CaFEAN: Carbon Footprint of the Economic Activity of Norway

Environmentally Extended Input-Output Analysis of Emissions from Norwegian Economic Activity

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For:

Norwegian Environment Agency

M-2651|2023

November 2023

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Summary

Conventional carbon accounting focuses on the greenhouse gas emissions that occur within the territory of a country. The influence on global greenhouse gas emissions of a nation often extends beyond its borders due to the role that international trade plays. Countries can create demand for goods and services produced in foreign nations that contribute to climate change, and as such may have agency to influence climate mitigation strategies beyond its borders.

The project Carbon Footprint of Economic Activity of Norway (CaFEAN) was initiated to produce statistically consistent estimates of global emissions resulting from Norwegian economic activity. The project takes a *consumption-based accounting* approach to emissions accounting in order to provide a complement to the conventional territorial and production-based accounts that are already produced by Statistics Norway. CaFEAN uses a global multi-regional input-output approach to capture global greenhouse gas emissions embodied in imports and creates a coupled model with Norwegian statistical data to link those imported emissions to the goods and services consumed within Norway. The coupled model approach ensures the matching of Norwegian economic, trade and air emission data for the domestic account.

The results of the project show an estimate of the carbon footprint of Norway to be 70.2 Mt CO_2-eq in 2020 in comparison to a production-based account of 65.3 Mt CO_2-eq. Sixty-one percent (42.8 Mt CO_2-eq) of the total carbon footprint was estimated to be embodied in imports. Whilst water transport and oil and gas mining were the largest sectors of greenhouse gas emissions from a production-basis, model results showed the construction and food products sector to be the largest sectors of greenhouse gas emission from a consumption-basis. On a production-basis, CO_2 emissions contributed 87% of emissions based on a global warming potential of a hundred-year time horizon, whilst on a consumption-basis, CO_2 contributed only 73%, with considerably more methane and nitrous oxide embodied in imports.

Since 2012, statistics show a reduction in the production-based account of 6% for greenhouse gas emissions in 2020. For the consumption-based results, a reduction of 22% was observed, largely due to a reduction in the emissions embodied in imports. The largest reductions were in the emissions embodied in the sector accommodation and food services, followed by emissions embodied in petroleum, chemicals and pharmaceuticals. A further update to the calculation after the effects of the reduced economic activity during the COVID pandemic is needed to investigate whether these reductions have been maintained since.

In comparison to existing estimates of the carbon footprint of Norwegian economic activity, the project results show a clearer adherence to Norwegian statistical data, which would validate the choice of method. Further work that focuses on succinctly explaining the differences in model outcomes would provide benefits in communicating the robustness of the various consumption-based accounting results. Within the model used, additional work to further validate the greenhouse gas emission accounts is recommended, with a particular focus on non-CO_2 emissions embodied in imports. These emissions contribute a significant amount of the Norwegian carbon footprint, and have seen the greatest change over time, yet have a significantly higher level of uncertainty in air emissions accounts in comparison to CO_2.

Analysis of structural change, with a focus on decomposing changes in volumes of economic activity and trade from changes in emissions intensity of production, or origin of goods and services will provide further insights into the causes of emissions reductions.

Sammendrag

Et lands utslippsregnskap fokuserer tradisjonelt sett på klimagassutslipp som skjer innenfor landegrensene. Påvirkningen et land har på globale klimagassutslipp strekker seg ofte utover landets grenser på grunn av internasjonal handel. Land kan skape etterspørsel etter varer og tjenester produsert i andre land som bidrar til klimaendringer, og kan derfor ha mulighet til å påvirke klimahandling utenfor sine grenser.

Prosjektet Klimafotavtrykk av norsk økonomisk aktivitet (CaFEAN) ble satt i gang for å utarbeide statistisk konsistente estimater av globale utslipp som følge av norsk økonomisk aktivitet. Prosjektet bruker en forbruksbasert regnskapsmetode for utslipp for å supplere det eksisterende territorielle og produksjonsbaserte regnskapet som produseres av Statistisk sentralbyrå. CaFEAN bruker en global flerregional kryssløpsmodell for å fange opp globale klimagassutslipp som er bundet i import, og skaper en koblet modell med norsk statistikk for å knytte disse importerte utslippene til varene og tjenestene som forbrukes i Norge. Den koblete modelltilnærmingen sikrer samsvaret mellom norske økonomiske, handels- og utslippsdata for de innenlandske utslippene i prosjektet.

Resultatene fra prosjektet viser et estimert klimafotavtrykk for Norge på 70,2 Mt CO_2-ekv i 2020. Til sammenligning var det produksjonsbaserte utslippet 65,3 Mt CO_2-ekv i samme år. 61 prosent (42,8 Mt CO_2-ekv) av det totale klimafotavtrykket er bundet i import. Mens sjøfart og olje- og gassutvinning var sektorene med størst utslipp i det produksjonsbaserte regnskapet, viste modellresultatene at bygge- og anleggsvirksomhet og matvareindustrien var de to sektorene med størst klimagassutslipp i det forbruksbaserte regnskapet. I produksjonsperspektivet bidro CO_2-utslipp med 87% av utslippene basert på et globalt oppvarmingspotensial over hundre år, mens i forbruksperspektivet bidro CO_2 bare med 73%, med betydelig mer metan og lystgass bundet i importen sammenlignet med det produksjonsbaserte regnskapet.

Mellom 2012 og 2020 viser utslippsstatistikken en reduksjon i klimagassutslippene på 6% i det produksjonsbaserte regnskapet. For de forbruksbaserte resultatene ser man en reduksjon på 22% i samme periode, hovedsakelig på grunn av en reduksjon i utslippene bundet i import. De største reduksjonene var i utslippene bundet i sektoren overnattings- og serveringsvirksomhet, etterfulgt av utslippene bundet i petroleum, kjemikalier og legemidler. En oppdatering av beregningen etter effektene av den reduserte økonomiske aktiviteten under COVID-pandemien er nødvendig for å undersøke om disse reduksjonene har blitt opprettholdt siden.

Sammenlignet med eksisterende estimater av klimafotavtrykket fra norsk økonomisk aktivitet, viser prosjektresultatene en tydeligere overenstemmelse med norsk statistikk, noe som bidrar til å validere valget av metode. Ytterligere arbeid som fokuserer på å forklare forskjeller i resultatene fra ulike modeller vil kunne bidra til bedre formidling av hvor robuste de ulike resultatene er. Det anbefales videre arbeid for å validere de forbruksbaserte utslippstallene fra modellen som er brukt i dette prosjektet, med særlig fokus på utslippene bundet i import og som ikke er CO_2. Disse utslippene bidrar betydelig til det norske klimafotavtrykket og står for den største endringen over tidsperioden 2012-2020, men utslippsdataene har en betydelig høyere usikkerhet sammenlignet med CO_2.

Analyse av strukturelle endringer, med fokus på å dekomponere endringer i størrelsen av økonomisk aktivitet og handel fra endringer i utslippsintensiteten av produksjon, eller i opprinnelsen til varer og tjenester, vil gi ytterligere innsikt i årsakene til utslippsreduksjoner.

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1 Introduction

Norway imports a significant share of the goods and materials that are used by Norwegian consumers, by the public administration, and by private businesses. The production and transportation of these goods result in emissions in other countries and are thus not included in Norway's official emission inventory. The official inventory only includes the emissions occurring within Norway's territory. The emissions embodied in imports or exports are not included, and hence do not give a full picture of the agency that Norwegian producers and consumers have over global emissions.

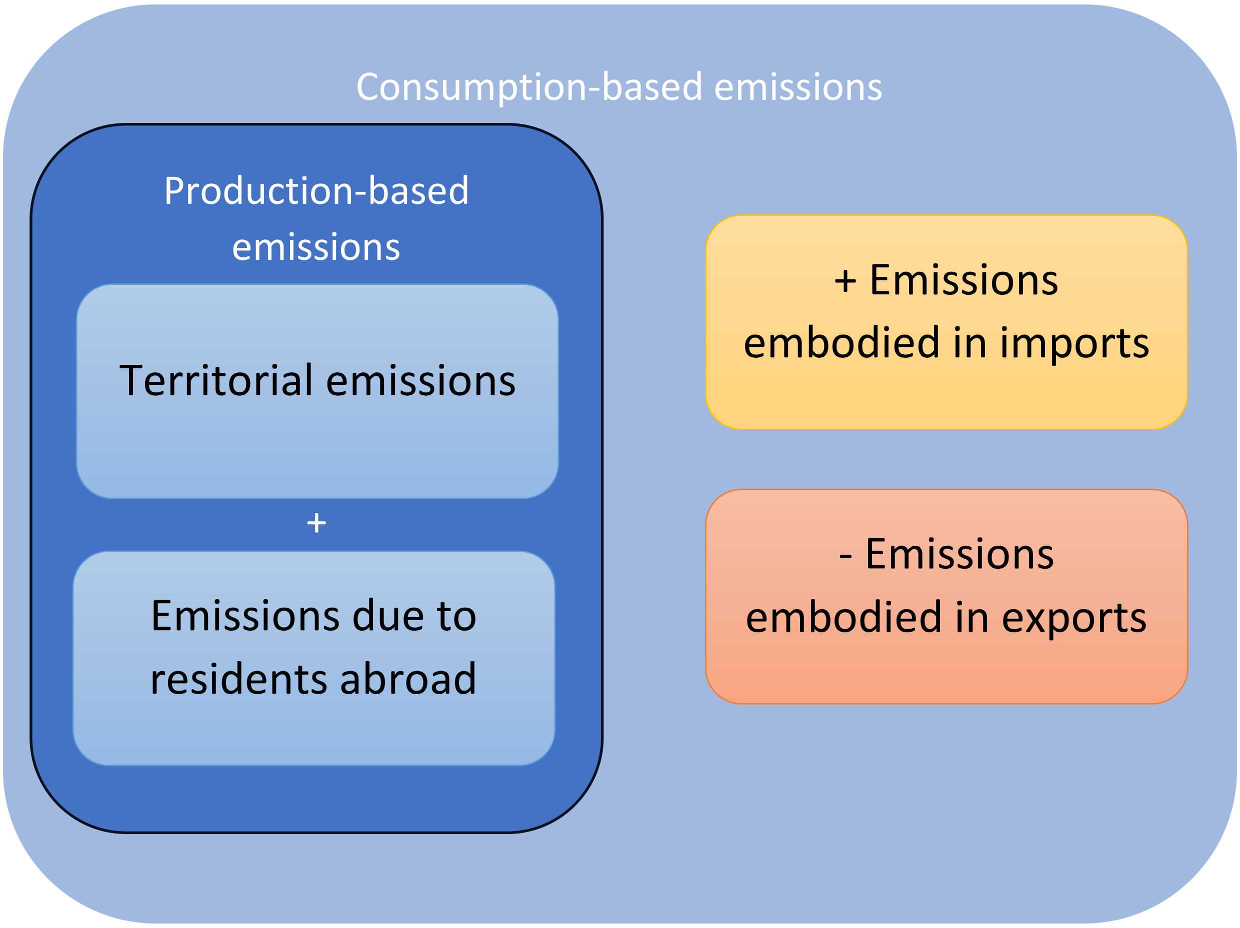

Figure 1 Infographic of consumption-based emissions (or carbon footprint) of a nation. Territorial emissions are reported as part of the UN Framework Convention on Climate Change obligations, territorial emissions, together with emissions from residents abroad (for example due to use of marine and airline bunker fuels) in total make "production-based emission" accounts. Adjusting for emissions embodied in imports, and excluding emissions embodied in exports gives the consumption-based emissions of a country.

The objective of the analysis described in this report has been to carry out an updated environmentally extended input-output analysis to gain better insight into the emissions from Norwegian economic activity no matter where emissions occur – domestically or abroad. The emission accounts described in this report are hence an extension of the current national greenhouse gas inventories with the aim to provide a more comprehensive picture of the emissions Norway may influence. The report includes a "consumption-based" perspective to the emission accounts. The Environment Agency was in 2023 given this task by the Norwegian Ministry of Climate and have contracted Vector Sustainability, with XIO Sustainability Analytics as a subcontractor, to perform the analysis in close collaboration with the Environment Agency and the Norwegian Agency for Public and Financial Management (DFØ). As a result, the project CaFEAN (the Carbon Footprint of Economic Activity of Norway) was initiated to produce statistically consistent estimates of global emissions resulting from Norwegian economic activity.

The project output covers the time period 2012-2020 and includes model results of emissions embedded within imported and exported goods, as well as the carbon footprint associated with different categories of final demand. Project results are broken down by economic sector, geographical origin, and category of final demand, with a distinction between domestic and foreign emissions.

The project builds on recent projects for a *coupled* model approach utilised in Sweden, Denmark, and the US. The coupled model approach builds on state-of-the-art global EEIO models, whilst adhering to latest Norwegian statistical data.

2 Method

2.1 Carbon footprints and consumption-based approaches

Carbon footprints (also known as consumption-based emissions) of a nation are calculated as an adjustment of territorial emissions to account for emissions abroad, and emissions embodied in traded goods (see Figure 1 and Hertwich and Peters, 2009). Territorial emissions are reported as part of the UN Framework Convention on Climate Change obligations. Territorial emissions, together with emissions from residents abroad (for example due to use of marine and airline bunker fuels consumed outside of Norway by Norwegian residents) in total make production-based emission accounts (Usubiaga and Acosta-Fernández, 2015). Adjusting for emissions embodied in imports, and excluding emissions embodied in exports gives the consumption-based emissions of a country.

Because of the production balance that occurs in national accounting, including imports and excluding exports from gross national product is equivalent to the metric of gross national expenditure in economic terms. Gross national expenditure is the summation of the "final demand" of an economy, which includes the final consumption expenditure on goods and services by households, non-profit institutions serving households and government, as well as gross fixed capital formation and changes in inventories. It includes expenditure on both domestically produced and foreign produced goods. As such, carbon footprints calculated to be consistent with national accounts calculate the carbon footprint of these items of final demand. This avoids the double counting of emissions within the supply-chain of producing goods and services, as items of final demand are not used in the production of goods or services in a current accounting year.

2.2 Background

There are two main methods for calculating consumption-based emissions: Environmentally extended input-output (EEIO) and life-cycle assessment (LCA). Compared to LCA, MRIO models provide a macro-economically consistent description of the global economy and can adhere to official statistics. While LCA model lack these, they generally provide higher levels of details, thus are more precise for individual product flows, and allow closer consideration of consumer choices. For example an assessment can be done to compare the carbon footprint of a banana produced in Spain vs Mexico with LCA, whilst most EEIO models produce insights at the level of the statistical input-output models, which usually simply show the impact of "food products" or at best "fruits and vegetables". However, to produce estimates of emissions from a national economy with the precision of LCA modelling would require extensive (and not always available) data.

EEIO modelling is a top-down approach which combines input-output data with data on environmental impacts. Input-output (IO) data are a core part of economic national accounts and provide the basis for the calculation of derived and aggregate economic indicators such as gross domestic product (GDP) and gross national expenditure (GNE). They show the consumption of goods and services by each industry in an economy, as well as by various categories of "final demand" (essentially households and government). IO tables are based on surveys on economic activity and expenditure by industry and households, as well as other collected data, including import and export statistics. Data on environmental impacts are often auxiliary datasets that are included as further direct inputs" or "wastes" from each industry in the economy. Through a basic IO "model" these environmental impacts can be allocated to the categories of final demand that ultimately consume goods and services. For example, the emissions that occur in the production of steel, are allocated to the users of that steel – for example, the vehicle industry – and then to the entity that ultimately purchases the vehicle.

EEIO models are usually carried out for specific regions but can be linked to form multi-regional input-output (MRIO) models, so that emissions embodied in production processes that include traded goods can be traced. MRIO models are considered the base standard to which to calculate consumption-based accounts in current times. Several MRIO models now exist, with EXIOBASE, GTAP (Dimaranan and Narayanan G, 2009), WIOD (Dietzenbacher et al., 2013), Eora (Lenzen, 2012) and Gloria (Lenzen et al., 2023) originating from academic research projects, and the OECD ICIO and Eurostat FIGARO being developed by government agencies (see section on data sources for more details – the project team are part of the principal developers of EXIOBASE).

MRIO models are born from compromise however, and the ability to link data from different jurisdictions around the world means that data that is reported in one country that is reported differently in a different country must be reconciled. Both countries cannot be correct if the same data flow is reported differently. Different MRIO models have different approaches to reconcile such differences and have different foci that help explain why different results come from different models.

As a result, different MRIO models report what some may consider "wildly" different results, especially for small trade-exposed countries (such as Norway). Some of these differences are due to product resolution, some come down to how purchases by residents abroad are handled, some due to how trade is reconciled, and others to basic choice of data and method to inform the MRIO model.

A web-portal that provides access to results from different MRIO models is available at www.environmentalfootprints.org, and the issue has been analysed in depth with the article: Variation in trends of consumption-based accounts (Wood et al., 2019). Results for Norway from that investigation show the importance of using national statistics for small trade exposed countries – production-based emission accounts for Norway as reported by the various MRIO models had an *average* difference across five models of 20%, and an *average* difference of consumption-based emission account of 18%. And this was for CO_2 only. Such large differences at the national level are often due to how bunker fuels and residents abroad are treated. Practically, no MRIO database has high levels of quality at the international level for such issues due to limited raw data availability and quality.

2.3 National Account Consistent models

Some of the data issues became well known in the statistical and academic community, and early efforts were instigated to provide a more robust picture at the country level. This included the Single-country National Accounts Consistent (*SNAC*) approach developed by Statistics Netherlands (Edens et al., 2015) and the UK-MRIO model (Wiedmann et al., 2010), both of which nested a domestic table in a global MRIO model. Both these approaches were relatively complex however, with the need to rebalance the global tables around the domestic data of either the Netherlands or the UK. They also provide estimates for the final demand of a country but cannot extract the carbon footprints of actual goods traded. Two different definitions of "emissions embodied in imports" exists. The first is a "net trade" approach and refers to the embodied emissions in the final good (like a car) that is purchased in Norway – even if the car was produced in Norway, it would still have emissions embodied in imports due to steel and rubber production overseas. The second definition is a "gross trade" approach and refers to the actual good being imported – here the emissions embodied in the traded good (such as imported steel) is assessed. It is non-trivial to be able to both account for the environmental impact of the good at the border (the "gross trade approach") and allocate that impact to a "final good" such as a car which may be used domestically or exported for consumption in another country. There is the risk of double counting such emission flows in a MRIO framework (Hertwich and Wood, 2018).

To circumvent these issues, the model used in this work is a so-called *simplified-SNAC* or *coupled model* approach as documented in (Wood, 2018) and (Palm et al., 2019). Instead of the approach described by Edens et al., which requires a full rebalance of the MRIO tables, it uses a relaxation of the widely used domestic technology assumption with MRIO data on technology used to produce imports. (The domestic technology assumption assumes that all goods and services are produced with Norwegian technology, whilst the MRIO approach uses country-specific data). As such the coupled model uses Norwegian data for the Norwegian input-output tables and environmental pressures, while import related emissions are calculated using an environmentally extended multiregional input-output (EE-MRIO) database. The coupling together of the domestic model with the coverage of imports is what makes the coupled model, as depicted below – Norwegian data is used to cover Norwegian supply chains (blue), whilst MRIO data is used to cover foreign supply chains (red).

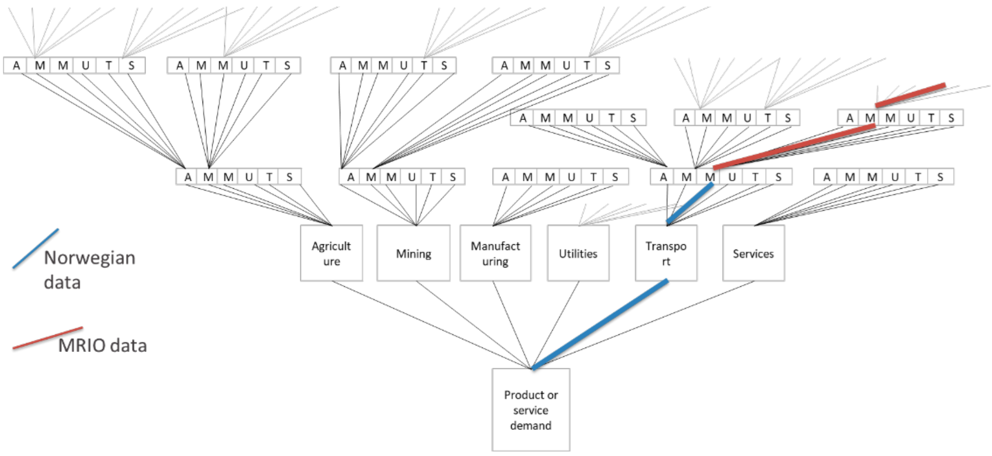

Figure 2 Depiction of a supply-chain "tree" where for a given demand on a product or service, there are infinitely more supply-chains feeding it. For one supply-chain, we show Norwegian transport requiring Norwegian manufacturing, requiring foreign manufacturing and so on. The blue parts of the supply-chain are covered by Norwegian data and the red by MRIO data in the coupled model.

