Compilation of a consumption based greenhouse gas account for Denmark using coupled models.

by

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December 2022

Technical report for Eurostat based on grant no. 101022790 — 2020-DK-ENVACC
WP4

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COMPILATION OF A CONSUMPTION BASED GREENHOUSE GAS ACCOUNT FOR DENMARK USING COUPLED MODELS.

Statistics Denmark
December 2022

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Preface

This report is one of the outcomes of a grant from Eurostat for the project **2020-DK-ENVACC.** The project has benefited from funding by the European Commission, Eurostat, through grant agreement no. 101022790 — 2020-DK-ENVACC

The project consists of four work-packages WP1-WP4. Together they intent to comply with specific request from our users for more and better green national accounts data.

This report is concerned with the latter WP4 "Consumption based greenhouse gas account for Denmark using coupled models". The project was carried out in the Green National Accounts section of the National Accounts division at Statistics Denmark.

The work has benefited greatly from consultations with Richard Wood, Professor at NTNU, University of Sydney, Central Coast, New South Wales, Australia.

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1. Introduction

Today, the Danish economy is a much more integrated part of the global economy than it used to be just a few decades ago. Imports and exports of products for final use has increased, but also imports and exports of intermediate products for use in production have increased substantially. Thus, production chains are more likely to cross borders than they were before due, partly, to the fact that transportation of goods and intermediate products around the world has become quite a lot easier and efficient.

This development have had a huge effect on greenhouse gas (GHG) emission inventories compiled by countries around the world. Thus, the more globalized a country's production processes becomes and the less the share of domestic production in domestic use becomes, the more misleading the national inventory is if used as a measure or indicator of the environmental consequences of domestic consumption.

Figure 1. *Share of imported and domestically produced intermediate consumption by Danish industries 1990-2021*

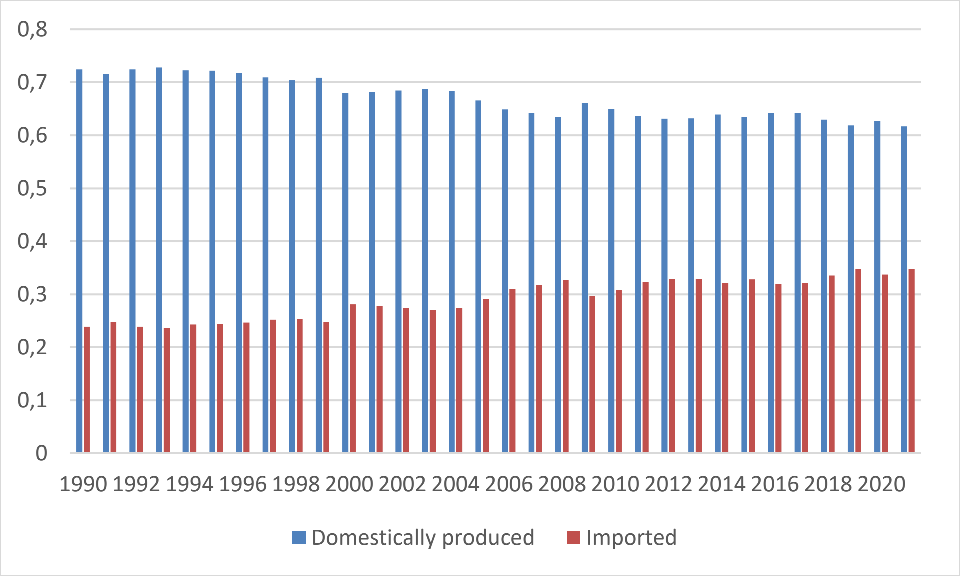


Figure 1 shows that share of imported intermediate consumption by Danish industries has increased almost 50 percent during the period 1990 through 2021. The fact that many production processes as well as final use rely more heavily on imported intermediate and final goods may change the relative shares of global emissions of GHGs between countries. Thus, Danish industries may have been able to comply with domestic as well as global demand at a seemingly decreasing environmental cost in terms of GHG emissions. But the increasing emissions embedded in imports for intermediate consumption are not accounted for in the Danish emissions inventory.

Thus, there is a need for a better understanding of the full environmental effects of domestic consumption in a globalized economy. This requires a tool that can capture all emissions embodied in final use no matter from which part of the production chain or which country it originates.

As a provider of statistics on greenhouse gas emission, Statistics Denmark wants to present a sufficiently comprehensive, meaningful and versatile picture of the emissions that can be ascribed to Danish economic activities. Many users of greenhouse gas emissions statistics in Denmark have become increasingly aware that the current inventories of emissions from domestic sources does not provide the full picture of the global greenhouse gas effects resulting from domestic consumption and therefore they have a demand for (official) statistics to cast some light on this issue.

For that reason, the goal of this project was to compile a new statistics covering global emissions of all GHG emissions that can be ascribed to Danish domestic final demand (consumption and investment) whether it occurs in Denmark or somewhere else in the rest of the world.

This project is not intended to be just another study of what is actually possible to calculate. Previously, a few such studies have been carried out by Statistics Denmark ending up more or less in the drawer. Therefore, the aim this time has been to actually clear the way for a dissemination of an official, yet experimental, Climate Footprint statistics that is published on the internet on an annual basis.

2. Methodology

This chapter includes presentation of the various ways to account for GHG emissions leading up to a demarcation of what should be included in the footprint calculation. It also discusses what emissions data to actually include in the calculation of the footprint because this question is quite not as trivial as it may seem at first. Furthermore, a thorough discussion is provided of various aspects of the modelling procedure.

2.1. Types of emission accounts

The international literature provides a discussion of a variety of different types of emission accounts. They all represent different ways to allocate the responsibility for the greenhouse gas emissions faced by the world. Currently, the two most dominating accounting principles are both production based

- Territorial based emissions accounts
- Residence principle based emission accounts

The territorial based emission account only considers emissions that occur within the borders of a specific country. This is the principle behind transmissions of emission inventories to UNFCCC. It means that emissions outside the borders due to production activities by residential units are not accounted for by the country itself (or by any other country).

