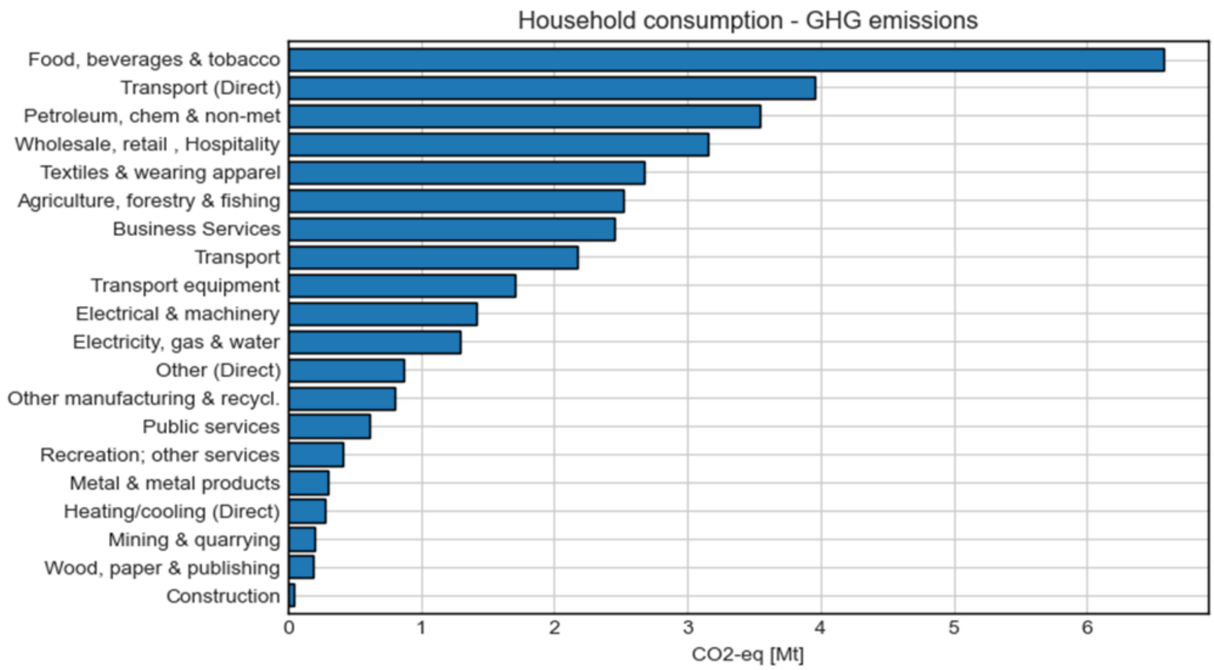
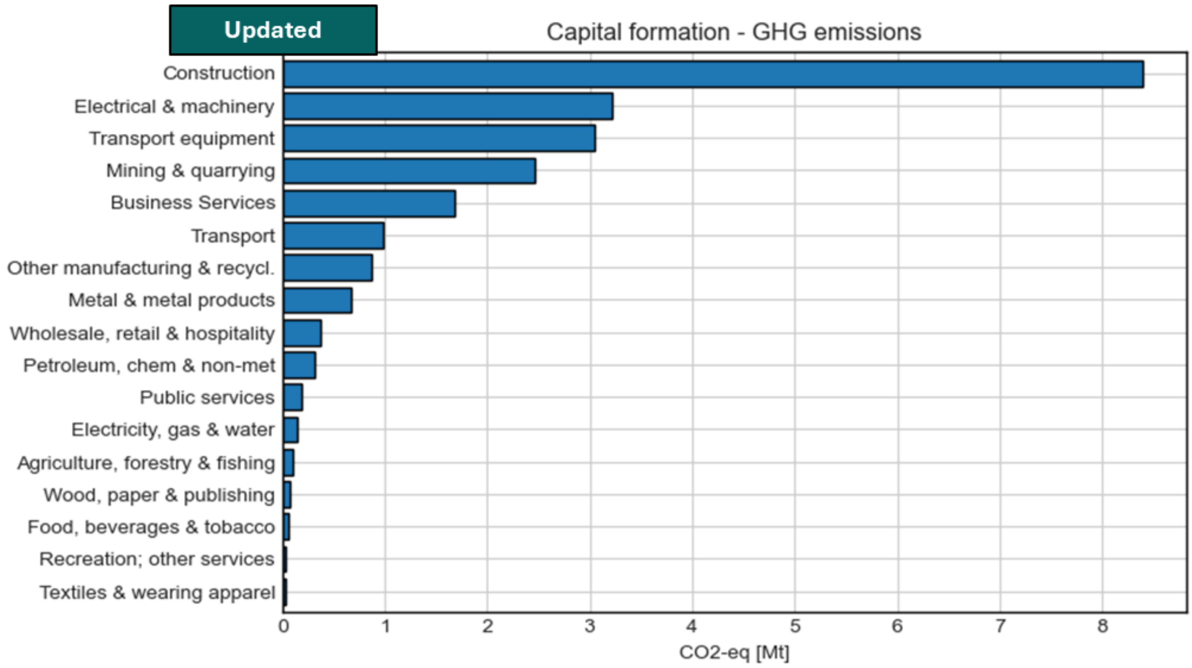


Figure 25 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).



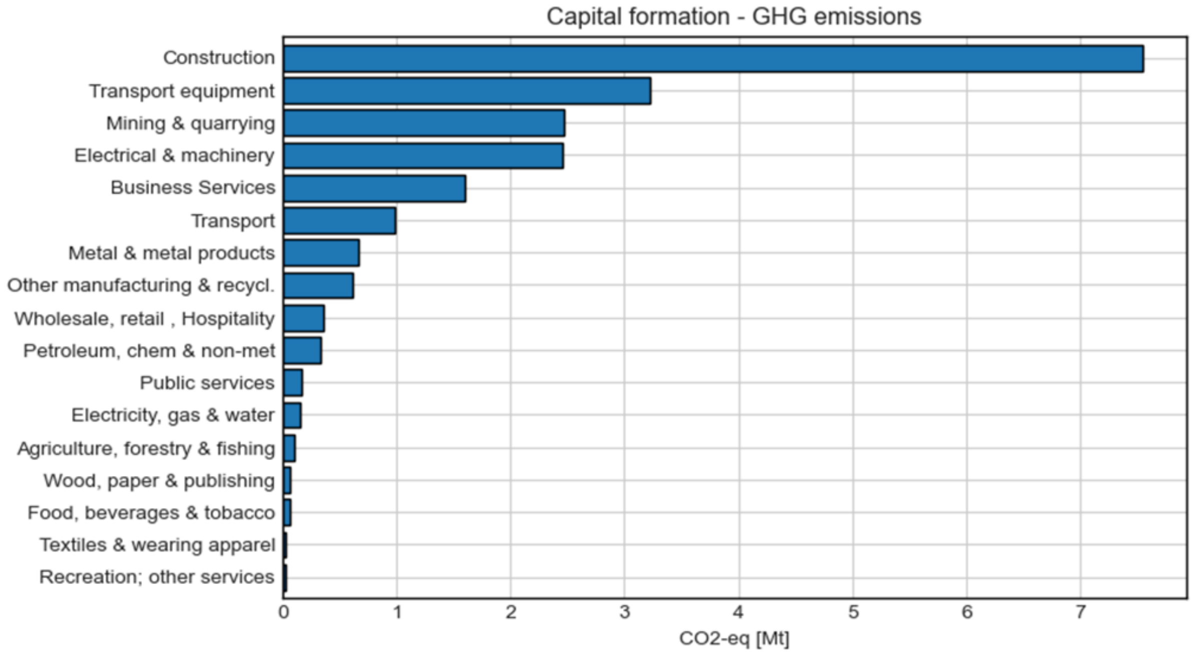


Figure 26 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).