Using Norwegian specific data is advantageous since Norwegian Statistics' existing high-quality and timely air emissions accounts and input-output tables can be used as input, providing a more accurate model than if based on an existing EE-MRIO table alone (where data on small trade-exposed countries, such as Norway, is often represented poorly). Environmental pressures arising outside of Norway due to demand in the Norwegian economy (i.e., due to imports) are then calculated using an EE-MRIO database. In this work, EXIOBASE is used due to data coverage, detail and availability, but any MRIO model can be used (albeit some have limitations on coverage).

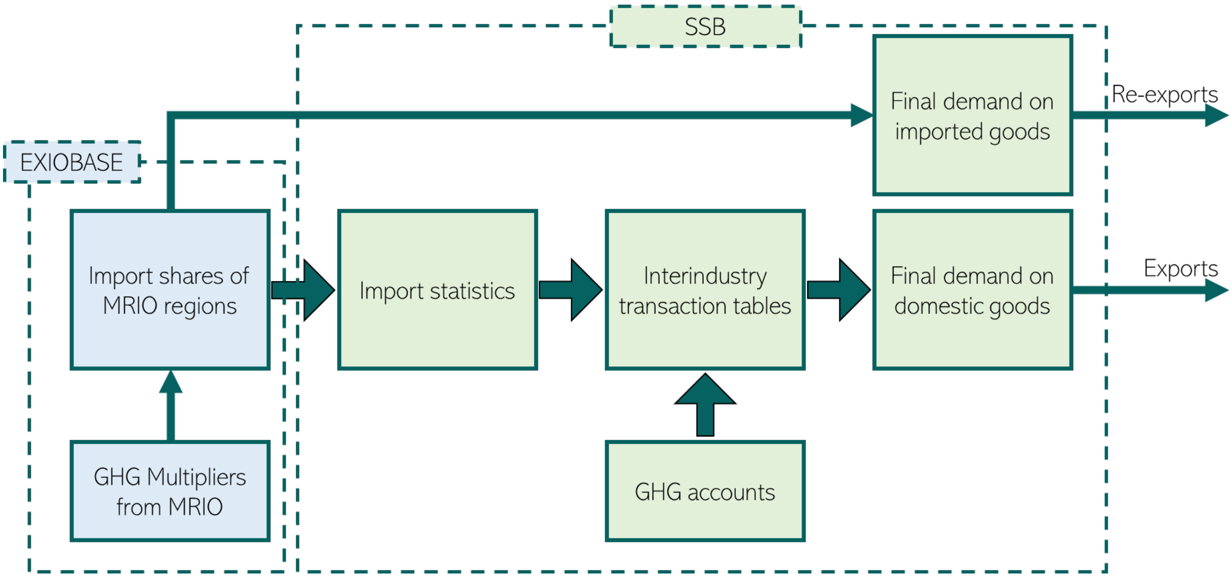

Figure 3 Diagrammatic of the coupled model approach. Norwegian data is in light green, and the accounts are principally built around this data for the calculation of all domestic supply-chains (to point of export). For emissions abroad, the MRIO model EXIOBASE is used. The MRIO model provides GHG emissions per euro of traded goods in native MRIO classification. This is then aggregated to the 65 sectors of the Norwegian model. Import shares are then used to connect the Norwegian IO import data (which only show sector level imports, not country of origin). The import shares define how much of an import flow comes from Denmark, Germany, China, etc. The import shares can be calculated directly from EXIOBASE. The domestic emissions accounts from SSB are provided in [SSB table 09298]*, while all other domestic data is provided by the* [input-output tables also published by SSB].

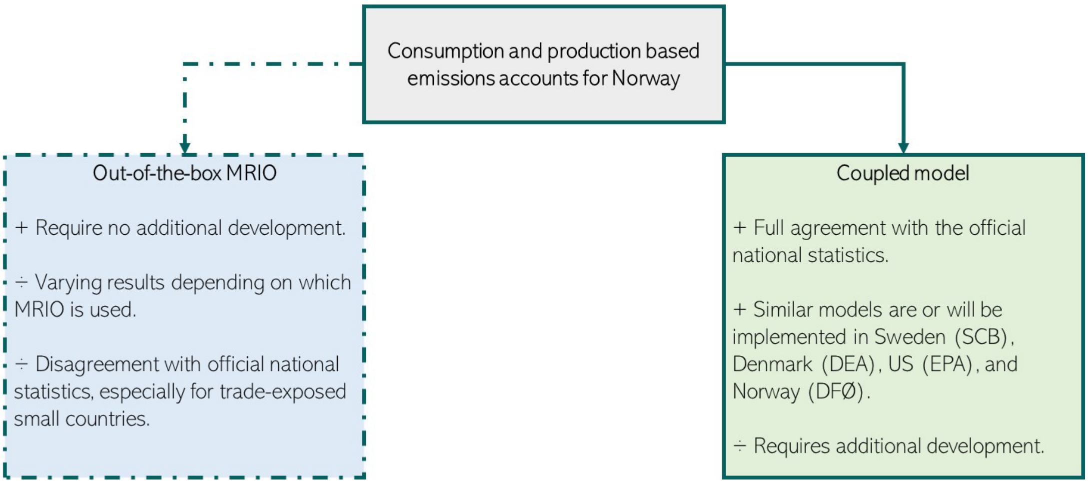

Figure 4 Summary of advantage and disadvantages of different approaches: conventional MRIO vs Coupled Model.

3 Data sources

The data sources used in this project are principally the Norwegian Air Emission Accounts, the Norwegian Input-Output tables, and a global multi-regional input-output (MRIO) model.

3.1 Norwegian IO

The Norwegian input-output tables are required to allocate production-based emissions to the final goods and services produced by the economy.

Norwegian input-output tables are available from SSB up until 2020 currently. The 2021 table is likely to be published by the end of the year. Consistent time-series of both supply-use tables and input-output tables are available back to 2012, with earlier tables back to 1992. A change in the System of National Accounts for the 2012 tables means that different accounting conventions applied to earlier tables, and a stable time-series is not guaranteed.

The Norwegian input-output tables are available at:

https://www.ssb.no/en/nasjonalregnskap-og-konjunkturer/metoder-og-dokumentasjon/supply-and-use-and-input-output-tables

3.2 Norwegian Greenhouse Gas Emissions

Norwegian production-based greenhouse gas emission accounts are published by SSB (as "Emissions from Norwegian economic activity[1]) for a time-series from 1990-2021 as of late-2023. Final 2022 values are expected to be released in November 2023. Greenhouse gas emission accounts for Norway include carbon dioxide (CO_2), nitrogen dioxide (N_2O), methane (CH_4), PFCs (perfluorocarbons), HFCs (hydrofluorocarbons), and SF6. Total emissions of greenhouse gases are calculated by adding up emissions for each component given in CO_2-equivalents GWP (100-year time horizon) value due to IPCC Fifth Assessment Report (AR5). All sources of greenhouse gases except land use, land use change and forestry are included. Biofuels are discussed separately below.

Whilst the air emission accounts are available online[2], the published accounts are only reported in a sector detail of 48 economic sectors and exclude biogenic CO_2. For the purposes of this project, SSB provided a copy of the Air Emission Accounts provided to Eurostat. These emission accounts are consistent with the 65-sector classification of the input-output tables and include emissions for biogenic CO_2 as well as all other greenhouse gas emissions listed above. Note these values differ slightly to the Air Emission Accounts published by SSB online. This is due to changes in methodology, including new emission factors and changes in models (HFC).

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[1] https://www.ssb.no/natur-og-miljo/miljoregnskap/statistikk/utslipp-fra-norsk-okonomisk-aktivitet

[2] https://www.ssb.no/natur-og-miljo/miljoregnskap/statistikk/utslipp-fra-norsk-okonomisk-aktivitet

3.3 MRIO data

MRIO models are generally available from 1995 until ca 2020. A range of MRIO databases were surveyed for the purposes of this project, with the choice being made to use the EXIOBASE (Stadler et al., 2018; Wood et al., 2015) dataset. EXIOBASE has coverage from 1995 to 2019 in v3.8.2 and will shortly have a new release of data until 2021 based on new energy and emission accounts. (EXIOBASE has 'nowcasted' emissions for more recent years). EXIOBASE is a global EE-MRIO database developed by a consortium of a range of European research institutions and financed by European research framework programs. The tables include 44 countries and 5 "rest-of-the-world" (RoW) regions and offer a level of detail of 163 industry sectors. EXIOBASE is built on country specific supply and use tables that are disaggregated and trade-linked to form a complete global multi-regional supply-use table. The disaggregation uses a range of auxiliary data on production volumes (such as FAOSTAT, IEA, material database data), detailed trade data (BACI, a derived product of the UN COMTRADE database), and co-efficient information for production processes in the form of input requirements per unit of production (partly from life-cycle inventory data, partly from detailed IO tables). At the highest level, the database is balanced to be consistent with the UN main aggregates. See Stadler et al 2018 for further details. EXIOBASE version 3 was originally developed to focus on trends of resource efficiency at macro-levels. As such, earlier efforts focussed mostly on macro-level and inter-temporal consistency. More recently, there has been further focus on the use of EXIOBASE at detailed product level, including using emission multipliers for corporate accounting. Such work needs a higher level of precision than earlier efforts. In the soon to be released version, EXIOBASE is benchmarked to the (more aggregated) FIGARO SUT data. Energy and emission accounts have also been more tightly integrated to the monetary accounts in order to increase the internal consistency of the data.

EXIOBASE production-based emission accounts cover all GHGs included in the project (CO_2, CH_4, N_2O, SF_6, HFCs and PFCs). The emissions cover all sources except the IPCC category Land use, land use change and forestry due to the difficulty in assigning emissions of indirect land use change. This exclusion is consistent with SSB Air Emission Accounts. The emissions from fuel combustion are calculated based on IEA energy balance data that is transformed and allocated to EXIOBASE industries before emission coefficients are applied (see Stadler et al 2018 for a full list of adjustments and data sources). For emissions not from fuel combustion, a range of data sources were firstly used at the individual industry level, before being scaled to match greenhouse gas emissions emission accounts from the PRIMAP database[3].

EXIOBASE was chosen in comparison to other MRIOs due to the full coverage of data (mostly greenhouse gas emissions), the availability of recent updates, which include biogenic CO_2, and the detailed knowledge of the database by the contracting team. EXIOBASE has been updated every 2-3 years over the last decade but is moving towards an annual update sequence in order to provide more reliable and up to date information. This is partly based on the more updated data sources available that are used in EXIOBASE.

For this work, version 3.8.2 was used (https://zenodo.org/record/5589597) due to non-CO2 emission factors not yet being finalised at the time this report was prepared in the soon to be released version. Version 3.8.2 has relatively good data quality up to 2019, based on good economic and emission data availability for 2019 at the time the database was produced. Emission estimates for 2020 are hence based on trend information in EXIOBASE used in the nowcast procedure (and hence does not include major changes in technology or trade relationships that may have occurred due to COVID. As

[3] https://primap.org/primap-hist/

EXIOBASE is only used to generate aggregate emissions embodied in import intensities, the use of the nowcast would be unlikely to have a major effect on results. Further updates should, however, switch to the newer EXIOBASE version in order to accurately track the changes resulting from impacts of the COVID pandemic.

A main alternate to EXIOBASE which was surveyed was the Eurostat FIGARO database. FIGARO currently has estimates from 2010 to 2020, but for CO_2 only. In the stakeholder phase, Eurostat indicated that future versions of FIGARO will include other greenhouse gas emissions. Hence in future work, the option to switch to FIGARO is possible. The construction of the model methodology means that the calculations to switch to a different database is relatively straightforward if desired.

4 Method choices

4.1 Time series from 2012 and onwards

SSB publishes historical IO tables back to 1992, but earlier versions are under a different System of National Accounts (SNA). From 2014 (which corresponds to the 2012 table), Norway and the rest of the European Union changed from SNA93 to SNA08. For a lot of countries, the change increased the level of GDP, as several expenditures were reclassified from current to capital expenditures[4]. The calculation of trade and trade margins also changed between the different SNA versions. As such, the decision was made to produce time-series estimates consistent with the most recent SNA, limiting the backwards compatibility to 2012.

It may be feasible to assess the impact of the changes in SNA across the break in the time-series, but we are not aware of research that has undertaken this question. The impact is likely to have a small impact at the aggregate level, but a more pronounced impact at the sector level. Also, the change from NACE1 to NACE2 (sector classifications) occurred between the available 2007 and 2009 tables.

4.2 Negative changes in inventories

The Norwegian Input-Output table is characterised by large quantities of negatives in the final demand column. Whilst most values in an input-output table correspond to the gross value of a physical transfer of ownership of goods and services, and are hence positive, the inventories column of final demand allows for both addition to inventories of goods, and the retrieval of goods from inventories. The retrieval of goods from inventories are entered as a negative value in final demand, as their value represents goods that were produced in previous years, but stored in inventories, and then retrieved in the current year. Inventories are also, however, sometimes used as balancing items to ensure total supply in a certain year equals total demand in the same year. Using inventories as a residual to balance supply and demand can sometimes lead to large negative elements.

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[4] https://www.ssb.no/nasjonalregnskap-og-konjunkturer/artikler-og-publikasjoner/derfor-vil-nivaet-pa-bnp-oppjusteres

In physical terms, the goods retrieved from inventories were not produced in the current year. Hence, for the purposes of the input-output calculation to allocate current year emissions to the final uses of the goods and services produced in that year, we exclude negative inventories from the calculation. Hence, the "gross production" that we allocate emissions to is a sum of the intermediate demand of goods and services, as well as the positive final demand of goods and services. This ensures that emissions are correctly allocated in the current year of the calculation. Whilst some of the emissions are allocated to inventories, that theoretically will be embodied in goods and services produced and used in later years, the method to allocate such emissions over time is complex and needs unavailable data on the use of inventories. For 2020, the results showed that the largest sector of inventories was for construction goods, which would likely be allocated to the same sector (construction) in future years.

4.3 Biogenic CO_2

Biogenic CO_2 refers to the CO_2 emissions from combustion of biofuels. Biogenic CO_2 needs to be treated separately due to the nature of carbon balances implicit in the absorption of CO_2 released during combustion processes. The sustainability of biomass used for fuel combustion is often highly dependent on the source of biomass, which is often not evident in aggregate national economic or energy accounts. Even when Biogenic CO_2 is excluded, the "upstream" non-biogenic emissions associated with the biogenic CO_2 emissions would be recorded (e.g. from methane from farming or CO_2 from fuel used in forestry).

Biogenic CO_2 is calculated exactly like all other combustion emissions. In the EXIOBASE dataset, the IEA energy balances are used which are then transformed into energy accounts in the EXIOBASE construction process (i.e., energy from biomass sources are allocated to economic sectors). These energy flows are then converted to emissions using process and fuel specific emissions factors (see Stadler et al 2018 for data sources). It is generally understood that the reporting of biomass is relatively uncertain. The documentation for the IEA world energy balances[5] has more information on what is included/excluded (See section on "Products" -> "Biofuels and Waste"). The use of fossil fuels in the production of biofuels will still be reported as regular CO_2 emissions and not as biogenic CO_2. LULUCF emissions are excluded.

For the Norwegian data, Statistics Norway have made available biogenic CO_2 emissions as part of their annual emission accounts reported to Eurostat in 65 sectors. These accounts have been used in this project only for the biogenic CO_2 calculation (and not included in the aggregate greenhouse gas calculation).

[5] https://wds.iea.org/wds/pdf/worldbal_documentation.pdf

5 Results

In this section, a summary of headline results is presented and given a brief discussion. Note that more detailed model results are available in the results files, and further investigation into detailed explanations of emission profiles is possible by interrogating those results. The purpose of this section is simply to provide a guide and summary to the most recent (2020) results, and the main results that capture changes over the time-series. Note that all “production-based” results, including those described in section 5.1 below, are reproductions of data available directly from the SSB Air Emission Accounts published in 2023 – they are not calculated results of the methods used in this project.

5.1 Greenhouse gases from Norwegian economic activity, 2020

In 2020, SSB reports overall GHG emissions in Norway as 65.3 Mt CO_2-eq (excluding biogenic CO_2) on a “production basis”. These are contained in the 2023 Air Emission Accounts provided to Eurostat. Of this 65.3 Mt, 56.7 Mt are CO_2, and other gases contributed (in CO_2-eq.) amounts of 5.4 Mt CO_2-eq. CH4; 2.2 Mt CO_2-eq. N_2O; 0.1 Mt CO_2-eq. SF_6; 0.7 Mt CO_2-eq. HFC; and 0.1 Mt CO_2-eq. PFC. Total greenhouse gas emissions can be broken down into a contribution of industries of 60.1 Mt CO_2-eq., and direct household emissions of 5.1 Mt CO_2-eq.

All industries and households	kt	Mt-CO2eq
Greenhouse gases total	-	65.3
Carbon dioxide (CO2)	56,700	56.7
Methane (CH4)	192	5.38
Nitrous oxide (N2O)	8.19	2.17
Sulphurhexafluoride (SF6)		0.076
Hydrofluorocarbons (HFC)		0.750
Perfluorocarbons (PFC)		0.145

Table 1 Greenhouse gases from Norwegian economic activity from the SSB Air Emission Accounts, Production basis, 2020

Of note, these values differ slightly to the Air Emission Accounts published by SSB in table 13932[6] as of 10th November 2023, where total GHG are 65.1 Mt CO_2-eq. This is mostly due to updates in methods recommended by the IPCC for emission factors between data versions. The main relative differences occur in the fluoride gases, but there are also substantive changes in methods for methane and nitrous oxide.

These values also differ from the “territorial accounts” as reported by SSB in the report “Emissions to air”[7] as an extract from table 13931[8]. These “territorial accounts” amount to 49.4 Mt CO_2-eq. in 2020,

[6] https://www.ssb.no/en/statbank/table/13932
[7] https://www.ssb.no/en/natur-og-miljo/forurensning-og-klima/statistikk/utslipp-til-luft
[8] https://www.ssb.no/en/statbank/table/13931

but exclude emissions from Norwegian residents abroad, which mainly includes water transport (14 Mt CO_2) and air transport (0.5 Mt CO_2) (see Introduction and Figure 1 for an explanation). The territorial accounts also include emissions due to foreign residence activity in Norway if the fuel is purchased in Norway. These emissions are not included in the Emissions to air from Norwegian economic activity.

5.2 Greenhouse gases embodied in gross imports and exports, 2020.

The results of the calculation of the Norwegian carbon footprint are provided in Figure 5 for the year 2020. In addition to the 65.3 Mt CO_2-eq. in the production account, 59.3 Mt of GHG in CO_2-eq. are embodied in gross imports, and 54.4 Mt of GHG in CO_2-eq. are embodied in gross exports. This results in a consumption-based account, or carbon footprint of Norway in 2020 of 70.2 Mt GHG in CO_2-eq. Note that production accounts and the footprint include direct household emissions of 5.3 Mt CO_2-eq, such as those from private car use (fuel combustion).