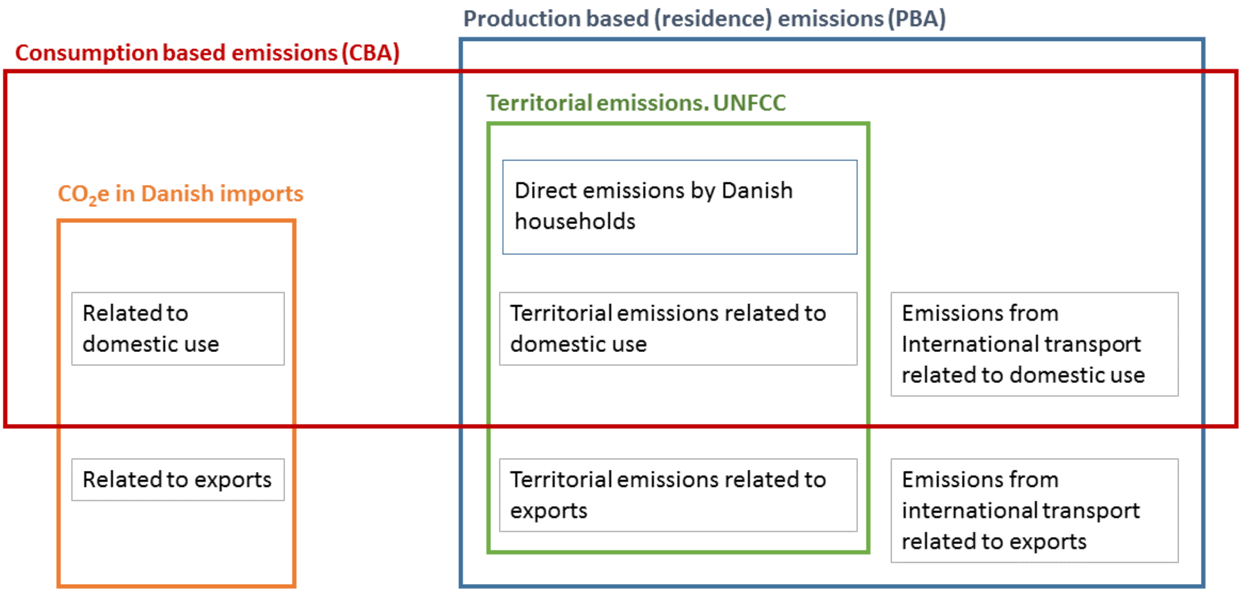
The residence principle is the same that is used in the compilation of the national accounts. It means that all emissions generated by resident production units must be accounted for no matter where in the world they actually appear. The residence principle is behind the compilation the Danish emissions inventory by Statistics Denmark.

In figure 2 below, the coverage of the territorial as well as the residence-based principles are displayed in the blue and green frames.

The territorial emissions in the green box that are common to both the residence principle and the territorial principle are

- Direct emissions by households (burning of fossil fuels for heating and transport)
- Emissions in Denmark by domestic production units as a response to domestic final demand
- Emissions in Denmark due to production of exports

Figure 2. *Territorial, residential and consumption based emission accounts*



Residence- or production based emission that are in the blue box, but not in the green box with territorial emissions, are emissions outside Denmark caused by Danish transport companies operating in the rest of the world. The majority of these emissions are due to export activities but a small share can be related to domestic consumption. Figure 2. also shows that the emissions in the rest of the world related to Danish imports are not part of either the territorial or the residential based emissions.

The major alternative to production-based emission statistics is the consumption-based emission statistics. The coverage of the consumption based emissions are shown by the red frame in figure 2. It includes those Danish production based emissions that relate to production of the Danish domestic final demand, excluding Danish production based emissions related to Danish exports. In addition, it includes emissions embedded in imports required to comply with domestic final demand directly or indirectly. Thus, emissions embedded in imports of products that are exported directly (re-exports) or indirectly through input of imported products in the production of Danish exports are not part of the consumption-based account.

Very often, a consumption based measure of carbon emissions is called "Carbon footprint" or similar names depending on what is actually measured. Sometimes Carbon Footprint actually only covers the one gas CO2, but sometimes it covers all greenhouse gases and is expressed in CO2-equivalents. A definition of the term "Carbon Footprint" can be found e.g. in Minx et al. (2009) who says: *"In agreement with the majority of the literature, we understand the CF as a purely consumption-based concept. In particular, we define CF as the direct and indirect greenhouse gas emissions – measured in tonnes of carbon dioxide equivalent using a 100-year horizon (Fuglestvedt et al., 2003) – required to satisfy a given consumption".*

The case in this project is to measure the "GHG footprint" of Danish consumption, where "consumption" is to be understood as the sum of domestic final use (household consumption, government consumption and investment).

In Danish, the estimated measure will be named "Klimaaftryk" which translates directly into "Climate print" or "Climate footprint". For the remainder of this report, it is addressed as "Climate footprint".

Naturally, many users of the statistics that results from this effort will be very interested in a measure of global emissions related to Danish exports in addition to the climate footprint. Therefore, although it is outside the scope of consumption-based accounting, we estimate the climate footprint of Danish exports as well and report it to the users along with the traditional footprint measure. This is done in order to provide “the full picture” of emissions, i.e. a complete allocation of the production based Danish emissions on domestic final demand on the one side and exports on the other side.

2.2. Climate footprint calculation methodology

Following the discussion related to figure 2 above, the contents of the Danish climate footprint is

Danish Climate Footprint

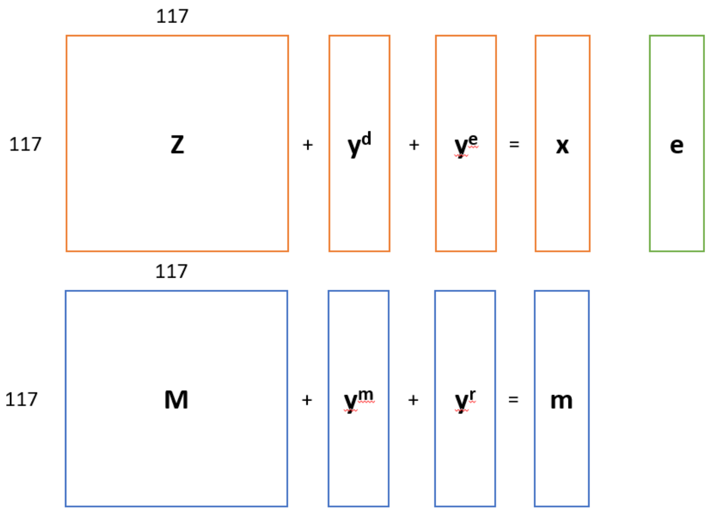
= GHG emissions from Danish resident production units that can be ascribed to domestic final use

\+ GHG emissions embedded in Danish imports that can be ascribed to domestic final use

\+ GHG emissions from Danish households due to burning of fossil fuels for heating and transport

Thus the basic aim of the footprint calculation for Denmark is to measure exactly that part of the global GHG emissions that can be attributed to the Danish domestic final use. The job is to split emissions between domestic use and exports, and to associate imports with production related emissions in the rest of the world by sector and country. Figure 3 shows a very basic picture of how the Danish national accounts is organized as an input-output table. Thus, in this very standard set up total output $\mathbf{x}$ is consists of production used as intermediate consumption by other industries $\mathbf{Z}$, final domestic demand (consumption and investment) $\mathbf{y^d}$ and exports $\mathbf{y^e}$. This production by industry results in GHG emissions by industry $\mathbf{e}$.