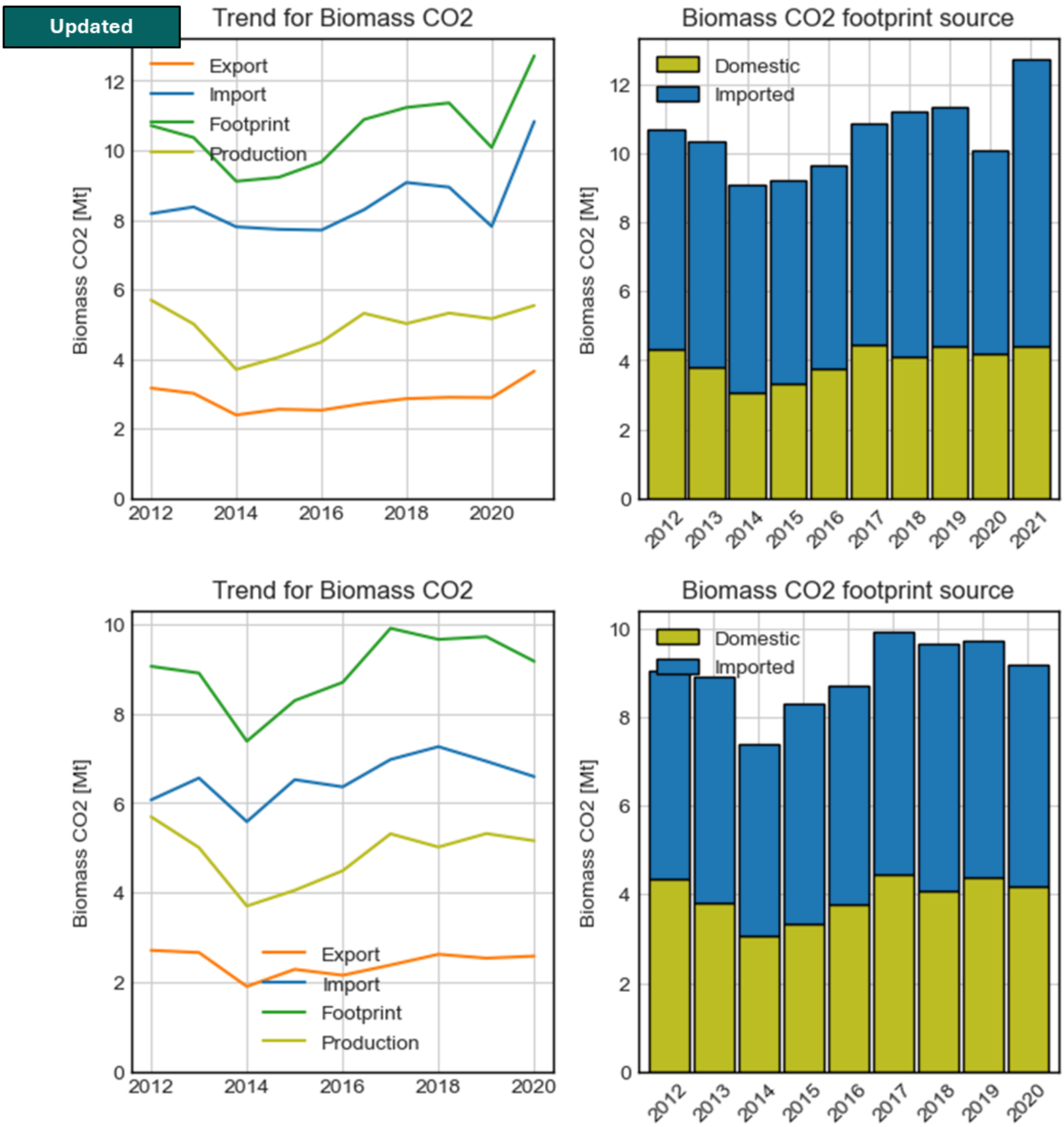


Figure 27 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).