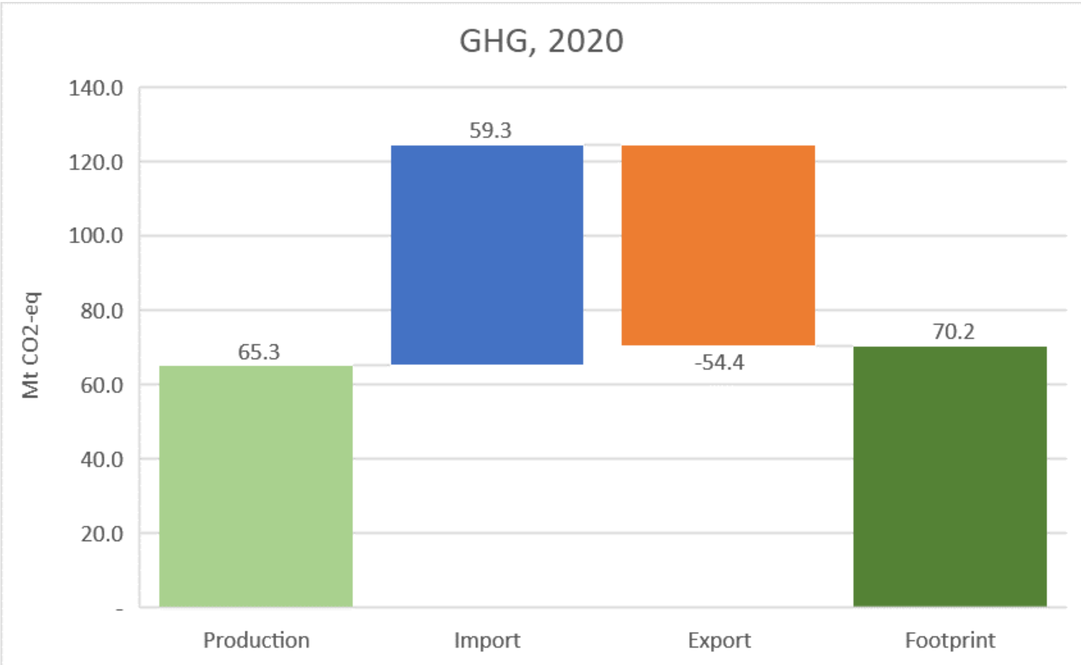

Figure 5 Emissions embodied in imports and exports, and resultant carbon footprint of Norwegian Economic Activity.

The footprint can be broken down into that from domestic sources (Equation 4, Appendix – Methods in depth), and that from imported sources (Equation 9, Appendix – Methods in depth). Likewise, the production account and imports can be broken down into the emissions that stay within Norway, and those that are embodied in exports. Figure 6 shows this breakdown. 27.4 Mt of GHG emissions of the production account are embodied in goods and services that remain in Norway. 37.8 Mt of GHG emissions of Norwegian production account (emissions or Norwegian resident activities) is embodied in exports. The footprint comprises the 27.4 Mt of GHG emissions from domestic sources, plus 42.7 Mt of GHG emissions embodied in imports (this is referred to as the “net import”). Total emissions embodied in imports sums to 59.3 Mt, with 16.6 Mt of GHG emissions embodied in imports, eventually embodied in exports. This 16.6 Mt is the difference between the emissions embodied “gross imports” (all goods that are imported into Norway), and that of "net imports" (only the emissions embodied in goods that remain in Norway, and excludes those that are eventually embodied in exports).

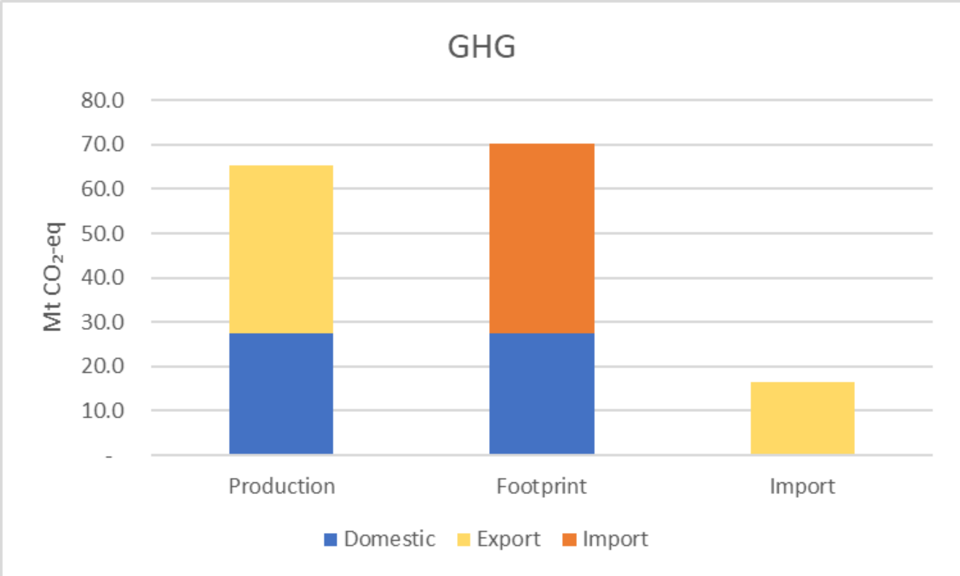

Figure 6 Greenhouse gas emissions of Norwegian production that remain in Norway, the emissions embodied in imports and exports, and resultant carbon footprint of Norwegian Economic Activity. Note the third column represents footprint of imports that are exported – either directly as re-exports, or after processing by Norwegian industry before export.

	Domestic	Export	Import	Total
Production	27.4	37.8		65.3
Footprint	27.4		42.8	70.2
Import		16.6		16.6

Table 2 Greenhouse gas emissions of Norwegian production that stays in Norway, the emissions embodied in imports and exports, and resultant carbon footprint of Norwegian Economic Activity. Mt CO_2-eq.

The majority of emissions embodied in imports (see Figure 7) are due to carbon dioxide emissions, with Methane contributing 13 Mt CO_2-eq. embodied in imports. The source of these emissions will be explored later. 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 (18% and 5% of the total footprint account for CH_4 and N_2O respectively). Both sets of results are under 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)[9]. Part of the reason for 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

[9] https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SPM.pdf

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.

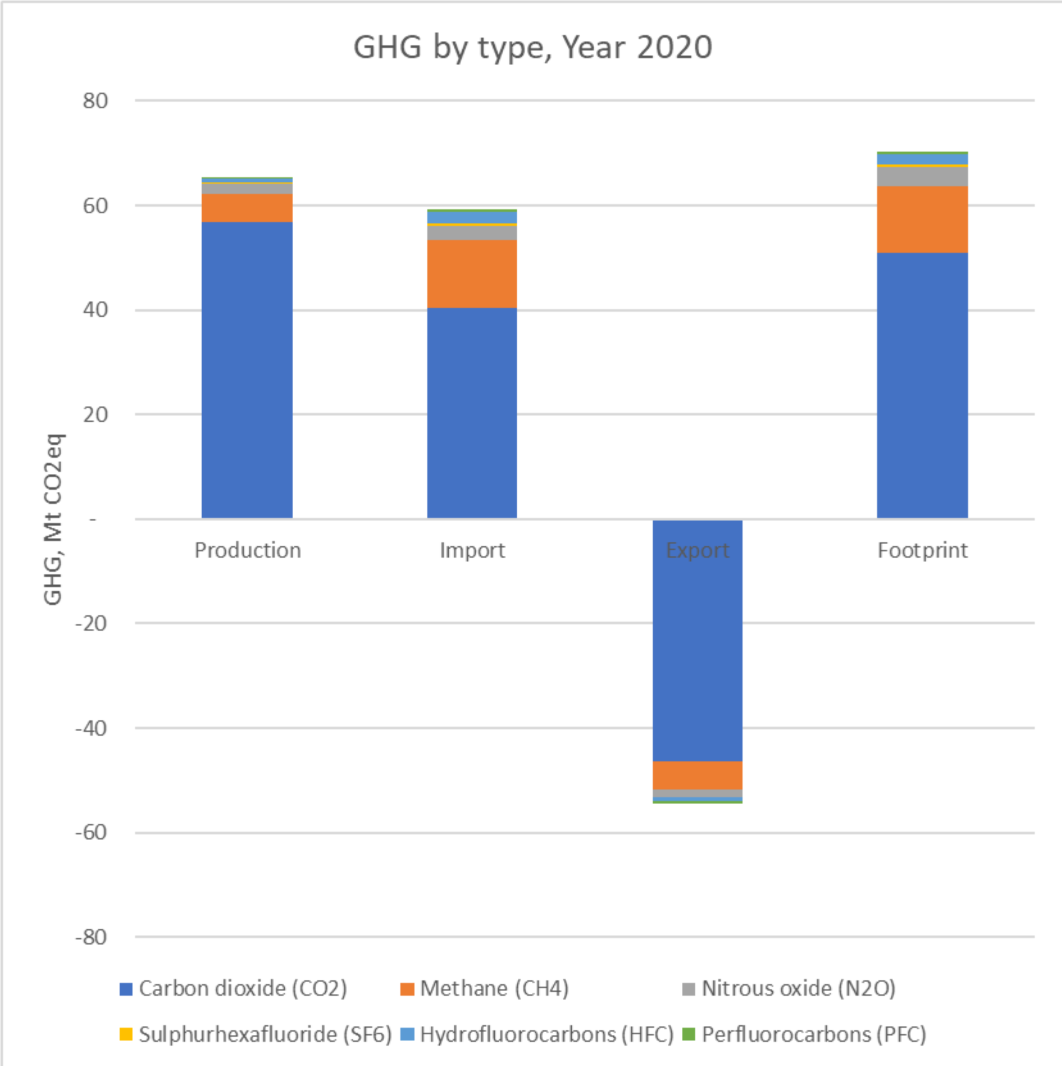

Figure 7 Emissions embodied in gross imports and exports, and resultant carbon footprint of Norwegian Economic Activity, by greenhouse gas.

5.3 Greenhouse gases embodied in imports and exports, 2012-2020

Overall greenhouse gas emissions from Norwegian Economic Activity are lower in 2020 than 2012 (see Table 3, Figure 8 and Figure 9). These results are consistent for all four measures of production-based; emissions embodied in gross imports; emissions embodied in gross exports[10]; and consumption-based

[10] 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.

(or footprint). Of note is a 10% increase in the production-based emission account in 2015, coinciding with a 15% drop in emissions embodied in imports for the same year. The main source of this increase 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).

A strong drop in emission accounts is also evident for 2019 to 2020. A drop in the order of 5-10 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 2020, production-based emissions were 5% higher than 2012.

Perspective	2012	2013	2014	2015	2016	2017	2018	2019	2020
Production	69.1	69.3	68.6	75.5	66.6	68.5	71.4	71.0	65.3
Imports	86.5	92.6	85.9	78.5	73.5	65.4	69.6	66.1	59.3
Exports	65.1	64.9	63.5	67.4	58.9	59.0	63.5	62.9	54.4
Footprint	90.5	96.9	91.0	86.6	81.3	75.0	77.6	74.2	70.2

Table 3 Greenhouse gas emissions: production-basis; emissions embodied in gross imports and exports; and resultant carbon footprint of Norwegian Economic Activity, 2012-2020. Mt CO_2-eq.

Perspective	2012	2013	2014	2015	2016	2017	2018	2019	2020
Production	100%	100%	99%	109%	96%	99%	103%	103%	94%
Imports	100%	107%	99%	91%	85%	76%	80%	76%	69%
Exports	100%	100%	98%	104%	90%	91%	98%	97%	84%
Footprint	100%	107%	101%	96%	90%	83%	86%	82%	78%

Table 4 Greenhouse gas emissions indexed to 2012: production-basis; emissions embodied in gross imports and exports; and resultant carbon footprint of Norwegian Economic Activity, 2012-2020. Mt CO_2-eq.

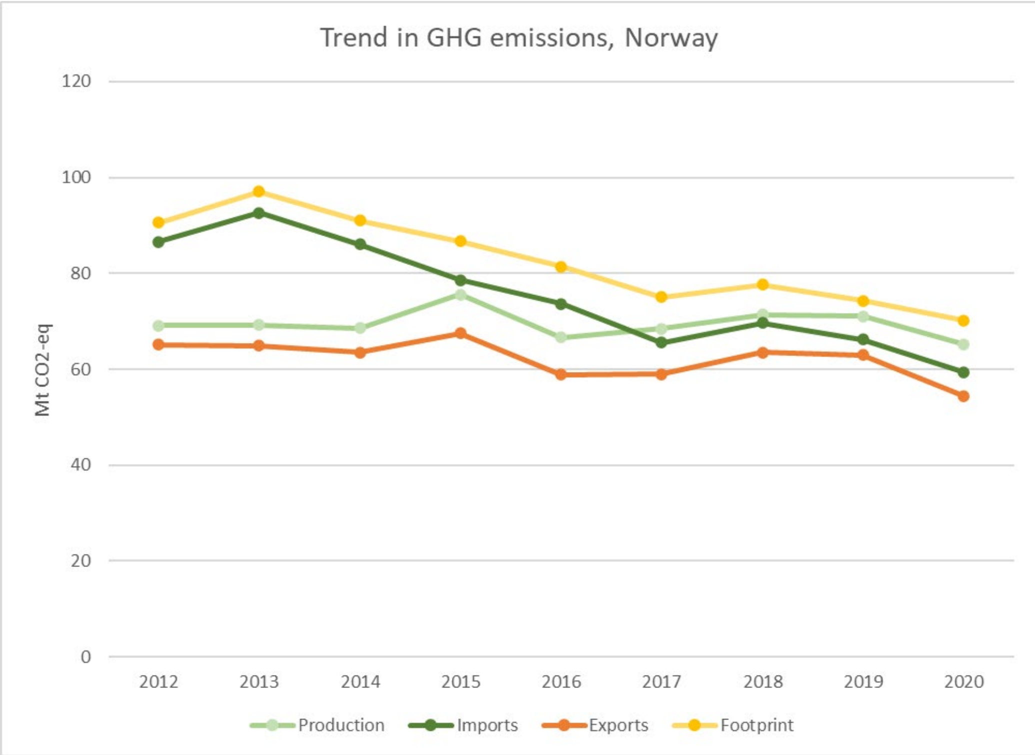

Figure 8 Trends in greenhouse gas emissions: production-basis; emissions embodied in gross imports and exports; and resultant carbon footprint of Norwegian Economic Activity, 2012-2020.

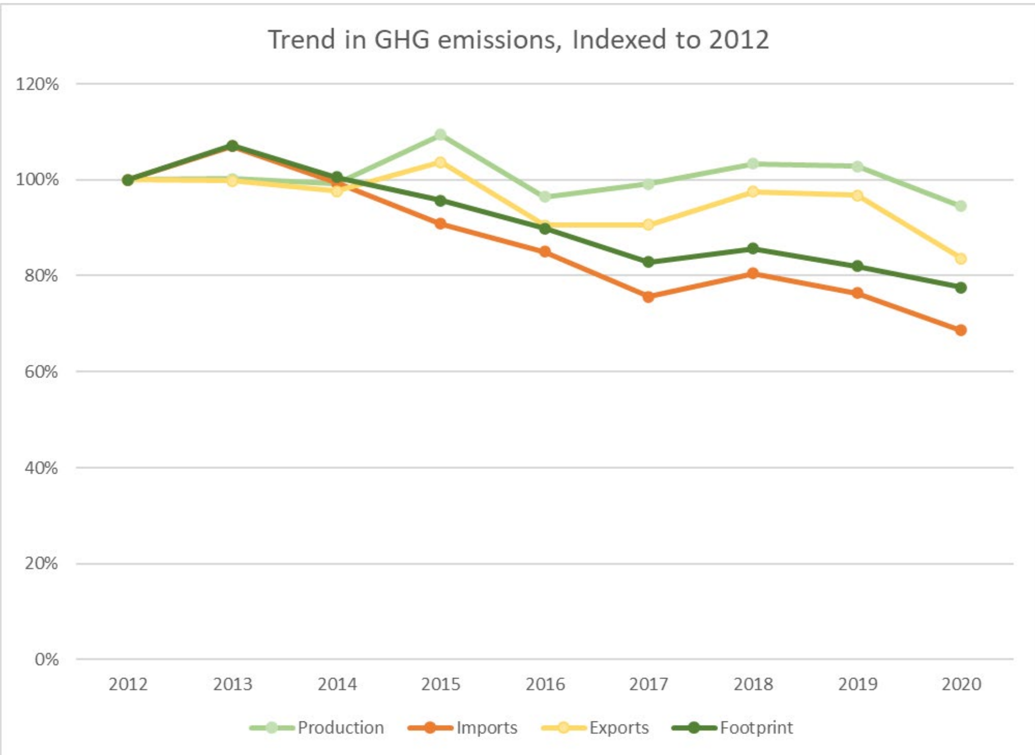

Figure 9 Trends in greenhouse gas emissions indexed to 2012 values: production-basis; emissions embodied in gross imports and exports; and resultant carbon footprint of Norwegian Economic Activity, 2012-2020.

The breakdown of the Norwegian footprint for greenhouse gas emissions is shown in Figure 10, distinguishing by domestic and foreign sources (see Figure 6 for a more detailed breakdown for 2020). 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 "net imports" and are emissions released in foreign countries embodied in goods and services that are consumed in Norway. The domestic component of the footprint is rather flat, with a slight decrease again in 2020. The emissions embodied in net imports have declined. The causes in terms of product groups and source of these emissions will be explored in later results. Note also 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 (see Table 2).

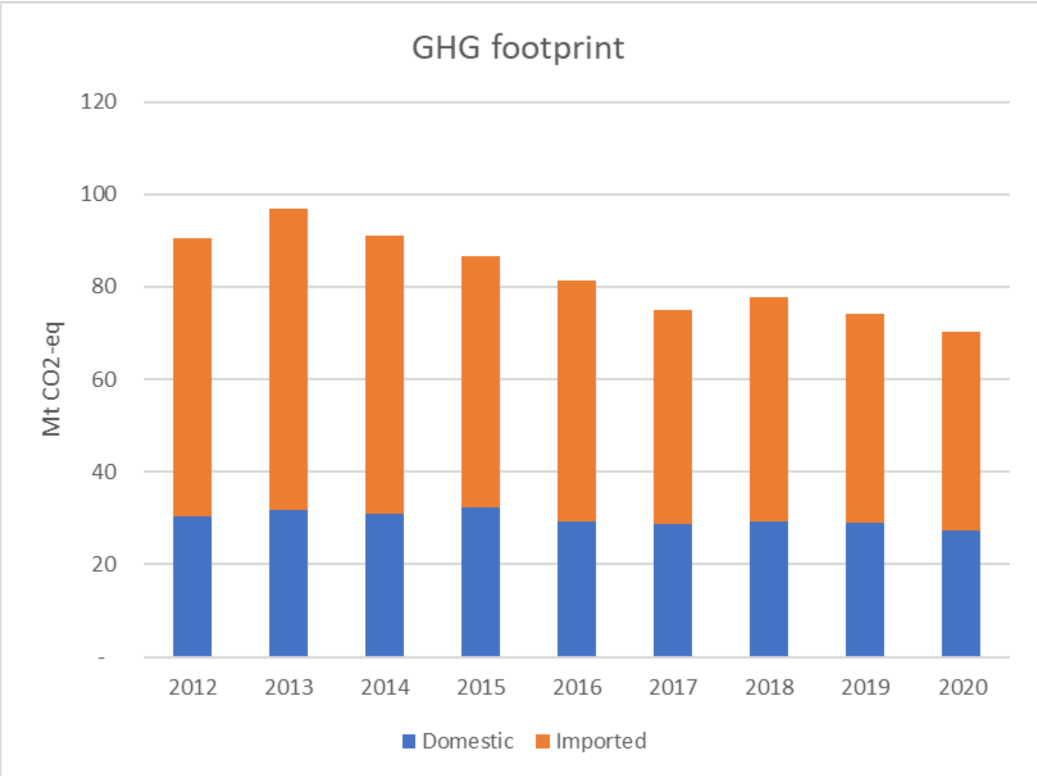

Figure 10 Trends in greenhouse gas footprints broken down into domestic and foreign (net-import) sources, kt CO_2-eq., 2012-2020.

5.4 Trends in greenhouse gases by emission type, 2012-2020

This section provides summary figures for trends in greenhouse gas emissions by emission type, similar to that in section 5.3. CO_2, CH_4 and N_2O emissions are shown. Emissions due to fluorocarbons are not shown explicitly (but are available in supporting result files). There is a much higher uncertainty on emissions from fluorocarbons. The figures here are included for completeness purposes, and further insight can be derived by analysing the detailed result files.

CO_2 emissions broadly follow the greenhouse gas emissions, with 87% of the greenhouse gas production account being CO_2 and 73% of the greenhouse gas footprint account being CO_2 in 2020. The discrepancy between these percentages points to the relatively higher importance of non-CO_2 gases embodied in imports (see following figures). Of note is that the import account for CO_2 has reduced the fastest of all accounts (Figure 11, left), whilst still dominating the domestic contributions (Figure 11, right). Further work is needed to distinguish between changes in volume of imports (NOK of imports expressed in constant prices) and the emissions intensity of foreign production (see discussion).