Figure 3. *Basic schematic of the Danish national accounts / input-output table*



Z	= Domestic production of intermediate consumption 117 by 117 industries
$\mathbf{y^d}$	= Domestically produced domestic final demand
$\mathbf{y^e}$	= Domestically produced exports
x	= Total output by 117 industries
e	= Emissions of GHG by 117 industries
M	= Imports for intermediate consumption to 117 industries by 117 foreign industries
$\mathbf{y^m}$	= Imported domestic final demand by 117 foreign industries
$\mathbf{y^r}$	= Imported exports (re-exports) by 117 foreign industries
m	= Total imports by 117 foreign industries

As pointed out previously, the footprint calculation actually is all about figuring how many emissions can be attributed to domestic final use $\mathbf{y^d} + \mathbf{y^m}$.

- Firstly all Danish residence based emissions by industry **e,** can be seen as the result of total final demand $\mathbf{y^d} + \mathbf{y^e}$, and, thus, for the footprint calculation the job is to split emissions **e** between the final demand components $\mathbf{y^d}$ and $\mathbf{y^e}$ because emissions related to exports are not part of the footprint.
- Secondly, it must be calculated how much import for intermediate consumption is involved in supplying $\mathbf{y^d}$
- Thirdly, the size of imports for direct final use $\mathbf{y^m}$ is readily available.
- Fourthly, it must be calculated how much global emissions is generated in the rest of the world due to the supply of Danish imports

A commonly applied technique that provides this information is input-output analysis (IOA), which by now is a well-established tool for the calculation of footprints of countries. (Hertwich and Peters 2009, Wiedmann, Wood et al. 2010, Moran, Lenzen et al. 2013, Tukker et al. 2020).

It is not only the detailed and complete depiction of activities throughout an economy that makes it a great tool, but also the ability of IOA to assess the direct and indirect environmental flows triggered by a given final demand that has attracted the attention of researchers and practitioners for decades.

Carbon footprint analysis aims to quantify all direct and indirect (embodied) GHG emissions caused by a given final demand. This requires the inclusion of emissions released worldwide to enable the production of the goods and services that finally are consumed in Denmark and, thus, makes input–output analysis a suitable methodology.

During the last 15 years input-output models have moved from representing just the economic flows in one country, to models of many countries, known as global multi-regional input-output (MRIO) models. In a study by Statistics Denmark from 2009 (Rørmose Jensen, P. et al. (2009)) the contents of emissions in the Danish imports was calculated using a so-called unidirectional trade model where the Danish imports from 51 countries was run through the input-output models of those 51 countries one by one. This procedure provided a pretty good picture of the contents of emissions in Danish imports, but the problem was that emissions embodied in trade in intermediate goods between countries as a result of the Danish demand was left out of the equation. The MRIO models available now takes care of the inter-country trade flows in addition to what happens in a single country. These global models are able to trace environmental impacts through complex global supply chains, linking between production and consumption in different parts of the world.

MRIO models in a combination with emissions data prepared in compliance with the SEEA framework has been regarded by various authors to be the best tool for calculating environmental footprints of nations (Tukker et al. 2020).

2.2.1. International input-output tables, MRIOs

Development of internationally linked input-output databases has been going on for at least 15 years. There exist a number of such international databases and the quality of the data is improving gradually. Three of them have been considered for use in this specific project

- OECD ICIO (Inter Country Input-Output). It can be downloaded from here www.oe.cd/ICIO . This database is now updated to 2018, and is free of charge. It has 45 unique industries based on ISIC Revision 4. The database is in reasonable agreement with Danish national accounts data. Air emissions data is limited to CO_2 from burning of fossil fuels.

- FIGARO is the intercountry input-output database compiled by EUROSTAT. Data covers the period 2010-2019. It can be downloaded here https://ec.europa.eu/eurostat/web/esa-supply-use-input-tables/data/database free of charge. It covers the EU countries 18 main EU trading partners and a “rest of the world” category to complete the global picture the database provides. It has 64 products and 64 industries.
- EXIOBASE 3 provides a time series of environmentally extended multi-regional input-output (EE MRIO) tables ranging from 1995 to a recent year for 44 countries (28 EU member plus 16 major economies) and five rest of the world regions. In its present version, it has 163 industries and 200 products. The original time series of EXIOBASE economic data ends in 2011 and data for more recent years has been updated from that year with trade and macroeconomic data from various sources. It can be downloaded here https://doi.org/10.5281/zenodo.5589597

Each of these databases can be set up as an environmentally extended multiregional input-output model with which it is possible to calculate a climate footprint of consumption e.g. for Denmark. They all include Denmark as an explicit part of the model, so it is possible to calculate climate footprint results that applies to the Danish domestic consumption.

The picture below shows the usual framework of a MRIO table. Contrary to the purely Danish table outlined above Denmark’s imports and export is shown in n-1 matrices – one for each of the other countries in the model.

Figure 4. *Typical organization of a MRIO model*

Typical organization of a MRIO table

	Intermediate consumption			Final demand			
	Country 1 1,....n	**Denmark 1,....n**	**Country 3 1,.....n**	**Country 1 1,..m**	**Denmark 1,...m**	**Country 3 1,...m**	**Total use**
Country 1 1,...n	..	Danish intermediate inputs im-ported from country 1	..	..	Danish domestic final demand imported from country 1	..	
Denmark 1,...n	Danish exports of intermediates to country 1	Danish intermediate inputs produced in Denmark	Danish exports of intermediates to country 3	Danish exports to final demand in country 1	Danish domestic final demand produced in Denmark	Danish exports to final demand in country 3	
Country 3 1,...n	..	Danish intermediate inputs im-ported from country 3	..	..	Danish domestic final demand imported from country 3	..	
Taxes							
GVA							
Output							

MRIOs like these are constructed on the basis of national supply and use tables and aligned through the foreign trade data. However, in many cases there are discrepancies between the same bilateral trade data when reported by the two countries involved. In order to even out these discrepancies it is necessary to balance the full table which in some cases can be rather hard on smaller economies which will have to take a relatively bigger adjustment or modification than larger countries.