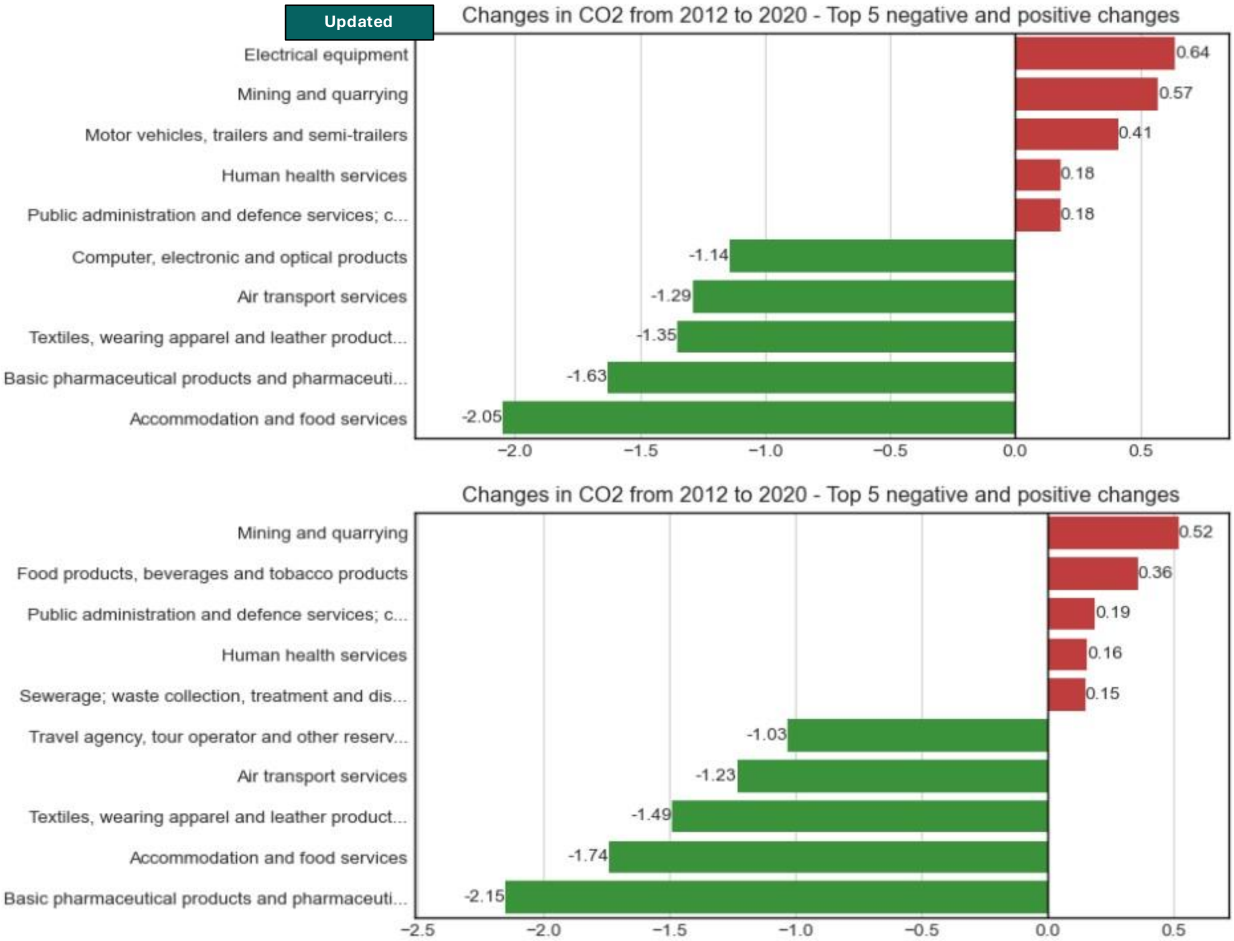


Table 5 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom)..

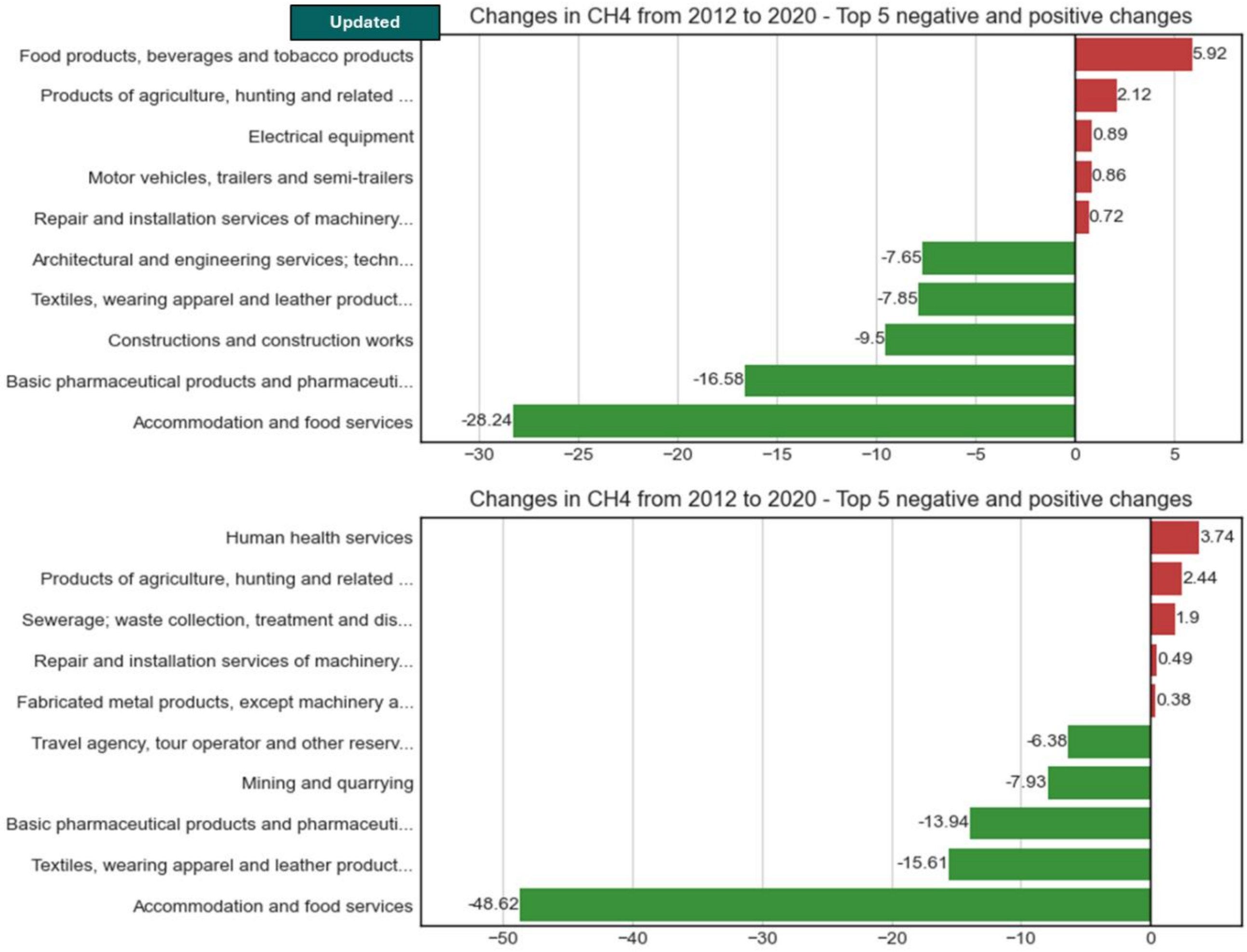
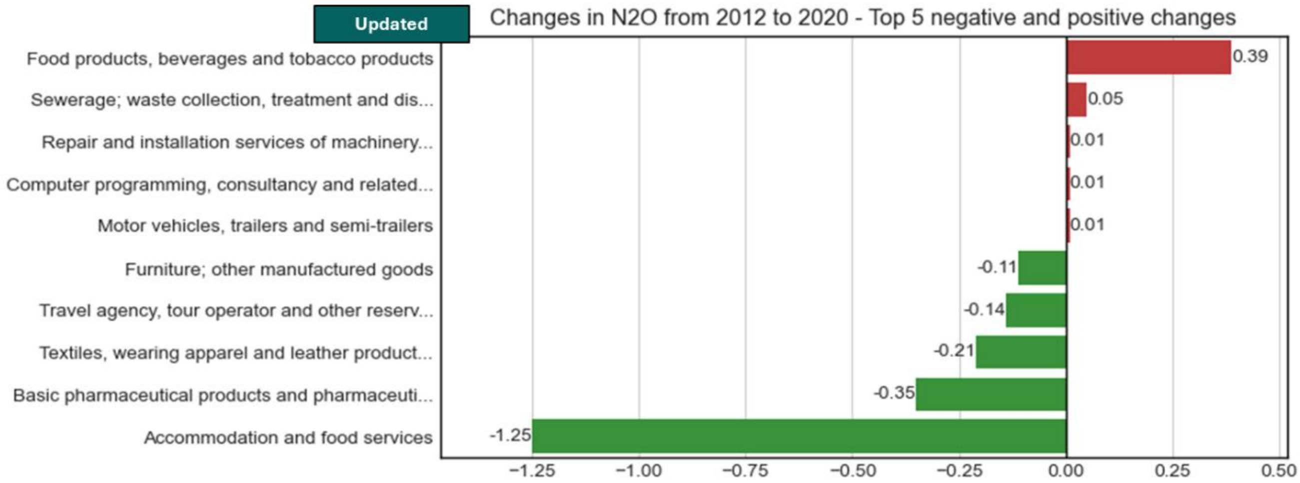


Table 6 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).