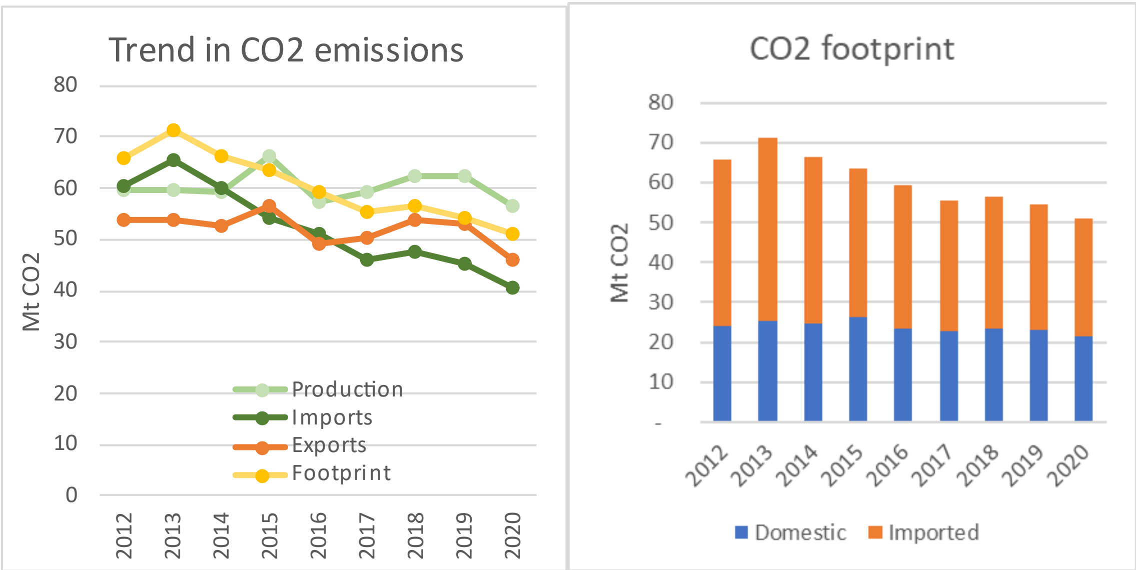

Figure 11 Trends in CO_2 emissions: production-basis; emissions embodied in gross imports and exports; and resultant carbon footprint of Norwegian Economic Activity, 2012-2020. Right hand side: footprint broken down by domestic versus foreign source. Note a portion of emissions embodied in imports will be embodied in exports, and not form part of the Norwegian carbon footprint – this explains the reasons for differences in the import emissions on the left- (net-concept) and right-hand (gross-concept) side.

Changes in CH_4 emissions are affected principally by the dominance of the import account, which is well over 80% of the total footprint account (Figure 12), due to the very small volumes of CH_4 reported by Statistics Norway. Norway imports a significant amount of agricultural and food products, which embody high levels of methane (and N_2O). Furthermore, the Norwegian statistics show imports of oil and gas products (despite the high levels of domestic production), and foreign products have much higher fugitive emissions associated with their production. Due to the aggregation effects in the Norwegian input-output table, the oil and gas sector is included in the more aggregate mining and quarrying sector, so there is potential for the aggregation of emissions intensive goods with non-emissions-intensive goods. However, the use of EXIOBASE, which has a detailed breakdown for mining and quarrying for the calculation of foreign emissions shows that extraction of crude oil is the main product group within this more aggregate sector. The EXIOBASE data shows 73% of the value of imports in mining and quarrying is from crude oil extraction, and 79% of the CH_4 emissions of the mining and quarrying sector are from imports of crude oil. Similar to CO_2 we see a decline in emissions embodied in imports which needs further investigation to determine whether it is due to import volume effects in constant price, or due to changes in emissions intensity of foreign goods. We would recommend that the CH_4 results are interpreted with some caution, due to the uncertainty in real world emissions (see discussion).

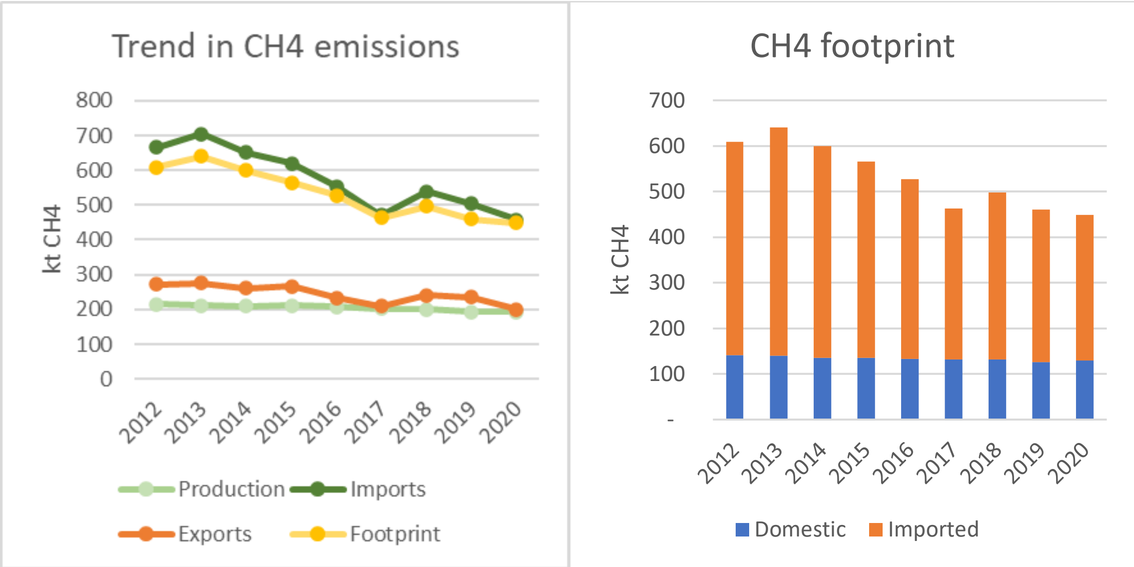

Figure 12 Trends in CH4 emissions: production-basis; emissions embodied in gross imports and exports; and resultant carbon footprint of Norwegian Economic Activity, 2012-2020. Right hand side: footprint broken down by domestic versus foreign source. Note a portion of emissions embodied in imports will be embodied in exports, and not form part of the Norwegian carbon footprint – this explains the reasons for differences in the import emissions on the left- (net-concept) and right-hand (gross-concept) side.

Changes in N_2O emissions follow similar trends to the other gases, with the dominance of the net-import account in the total footprint maintained over the time series (Figure 13, right), but at a slightly reduced rate (Figure 13, left). Production emissions have been rather flat, with a slight decline in emissions embodied in exports.

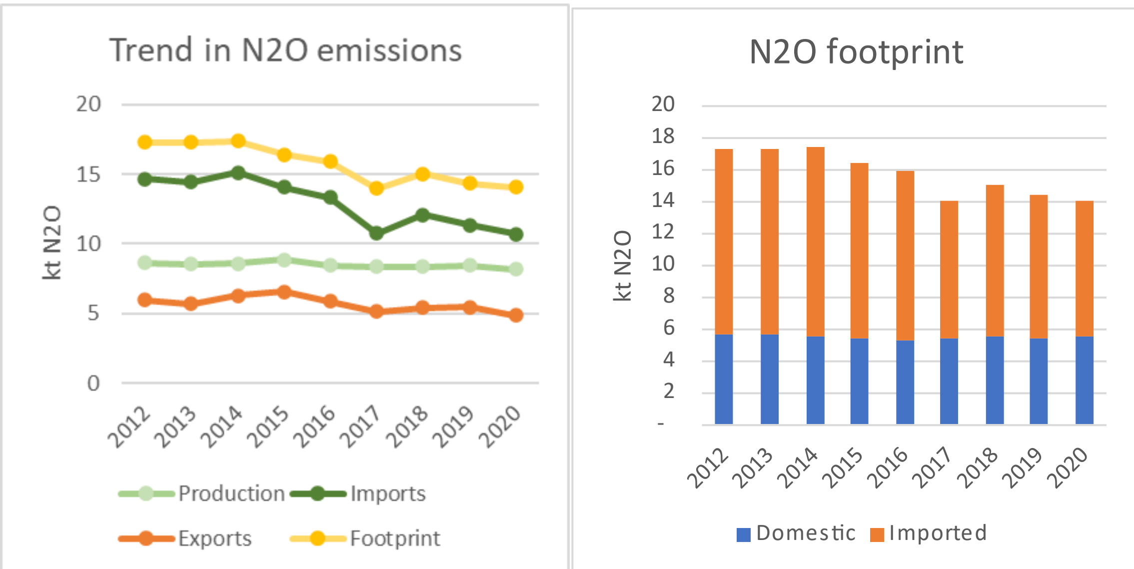

Figure 13 Trends in N_2O emissions: production-basis; emissions embodied in gross imports and exports; and resultant carbon footprint of Norwegian Economic Activity, 2012-2020. Right hand side: footprint broken down by domestic versus foreign source. Note a portion of emissions embodied in imports will be embodied in exports, and not form part of the Norwegian carbon footprint – this explains the reasons for differences in the import emissions on the left- (net-concept) and right-hand (gross-concept) side.

5.5 Greenhouse gases by product group, 2020

The below series of charts show greenhouse gas emissions by product group. To aid the visualisation, the 65 sectors of the Norwegian air emissions accounts and input-output tables are aggregated to 17 sectors as per the aggregation key in the appendix. The full sector breakdown can be found in the result files.

Direct household emissions (those emissions from residential transport and combustion of fuels in the home) are not shown in these product-group charts in this section, only emissions due to industrial activity.

The first figure shows the direct emissions by industrial sector in Norway (Figure 14). They are results taken directly from the SSB Air Emission Accounts and do not include the supply-chain perspective. In summation, they total the Norwegian production account. The two largest sectors are transport and mining. The transport emissions are dominated by water transport (16.3 Mt CO_2-eq), of which international water transport (emissions by residents abroad) is the main component and the main difference to the territorial accounts. The mining sector is dominated by oil and gas mining. The breakdown by type of gas is provided in Figure 15 and highlights the prevalence of CH_4 and N_2O in the agricultural sector. The methane emissions in the electricity, gas and water sector are likely dominated by the inclusion of sewerage services in this sector.

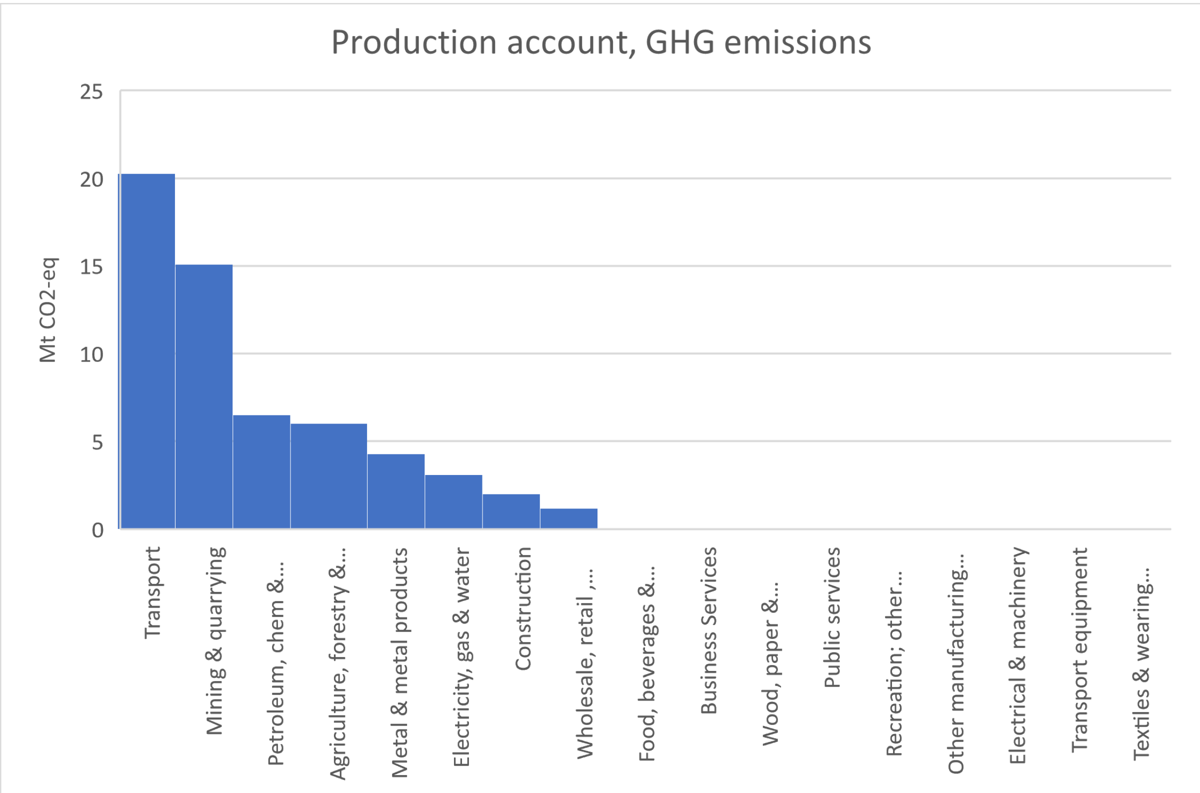

Figure 14 Emissions by emitting sector (production account), aggregated to 17 sectors. Obtained from SSB Air Emission Accounts, 2020. Greenhouse gas emissions (blue bars) in Mt CO_2-eq. Full aggregated sector names can be found in the Appendix 6 – section 1.

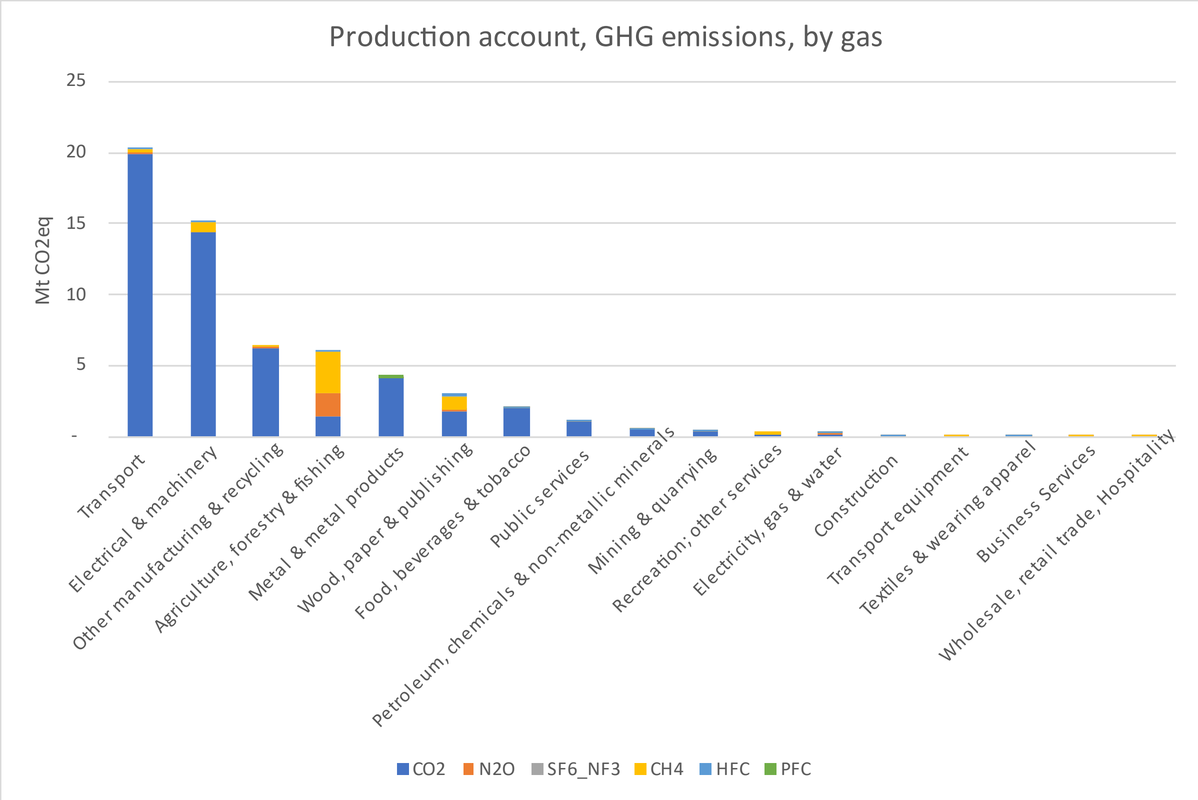

Figure 15 Emissions by emitting sector (production account) broken down by gas, aggregated to 17 sectors. Obtained from SSB Air Emission Accounts, 2020. Kt CO_2-eq. Direct household emissions are not included in this figure. Full aggregated sector names can be found in the Appendix 6 – section 1.

Next, we discuss the emission footprints by final goods/service in Norway (Figure 16). They include emissions due to household consumption, government consumption and capital formation, and include both domestic and foreign emissions, as well as the final demand of domestically produced goods and imported goods. They exclude emissions embodied in exported goods. In summation, they total the Norwegian footprint account. The sector breakdown shown here is the same sector breakdown as the production account (65 NACE sectors aggregated to 17 sectors). In these results, we refer to the "final demand" for goods and services from the sector, however. 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 categories.

The two largest final demand sectors are construction and public services. The construction sector has a footprint of 9.4 Mt CO_2-eq., whilst the public services, which has very small direct emissions (see above), has a footprint of 7.0 Mt CO_2-eq. The public service sector includes public administration, health services, education and social services, and is a significant sector of the Norwegian economy. The breakdown by type of gas is provided in Figure 17. The expected allocation of CH_4 and N_2O, mainly from the agricultural sector to food products and agricultural goods is evident.

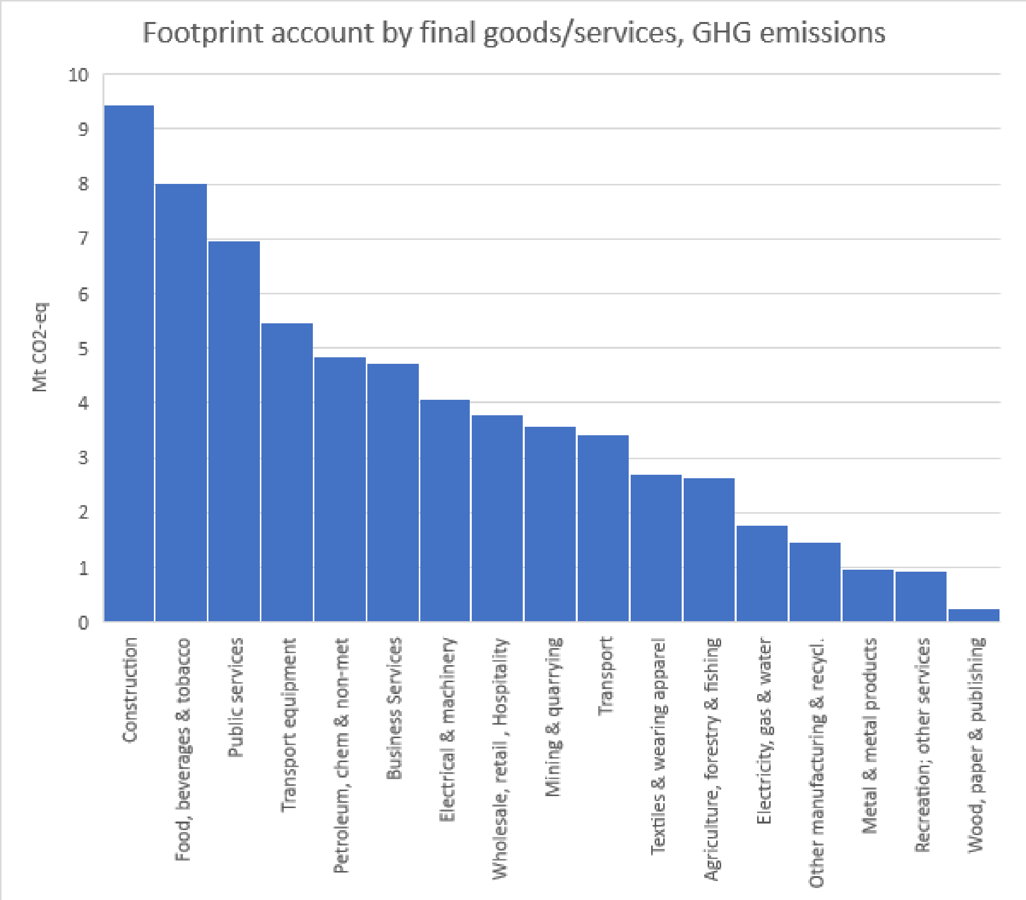

Figure 16 Emissions embodied in final products, as calculated, aggregated to 17 sectors, 2020. Greenhouse gas emissions, Mt CO_2-eq. Direct household emissions are not included in this figure. Full aggregated sector names can be found in the Appendix 6 – section 1.