In the project we spent some time going through the three databases to see if and how well they would suit our purpose. After careful consideration, we decided to go with EXIOBASE 3 for the following reasons (among others)

- The environmental extension of the model is quite comprehensive and up-to-date (2021). It covers all gases that contributes to global warming CO2, CH4, N2O and F-gasses in all industries in all countries in the database.
- EXIOBASE has more industries than the other databases and therefore it covers the Danish imports from 117 foreign industries better.
- Although the most recent years in EXIOBASE (from 2012 to 2022) is basically the result of a mathematical update procedure based on macroeconomic aggregates and the structure of the 2011 table, it is more up-to-date (2022) than the other databases.

2.2.2. Is EXIOBASE enough on its own?

Although it would seem like an easy task to calculate the new GHG footprint statistics using just EXIOBASE we did find it worthwhile to consider closely if such a calculation would provide all the results required to tell the statistical story we want to. The results of some of the main considerations we had are

- Would calculations of the domestic part of the Danish footprint be aligned with footprints and multipliers we had already published on the basis of the Danish input-output model?
- Can we trust that new versions of EXIOBASE are supplied in a regular way supporting e.g. an annual dissemination of this statistics?
- Is the detail or granularity of EXIOBASE data sufficiently high? The sectoral detail in EXIOBASE is even higher than in the Danish data, so no problem there. As almost all of the MRIO databases EXIOBASE is much aggregated in the final use dimension. Thus, household consumption is represented in just one column, whereas in the Danish national accounts there is 74 groups of household consumption classified according to COICOP. By using just EXIOBASE we would not be able to provide data on the more detailed consumption groups which is demanded by many users.
- Is the representation of the (very trusted by users) Danish national accounts in EXIOBASE so good and precise that it makes users confident that the results of the footprint calculation is trustworthy? This is a very important question and to answer it we made a careful comparison of some specific data in EXIOBASE with equivalent data in the Danish national accounts. The result is presented in section 2.2.3 below.

2.2.3. Danish National Accounts in EXIOBASE?

Before applying EXIOBASE as the sole instrument for calculating the Danish climate footprint we took a look at how some of the Danish data in EXIOBASE looked like in comparison with the actual numbers in our own input-output tables.

One of the most important industries in relation to greenhouse gas emissions from Danish economic activities is the Water Transport industry. In the production based emission inventories, this industry is responsible for more than 50 percent of total Danish CO_2 emissions. However, a very large share of its output ends up as exports, which is not part of the Climate footprint. Consequently, some major differences are expected in the emission account depending on whether it is based on production or consumption. Therefore, we paid specific attention to this industry in a comparison between the Danish national accounts and EXIOBASE.

Table 1. *Key figures for the Danish Water Transport industry in EXIOBASE and the Danish national accounts respectively.*

2019	EXIOBASE 3.8	Danish NA, IOT	EXIOBASE 3.8	Danish NA, IOT
	Mill. DKK	*Mill. DKK*	*percent*	*percent*
Total output	**137.637**	**246.064**		
- intermediate input to Danish industries	102.024	21.474	74	9
- domestic final demand	15.935	3.453	12	1
- exports	19.678	221.137	14	90
Total input	**139.517**	**212.726**		
- from domestic sources	81.849	14.677	59	7
- imported	57.668	198.048	41	93
Gross Value Added	**-1.880**	**33.339**		

It is evident from the numbers in table 1 that something has gone wrong in the compilation of EXIOBASE with respect to the Danish Water Transport industry. First, total output in EXIOBASE is just a little more than half the number it should be. Secondly, output is allocated very differently between uses in EXIOBASE compared to what is the case in the Danish national accounts. In EXIOBASE 74 percent of output is intermediate consumption by Danish industries, which deviates sharply from the 9 percent it constitutes in the national accounts. In reality, 90 percent of output is exported which leaves just this little bit for domestic use.

In addition, there is a huge divergence between the two with respect to the origin of the intermediate input in the Water transport industry. In EXIOBASE 59 percent is supplied by domestic sources (other industries) while in the national accounts only 7 percent is supplied by domestic sources. Consequently, EXIOBASE does not reflect the huge amount of imports by this industry correctly. Thus, 93 percent of total intermediate consumption is imported, while in EXIOBASE only 41 percent of inputs in this industry is imported. Finally, in EXIOBASE total input in purchaser's prices in this industry is larger than total output. It leaves nothing for Gross Value Added (GVA), which is therefore negative by 1.3 percent of total output. In the Danish national accounts, there is a positive GVA in this industry amounting to almost 14 percent of total output.

In terms of energy and CO_2 emissions, this is a very important industry in the Danish Economy. The use of energy by this particular industry is about the same size as the sum of all other industries and households together. The CO_2 emissions are equally dominant in the picture. Despite total output in this industry being quite a lot lower in EXIOBASE, a major part of emissions would end up in the Danish climate footprint because it is domestic use by Danish industries and households.

Other data were compared between the two sources and some of them were quite alarming as well. One example is that the total imports to Denmark in EXIOBASE were 30-40 percent lower than the actual value in the Danish national accounts.

Conclusion

In the light of the points mentioned above it was decided that we could not use EXIOBASE as a standalone tool for calculating the Danish GHG footprint. The main reason were that some of the most important data that were compared between EXIOBASE and the Danish national accounts were very different. As compilers of the new statistics we would know from the beginning that the results were not to trust completely and for the more advanced users it would probably be the same thing. Another reason is the very aggregate presentation of final demand that would disable us from a dissemination some interesting more detailed results.

2.3. Modelling framework

The problems of inconsistencies between the databases and national data as described in the previous section has been experienced by other statistical agencies as well (Edens et al. 2015, Hambÿe, et. al. 2018). In the literature two different ways to deal with the problems have emerged

- A replacement of national data in an MRIO by the more correct national accounts data and a rebalancing of the entire database[1]. This procedure has been labelled SNAC (Single-country National Accounts Consistent footprint). It is argued that MRIOs are for global analyses while SNAC's are better for national measures. (Edens et al. 2015, Hambÿe, et. al. 2018). Following (Tukker, 2020) the advantages of SNAC are seen as

    - Carbon emissions at the national level (often 50% or more of a CCF) are more precisely estimated
    - The residential principle is applied more properly
    - The domestic block (national IO data) is represented more properly
    - The sectors contributing most to uncertainty in CCFs, such as the electricity and transport sectors (as far as related to the national level) are represented more properly

- Another suggestion is to use a so-called simplified SNAC (Tukker et. al. 2018). This involves using the national IO table and emissions data as an official foreground to the model and using a MRIO in the background to calculate emission contents of the imports only. The simplified SNAC concept does not involve replacement of the national data in the MRIO the following necessary rebalancing the entire MRIO which is a huge and time consuming job. Therefore the simplified SNAC is regarded as a much less burdensome project.