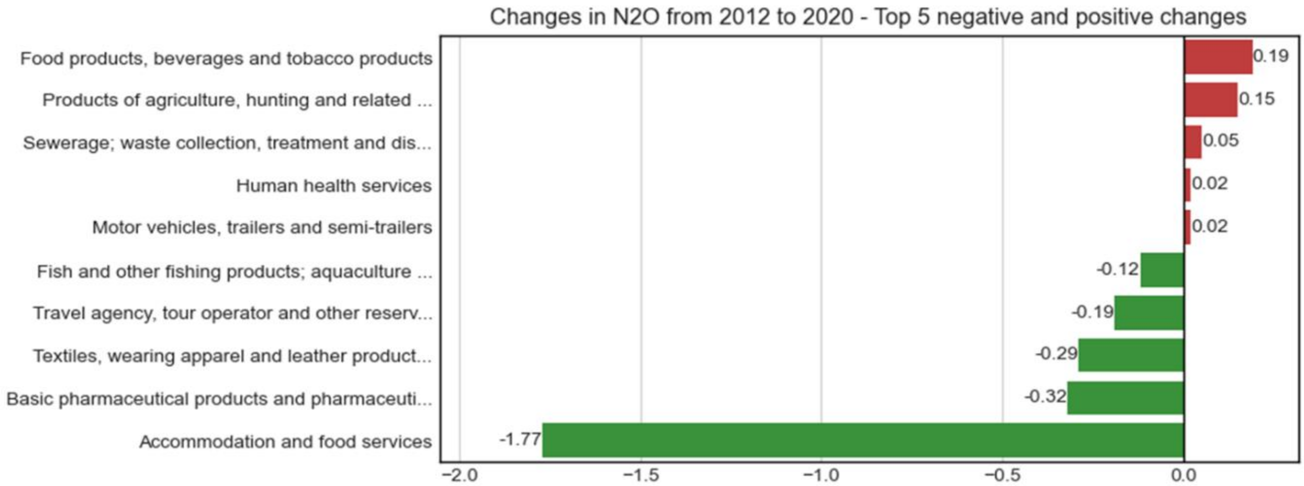


Table 7 from the CaFEAN report made with EXIOBASE 3.9 (top) and EXIOBASE 3.8 (bottom).

Appendix 2

Method documentation for the sectoral analysis

1. Introduction

This document describes the datasets and method used to deflate (i.e., adjusting for price changes) parts of the CaFEAN model to investigate the effect of volume and price changes on the footprint results. It first describes the additional datasets needed for the deflation, and then explains the method used for the analysis. The method section explains 1) how the deflator datasets are mapped to the input-output (IO) classification; 2) how the deflators are calculated; 3) how the deflators are applied to deflate the stressors; and 4) how to interpret the deflated stressors. The method section is followed by a result section, which explains how the deflated stressors are used in the results. At the end a *caveat* section points out things to be careful about when interpreting the results.

2. Datasets

Two datasets from Statistics Norway (SSB) are used for the deflation:

1. 09170: Production account and income generation, by industry 1970-2023 (A64 industry classification)
2. 07337: Import of goods and services 1970-2023

The first is used to create domestic deflators (referred to as domestic deflator dataset below), while the latter is used for import deflators (referred to as import deflator dataset below).

These do not map one-to-one to the Norwegian input-output tables, so a concordance table is used to map these. These can be found in the GitHub repository (data/00_auxiliary/mappings/deflators_mapping.xlsx).

3. Methods

In the following, it is assumed that the reader is familiar with the methodology used in the CaFEAN model and understand input-output modelling and its nomenclature.[1]

3.1. Mapping to input-output classification

First step in the procedure is to map the two deflator datasets to the IO classification. In the mapping procedure, 3 cases occur for the different sectors. These are mapped as follows in the procedure:

1. One-to-one mapping: the sector in the deflator data is mapped directly to the IO sectors.
2. One-to-many mapping: the sector in the deflator data is used for multiple IO sectors.

[1] For documentation of the methodology behind the CaFEAN model, see *CaFEAN: Carbon Footprint of the Economic Activity of Norway - miljodirektoratet.no*

3. Many-to-one mapping: the sectors in the deflator data are averaged based on their monetary values and used as a deflator for the IO sector.

One-to-one mappings are preferred as they will provide more accurate deflators, but the data is unfortunately not available. The domestic deflator dataset has deflators for 64 industries, which maps almost perfectly to the Norwegian IO classification, but there are a couple of one-to-many and many-to-one mappings. The import deflator dataset has deflators for only 30 products, which means that there are only a few one-to-one mappings.

3.2. Deflators

Deflators are multipliers used to remove the effect of price changes by transforming them to constant prices. Different deflators are used for the different parts and sectors of the input-output table. They are calculated as follows

$$\text{deflator}^{i}_{s,t} = \frac{(\text{Constant 2015 prices })^{i}_{s,t}}{(\text{Current prices})^{i}_{s,t}}$$

where subscript *i* refers to variables and subscript *s* refers to the sector in the IO classification. Two sets of deflators, “Output at basic values” and “Imports” are made directly from the domestic and import deflator datasets (SSB tables 09170 and 07337), respectively.

3.3. Deflating the CaFEAN model stressors

In this step the deflators are used to deflate both the domestic and import emission stressors (i.e., emission per unit of monetary flow) in the CaFEAN model.

3.3.1. Domestic emission stressors

The domestic emission stressors are calculated using the data provided by SSB as

$$S^{domestic,constant}_{g,s,t} = \frac{F^{domestic}_{g,s,t}}{x^{domestic,constant}_{s,t}}$$

using

$$x^{domestic,constant}_{s,t} = x^{domestic,current}_{s,t} * \text{deflator}^{output\ at\ basic\ prices}_{s,t}$$

Where *S* is the domestic emission stressor, *F* is the total industry/import emissions accounts, *x* is the total industry output (in monetary terms), subscript *g* refers to the emitted greenhouse gas, *s* to sector in the IO classification, and *t* the year. *F* and *x* are both provided by the CaFEAN model and are stored as interim values in “/data/02_interim/territorial emissions/industry emissions.xlsx” and “/data/02_interim/norwegian IO/*”, respectively[2].

3.3.2. Import emission stressors

In the CaFEAN model, the monetary import flows as well as the emissions embodied in the imports (CO2, CH4 etc.) are calculated using EXIOBASE in its 163 industry by industry classification using the script “01_prepare_exiobase.py”, which produce the output “/data/02_interim/exiobase/exio_no_bp_raw.xlsx”.

[2] x is calculated as the sum of Z and Y, $x_s = \sum_r Z_{s,r} + \sum_r Y_{s,f}$, where *r* is the input sector and *f* the final demand category.

The monetary flows (in EXIOBASE classification) are converted from millions of euros to millions of Norwegian kroners using yearly exchange rates as (included as auxiliary data in the GitHub repository).

$$x_{s_{EXIOBASE},t}^{import,current} = x_{s_{EXIOBASE},t}^{import,current,M.EUR} * \text{exchange\_rates}_t$$

where x^{import} is imports into the Norwegian economy as reported by EXIOBASE.