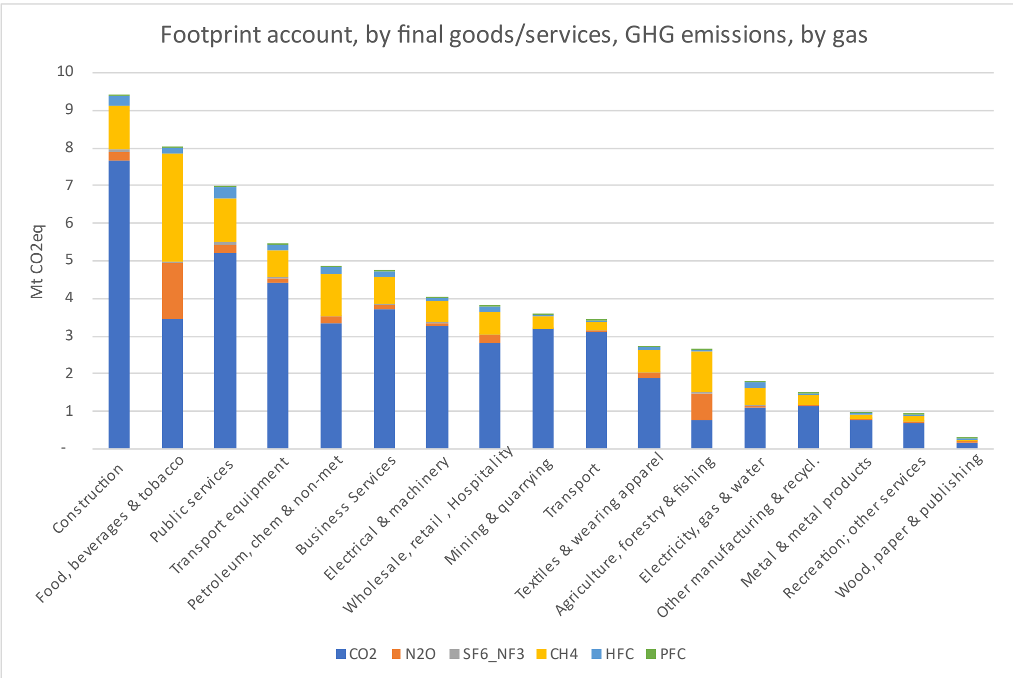

Figure 17 Emissions embodied in final products, as calculated, aggregated to 17 sectors, 2020, by type of gas, Mt CO_2-eq. Direct household emissions are not included in this figure.

The footprints can also be broken down into emissions from domestic and foreign sources (as per explanation in Figure 6, net-trade result). Figure 18 shows the division of Figure 16 into the domestic and foreign components. This highlights already the significance of imported manufactured goods (very high percentage imports of electrical and machinery, etc.), which will be further explored in Figure 19.

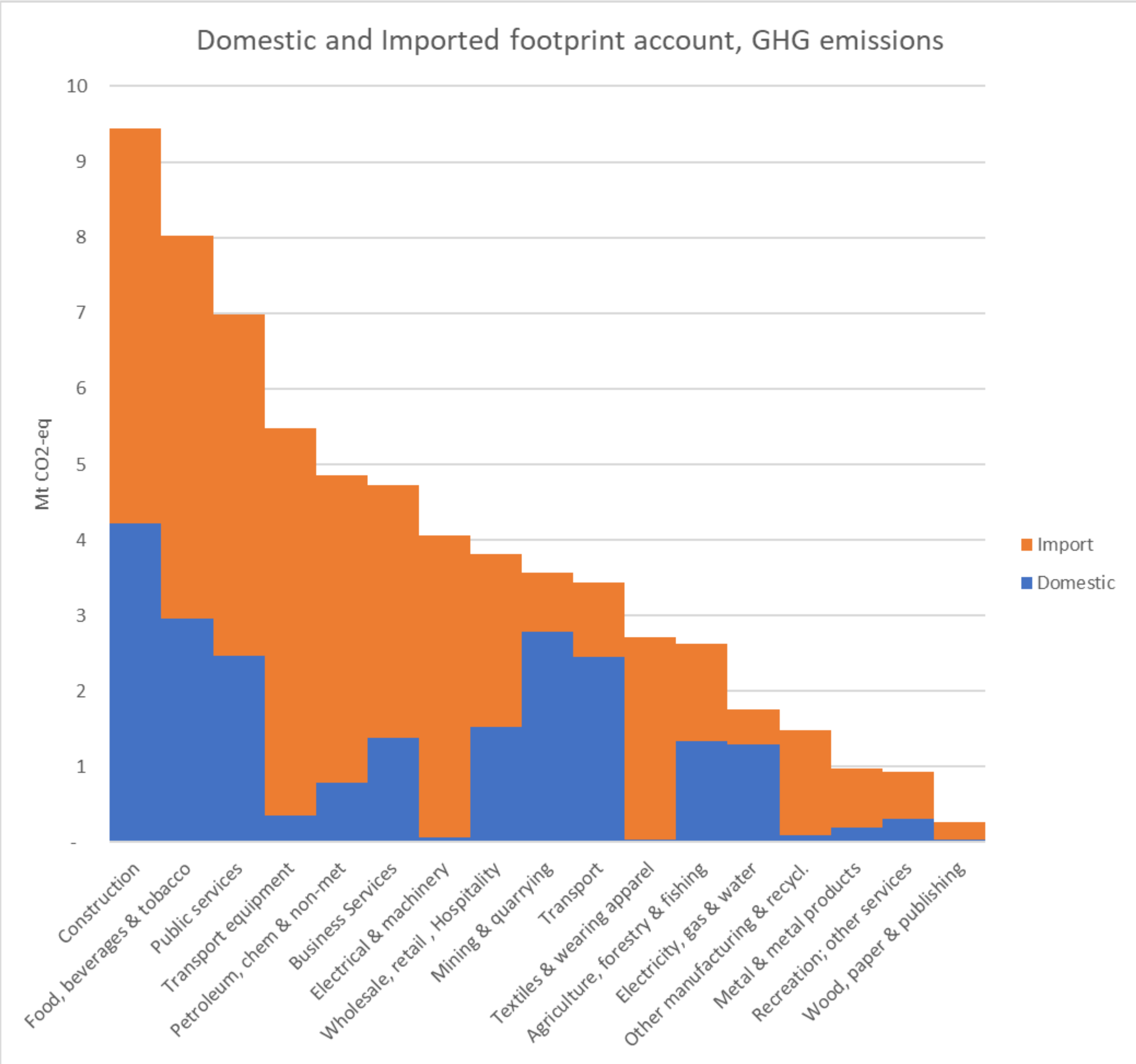

Figure 18 Emissions embodied in final products, broken down by import (orange) and domestic (blue) sources, as calculated, aggregated to 17 sectors, 2020. Greenhouse gas emissions, Mt CO_2-eq. Direct household emissions are not included in this figure.

Figure 19 shows the emissions embodied in goods and services that are imported into Norway. Whilst Figure 18 shows the component of the emissions footprint final good or services that occurs overseas (net-trade approach), Figure 19 shows the emissions embodied in goods and services actually imported (gross-trade approach). The difference being that imported goods and services may go direct to final demand but may also be inputs into production processes in Norway. For example, whilst Figure 19 shows that construction services are not imported into Norway (or more precisely have zero embodied emissions in imports), Figure 18 shows that emissions embodied in intermediate goods and services, such as construction materials, machinery and equipment are a significant component of the footprint of construction services. From Figure 19 we can see that that indeed manufactured goods are the primary source of embodied emissions in imports. Petroleum, chemicals and non-mineral products were the highest category of 15.3 Mt CO_2-eq. Electrical and machinery has over 8 Mt CO_2-eq. embodied emissions, followed by metal and metal products (6.6 Mt CO_2-eq.), food and beverages (5.0 Mt CO_2-eq.) and transport equipment (4.9 Mt CO_2-eq.).

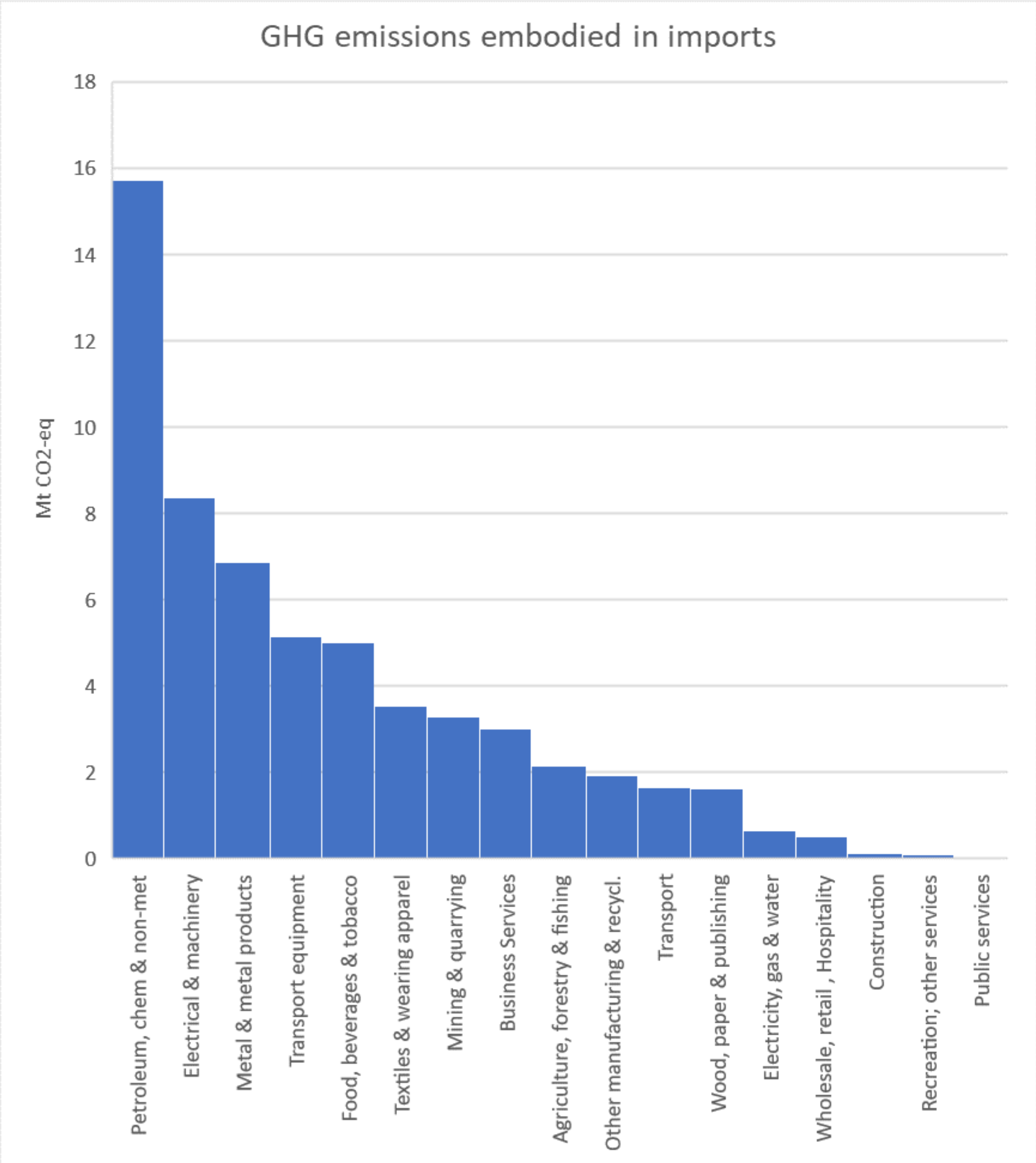

Figure 19 Emissions embodied in imported products (gross-trade), as calculated, aggregated to 17 sectors, 2020. Greenhouse gas emissions, Mt CO_2-eq. Full aggregated sector names can be found in the Appendix – section 1.

Switching to the export perspective, it is possible to also show the emissions embodied in exported products. Transport is the largest sector here with 17.7 Mt CO_2-eq., again, principally from the emissions associated with water transport by non-residents, for example emissions from shipping activity by Norwegian registered companies operating abroad. Mining and quarrying, dominated by the (upstream) emissions embodied in the export of oil and gas amounts to 13.6 Mt CO_2-eq. 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 is included, whereas the emissions from the combustion of these emissions outside of Norway are not included. A quick analysis of the World Extended Energy Balances by the International Energy Agency (data source used for the energy and emissions accounts in EXIOBASE) shows that in 2020, Norway exported energy products with the potential CO2 emissions of 507 Mt. Crude oil and natural gas exports accounted for 236 Mt and 220 Mt, respectively. These are however only potential emissions, as the emission factors depend on the process in which the energy product is combusted. For this analysis, the average Norwegian emission factor was used for each exported energy product.

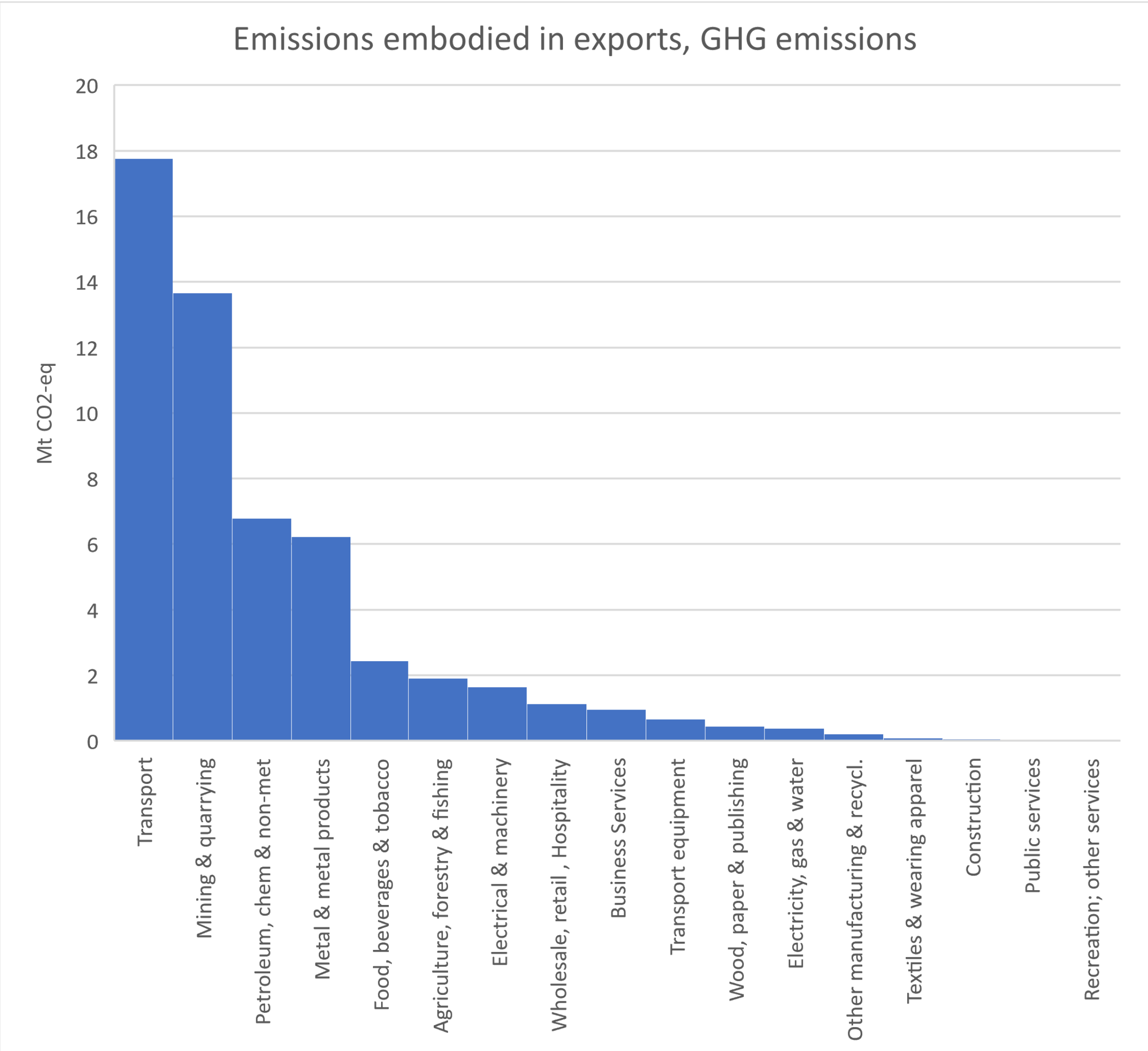

Figure 20 Emissions embodied in exported products, as calculated, aggregated to 17 sectors, 2020. Greenhouse gas emissions, Mt CO_2-eq. Full aggregated sector names can be found in the Appendix 6 – section 1.

5.6 Changes in greenhouse gases by product group, 2012-2020

Switching to the full sector resolution, we next investigate the net change in emission footprints per product between 2012 and 2020. Analysis was also done for intermediate years (especially with a focus on the changes prior to the pandemic). Throughout all gases, we find the largest reduction in the hospitality sector *Accommodation and food services* – (Table 5 – Table 7), followed by petroleum and chemicals. Whilst some of this reduction was due to the economic downturn in certain sectors due to the COVID pandemic, the top 3 sectors of reduction, also recorded the top 3 reductions in the period 2012-19. The reduction in emissions embodied in air transport services occurred mainly in 2019-2020. As per previous temporal results, to fully explain whether these changes were due to production practices or volume of imports would need constant price import data, and a decomposition of the result. This could be looked at in further work.

Notably, the emissions embodied in construction services and public services were not amongst the sectors that saw the largest positive or negative changes (despite being the largest sectors of the footprint results for 2020). Construction services were flat over the period 2012-2020. Public services were also flat, mainly due to a reduction in the footprint of education, offsetting a 0.3 Mt CO_2-eq. increase in health services.

Products	GHG; Mt CO2-eq
Accommodation and food services	-3.59
Petroleum, chemicals and pharmaceuticals	-2.66
Textiles, wearing apparel and leather products	-2.04
Air transport services	-1.37
Travel agency, tour operator and other reservation services and related services	-1.28
Products of agriculture, hunting and related services	0.18
Mining and quarrying	0.25
Sewerage and waste management	0.27
Human health services	0.31
Food products, beverages and tobacco products	0.40

Table 5 Changes in greenhouse gas emissions by product group, 2012-2020, top 5 positive and negative contributions. 65 product group detail.

Products	CH4; kt
Accommodation and food services	-48.62
Textiles, wearing apparel and leather products	-15.61
Petroleum, chemicals and pharmaceuticals	-13.94
Mining and quarrying	-7.93
Travel agency, tour operator and other reservation services and related services	-6.38
Fabricated metal products, except machinery and equipment	0.38
Repair and installation services of machinery and equipment	0.49
Sewerage and waste management	1.90
Products of agriculture, hunting and related services	2.44
Human health services	3.74

Table 6 Changes in methane emissions by product group, 2012-2020, top 5 positive and negative contributions. 65 product group detail.

Products	N2O; kt
Accommodation and food services	-1.77
Petroleum, chemicals and pharmaceuticals	-0.32
Textiles, wearing apparel and leather products	-0.29
Travel agency, tour operator and other reservation services and related services	-0.19
Fish and other fishing products; aquaculture products; support services to fishing	-0.12
Motor vehicles, trailers and semi-trailers	0.02
Human health services	0.02
Sewerage and waste management	0.05
Products of agriculture, hunting and related services	0.15
Food products, beverages and tobacco products	0.19

Table 7 Changes in N_2O emissions by product group, 2012-2020, top 5 positive and negative contributions. 65 product group detail.