  The simplified SNAC procedure can be applied for all countries that have limited 'feedback emissions' (i.e. emissions and resource use in their exports that also appear in their imports via global value chains) (Tukker et al., 2020). A recent study by (Moran et al. 2018) showed that in the Danish case, the feedback effect that is neglected if only emissions embodied in Danish imports are calculated by EXIOBASE, amounts to 0.4 percent of all emissions. Considering the amount of uncertainty involved in this calculation it is a figure that we decided to accept.

The recommendation to use the simplified SNAC procedure found in Tukker et al., 2020 which is based on research and experience in the academic world as well in other NSIs (National Statistical Institutes) founded the basis for the choice made by Statistics Denmark to work with this method.

2.3.1. The concept of coupled models

The calculation of the consumption-based account can be broken down into 4 principal parts to be implemented mathematically separately:

[1] Research by Wiebe and Lenzen (2016) indicate that results do not differ substantially depending on whether the MRIO is rebalanced or not.

1. Allocation of Danish production emissions from industrial sources to Danish final demand.This is essentially the allocation of the Danish production-based emissions through the Danish input-output table (representing Danish supply-chains) to Danish final demand. A component of the production-based emissions are also allocated to exports through this calculation. These emissions embodied in exports do not form part of the consumption-based account but are interesting in a political context.
2. The estimation of emissions embodied in imports used in intermediate production of the Danish economy. This is the emissions embodied in the import of goods/services used by Danish industry (as shown in the figure above). For example, emissions associated with foreign feed production used by the Danish agricultural industry would be included here. These are subsequently allocated to Final Demand (the domestic as well as the export part) through the Danish input-output table in the same manner as the Danish production-based emissions described above.
3. The estimation of emissions embodied in imports imported directly to final consumers.This is the emissions embodied in the imports of goods/services purchased directly by Danish consumers – for example, the emissions embodied in vehicle or consumer electronic device that is wholly produced overseas.
4. The household emissions – which is simply the emissions directly produced by households (gas cooking, private vehicle use).

The input-output equations
The basis of a standard input-output model is starts from the matrices depicted in figure 3.

(1) $$\boldsymbol{x} = \sum_{j=1}^{n} \boldsymbol{Z}_{i,j} + \boldsymbol{y^d} + \boldsymbol{y^e}$$

A matrix $\boldsymbol{A^d}$ of technical coefficients related to the domestic production is calculated as

(2) $$\boldsymbol{A^d} = \boldsymbol{Z}\widehat{\boldsymbol{x}^{-1}}$$

Then (2) is rearranged and substituted into (1) and the **Z** matrix is replaced by the product of a matrix of technical coefficients and total output

(3) $$\boldsymbol{x} = \boldsymbol{A^d x} + (\boldsymbol{y^d} + \boldsymbol{y^e})$$

Then the equation is solved for x

(4) $$\boldsymbol{x} = \left(\boldsymbol{I} - \boldsymbol{A^d}\right)^{-1}\left(\boldsymbol{y^d} + \boldsymbol{y^e}\right) = \boldsymbol{L^d}\left(\boldsymbol{y^d} + \boldsymbol{y^e}\right)$$

where $\boldsymbol{I}$ is the identity matrix and $\boldsymbol{L^d}$ is the Leontief inverse matrix for the domestic economy.

Now we define $\boldsymbol{s^d}$ as a vector of domestic emission coefficients

(5) $$\boldsymbol{s^d} = \boldsymbol{e}\widehat{\boldsymbol{x}^{-1}}$$

where $\boldsymbol{e}$ is a vector of GHG emissions by 117 industries being divided by total output $\boldsymbol{x}$**.** The vector $\boldsymbol{s^d}$ is put in the diagonal of a matrix of zeros to get $\widehat{\boldsymbol{s^d}}$. When we pre multiply with $\widehat{\boldsymbol{s^d}}$ on both sides of the equation in (4) we get

(6) $$\boldsymbol{e} = \widehat{\boldsymbol{s^d}}\boldsymbol{L^d}\left(\boldsymbol{y^d} + \boldsymbol{y^e}\right)$$

Since we are only interested in the footprint of the domestic final use, we will drop the exports element

$$(7) \qquad \boldsymbol{e^d} = \widehat{\boldsymbol{s^d}}\boldsymbol{L^d}\boldsymbol{y^d} + \boldsymbol{e^h}$$

where $\boldsymbol{e^d}$ is a vector of domestic emissions due to domestic final demand and $\boldsymbol{e^h}$ is the direct emissions from households due to burning of fossil fuels for heating or transportation . This is the first element of the coupled models. For this domestic part, no MRIO was needed. Now, the calculation of the emissions content of imports is where we need to couple the domestic model with the MRIO model.

First, we must calculate the amount of intermediate imports necessary for domestic industries to produce what is required in the $\boldsymbol{y^d}$ vector.

$$(8) \qquad \boldsymbol{m^d} = \boldsymbol{A^m}\boldsymbol{L^d}\boldsymbol{y^d}$$

where $\boldsymbol{m^d}$ is the amount of intermediate imports for Danish industries. The vector of imports for final demand is given

$$(9) \qquad \boldsymbol{m^m} = \boldsymbol{y^m}$$

where $\boldsymbol{m^m}$ is imports direct for final demand

Thus, the total imports by foreign industry is the sum of the two elements above

$$(10) \qquad \boldsymbol{m} = \boldsymbol{m^d} + \boldsymbol{m^m}$$

Now the next step is to apply the EXIOBASE model to calculate the emissions content of the $\boldsymbol{m}$ vector.

EXIOBASE is organized roughly as in figure 4 above. The version of EXIOBASE used in this project is the industry by industry version with the following characteristics

- 163 industries
- 44 countries and 5 regions, i.e. a total of 49 “countries”
- Thus, the intermediate consumption matrix is (163*49) * (163*49) which is equal to 7,987 * 7,987
- An $\boldsymbol{S}$ vector of emission intensities covering each industry in each country, length 7,987
- 7 components of final demand for each country, i.e. a matrix of final demand of the size 7,987 * (49*7) = 7,987 * 343

This means that a matrix of emissions multipliers can be calculated.

$$(11) \qquad \boldsymbol{Q} = \widehat{\boldsymbol{S}}\boldsymbol{L}$$

where L is the MRIO Leontief inverse matrix.

In principle, if EXIOBASE and the Danish national accounts were compatible in every way we could calculate the total emissions embodied in the Danish imports as

$$(12) \qquad \boldsymbol{e^m} = \boldsymbol{Qm}$$

However, the MRIO multipliers cannot be applied to the Danish imports directly because they are in

- different currency
- different units

- different country classification.
- different industry classification and

Therefore, in order to use the $\boldsymbol{Q}$ matrix of EXIOBASE multipliers we need a correspondence or concordance matrix $\boldsymbol{K}$ that can make $\boldsymbol{Q}$ and $\boldsymbol{m}$ compatible. The construction of the matrix $\boldsymbol{K}$ is decisive in the coupled model framework.