Like to the mapping issue with the deflators, the mapping from EXIOBASE to the Norwegian IO is not a perfect one-to-one mapping. There are a couple of one-to-many mappings from EXIOBASE to the Norwegian IO, which would cause the same EXIOBASE flow to be allocated to multiple Norwegian IO flows (i.e., double counting)[3]. To avoid this, the concordance matrix is weighted by the size of the flows as reported by EXIOBASE:

$$C_{s,s_{EXIOBASE},t}^{weighted} = \frac{C_{s,s_{EXIOBASE}} * x_{s_{EXIOBASE},t}^{import,current}}{\sum_s C_{s,s_{EXIOBASE}} * x_{s_{EXIOBASE},t}^{import,current}}$$

This weighted concordance matrix is used to map both the monetary import and embodied emissions flows to the Norwegian IO classification as

$$x_{s,t}^{import,current} = x_{s_{EXIOBASE},t}^{import,current} * C_{s,s_{EXIOBASE},t}^{weighted}$$

$$F_{g,s,t}^{import} = F_{g,s_{EXIOBASE},t}^{import} * C_{s,s_{EXIOBASE},t}^{weighted}$$

As for the domestic stressors, the deflated import stressors are calculated as

$$S_{g,s,t}^{import,constant} = \frac{F_{g,s,t}^{import}}{x_{s,t}^{import,constant}}$$

using

$$x_{s,t}^{import,constant} = x_{s,t}^{import,current} * \text{deflator}_{s,t}^{imports}$$

Where *S* is the emission embodied in imports stressor, *F* is the total emissions embodied in imports accounts, *x* is the imports in monetary terms, subscript *g* refers to the emitted greenhouse gas, *s* to the sector from which the good is imported from in the IO classification, and *t* the year.

3.4. Interpreting the deflated stressors

The deflated stressor itself is not really of interest, as it is just an estimate of the amount of emitted gas, *g,* per million of NOK output in 2015 prices that sector *s* produces in year *t* (or per million of NOK imported in 2015 prices from sector *s* in a year *t*).

The percentage change in the deflated stressors is however of interest, as it is an estimate of the changes in emissions intensity of the sectors (or imported goods). The percent change is calculated as

[3] This was not an issue in the original CaFEAN model as both numerator and denominator in the stressors (emissions embodied in imports per monetary import flow) were double counted equally and would therefore cancel each other out when applied in the model.

$$S_{g,s,t}^{constant,\%\,change} = \frac{S_{g,s,t}^{constant} - S_{g,s,t=2012}^{constant}}{S_{g,s,t=2012}^{constant}} * 100$$

Although not a trivial task, SSB considers changes in both quantity and quality of the products within a sector group when estimating the deflators[4]. Hence, changes in the deflated stressor should reflect changes in emission per produced product. Consider the case of the average cars bought in 2012 and 2020. As a simplified example, let's say that in 2012, the average car came without a GPS installed and drivers had to purchase one separately, while in 2020 the average car came with a GPS installed. So, when deflators are made, it needs to account for this change in quality (i.e., GPS included) in the changed prices, instead of just comparing the average price for car purchases. Some products may experience a decline in quality over the years (e.g., average t-shirts made from cheaper and less durable textiles), while other products may not see any change in quality over the years (e.g., apples), For the latter, deflators are more straightforward to make. Some precision in the deflators is further lost when they are mapped to the IO classification, as they may no longer be as representative for the sector.

The non-deflated stressor percentage change, which is calculated similarly, reflects changes in emissions per monetary output.

A positive/negative percentage change in the deflated stressor implies an increasing/decreasing emission intensity for that sector or imported good since 2012. It should be noted, that for the domestic stressor, it is a measure of emission intensity of the sector, while for the import stressor, it is the emission intensity of the full supply chain of the imported good outside of Norway.

Comparing the percentage changes in the deflated stressor with the regular stressor also provides some further insights. There are especially two cases of interest:

1. Change in deflated stressor is positive, while change in regular stressor is negative: Sector (or imported good) is more emission intensive, but costs more per unit of emitted greenhouse gas.
2. Change in deflated stressor is negative, while change in regular stressor is positive: Sector (or imported good) is less emission intensive, but costs less per unit of emitted greenhouse gas.

4. Results

The deflated stressors are not used directly in the analysis. Instead, they are used to help understand the footprint of sectors and how changes in emission intensity may have impacted it.

The script, *detailed_sectoral_analysis.py*, produces two datasets (one with and one without *final sector* aggregated) with the following columns:

- **Year**: The year at which the economic activity and emission of greenhouse gas takes place. Ranges from 2012 to 2021.

[4] https://www.ssb.no/nasjonalregnskap-og-konjunkturer/artikler-og-publikasjoner/_attachment/296829

- **Variable**: Whether the emission occurs domestically (*Domestic*) or if the emission is embodied in imports (*Import*).
- **Final sector**: The sector that delivers the good or service to final demand. Either at the full 64 sector IO classification or the aggregate 17 sector classification (version with suffix "_agg.tsv").
- **Source sector**: The sector that causes the emissions in the supply chain of the final sector. Provided at the full 64 sector classification.
- **Footprint**: The amount of GHG emissions emitted in source sector to satisfy the demand on the good or service provided by final sector. In megatons of CO2 equivalent.
- **Source sector footprint share**: The *source sector*'s share (in percentages) of the total footprint of *Final sector*.
- **Absolute difference in source sector footprint share from 2012**: Difference in *Source sector footprint share* from 2012 to *year*.
- **Absolute difference in footprint from 2012**: Absolute difference in footprint from 2012 to *year* occurring in *source sector* due to final demand on *final sector*. In megatons of CO2 equivalent.
- **Percentage change in footprint from 2012**: Percentage change in footprint from 2012 to *year* in *source sector* due to final demand on *final sector*.
- **Percentage change in stressor (current prices) from 2012**: Percentage change in non-deflated stressor for *source sector* from 2012 to *year*.
- **Percentage change in stressor (constant prices) from 2012**: Percentage change in deflated stressor for *source sector* from 2012 to *year*.
- **Source sector: F**: Total emissions in *source sector* in *year*. In megatons of CO2 equivalent.
- **Source sector: x (current)**: Total output of *source sector* in *year*. In millions of Norwegian kroner.
- **Source sector: x (constant)**: Total output of *source sector* in *year*. In millions of Norwegian kroner in 2015 prices.
- **Percentage change in source sector: F**: Percentage change in total emissions in *source sector* from year 2012 to *year*.
- **Percentage change in source sector: x (current)**: Percentage change in total output of *source sector* from year 2012 to *year*.
- **Percentage change in source sector: x (constant)**: Percentage change in total output of *source sector* from year 2012 to *year*.

In the script, there is a function made available to easily dissect the results. It takes in the following arguments:

- **final_sector**: The name of the final sector the user wants to analyze. If an integer is given, *n*, it picks the final sector with the *n*'th highest footprint. Default is 1.
- **year**: The year for which we want to analyze the final sector. Default is 2021.
- **source_share_limit**: The cut-off limit for *source sector footprint share* in the dataset used to ignore sectors with only small contributions to the footprint of final sector. Default is 5 (percent).
- **variable**: Whether to choose final sector based on its domestic footprint ranking or import footprint ranking. If None is given, then it chooses based on the total footprint of the final sector.