5.7 Regional origin of emissions

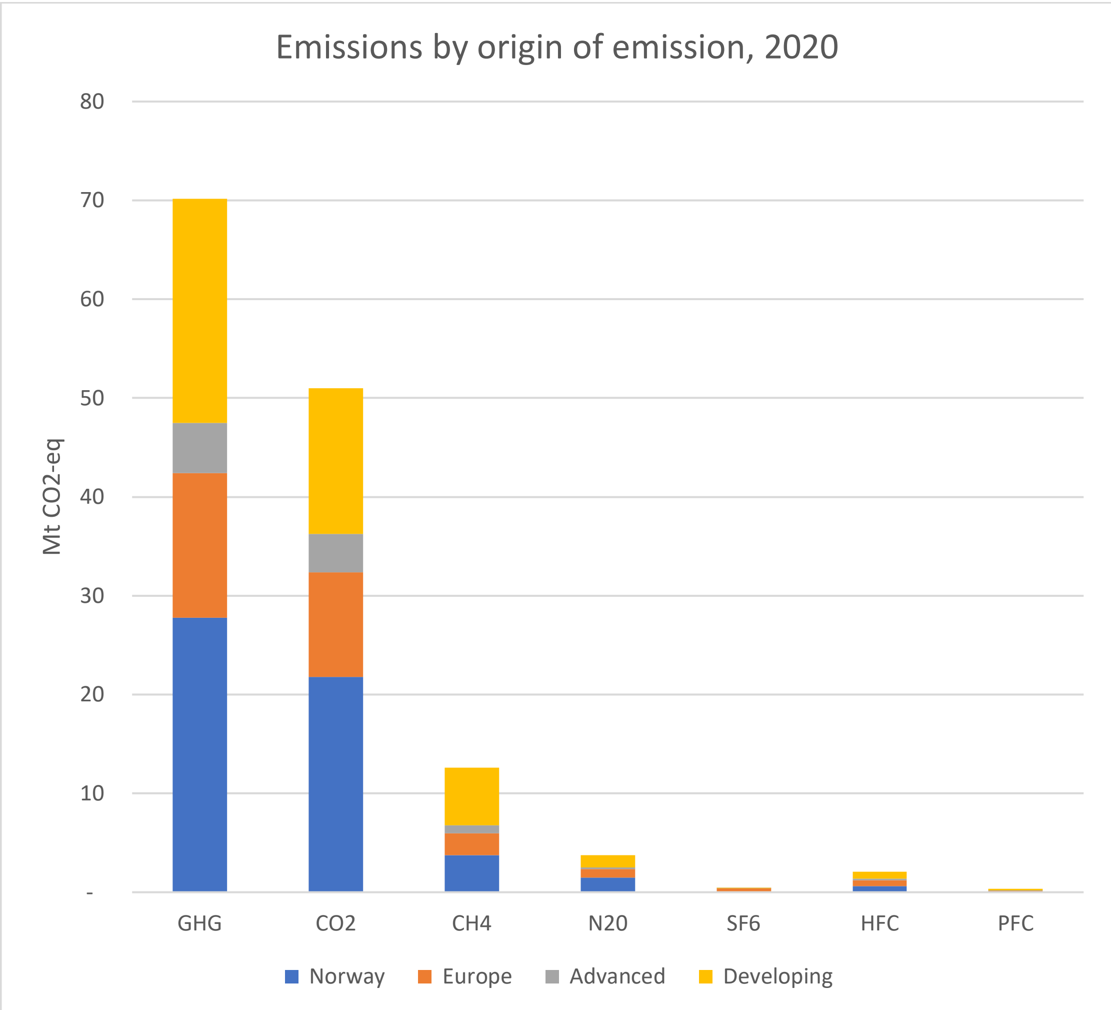

Figure 21 Emissions embodied in final products, by origin of emissions, as calculated, 2020. The country classification into Advanced and Developing economies can be found in the Appendix.

This section breaks down the carbon footprint of Norway into region of origin. Whilst the "domestic" and "import" components were presented in section 5.2, this section further breaks down the "import" component into region of origin. 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. The aggregation key is provided in the appendix.

Figure 21 show the origin of emissions by emission type for the year 2020. For most emission types, except CO_2, the emissions are sourced from domestic or advanced economies. CO_2 emissions, however, have significant origins in developing countries (largely dominated by imports from China).

The breakdown of the embodied greenhouse gas emissions by sector of final demand is provided in Figure 22. Here the strong results for construction materials, machinery and equipment imported from developing countries are evident.

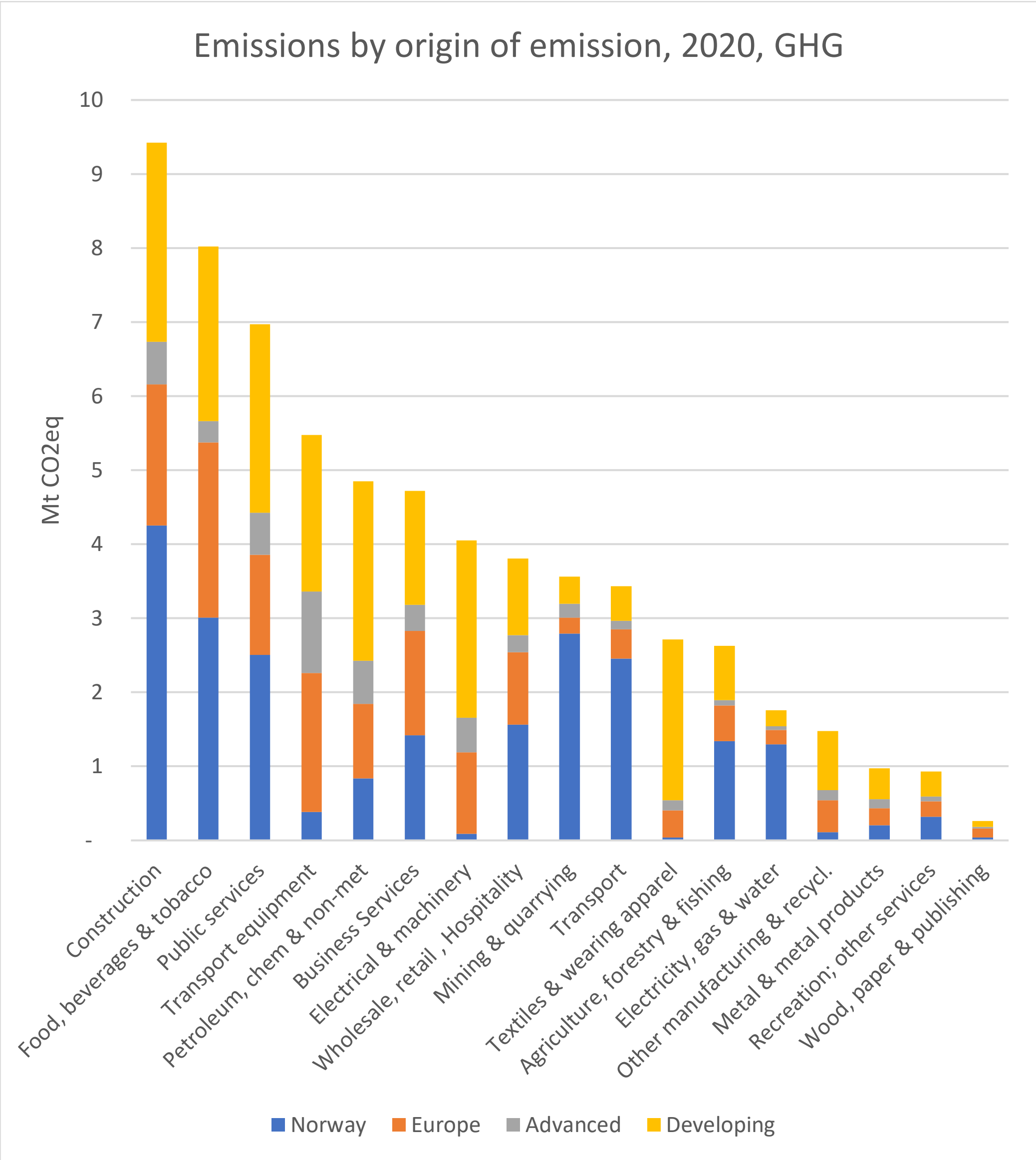

Figure 22 Emissions embodied in final products, by origin of emissions, as calculated, aggregated to 17 sectors, 2020. Greenhouse gas emissions, Mt CO_2-eq. Note, excludes direct household emissions. The country classification into Advanced and Developing economies can be found in the Appendix.

5.8 Final demand categories – household and government

In this section, the results are broken down by final demand category (see methods). Households (*Final consumption expenditure by households* in the official accounts) are by far the largest category of final demand – both in terms of expenditure and carbon footprint (Figure 23). Households account for roughly one-third of expenditure of final demand (excluding exports) in 2020, but as they tend to purchase on average more emission intensive goods than other sectors, they account for roughly half of the national carbon footprint. 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 emission intensities (Figure 24). It should be noted that the provision of public services (rather than the expenditure for the services) is accounted for as an industry in the input-output tables. The government has a dual role of providing public services and paying for them. In the provision of government services, the carbon footprint of government procurement could be calculated, but as an intermediate producer, rather than a component of the national carbon footprint. Furthermore, government expenditure on fixed capital investments is included in gross fixed capital formation, along with private investments (roughly 30% of national carbon footprint). *Final consumption expenditure by non-profit organisations serving households (NPISH)* play only a very minor role in the Norwegian final demand. Changes in inventories contributes 7 Mt CO_2-eq, a not inconsequential component. In the detailed results, it shows this largely due to construction of 1.8 Mt CO_2-eq (incomplete construction projects or components of construction), food products of 1.4 Mt CO_2-eq, mining and quarrying of 0.9 Mt CO_2-eq and petroleum products of 0.5 Mt CO_2-eq. These results are the addition to inventories of these goods for future years usage, but should be treated with caution, due to the sometime use of inventories as a balancing item in input-output tables.

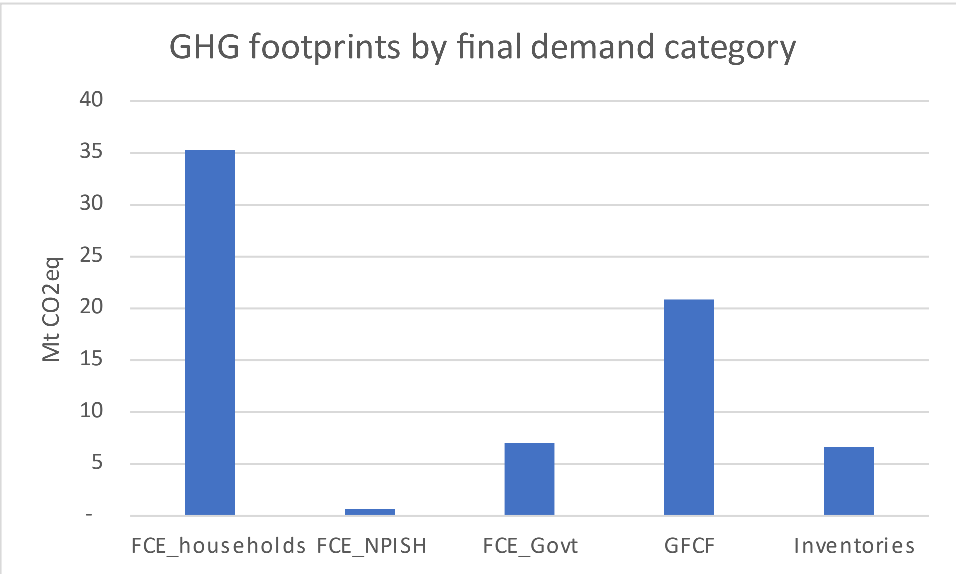

Figure 23 Breakdown of GHG footprint, by final demand category, 2020. Greenhouse gas emissions, Mt CO_2-eq. (FCE_households: Final consumption expenditure by households, FCE_NPISH: Final consumption expenditure by non-profit institutions serving households, GFCF: Gross fixed capital formation, Inventories: Changes in Inventories)

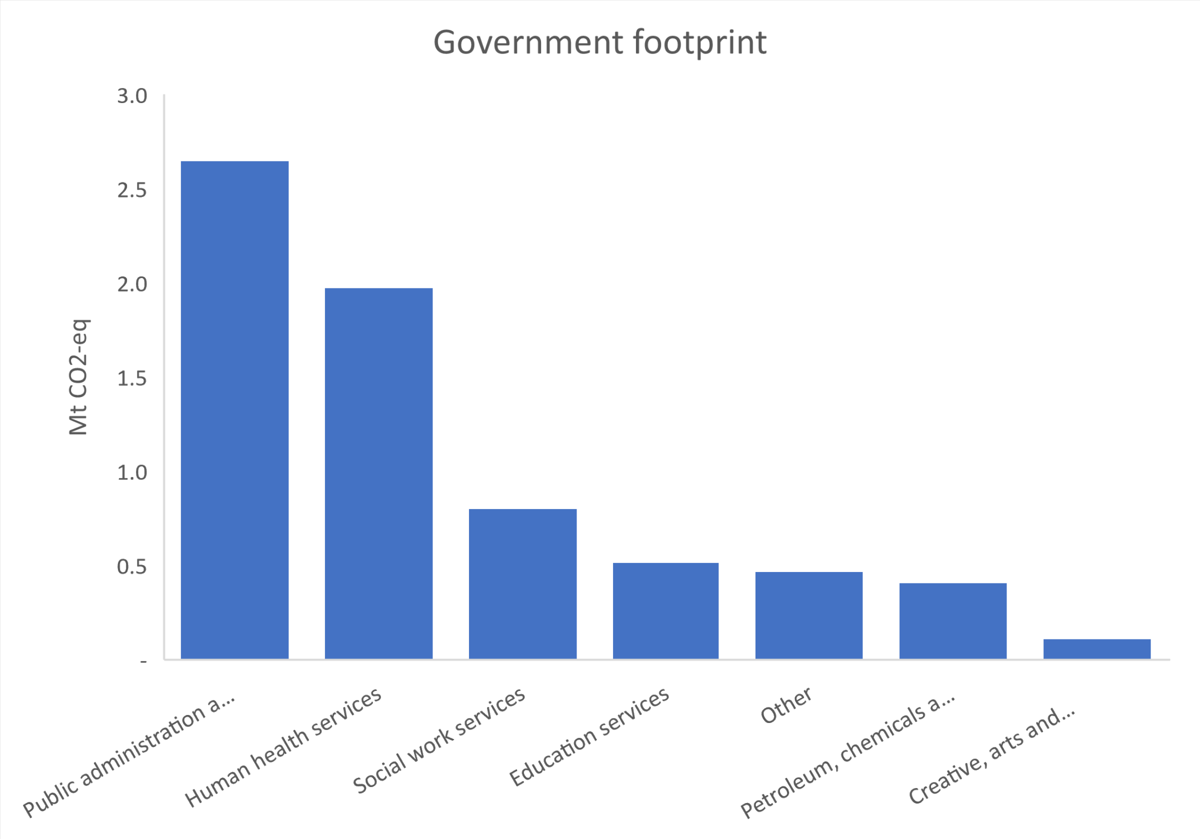

Figure 24 Breakdown of GHG footprint for government final consumption, by product group at the 65-sector level, 2020. Greenhouse gas emissions, Mt CO_2-eq. Categories are not aggregated to 17 sectors due to the concentration of footprints in relatively few sectors at the 65-sector classification.

The household carbon footprint (Figure 25) is dominated by food emissions. Over 6.5 Mt CO_2-eq. are embodied in the supply chain of manufactured food, and an additional 2.5 Mt CO_2-eq. is embodied in agricultural produce and 3.2 Mt CO_2-eq. in hospitality (which encompasses accommodation and food services, as well as the provision of wholesale and retail services). Note that in the figure below (in contrast to the product level results in section 5.5), direct emissions from household use are presented alongside the goods and services produced in the economy in order to give a complete household account. 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), and an additional 2.1 Mt CO_2-eq. are due to the purchase of transport services (air transport and road transport such as taxis and buses – this would include the full supply-chain of providing the transport service, so both the fuel combustion emissions, and other emissions in the supply chain of the sector such as due to repair and maintenance. 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 consistency of the input-output tables with national accounting conventions. The contribution of capital is relatively minor compared to the fuel use. The further investigation of capital footprints follows the household result (Figure 26), but the items included in capital footprints are used in the provision of both household and industrial services.

The third most important category in the household account is petroleum products, chemicals, pharmaceuticals and non-metallic minerals, which are aggregated in one product group in the

Norwegian input-output tables. Whilst this excludes the combustion of fuels in vehicles by households (counted in the direct household emissions), it includes the supply-chain emissions in the provision of those fuels. Textiles and wearing apparel contribute 2.7 Mt CO_2-eq.

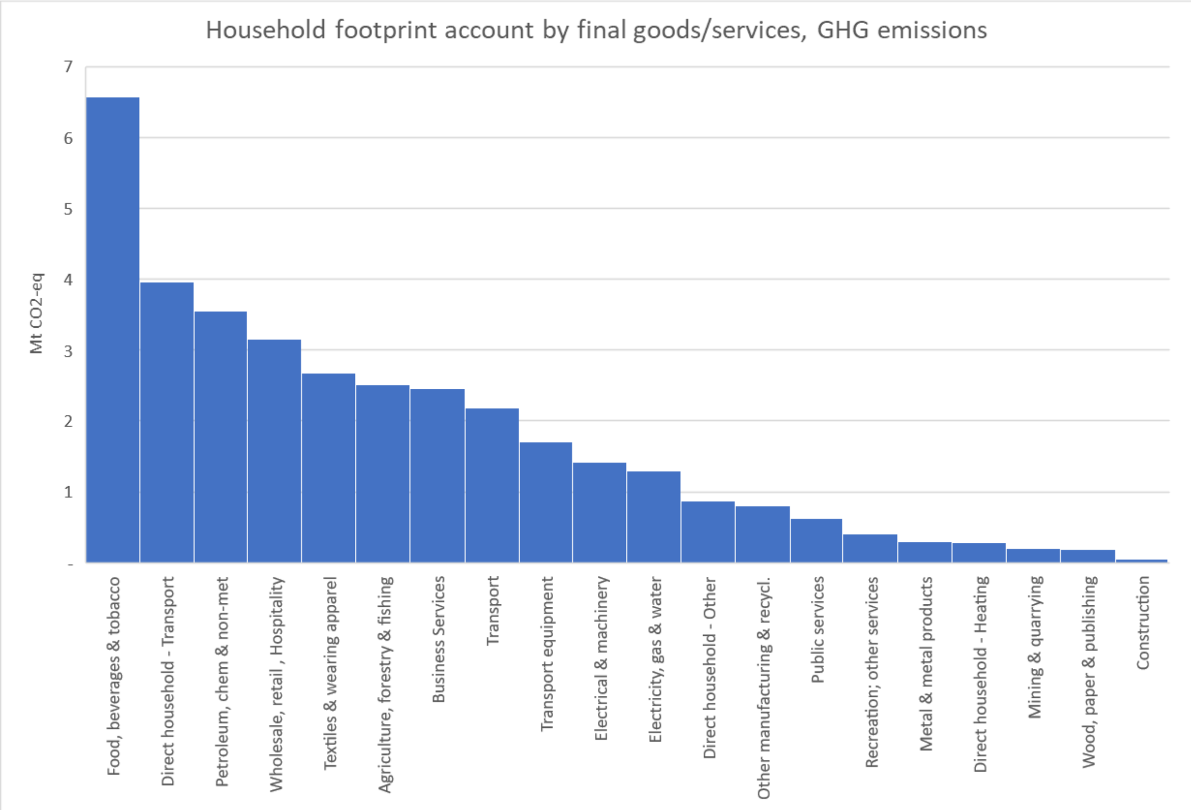

Figure 25 Breakdown of GHG footprint household final consumption, by product group, 2020. Greenhouse gas emissions, Mt CO_2-eq.

The main contributions to the greenhouse gas footprint of gross fixed capital formation are shown in Figure 26. 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 verse private investments. The footprint captures the fully supply-chain emissions, so would include the emissions due to production of steel, cement or wood used in construction, as well as the direct emissions of the sector itself. Further analysis of this sector could use a structural path analysis or production-layer decomposition approach to break down the relative contributions of different products in the construction result, but this would need further calculations performed, and could be considered for follow-up work.

Other major items are predictably transport equipment, machinery, equipment and electronic devices. The mining and quarrying sector shows the third highest impact. This footprint relates to the goods and services that the mining and quarrying sector produces, rather than what it consumes. It is not immediately obvious what the main items would be here, but it possible that some of the production of the sector is not just oil and gas, but also advanced software or mining specific equipment that the sector produces in house.