The first three steps are rather straight forward. Thus, $\boldsymbol{K}$ must transfer between Danish Kroner and Euro which is just a single factor per year. Secondly it is crucial to keep track of all the different units involved. Units of emissions data that is used in the $\boldsymbol{S}$ vector must be the same tonnes or 1000 tonnes that is used for emissions in the domestic part of the model. Moreover the monetary data must after the currency conversion also be at the same level as the monetary data in the domestic part of the model calculated with the Danish input-output model.

Thirdly, the country classification must be equal. Applying data from the foreign trade statistics and balance of payments statistics imports by the approximately 2,350 products is split by 239 countries. To transfer this distribution from products to industries we used the market share matrix that is used in the compilation of the annual IO tables at Statistics Denmark.

(13) $$\boldsymbol{M_c} = \boldsymbol{C}[\widehat{\boldsymbol{C\iota}}]^{-1}$$

where $\boldsymbol{M_c}$ is a distribution matrix that gives the distribution of imports of 2,350 products by 239 countries normalized by its row sums. The matrix $\boldsymbol{C}$ is represents imports by 2,350 products and 239 countries. It is prepared annually be the national accounts section at Statistics Denmark on the basis of a much larger matrix from the foreign trade statistics and balance of payments statistics imports mapping around 10,000 products to 239 countries and a similar mapping of services from the balance of payments. The vector $\boldsymbol{i}$ is a 239*1 summation vector that sums across the columns of the $\boldsymbol{C}$ matrix. Thus, each of the rows sums to one if there is an import of that specific product and otherwise the sum is zero.

Now to go from the product level to the industry level we need some information about where

(14) $$\boldsymbol{D} = \boldsymbol{V}\widehat{\boldsymbol{x}^{-1}}$$

where $\boldsymbol{D}$ is the market share matrix in the dimension (2,350*117), $\boldsymbol{V}$ is the supply matrix in the dimension (2,350*117). As $\boldsymbol{V}$ only is about production in Denmark, there are more than 600 rows with no information because the products are not produced in Denmark. Therefore a one is put for the industry where the product would most likely have been produced if it had been produced in Denmark. Eventually we get the matrix we need

(15) $$\boldsymbol{D_c} = \boldsymbol{D'M_cB}$$

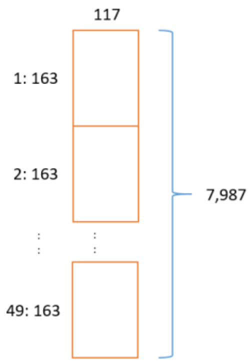
where $\boldsymbol{D_c}$ is a distribution matrix 117*49 where the rows sums to one. The matrix $\boldsymbol{B}$ is a 239*49 matrix that aggregates the 239 countries in the Danish imports data to the 49 EXIOBASE countries. This is a straight forward correspondence.

Finally the $\boldsymbol{K}$ matrix has to deal with the differences in the industry classifications between the Danish IO table and EXIOBASE. This is a somewhat more tricky part of $\boldsymbol{K}$ matrix. EXIOBASE has 163 industries and the Danish IO table has 117 industries. So going from 117 to 163 necessarily involves a number of cases of splitting a Danish industry into more than one EXIOBASE industry.

As a first attempt we applied just a uniform distribution of one Danish industry. Thus, when the one Danish agricultural industry was transferred to EXIOBASE we would distribute it evenly between the 17 different EXIOBASE agricultural industries with 1/17 each. Later on in the project we decided to use information about the Danish imports in EXIOBASE to compile a more empirically based key.

Thus, the amount of imports that Denmark according to EXIOBASE currently buys from the 17 agricultural sectors in each country is now the basis for an annually updated empirical key that distributes the actual Danish agricultural import between the 17 EXIOBASE industries.

The key matrix $\boldsymbol{K}$ is a stack of 49 matrices in the dimension 163*117 which gives the full dimension of the matrix 7,987 * 117. The matrix $\boldsymbol{D_c}$ discussed above is an integrated part of $\boldsymbol{K}$.



Each column corresponds to a National Account industry and each row corresponds to an EXIOBASE sector-in-region. If K_((AT,i01.a). 010000) = 0.025, it would for instance mean that 2.5% of the imports to Denmark from the total international "010000" sector should be allocated as import from the "i01.a" sector in the "AT" region. Since $\boldsymbol{K}$ merely distributes the values of $\boldsymbol{m}$, all values of $\boldsymbol{K}$ are weakly between 0 and 1, and each column of $\boldsymbol{K}$ sums to 1. When this key matrix is multiplied by the 117*1 vector of Danish imports it is capable both of distributing the total imports by 49 countries and transferring it from 117 industries to 163 industries. Thus, for each of the 49 countries there is a 163*117 conversion matrix which is scaled exactly to cover the amount of imports that came from that particular land in that particular year.

Moreover $\boldsymbol{K}$ could cover the currency question as well as make shure that all the units on emissions and the monetary values were aligned.

Now we can calculate the total emissions embodied in the Danish imports as

(16) $$\boldsymbol{e^m_{exio}} = \boldsymbol{QKm}$$

This calculation of $\boldsymbol{e^m_{exio}}$ results in a 7,987*1 vector of emissions related to total Danish imports. The same formula can easily be used for other issues of the $\boldsymbol{m}$ vector. Experiments can be made with the Danish IO model resulting in a variety of $\boldsymbol{m}$ vectors and this setup with EXIOBASE will contribute with emissions embodied in imports.

In this project we have also worked with a possibility to attribute emissions not only to a final demand category but also to the "demanding industry" i.e. the industry where the demand was initially put. That can be accomplished in a loop where the first step is to diagonalize the vector of final demand. Thus equation (8) is changed to

(17) $$\boldsymbol{M^d} = \boldsymbol{A^m L^d} \widehat{\boldsymbol{y^d}}$$

Where the result is now a 117 by 117 import matrix $\boldsymbol{M^d}$ instead of just a column vector. Now the $\boldsymbol{m}$ vector in (16) must be replaced 117 times in a loop one demanding industry at a time in order to calculate imports also by demanding sector.

The $\boldsymbol{e^m_{exio}}$ vector contains the total for the Danish climate footprint embedded in our imports. However, it does so by 163 industries which is not directly compatible with the 117 industries that is the classification of the results from the domestic part of the model. So at the detailed level the numbers are not possible to add up.