The function returns a subset of the previously mentioned dataset. It is used to produce the results presented in the summary deliverable.

5. Caveats

As explained above, the deflators available do not perfectly match the input-output sector classification. This increases the uncertainty of the constant price emission intensities, especially for the imports. One should therefore be careful to draw any too hard conclusions when interpreting the absolute numbers, but rather analyse the observed trends. Note: there are no import deflator for *Water transport services*, so its constant price emission intensity is simply set to zero.

Furthermore, it should be noted that the deflators used for import are Norwegian import deflators rather than deflators for the production that occurs abroad. Thus, there is no distinction between price effects arising from changed production costs abroad or price effects due to changing exchange rates. However, the deflation should account for both.

In the above, and in the example presented in the summary deliverable, results for all years are benchmarked against the earliest year available, 2012. It should be noted that input-output models, especially global MRIO models, might be subject to major year-to-year fluctuations. Some of these fluctuations are real, but others are simply noise that are introduced in the reconciliation and balancing procedure that creates the models. In EXIOBASE most of these are accounted for, but outliers persist. To produce more reliable results, an option is to average the numbers over multiple years, e.g., compare first 3-year period with last 3-year period rather than single years.

Appendix 3

Method documentation for household footprint analysis

1. Introduction

This document describes the datasets and method used to disaggregate the household footprint calculated by the CaFEAN model and allocate it to SSB's consumer expenditure surveys. First, the datasets used are described, followed by a method section, and a brief description of how the results are provided. At the end of the document, there a *caveat* section explains the limitations of the data and methodology.

2. Datasets

The analysis is based on the footprint results produced by the CaFEAN model, which is based on the Norwegian basic price input-output tables and the multi-regional input-output model EXIOBASE.

In addition to that, it requires a few datasets from SSB, which are all listed below.

Statistics Norway (SSB) published their consumer expenditure survey for the year 2022 in 2023, from which the following tables are used:

- 14100: Expenditure per household per year, by commodity and service group, contents and year [COICOP Level 4].
- 14152: Expenditure per household per year, by commodity and service group, type of household, contents and year [COICOP Level 3].
- 14156: Expenditure per household per year, by commodity and service group, income per consumption unit, contents and year [COICOP Level 2]
- 14157: Expenditure per household per year, by commodity and service group, type of household, income quartile, contents and year [COICOP Level 2].
- 14161: Expenditure per household per year, by commodity and service group, centrality, contents and year [COICOP Level 2].

These are used to disaggregate the footprint of household consumption as well as to allocate to different household groups.

The following yearly household and population statistics datasets from SSB are used to scale up the surveys as well as getting results on per household and per person level:

- 10986: Private households and persons in private households, by type of household (C) 2005 - 2023
- 06070: Private households, by type of household (M) (UD) 2005 – 2023
- 07459: Population, by sex and one-year age groups (M) 1986 – 2024
- 12563: Households, by size of income per household type. Highest value in decile, number and per cent (C) 2005 – 2022

Trade and transport margins are extracted from the Norwegian supply table for the year 2021:

- ESA Questionnaire 1500 - Supply table at basic prices, including a transformation into purchasers' prices

To map between the survey and IO classifications, a concordance matrix is provided in the GitHub repository (/data/00_auxiliary/concordances/survey_and_io.xlsx).

3. Method

In the following, it is assumed that the reader is familiar with the methodology used in the CaFEAN model and understand input-output modelling and its nomenclature.

3.1. From basic to purchaser price footprints

The footprints calculated by the CaFEAN model are made using the basic price Norwegian input-output tables. However, the household surveys are in purchaser prices, i.e., trade and transport margins have been allocated to the goods that are consumed. So, before the household footprint can be disaggregated and allocated using the survey, the household footprint of trade and transport sectors needs to be reallocated to the actual goods consumed. The method described below is identical to the one applied in the Green EUROMOD project[1].

The starting point is the final demand household consumption (domestic and import) in basic prices and its corresponding GHG[2] footprint (in CO2 equivalents) calculated using the CaFEAN model:

$$Y_p^{bp} = Y_{p,household}^{domestic,bp} + Y_{p,household}^{import,bp}$$

$$F_p^{bp} = F_{p,household,GHG}^{bp}$$

where *Y* is the final demand of households, *F* is the footprint, superscript *bp* indicates the footprint is calculated using the basic price tables, and *p* is the product in the Norwegian IO classification. Note: in the following all final demand always refers to final demand of households.

From the supply tables, *Trade and Transport Margin* (*TTM*) shares of total supply in purchaser prices (superscript pp) for each IO product are calculated as:

$$M_p^{TTM\ share} = \frac{x_p^{TTM,supply\ table}}{x_p^{bp,supply\ table}}$$

And similarly for *Taxes Less Subsidies (TLS)*:

$$M_p^{TLS\ share} = \frac{x_p^{TLS,supply\ table}}{x_p^{bp,supply\ table}}$$

These shares are used to calculate *TTM* and *TLS* of the final demand household consumption.

[1] See https://joint-research-centre.ec.europa.eu/scientific-activities-z/fiscal-policy-analysis-0/taxation-and-social-policy-households/taxation-consumption-including-green-taxation/green-euromod_en
[2] The script can easily be adapted to do the analysis for specific greenhouse gasses, e.g., CH4.

$$Y_p^{TTM} = M_p^{TTM\,share} * Y_p^{bp}$$

$$Y_p^{TLS} = M_p^{TLS\,share} * Y_p^{bp}$$

And the final demand household consumption in purchaser prices.

$$Y_p^{pp} = Y_p^{bp} + Y_p^{TTM} + Y_p^{TLS}$$

In the following, margin products (subscript *mp*) are products for which $Y^{TTM} < 0$, and non-margin products (subscript *nmp*) are products for which $Y^{TTM} \geq 0$[3].

We calculate for each margin product its TTM share of its basic price final demand:

$$Y_{mp}^{TTM,reallocate\,share} = -\frac{Y_{mp}^{TTM}}{Y_{mp}^{bp}}$$

We use those shares to determine how much of the basic price footprint needs to be reallocated:

$$F_{mp}^{TTM,reallocate} = F_{mp}^{bp} * Y_{mp}^{TTM,reallocate\,share}$$

This is the *TTM* footprint of the trade and transport services that is used to deliver goods, such as food, to final consumers.

For the non-margin products, we calculate their *TTM* share of the aggregate consumption of non-margin products:

$$Y_{nmp}^{TTM,receiving\,share} = \frac{Y_{nmp}^{TTM}}{\sum_{nmp} Y_{nmp}^{bp}}$$

That provides the share of the *TTM* footprint that they receive, and we therefore can calculate the *TTM* footprint of non-margin products as:

$$F_{nmp}^{TTM,reallocate} = Y_{nmp}^{TTM,receiving\,share} * \sum_{mp} F_{mp}^{TTM,reallocate}$$

To get the purchaser price footprint, we need to add the footprint of the non-margin products and subtract the footprint of margin products to/from the basic price footprint:

$$F_p^{pp} = F_p^{bp} + F_{nmp}^{TTM,reallocate} - F_{mp}^{TTM,reallocate}$$

That is the footprint which will be disaggregated and allocated to the consumer expenditure surveys.