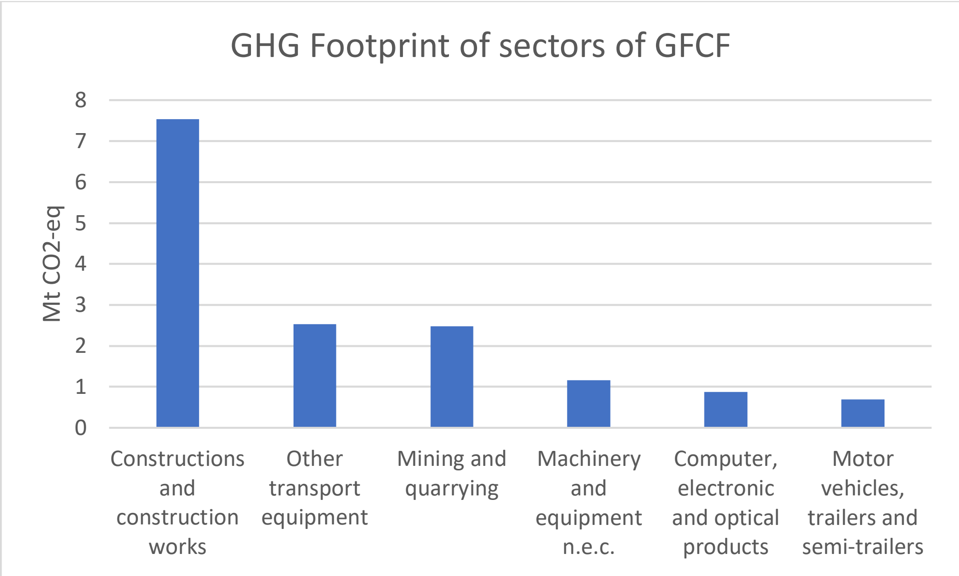

Figure 26 Breakdown of GHG footprint for gross fixed capital formation (GFCF), by product group at the 65-sector level, 2020. Greenhouse gas emissions, Mt CO_2-eq. Categories are not aggregated due to the concentration of footprints in relatively few sectors.

5.9 Biomass CO_2

Carbon dioxide emissions due to biomass combustion are presented in this section. Note that these figures should be considered experimental, due to the less advanced accounting conventions around biogenic CO_2 (see 4.3). 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 a roughly 50/50 split between biomass from domestic sources and foreign sources in the footprint using biomass CO_2.There was a higher rate of growth (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.

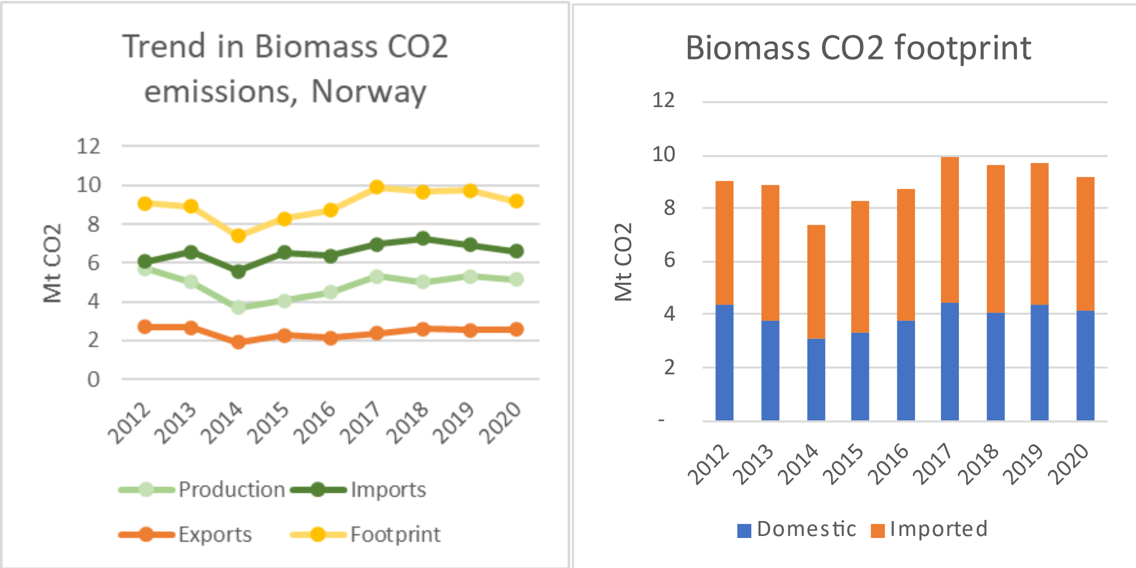

Figure 27 Trends in biomass CO_2: production-basis; emissions embodied in imports and exports; and resultant carbon footprint of Norwegian Economic Activity, 2012-2020. Right hand side: footprint broken down by domestic versus foreign source. Note a portion of emissions embodied in imports will be embodied in exports, and not form part of the Norwegian carbon footprint – this explains the reasons for differences in the import emissions on the left- and right-hand side.

6 Discussion

6.1 Validation

In terms of validating model results against previous estimates, there are several external estimates that can be used to compare results. However, all are model results, and as indicated in the motivation for choice of a coupled model, the results vary significantly. EXIOBASE[11] and GLORIA (v057) provide footprints of both greenhouse gas emissions and carbon dioxide. The FIGARO database produced by Eurostat gives estimates for carbon footprints at the same product level as this project, but only for CO_2 emissions[12]. The Global Carbon Project (GCP)[13] provides estimates CO_2 from fuel combustion and cement only. A supplementary results files shows the totals from available MRIO models (see also Table 8 and Table 9), as well as detailed FIGARO results.

CO2		2012	2013	2014	2015	2016	2017	2018	2019	2020
CaFEAN	Production	58,099	58,391	57,906	64,939	56,321	58,875	61,964	62,333	56,733
CaFEAN	Footprint	64,390	69,812	65,110	62,315	58,144	54,726	55,983	54,404	50,986
FIGARO	Production	59,582	59,791	59,437	66,318	57,484	59,578	62,579	62,348	58,086
FIGARO	Footprint	66,092	68,711	66,908	64,718	66,506	66,858	70,000	71,755	64,933
GCP	Production	44,300	44,586	45,046	45,590	44,765	44,242	44,393	42,784	41,196
GCP	Footprint	48,362	48,983	48,609	50,577	49,521	50,313	49,776	49,111	47,107
GLORIA	Production	35,794	36,109	35,992	38,062	37,410	37,141	36,356	34,766	33,446
GLORIA	Footprint	46,743	46,334	44,041	42,823	43,709	42,377	44,327	40,059	34,850
EXIOBASE382	Production	67,911	71,454	69,401	68,383	68,660	66,713	67,811	65,991	70,008
EXIOBASE382	Footprint	57,462	57,427	58,540	61,044	60,847	65,255	65,442	64,550	66,649

Table 8 Comparison of CO_2 only results for different projects. Kt CO_2. See text for partial explanations of differences. Note GCP explicitly excludes bunker fuels.

By design, the production-based account of this project mirrors the Statistics Norway data on greenhouse gas emissions according to the residential principle. The results in this project show an 8% higher footprint account in comparison to the production-based account, but if we only look at CO_2, the project results show a 10% lower footprint than production. Statistics Norway reports very low domestic CH_4/N_2O, and the amounts of those gases embodied in imports is much higher. For CO_2 only, other available models all report different quantities, and also trends. The Global Carbon Project has a significantly lower production and footprint account, likely because it only includes CO_2 from fuel combustion and cement, and excludes bunker fuels, which are significant in the water transport sector for Norway. The Global Carbon Project also does not use a full MRIO approach to calculate footprints.

[11] https://zenodo.org/doi/10.5281/zenodo.3583070
[12] https://ec.europa.eu/eurostat/cache/metadata/en/env_ac_co2fp_esms.htm
[13] https://www.globalcarbonproject.org/carbonbudget/22/data.htm

GLORIA also has a significantly lower result as well, even lower than the GCP result. It is not clear from documentation the source of the discrepancy, but as GLORIA follows the EDGAR database[14], it would be based on territorial, not residential accounts. EXIOBASE 3.8.2 has higher results for both production and consumption accounts, likely due to the inclusion of water transport services, and the sensitivity of this sector to the overall result. EXIOBASE has also had high levels of oil and gas flaring emissions, whilst Norwegian data shows this to be quite low amounts for Norway. A deeper comparison goes beyond the scope of this project. The Eurostat model FIGARO is the most useful point of comparison, due to its recent publication, use of a full MRIO approach, and due to the statistical authority of Eurostat. Only CO_2 results can be compared however, due to the lack of non-CO_2 results in FIGARO.

GHG		2012	2013	2014	2015	2016	2017	2018	2019	2020
CaFEAN	Production	69,080	69,253	68,557	75,542	66,645	68,490	71,398	71,038	65,254
CaFEAN	Footprint	90,563	97,002	91,026	86,698	81,350	75,014	77,616	74,255	70,221
GLORIA	Production	64,328	64,516	64,446	67,311	66,546	66,486	65,043	61,827	59,972
GLORIA	Footprint	74,326	74,568	71,291	68,455	70,331	68,057	70,421	65,064	58,346
EXIOBASE382	Production	93,520	100,640	94,223	93,392	93,338	88,015	90,319	87,195	91,697
EXIOBASE382	Footprint	82,923	82,421	83,409	86,523	85,144	88,087	88,187	85,308	88,339

Table 9 Comparison of GHG results for different projects. Kt CO_2-eq. See text for partial explanations of differences.

FIGARO reports the production-account to be 2% higher that the data used in this project, but also estimates the footprint to be 27% higher than the estimate in this project. The principal difference is a much higher estimate for emissions embodied in electricity, basic metals and water transport services. FIGARO reports carbon footprints (CO_2 only) of 11.9 Mt CO_2 for electricity, 7.7 Mt CO_2 for basic metals and 7.4 Mt CO_2 for water transport. In comparison, the estimates of this project are 0.7 Mt CO_2 for electricity, 0.3 Mt CO_2 for basic metals and 1.4 Mt CO_2 for water transport. The estimates of this project follow the Statistics Norway input-output data which show a very minor import of electricity into Norway in 2020 (0.6 billion NOK, or 1% of total electricity production). It is unclear why FIGARO has a much higher estimate for electricity imports. Domestic production of electricity is largely free of greenhouse gas emissions due to the prevalent use of hydroelectricity. For basic metals, Norwegian input-output data shows the vast majority of production exported, with 97% of the final demand for basic metals being exports. There were significant negative inventories of basic metals in the imports use table of Norway (ca 6 billion NOK or 18% of imports), and a differing interpretation may explain some of the differences in result, but unlikely to explain the full difference between the 0.3 Mt CO_2 result here and the 7.7 Mt CO_2 result of FIGARO.

FIGARO also shows a different trend in results to the results of this project. From 2012 to 2019, FIGARO shows an increase in the CO_2 footprint of 9%, followed by a 10% drop in 2020. In comparison, the results of this project estimate a 16% drop over the full time-series. Again, the differences can be traced back to some major changes in a few main sectors. Water transport is again the largest contributor in differences over time, followed by basic metals. As the Norwegian input-output table shows very small final demand, excluding exports, of water transport and basic metals over the time-

[14] https://edgar.jrc.ec.europa.eu/

series, the carbon footprints of the sectors are low (ca 2 Mt CO_2 for water transport and 0.2 Mt CO_2 for basic metals) and reasonably stable in the project results. As FIGARO estimates a much higher footprint (7.4 and 7.7 Mt CO_2 in 2020 for water transport and basic metals respectively) and shows large growth in the transport footprint and fluctuations in the results for basic metals (ca +/- 4Mt CO_2), these sectors drive a significant share in the upward trend in FIGARO results not seen in the coupled model. In contrast, the sector *Textiles, wearing apparel and leather products* shows a reduction in carbon footprint in the results of this project from ca 3.4 Mt CO_2 in 2012 to 1.9 Mt CO_2 in 2020; whilst for FIGARO the results reduce from ca 0.27 Mt CO_2 to 0.17 Mt CO_2. The sector has significantly higher final demand than basic metals, and 90% of the final demand is serviced directly by imports according to the Norwegian input-output tables. The results of this project imply about 4% of the Norwegian CO_2 footprint is due to the sector, whilst FIGARO estimates that the contribution is 0.3%. The share of household expenditure on the sector compared to total household expenditure was 4% in 2020. Two other sectors that drive significant differences in the trend results are *petroleum, chemicals and pharmaceuticals* (2.8 Mt CO_2 footprint in this project in 2020) and *accommodation and food services* (0.8 Mt CO_2 footprint in this project in 2020). The former is an aggregated sector in the Norwegian input-output table but is disaggregated in FIGARO. For *accommodation and food services,* a significant share of the CO_2 footprint is estimated to come from imports in both databases, yet the result is significantly higher in this project.

Particularly for t*extiles, wearing apparel and leather products* and *accommodation and food services,* further investigation is needed to determine the stability and contribution of the emission intensities used, and due to potential strong variation in prices of textile goods and country of origin of imports, a decomposition in constant prices would give the best insight into the accuracy of this specific result (and hence potential focus on mitigation options).

Results for the footprints of non-CO_2 emissions are harder to validate. FIGARO and the Global Carbon Project do not provide estimates, and the EXIOBASE results have overlap to the actual data used in this project (hence differences can be directly ascribed to the difference between Norwegian emission and economic data produced recently by Statistics Norway, and that data which is in EXIOBASE. Non-CO_2 emissions also have a much higher level of uncertainty. Methane estimates have been shown to be systematically underestimated by most countries[15], and similar methodological issues exist for N_2O and fluorocarbons.

6.2 Reflections on uncertainty

Norway is a trade-exposed country, especially in terms of emissions intensive goods (oil and gas; water transport). Hence it is not completely surprising that model results vary. Whilst footprint results usually show a +/-10% variation at the national level, in the previous section, different models were closer to +/-30%. Most of this difference is *likely* due to different accounting concepts used (residential vs territorial approach, coverage of different sources of emissions), and less due to actual uncertainty in data points. However, for the models that used a residential principle for the production account, there was still a high level of variation in results, particularly at product level for some key products when comparing FIGARO and CaFEAN results. The decision to use Norwegian statistical data in both the energy accounts and the input-output tables ensures that the outcomes of this project are consistent with Statistics Norway data.

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[15] https://www.iea.org/reports/global-methane-tracker-2023/understanding-methane-emissions

In terms of coverage of types of air emissions, the project included CO_2, CH_4, N_20 and fluorocarbons. CO_2 is the most well studied air emission type, and the most stable in terms of quantity released per unit of fuel combustion. Whilst some variation was seen between sector level results between FIGARO and CaFEAN for CO_2, it can be expected that even higher differences would be seen for other greenhouse gas emission types and for CO_2 from biomass.

In general, the results can be seen to be an outcome of the combination of the emissions intensity of product (or consumption) and the activity level of production or consumption. The comparison to FIGARO results showed that the activity levels of certain key sectors were responsible for the divergence in results in comparison to CaFEAN. Norway, being a relatively small country in terms of economic output likely sees a larger divergence in data when integrated into a full MRIO framework, such as FIGARO. Small changes in the scope of FIGARO data for sectors such as basic metals had a high impact on the results for Norway. Whilst the major differences between FIGARO and CaFEAN results are traceable to differences in activity levels for key sectors, there were also some differences not directly or fully explainable by activity levels for import-exposed such as clothing and textiles, and accommodation and food services. Checks on emission intensities versus import volume by origin country would be needed there. Such further work is important due to the high volume of emissions embodied in imports for Norway, particularly for non-CO_2 emissions.

Perhaps of higher concern is the divergence in trends in results between modelling efforts. Usually, even when differences in concepts means results vary in absolute levels between models, the trends are much more consistent (Wood et al., 2019). Initial comparisons to the FIGARO work mostly identify differences in activity level in FIGARO data for key sectors (water transport, basic metals) that drive the differences. However, it is not completely possible to understand all causes without a decomposition of results into intensity and activity effects, and to be able to interpret these effects in constant price terms.

6.3 Further work

Due to differences in the trends in Norwegian footprint accounts between this project and other less targeted work, it is recommended that further investigation is done to provide clear signals on the causes for differences. Such work will be facilitated by the increased availability of data in other projects (updates to the EXIOBASE dataset, inclusion of non-CO_2 emissions in FIGARO). However, even in this project, investigating methods for extending the time-series back across changes in statistical methods (i.e., prior to 2012), and updated past the initial impact of the COVID pandemic will help facilitate such comparison.

In terms of further validation and understanding of causal effects in changes in the Norwegian carbon footprint, it is recommended that as far as possible, activity data (the economic data used in the input-output tables) is estimated in constant price in order to be able to compare the stability of economic trends and emission intensities over time. There needs to be further investigation into the robustness of the trends in the footprint result, in order to be confident of the long-term direction of the result. Such analysis would be important for properly understanding the reliability of the emissions embodied in import result which stems from the combination of the MRIO emission intensity estimate, and the import volumes specified in the Norwegian input-output tables. Particularly for non-CO_2 emissions, this result of the emissions embodied in imports dominated the domestic effect.

An alignment of results to potential demand-side policy would also allow the prioritization of sector-specific results. For example, whilst the treatment of the water transport sector has a high impact on both production and consumption results, it is a relatively self-contained sector in terms of supply-chain complexity. Policy that targets biomass CO_2 may instead need a tighter focus on heat and construction. A break down of some of the sector level results might help to further provide valuable insights, such as by detailing the relative contributions of transport fuels vs stationary energy embodied in materials used in the construction sector.

It is further recommended that the work is extended into scenario analysis, and to link the work into the Norwegian household consumption survey. The scenario analysis will further identify sectors of concern in the future as the divergences grow between low-carbon technology development and economic growth. The link to household consumption surveys will enable to analyse the distributive effects on different socio-economic groups and different geographical areas.

7 Appendix - Classifications

Appendix 1 – Mapping of Norwegian NACE sectors used in input-output tables to 17 sectors for visualisation purposes in this work.

Norwegian NACE sectors	Aggregated sectors
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, chemicals & non-metallic minerals
Chemicals and chemical products	Petroleum, chemicals & non-metallic minerals
Basic pharmaceutical products and pharmaceutical preparations	Petroleum, chemicals & non-metallic minerals
Rubber and plastics products	Petroleum, chemicals & non-metallic minerals
Other non-metallic mineral products	Petroleum, chemicals & non-metallic minerals
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 & recycling
Repair and installation services of machinery and equipment	Other manufacturing & recycling
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 trade, Hospitality
Wholesale trade services, except of motor vehicles and motorcycles	Wholesale, retail trade, Hospitality
Retail trade services, except of motor vehicles and motorcycles	Wholesale, retail trade, 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 trade, 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 2 – Mapping of regions to four aggregates for results presentation

Exiobase_ISO3	Name	RegionAggregation
AUT	Austria	Europe
BEL	Belgium	Europe
BGR	Bulgaria	Europe
CYP	Cyprus	Europe
CZE	Czechia	Europe
DEU	Germany	Europe
DNK	Denmark	Europe
EST	Estonia	Europe
ESP	Spain	Europe
FIN	Finland	Europe
FRA	France	Europe
GRC	Greece	Europe
HRV	Croatia	Europe
HUN	Hungary	Europe
IRL	Ireland	Europe
ITA	Italy	Europe
LTU	Lithuania	Europe
LUX	Luxembourg	Europe
LVA	Latvia	Europe
MLT	Malta	Europe
NLD	Netherlands	Europe
POL	Poland	Europe
PRT	Portugal	Europe
ROM	Romania	Europe
SWE	Sweden	Europe
SVN	Slovenia	Europe
SVK	Slovakia	Europe
GBR	Great Britain	Europe
USA	USA	Advanced
JPN	Japan	Advanced
CHN	China	Developing
CAN	Canada	Advanced
KOR	South Korea	Advanced
BRA	Brazil	Developing
IND	India	Developing
MEX	Mexico	Developing
RUS	Russia	Developing
AUS	Australia	Advanced
CHE	Switzerland	Europe
TUR	Turkey	Developing
TWN	Taiwan	Advanced
NOR	Norway	Norway
IDN	Indonesia	Developing

ZAF	South Africa	Developing
WWA	RoW Asia	Developing
WWL	RoW America	Developing
WWE	RoW Europe	Europe
WWF	RoW Africa	Developing
WWM	RoW Middle East	Developing

8 Appendix - Methods in depth

The consumption-based account calculation in the coupled model can be broken down into three principal parts to be implemented mathematically separately:

1. The allocation of Norwegian production emissions from industrial sources to final products produced in Norway.
   a. This is essentially the allocation of the Norwegian production-based emissions through the Norwegian input-output table (representing Norwegian supply-chains) to Norwegian final demand.
2. The estimation of emissions embodied in imports used in intermediate production of the Norwegian economy.
   a. This is the emissions embodied in the import of goods/services used by Norwegian industry. For example, emissions associated with foreign feed production used by the Norwegian agricultural industry would be included here.
3. The estimation of emissions embodied in imports imported directly to final consumers.
   a. This is the emissions embodied in the imports of goods/services purchased directly by Norwegian consumers – for example, the emissions embodied in vehicle or consumer electronic device that is wholly produced overseas.