Therefore we need another conversion matrix to take the results back from the 163 to the 117 classification. Going from 163 to 117 involves mostly simple aggregations from many-to-one than when going the other way. Nevertheless, there are some of the 163 industries that need to be split when converting to the 117 classification. There is a few cases where one EXIOBASE industry maps into more than one industry in the Danish 117 industry classification. So far we have used a uniform distribution here

(18) $$\boldsymbol{e^m} = \boldsymbol{H e^m_{exio}}$$

where $\boldsymbol{H}$ is an aggregation matrix in the dimension (117*49) * (163*49). It is the intention is to construct an empirical key here as well. A new and more accurate $\boldsymbol{H}$ key matrix will not alter the total footprint, but may have small effects on the distribution by industry.

3. Data and some special challenges

One of the advantages of using a coupled model framework is that being a NSI we have full control of the domestic model and all of the required data that is used to run it. That is not entirely true for the MRIO part for the calculation of emissions contents in imports. Various aspects of the model is more or less out of control. Is the quality good enough, and is it as timely as required? In this section we take a closer look at a couple of the specific data challenges we encountered.

3.1. Extreme emission intensity values

Concerning the quality we already took a look at the Danish water transport industry previously. Another example that turned out to be a huge problem in the footprint calculation is the size of some of the emission intensities i.e. the $\boldsymbol{S}$ values.

In the first version of our model we calculated emissions multipliers as in equation (11). When they were used to calculate emissions content of the Danish imports it resulted in gigantic footprints. After some research we found that it resulted from a number of extreme outliers among the multipliers. The largest 7 multipliers can be seen in table 2 below.

Thus, the most extreme value says that every single EURO worth of imports from the *Re-processing of secondary plastic into new plastic* in Mexico, will result in 372,548 tons of emissions of GHG. As the Danish data indicated an import worth 2 mill. EURO from this specific industry in Mexico we ended up with a footprint of 729 billion tons from just this very small import.

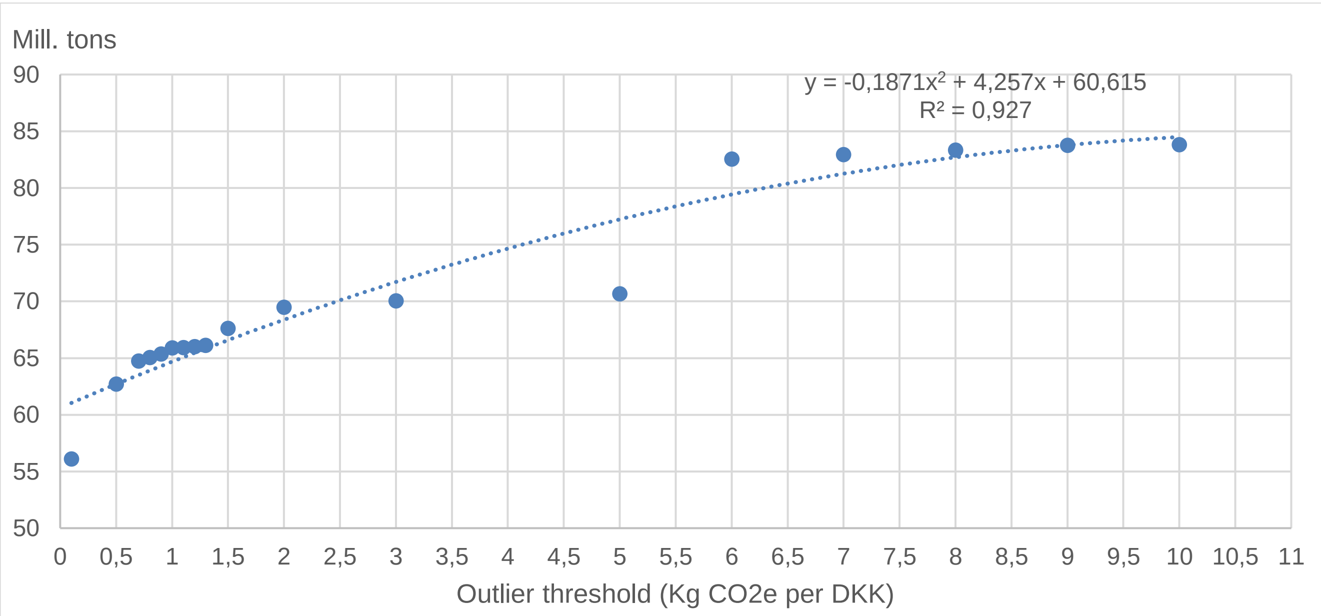
Table 2. *Outliers in EXIOBASE multipliers 2019*

Region	Sector	Multiplier from EXIOBASE (mill tons /mill.EUR)	Danish imports. (Mill. EUR)	Emissions = S*L*m (mill. tons CO2e)
MX	Re-processing of secondary plastic into new plastic	372,548	2.0	728,969
NL	Production of electricity by tide, wave, ocean	203,960	0.0	0
PT	Mining of aluminium ores and concentrates	146,829	0.9	135,065
PT	Mining of iron ores	123,044	0.9	113,186
NL	Production of electricity by solar thermal	44,390	0.0	0
MX	Extraction, liquefaction, and regasification etc.	29,915	0.0	0
FI	Re-processing of secondary plastic into new plastic	27,823	18.7	519,024

It turns out that most of the outliers in EXIOBASE occur in the energy and emission accounts because the approach used to construct them differs from the monetary accounts. Mostly they are for industries with essentially 0 activity, where a small amount of energy and emissions is allocated to a very very small amount of activity. In absolute terms it doesn't show up, but switch to intensities, and they make no sense.

At first we were not aware that the problem starts with the intensities ***S***, so in order to solve this problem we decided to rule out those multipliers that had a value above a certain threshold. But where to set the threshold? A sensitivity analysis showed that the placement of the threshold matter a lot

Figure 5. *Sensitivity analysis of threshold for multiplier outliers*



Thus, setting the threshold at 0.1 kg CO_2e per DKK yields a footprint at around 55 mill. tons while setting it at 10 kg CO_2e per DKK yields a footprint at around 85 mill. tons. Because the result seemed quite stable around 1, we chose this threshold. So after quite a lot of testing and sensitivity analysis we ended up setting the threshold at 1 kg CO_2e per 1 DKK, which translates into 7.5 kg CO_2e per EURO.