3.2. Balancing survey expenditure with household expenditure

The total expenditure reported by the surveys do not necessarily equate the final demand household expenditure as reported by the input-output tables. There are three main reasons for that. First, and the primary reason in this case, is that the household survey is for the year 2022, while the latest available input-output table for the Norwegian economy is for the year 2021. Second, empirical errors and uncertainties in either the household survey or the input-output

[3] The set of products equals the sum of the sets of non-margin and margin products, i.e., $\{p\} = \{nmp\} + \{mp\}$

tables are also a likely cause for discrepancies between the two datasets. Consumers may, on purpose or not, misreport their consumption of certain goods.

Nonetheless, the main purpose of this task is not to correct for these errors, but mainly to find the best estimate for allocating the footprint in the IO classification to the COICOP level 4 classification. To do so, we apply the generalised RAS-algorithm (GRAS)[4] to balance the survey with most detailed (in terms of products) survey, namely survey 14100. The GRAS algorithm has been widely used in literature to balance inconsistent datasets[5].

Before applying the GRAS algorithm, the household survey needs to be scaled up twice. First it needs to be multiplied with the number of households in Norway (SSB statistics 10986), as the survey is per household:

$$Y_{cp_4}^{14100,total} = Y_{cp_4}^{14100,per\ household} * \text{number of households}$$

where the subscript cp_4 is the consumer product at COICOP level 4 classification.

Then the household survey is scaled up to match the IO final demand household consumption total (in purchaser prices):

$$Y_{cp_4}^{14100,rescaled} = Y_{cp_4}^{14100,total} * \frac{\sum_p Y_p^{pp}}{\sum_{cp_4} Y_{cp_4}^{14100,total}}$$

The starting point for the GRAS algorithm is a binary many-to-many concordance matrix, *C*, that states which household survey products (COICOP level 4) can map to which input-output sectors. The concordance matrix is provided in the GitHub repository (/data/00_auxiliary/concordances/survey_and_io.xlsx).

$$C_{cp_4,p}^{absolute} = \text{GRAS}\left(C_{cp_4,p}^{binary}; Y_{cp_4}^{14100,rescaled}; Y_p^{pp}\right)$$

The output is a matrix that provides a best estimate for a matching between the two datasets. Ideally, one should have $\sum_{cp_4,p} C_{cp_4,p}^{absolute} = \sum_{cp_4} Y_{cp_4}^{14100,rescaled} = \sum_p Y_p^{pp}$, but this may not always be the case if non-zero expenditures in one dataset only has zeros reported in potential flows in the other dataset. In this analysis, it is however not the case. In the results we also provide numbers for how much $Y_{cp_4}^{14100,total}$ differs from the post-scaling expenditure, $Y_{cp_4}^{14100,rescaled}$, and post-balancing expenditure $\sum_p C_{cp_4,p}^{absolute}$.

Last step is to normalise the matrix, to turn it into an allocation matrix from the IO classification to COICOP level 4 classification:

$$C_{cp_4,p}^{allocation} = \frac{C_{cp_4,p}^{absolute}}{\sum_{cp_4} C_{cp_4,p}^{absolute}}$$

The procedure described above however only allocates emission embodied in purchases by households. Households also cause direct emissions. These emissions are reported separately in the Norwegian territorial emissions dataset in the three categories: *Transport*, *Heating/cooling*, and *Other*. As before, a binary concordance matrix is used, but it is now

[4] See https://doi.org/10.1080/0953531032000056954 for original publication and https://doi.org/10.1080/0953531042000219268 for a comparison of GRAS with different methods.
[5] See https://doi.org/10.1080/17421772.2020.1825782 for a recent publication on the topic.

weighted by the expenditure on products which are likely to cause the emission (e.g., transport emissions are allocated to purchase of petrol[6])

$$C^{absolute,direct}_{cp_4,hp} = C^{binary,direct}_{cp_4,hp} * Y^{14100,rescaled}_{cp_4}$$

Where subscript *hp* refers to the three direct emission categories: *Transport, Heating/cooling,* and *Other*. As before, these are normalised

$$C^{allocation,direct}_{cp_4,hp} = \frac{C^{absolute,direct}_{cp_4,hp}}{\sum_{cp_4} C^{absolute,direct}_{cp_4,hp}}$$

In the next sections, it is assumed that $C^{allocation,direct}_{cp_4,hp}$ is included in $C^{allocation}_{cp_4,p}$ for simplicity, and that *hp* is a subset of *p*.

3.3. Allocate to surveys

The allocation matrix is used to reallocate the purchaser price footprint in the IO classification to the COICOP level 4 classification of survey 14100:

$$F^{14100}_{cp_4} = C^{allcoation}_{cp_4,p} \cdot F^{pp}_{p}$$

The survey 14100 footprint is however not of particular interest, as it is just a disaggregation (by expenditure) of the household footprint. Instead, it is the other four surveys, that provides insights into how expenditures (and thereby the carbon footprint) differ between households depending on the type, centrality, and income.

The other four surveys are however only available at COICOP level 2 or 3 classification, subscripted cp_2 and cp_3, respectively. So, the survey 1400 footprint needs to be aggregated before it can be applied to the other surveys. As the COICOP classification is hierarchical, it is straightforward using a binary concordance matrix:

$$F^{14100}_{cp_2} = C^{binary}_{cp_2,cp_4} \cdot F^{14100}_{cp_4}$$

$$F^{14100}_{cp_3} = C^{binary}_{cp_3,cp_4} \cdot F^{14100}_{cp_4}$$

Before the footprint can be allocated to the other four surveys, the surveys need to be scaled up from per household expenditure levels to national totals. Statistics 10986 is used to scale up survey 14152 (household type) and survey 14156 (income quartile), while statistics 06070 is used to scale up survey 14161 (centrality). Statistics 12563 could not be used to scale up survey 14157, as the categories used in the datasets did not match. Survey 14157 is therefore not included in the analysis. This gives the following three datasets:

$$Y^{14152,total}_{cp_3,t} = Y^{14151,per\ household}_{cp_3,t} * \text{number of households}_t$$

$$Y^{14156,total}_{cp_2,t} = Y^{14156,per\ household}_{cp_2,t} * \text{number of households}_t$$

$$Y^{14161,total}_{cp_2,t} = Y^{14161,per\ household}_{cp_2,t} * \text{number of households}_t$$

Where *t* is the category in the consumption survey, i.e., household type in survey 14152, income quartile in survey 14156, and centrality index in survey 14161.

[6] See concordance table for full matching.

These are then normalised to get consumer product expenditure shares per survey category:

$$Y_{cp_3,t}^{14152,shares} = \frac{Y_{cp_3,t}^{14152,total}}{\sum_t Y_{cp_3,t}^{14152,total}}$$

Which then are used to allocate the aggregated footprints to the household categories in the survey:

$$F_{cp_3,t}^{14151} = Y_{cp_3,t}^{14152,shares} * F_{cp_3}^{14100}$$

$$F_{cp_2,t}^{14156} = Y_{cp_2,t}^{14156,shares} * F_{cp_2}^{14100}$$

$$F_{cp_2,t}^{14161} = Y_{cp_2,t}^{14161,shares} * F_{cp_2}^{14100}$$

Household statistics (as used above) and population statistics are used to turn these results into per household and per person footprints. However, as it was not possible to retrieve any statistics on number of persons living in households in each income quartile, the footprint results of survey 14156 could not be calculated on per capita level.