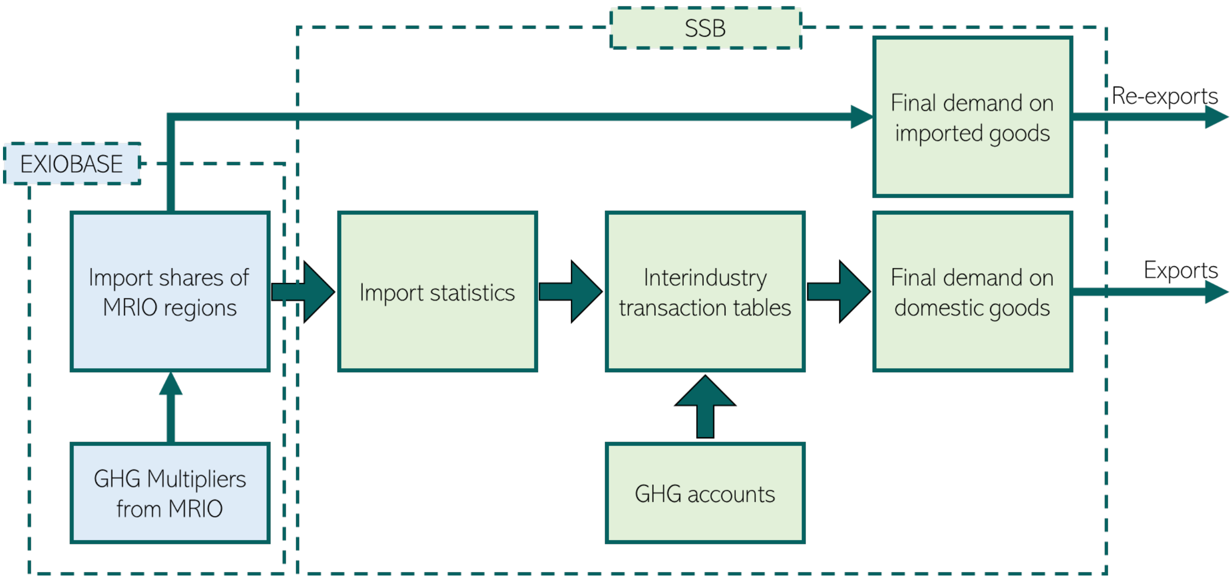

Figure 28 Diagrammatic of the coupled model approach. Norwegian data is in light green, and the accounts are principally built around this data for the calculation of all domestic supply-chains (to point of export). For emissions abroad, the MRIO model EXIOBASE is used. The MRIO model provides GHG emissions per euro of traded goods in native MRIO classification. This is then aggregated to the 65 sectors of the Norwegian model. Import shares are then used to connect the Norwegian IO import data (which only show sector level imports, not country of origin). The import shares define how much of an import flow comes from Denmark, Germany, China, etc. The import shares can be calculated directly from EXIOBASE.

Emissions embodied in exports are included in the calculation i.e., the emissions from the value chain until the product is exported from Norway. Downstream emissions (emissions occurring outside of Norway due to the supply of Norwegian goods and services – for example the emissions occurring due to the combustion of oil and gas overseas) requires a slightly different approach (and is not additive to consumption-based emissions). Income based approaches (Marques et al., 2012) provide best insights here.

Some prior knowledge is required for the further understanding of the input-output modelling below. A more detailed write-up behind the concept of the model is available at: https://doi.org/10.5281/zenodo.1489942. A list of variables is included in the section "Notation" below.

8.1 Norwegian domestic emissions

The Norwegian IO model is the mechanism for the allocation of Norwegian production emissions to final goods, as well as for the allocation to final demand of the emissions embodied in imports which are used in intermediate production of the Norwegian economy. Both are data downloadable from Norwegian statistics.

The impacts from the domestic model in domestic final demand are calculated as:

$$\boldsymbol{D^d} = \boldsymbol{s^d}\left(\boldsymbol{I} - \widehat{(\boldsymbol{A^d})}\right)^{-1}\boldsymbol{Y^d} \qquad \textit{Equation 1}$$

Where $\boldsymbol{D^d}$ is the domestic component of the Norwegian footprint, $\boldsymbol{s^d}$ is the emissions intensity of Norwegian production (Norwegian emissions by sector divided by output by sector), $\boldsymbol{I}$ is an identity matrix (a matrix of ones along the diagonal), $\boldsymbol{A^d}$ is the technical coefficients of the domestically produced output used by Norwegian industries, $\boldsymbol{Y^d}$ is the final demand of Norwegian produced output.

The domestic coefficients are calculated as:

$$\boldsymbol{A^d}_{.,j} = \frac{\boldsymbol{Z}_{.,j}}{\boldsymbol{x_j}} \qquad \textit{Equation 2}$$

Where $\boldsymbol{A^d}_{.,j}$ are the coefficients of each intermediate input, by sector *j*, $\boldsymbol{Z}_{.,j}$ are the actual Norwegian intermediate inputs (domestically sourced), by sector *j* and $\boldsymbol{x_j}$ is the industrial output by sector *j*.

Define the Leontief inverse matrix and shows the amount of domestic production required to fulfil a unit of Norwegian final demand.

$$\boldsymbol{L^d} = \left(\boldsymbol{I} - (\boldsymbol{A^d})\right)^{-1} \qquad \textit{Equation 3}$$

and with a diagonal hat shows diagonalization to keep the sector dimension of the calculation:

$$\boldsymbol{D^d} = (\widehat{\boldsymbol{s^d}\boldsymbol{L^d}})\boldsymbol{Y^d} \qquad \textit{Equation 4}$$

Gives the domestic emission footprints for each product.

8.2 Emissions embodied in imports – coupled approach.

For the impacts embodied in imports, the calculation stems from the basic economic balance where total imports $\boldsymbol{m}$ is the sum of intermediate imports $\boldsymbol{A^m x}$ and the sum over the *k* categories (columns) of final imports $\boldsymbol{Y^m}$:

$$\boldsymbol{m} = \boldsymbol{A^m x} + \sum_{k} \boldsymbol{Y_{.,k}}^{\boldsymbol{m}} \qquad \text{Equation 5}$$

Note that $\boldsymbol{A^m x}$ is imports to Norwegian producers and $\boldsymbol{Y^m}$ is import of products purchased directly by the final consumer. To calculate the emissions embodied in imports, we need to know the emissions embodied in imports per unit of import. This information comes from the EXIOBASE model, and is referred to as the MRIO multiplier, denoted $\boldsymbol{Q^{imp,65}}$. There are a few steps involved in arriving at the multiplier relevant for Norwegian imports, and in the Norwegian industry classification – further notes are provided on this topic below in the section "Multipliers for emissions embodied in imports from EXIOBASE".

The multiplier $\boldsymbol{Q^{imp,65}}$ shows the emissions per unit of imported goods/services and can simply be multiplied by the economic value of the imports, which gives the emissions embodied in imports to each sector, $\boldsymbol{D^m}$

$$\boldsymbol{D^m} = \boldsymbol{Q^{imp,64} m} \qquad \text{Equation 6}$$

Of note, the emissions embodied in imports corresponds to the goods/services imported into Norway, regardless of *who* imports the goods/services. For example, the emissions embodied in imports corresponding to the agricultural sector would include feed import to the agricultural sector, as well as agricultural production such as grains used directly by households, the food manufacturing sector, and other industries.

In order to allocate the emissions embodied in imports to the final goods and services consumed by Norwegian residents, we must apply the import balance of Equation 10 to break down information about which intermediate user $\boldsymbol{A^m x}$ or final user $\boldsymbol{Y^m}$ imports the goods/services.

That is,

$$\boldsymbol{D^m} = \boldsymbol{Q^{imp,65} m} = \boldsymbol{Q^{imp,65}}(\boldsymbol{A^m x} + \boldsymbol{Y^m}) \qquad \text{Equation 7}$$

$\boldsymbol{Q^{imp,65} A^m}$ shows the total imported emissions per unit of Norwegian production for intermediate use of imports. It is a matrix multiplication between the variable $\boldsymbol{Q^{imp,65}}$ specified in Equation 15 and the intermediate import component of the coefficient matrix "A".

Now, as $\boldsymbol{x} = \left(\boldsymbol{I} - \left(\boldsymbol{A^d}\right)\right)^{-1} \boldsymbol{Y^d}$ (from basic input-output relationships), we can substitute to get:

$$\boldsymbol{D^m} = \boldsymbol{Q^{imp,65} m} = \boldsymbol{Q^{imp,65}} \left(\boldsymbol{A^m} \left(\boldsymbol{I} - \left(\boldsymbol{A^d}\right)\right)^{-1} \boldsymbol{Y^d} + \boldsymbol{Y^m}\right) \qquad \text{Equation 8}$$

And simplifying using the notation for the Leontief inverse as above:

$$\boldsymbol{D^m} = \boldsymbol{Q^{imp,65}A^mL^dY^d} + \boldsymbol{Q^{imp,64}Y^m} \qquad \textit{Equation 9}$$

$\boldsymbol{Q^{imp,65}A^mL^d}$ is a matrix multiplication between the matrix $\boldsymbol{Q^{imp,65}A^m}$ (which shows imported emissions per unit of Norwegian production) and $\boldsymbol{L^d}$ (which shows the total Norwegian production required per unit of final demand).

Equation 13 is thus allocating the emissions embodied in imports $\boldsymbol{D^m}$ (on the left-hand side) to the final goods/services of Norwegian finally produced goods ($\boldsymbol{Y^d}$) and imports direct to final demand ($\boldsymbol{Y^m}$) – on the right-hand side.

The total environmental footprint from industrial sources is the summation of Equation 7 and 13, and make the total Norwegian footprint for goods and services as:

$$\boldsymbol{D^{d+m}} = \boldsymbol{s^dL^dY^d} + \boldsymbol{Q^{imp,65}A^mL^dY^d} + \boldsymbol{Q^{imp,65}Y^m} \qquad \textit{Equation 10}$$

8.3 Emissions embodied in imports - Multipliers derived from EXIOBASE.

For Equation 10 and onwards, emission “multipliers” are required, which show the upstream life-cycle emissions per unit of imports. These multipliers are extracted from the EXIOBASE dataset but require reclassification (due to differing industry classifications between EXIOBASE and the Norwegian IO table) before implementation in the Coupled model (Equation 10 and onwards).

The re-classified multipliers (in Norwegian IO classification) are generated by the division of absolute values of emissions embodied in imports by the economic value of imports in order to obtain emission multipliers per unit of imports. This division is done on derived accounts in absolute terms, as the reclassification involves aggregation across multiple industries. Aggregation can be performed directly for values in absolute terms, but not for intensity values such as multipliers.

Two sets of data are needed from EXIOBASE:

1) Emissions embodied in imports – these are the full supply chain emissions to point of purchase (i.e., total upstream life-cycle emissions) of sector imports as calculated via the EXIOBASE MRIO. Hence, the value in "Cattle farming" will include all supply chain emissions of cattle farming imports, including the emissions released in cattle farming imports directly, and any emissions associated with feed production used in cattle farming.
2) Value of imports (Reported in million Euro in the EXIOBASE database) - these are the total imports into Norway as reported in EXIOBASE. Please note, that the import into Norway from EXIOBASE does not necessarily equal the import into Norway according to Statistics Norway. This is due to the fact that global import = global export in a global MRIO such as EXIOBASE, and to make sure this is the case the trade data in EXIOBASE is re-balanced. In addition, re-exports (imports that are directly exported without any transformation by Norwegian producers) are excluded from a MRIO calculation. As the import-value from EXIOBASE is used only as a weight in the calculation of the emission multipliers from EXIOBASE, the re-balancing is not seen as an issue that affects the carbon footprint in the coupled model (Note that the actual volume of imports is defined by SSB

data). For full details on the handling of trade data in EXIOBASE, the reader is referred to Stadler et al 2018.

The multipliers derived from EXIOBASE are produced by the function “ExtractMultipliers”. All steps are documented in the accompany programming script. Multipliers including and excluding capital are calculated.

These two sets of data are then aggregated to the 65-sector classification for Norway, using the concordance “sector_matching.xlsx” (provided along with the code). Note the concordance should be as precise as possible – the purpose of it is to allocate the most relevant multiplier from EXIOBASE to the most relevant Norwegian industry. In practice, it is likely that there are a number of many-to-many, many-to-one and one-to-many links in the concordance. This does not present a problem mathematically, but has some conceptual implications:

- In the case of one EXIOBASE sector linking to many Norwegian sectors, the Norwegian sectors will each be assigned the same EXIOBASE multiplier – for example “Hotels and restaurants” is one sector in EXIOBASE, whilst it is split in the Norwegian IO table. As EXIOBASE does not provide any more detail on differences in emissions intensity between Hotels and Restaurants, the best we can do is assign the aggregate emissions multiplier to both sectors.
- In the case of many EXIOBASE sectors linking to one Norwegian sector. This occurs for agriculture, where EXIOBASE has 15 agricultural industries, and Norwegian statistics has one. As the Norwegian IO model can only treat the aggregate import of agricultural goods, the EXIOBASE data must be aggregated. Hence a simple aggregation of EXIOBASE emissions embodied in imports and import value is taken to give a single multiplier for the Norwegian model. Note that the multiplier is a “weighted” multiplier of the 15 EXIOBASE sectors based on import value.
- In the case of many EXIOBASE sectors linking to many Norwegian sectors, both the above steps are implemented together – all EXIOBASE emissions embodied in imports for the relevant sectors are aggregated, and the same is done for import value. The emission multiplier is calculated as the division of the aggregated emissions embodied in imports by the aggregated imports; then the emission multiplier is assigned to all relevant Norwegian industry sectors.
- When there are one-to-many or many-to-many linkages (occurring for the Chemicals n.e.c. – Chemicals and chemical products/Basic pharmaceutical … complex in the mapping), the intermediate steps of calculating aggregate “emissions embodied in imports” and “imports” will show double counting of values such that if you sum the value of the aggregated imports over the whole economy, it will be larger than known imports. However, this double counting occurs consistently for both imports and footprints, such that the calculation of multipliers cancels the double counting out.

Mathematically we can express this as:

- $\mathbf{Q^{imp}}$ – the emission multipliers in EXIOBASE classification; dimension 163 industries. Note these multipliers are calculated explicitly for Norwegian imports.
- $\mathbf{D^{imp}}$ – the value of emissions embodied in imports, as extracted from EXIOBASE; dimension 163 industries.
- m – the value of imports to Norway, as extracted from EXIOBASE; dimension 163 industries. $\hat{\mathbf{m}}$ signifies diagonalisation.

Now, using a $'$ to signify matrix transposition,

$$D^{imp'} = Q^{imp}\widehat{m} \qquad \text{Equation 11}$$

Or alternatively,

$$Q^{imp'} = D^{imp'}\widehat{m}^{-1} \qquad \text{Equation 12}$$

As this data is in EXIOBASE classification, we introduce a concordance matrix as discussed above: G – the relationship between EXIOBASE 163 and Norwegian 65 industries. Dimension 163 EXIOBASE industries by 65 Norwegian industries.

Now we aggregate emissions embodied in imports and imports separately:

$$D^{imp,65} = \llbracket(D\rrbracket^{imp'} * G\big)' \qquad \text{Equation 13}$$

$$m^{65} = \llbracket(m\rrbracket' * G)' \qquad \text{Equation 14}$$

And calculate the aggregated multipliers, the same as in equation 19:

$$Q^{imp,65} = \left(D^{imp,65'} * (\widehat{m^{65}})^{-1}\right)' \qquad \text{Equation 15}$$

Gives us the multipliers in Norwegian classification. The «import» multipliers cover the supply chain to the point of import into Norway.

8.4 Potential disaggregation of Scope 3 emissions

Scope 1, 2 and 3 emissions are used by the Greenhouse Gas Protocol, mainly for corporate accounting in environmental, social and governance reporting. Scope 1 emissions refer to direct emissions of an entity, scope 2 to the emissions from electricity, and scope 3 to all other indirect emissions. The breakdown can be applied to the calculation methodology here, especially if "emission factors" (e.g., kg CO_2/NOK) are generated. The application in a national accounting framework makes less sense, however, and is not commonly done.

The default setup of the coupled model calculates consumption-based accounts that aggregates Scope 2 and 3 emissions together. Scope 1 emissions in a national consumption-based carbon accounting approach would be the direct emissions associated with activity by final demand entities (e.g., heating or cooking by households using natural gas, vehicle use of households using internal combustion engines). Scope 2 emissions can be extracted from the IO model as the direct purchase of electricity going to final demand. Electricity can be sourced from either domestic or foreign suppliers. Only direct emissions due to electricity production would be included, and not emissions upstream (e.g., due to coal mining). An additional note is that the Norwegian IOTs aggregate electricity with gas, heat and cooling (including district heating) in the sector called "Electricity, gas, steam and air-conditioning", so a breakdown of electricity only would not be possible.

After some discussion within the project team, whilst the breakdown of emission accounts into scope 1, 2, 3 is technically feasible in the model setup, it is unlikely to provide any additional clarity or relevant insights. It is noted that scope 1 and 2 emission factors are usually done on a physical basis (e.g., per kWh or litre of fuel consumed), whilst this project is purely using monetary input-output tables (which can only provide spend-based factors). As such, it was decided not to report results into a scope 1, 2 and 3 breakdowns.

8.5 Product vs Industry tables

The Norwegian IOTs provided by SSB are defined as product by product, but they are reported and treated as equivalent with industry-by-industry tables. Emissions data are usually reported by industry, but due to the classification used in the IO tables, the SSB convention is followed, treating the product and industry dimensions as equivalent. For the purposes of this study, it is not considered an issue, but it may help in clarifying naming conventions.

8.6 Notation

Variables used in the derivation are defined as:

Variable	Name	Description
I	The identity matrix	The Matrix "I" has "1" in the diagonal and the number 0 outside the diagonal and it is used in the calculation of the Leontief Inverse
$\boldsymbol{A^d}$	Coefficient matrix - domestic	Inter-industry coefficients of domestic transactions (direct requirements matrix), dimension *n x n*
$\boldsymbol{A^m}$	Coefficient matrix - imports	Inter-industry coefficients of import transactions (direct requirements matrix), dimension *n x n*
$\boldsymbol{K^d}$	Capital coefficient matrix - domestic	Inter-industry coefficients of domestic capital (direct requirements matrix), dimension *n x n*
$\boldsymbol{K^m}$	Capital coefficient matrix - imports	Inter-industry coefficients of import capital use (direct requirements matrix), dimension *n x n*
$\boldsymbol{A^{mK}}$	Coefficient matrix	Inter-industry coefficients of import transactions (both current and capital) (direct requirements matrix), dimension *n x n*
$\mathbf{L}^{\boldsymbol{d}}$	Leontief inverse	Leontief inverse (total requirements matrix), Domestic transactions only, dimension *n x n*
$\mathbf{Y}^{\boldsymbol{d}}$	Final demand, domestic	Final demand matrix of domestically produced goods (sectors and final demand categories), dimension *n x r*
$\mathbf{Y}^{\boldsymbol{m}}$	Final demand, imports	Final demand matrix of imported goods (sectors and final demand categories), dimension *n x r*
$\mathbf{x}$	Gross output	Total output of industries, dimension *n*
$\mathbf{m}$	imports	Monetary imports, dimension *n x n*
$\boldsymbol{s^d}$	Emission coefficients	Emissions per unit output of production sectors, domestic sectors only, data made available as a matrix of air emissions, but only 1 category of air emission modelled at a time, hence dimension 1 x *n*.
$\mathbf{D}$	footprints	Footprint of final demand, superscript *d* signifies that they relate to Norwegian domestic consumption
$\boldsymbol{Q^{imp,65}}$	multipliers	Emissions per unit of final demand, superscript signifies that they relate to Norwegian imports, in 65 sector classification
$\boldsymbol{Q^{impK,65}}$	multipliers	Emissions per unit of final demand, superscript signifies that they relate to Norwegian imports and include endogenized capital, in 65 sector classification
i,j		Industries, 65 sectors in the Norwegian model
n		Air emission categories

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