4. Results

A table is provided for each survey with COICOP product level along the rows and two-level column levels:

1. **Variable**: Total, per household, or per person.
2. **Survey category**: Centrality, household type, or income quartile.

The cells then contain the footprint. The *total* columns are in megatons CO2-eqv., while the others are in tons CO2-eqv. Aggregated product group versions (i.e., COICOP level one) of the tables are also provided for per person/household results. These results can be found in GitHub repository (data/03_results/Household survey footprints/[year]/).

Furthermore, the disaggregated household footprint in COICOP level 4 (i.e., $F_{cp_4}^{14100}$) is provided as an interim dataset[7].

5. Caveats

In input-output modelling, footprints are allocated according to monetary shares in the supply chain. The footprint calculation does not distinguish between quality of products within each sector. Hence, if person A purchases a car twice the price of person B, person A's carbon footprint will be twice that of person B, regardless of the emission intensities of the actual cars. So, person A's car might in reality be more environmentally friendly than person B's car, but the input-output model does not distinguish between different types of cars, and therefore assumes carbon intensity to be proportional to prices. This is essential when interpreting the footprint results of survey 14156, where different income quartiles are analysed.

[7] Interim datasets are not uploaded to the GitHub repository, but only created locally when the code is run.

The categories used in the surveys do not always perfectly align with the categories used in the household and population statistics. These are some minor misalignments such the age of the kids in the category "Cohabiting couple with small children (youngest child 0-5 years)" which is mapped to "Couples with children, youngest child 0-6 years".

The transformation to purchaser prices also assumes that the *trade and transport margins* (TTM) are the same for domestic and imported goods. This is unlikely to have any major impacts on the results.

Appendix 4

Sector aggregation

Aggregation key used for sectors.

src	agg
Products of agriculture, hunting and related services	Agriculture, forestry & fishing
Products of forestry, logging and related services	Agriculture, forestry & fishing
Fish and other fishing products; aquaculture products; support services to fishing	Agriculture, forestry & fishing
Mining and quarrying	Mining & quarrying
Food products, beverages and tobacco products	Food, beverages & tobacco
Textiles, wearing apparel and leather products	Textiles & wearing apparel
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	Wood, paper & publishing
Paper and paper products	Wood, paper & publishing
Printing and recording services	Wood, paper & publishing
Coke and refined petroleum products	Petroleum, chem & non-met
Chemicals and chemical products	Petroleum, chem & non-met
Basic pharmaceutical products and pharmaceutical preparations	Petroleum, chem & non-met
Rubber and plastics products	Petroleum, chem & non-met
Other non-metallic mineral products	Petroleum, chem & non-met
Basic metals	Metal & metal products
Fabricated metal products, except machinery and equipment	Metal & metal products
Computer, electronic and optical products	Electrical & machinery
Electrical equipment	Electrical & machinery
Machinery and equipment n.e.c.	Electrical & machinery
Motor vehicles, trailers and semi-trailers	Transport equipment
Other transport equipment	Transport equipment
Furniture; other manufactured goods	Other manufacturing & recycl.
Repair and installation services of machinery and equipment	Other manufacturing & recycl.
Electricity, gas, steam and air-conditioning	Electricity, gas & water
Natural water; water treatment and supply services	Electricity, gas & water
Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	Electricity, gas & water
Constructions and construction works	Construction
Wholesale and retail trade and repair services of motor vehicles and motorcycles	Wholesale, retail , Hospitality
Wholesale trade services, except of motor vehicles and motorcycles	Wholesale, retail , Hospitality
Retail trade services, except of motor vehicles and motorcycles	Wholesale, retail , Hospitality
Land transport services and transport services via pipelines	Transport
Water transport services	Transport
Air transport services	Transport
Warehousing and support services for transportation	Transport
Postal and courier services	Business Services
Accommodation and food services	Wholesale, retail , Hospitality

Publishing services	Business Services
Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	Business Services
Telecommunications services	Business Services
Computer programming, consultancy and related services; information services	Business Services
Financial services, except insurance and pension funding	Business Services
Insurance, reinsurance and pension funding services, except compulsory social security	Business Services
Services auxiliary to financial services and insurance services	Business Services
Real estate services (excluding imputed rents)	Business Services
Imputed rents of owner-occupied dwellings	Business Services
Legal and accounting services; services of head offices; management consulting services	Business Services
Architectural and engineering services; technical testing and analysis services	Business Services
Scientific research and development services	Business Services
Advertising and market research services	Business Services
Other professional, scientific and technical services; veterinary services	Business Services
Rental and leasing services	Business Services
Employment services	Business Services
Travel agency, tour operator and other reservation services and related services	Business Services
Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	Business Services
Public administration and defence services; compulsory social security services	Public services
Education services	Public services
Human health services	Public services
Social work services	Public services
Creative, arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services	Recreation; other services
Sporting services and amusement and recreation services	Recreation; other services
Services furnished by membership organisations	Recreation; other services
Repair services of computers and personal and household goods	Recreation; other services
Other personal services	Recreation; other services
Services of households as employers; undifferentiated goods and services produced by households for own use	Recreation; other services
Services provided by extraterritorial organisations and bodies	Recreation; other services

Appendix 5

Region aggregation

Aggregation key used for regions.

src	agg	name
AT	Europe	Austria
BE	Europe	Belgium
BG	Europe	Bulgaria
CY	Europe	Cyprus
CZ	Europe	Czechia
DE	Europe	Germany
DK	Europe	Denmark
EE	Europe	Estonia
ES	Europe	Spain
FI	Europe	Finland
FR	Europe	France
GR	Europe	Greece
HR	Europe	Croatia
HU	Europe	Hungary
IE	Europe	Ireland
IT	Europe	Italy
LT	Europe	Lithuania
LU	Europe	Luxembourg
LV	Europe	Latvia
MT	Europe	Malta
NL	Europe	Netherlands
PL	Europe	Poland
PT	Europe	Portugal
RO	Europe	Romania
SE	Europe	Sweden
SI	Europe	Slovenia
SK	Europe	Slovakia
GB	Europe	United Kingdom
US	Advanced	United States
JP	Advanced	Japan
CN	Developing	China
CA	Advanced	Canada
KR	Advanced	South Korea
BR	Developing	Brazil
IN	Developing	India
MX	Developing	Mexico
RU	Developing	Russia
AU	Advanced	Australia

CH	Europe	Switzerland
TR	Developing	Türkiye
TW	Advanced	Taiwan
NO	Norway	Norway
ID	Developing	Indonesia
ZA	Developing	South Africa
WA	Developing	RoW Asia
WL	Developing	RoW America
WE	Europe	RoW Europe
WF	Developing	RoW Africa
WM	Developing	RoW Middle East