We are well aware that this a quite arbitrary choice and it is definitely high on the agenda to replace this measure with an empirically more sound measure. The best solution is to have new versions of EXIOBASE where this problem has been taken care of. The people behind EXIOBASE are well aware of this issue and they have said "*For long-term, we are working (almost finished) on reimplementing the energy/ emissions estimates to take into consideration the economic activity so that this does not occur". (October 2021).*

But while we are waiting for that, a second best solution would be to compare the specific 7,987 (163*49) ***S*** values with the 163 average ***S*** value across the 49 countries. Although it is a quite small sample there will definitely be extreme outliers that can be replaced e.g. by the average of the remaining values. When one outlier is removed or reversed to the average, the procedure can be repeated and the expectation is the procedure will converge very fast to a situation where the extreme value in one sector across 49 countries does not diverge significantly from the average of the remaining values.

3.2. Years covered

The Danish national accounts and input-output tables are currently available for the time period 1966-2019 in full dimension. For the years 2020 and 2021 preliminary versions of the IO table is published at the 69 sector level instead of the usual 117 industries. This calculation makes use of a wide range of data being compiled as preliminary macroeconomic aggregates by the national accounts department. This data, although not being published, exist in a 117 industry version as well. Therefore, the compilation of the two preliminary IO tables are actually also compiled at the 117 industry level before being aggregated to the 69 industry level which is published. For the calculation of the footprints, the "unofficial" IO tables at 117 industries have been applied.

GHG emissions data is being published in September after the end of the statistical year i.e. yyyy + 9 month. So already 9 month after the end of a statistical year it is possible to calculate a preliminary version of the Danish part of the coupled model. Climate Footprint. The part of the model that uses a MRIO table to calculate the emissions in the Danish imports is also currently available for the most recent year 2021. However, the quality of the EXIOBASEs for the most recent years are very uncertain, and therefore the next paragraph covers our methodological consideration about how to deal with this.

The aim in the project was to calculate a full time series of Climate Footprints from 1990 to 2020 (now 2021). The year 1990 is important in climate policy discussions because it is the base year for GHG emission reduction targets.

The interface between the Danish and the international part of the model, i.e. imports by industry and country, we only covered with data for the distribution by country from 2010 and onwards. Therefore the time series of footprints currently only covers the period from 2010. But as all data except for this distribution of imports by country are available for the full period 1990-2021 we are currently looking into a method to estimate the distribution for the years 1990-2009.

3.3. Is forecasted EXIOBASEs in sync with the economic reality?

One of the reasons that we chose EXIOBASE for the calculation of emissions in the Danish imports was that it is very up-to-date. Actually, an EXIOBASE for 2022 which is not even ended yet is provided.

The following text can be found on the EXIOBASE homepage
https://zenodo.org/record/5589597

The original EXIOBASE 3 data series ends 2011. In addition, we also have estimates based on a range of auxiliary data, but mainly trade and macro-economic data *which go up to 2022 when including IMF expectations. A lot of care must be taken in use of this data. It is only partially suitable for analysing trends over time!*

As of v3.8 (doi: 10.5281/zenodo.4277368), the end years of real data points used are: 2015 energy, 2019 all GHG (non fuel, non-CO2 are now-casted from 2018), 2013 material, 2011 most others, land, water.

In December 2021 we published a footprint for 2020, and here in December 2022 we are working on the footprint for 2021. We have preliminary versions of all the Danish data so we can compile the domestic footprint and calculate the amount of imports it requires. From 2020 to 2021 the Danish economy recovered greatly from the Covid-19 pandemic that affected the country in 2020 and beginning of 2021. The recovery generated a rather huge increase in imports in current prices due partly to an increase in imported volumes and partly to increasing prices on energy and food that started to appear towards the end of 2021.

However, it is our hypothesis, that the EXIOBASE versions 2020 and 2021 does not reflect very well neither the pandemic in 2020 nor the boom and increasing prices in 2021. For the coupled model to work properly it is necessary that the economic development reflected in the domestic model and in the global model is on a fairly identical path. If that is not the case, it could happen that the emission coefficients $\boldsymbol{S}$ in EXIOBASE are almost identical from e.g. 2020 to 2021 because total output $\boldsymbol{X}$ which is the denominator in the fraction that calculates $\boldsymbol{S}$, does not develop very much due to low and stable prices. Then $\boldsymbol{S}$ are used to calculate and equally stable global emissions multipliers $\boldsymbol{Q}$. Then if the Danish imports $\boldsymbol{m}$ increases rather much in current prices due to beginning inflation the footprint $\boldsymbol{Qm}$ will also increase rather much. Thus, inflation in the Danish import figures will drive up the size the footprint which is wrong. The increase in $\boldsymbol{m}$ due to inflation should have been mitigated by a similar decrease in $\boldsymbol{Q}$ enabled by a decrease in $\boldsymbol{S}$ which again would be the result of an increase in the denominator total output $\boldsymbol{X}$ due to beginning inflation. Because the current inflation was not anticipated when 2021 EXIOBASE was compiled the $\boldsymbol{X}$ vector did not grow enough in current prices and therefore $\boldsymbol{Q}$ was not able to mitigate the inflationary increase in $\boldsymbol{m}$ and the footprint for 2021 became too large in the first calculation.

In order to deal with this problem it was decided to try to use EXIOBASE 2019 for the footprint calculation in all three years 2019-2021. To enable this calculation, the import data $\boldsymbol{m}$ for 2020 and 2021 must to be deflated back to the same price level (2019) as the EXIOBASE model for 2019. To do this, we need to compile some price indices

(19) $$\boldsymbol{p\_m_t} = \frac{\sum_{j=1}^{n} \boldsymbol{Am_t^p x_t^p}}{\sum_{j=1}^{n} \boldsymbol{Am_t^c x_t^c}}, \quad t \in 2020{,}2021 \quad \left[\frac{p_{t-1}q_t}{p_t q_t}\right]$$

where

$\boldsymbol{p\_m_t}$ is a vector of import price indices
$\boldsymbol{Am_t^p}$ is the matrix of import coefficients by industry in previous years prices
$\boldsymbol{x_t^p}$ is the vector of total output in previous years prices at year t
$\boldsymbol{Am_t^c}$ is the matrix of import coefficients by industry in current prices
$\boldsymbol{x_t^c}$ is the vector of total output in current at year t

Now we can calculate the deflated import vectors as

(20) $$\boldsymbol{m_{2020}^k} = \boldsymbol{m_{2020}^c p\_m_{2020}} \quad \left[\frac{\boldsymbol{p_{t-1}}}{\boldsymbol{p_t}} \boldsymbol{p_t q_t} = \boldsymbol{p_{t-1} q_t}\right]$$

(21) $$\boldsymbol{m_{2021}^k} = \boldsymbol{m_{2021}^c p\_m_{2020} p\_m_{2021}} \quad \left[\frac{\boldsymbol{p_{t-2}}}{\boldsymbol{p_{t-1}}} \frac{\boldsymbol{p_{t-1}}}{\boldsymbol{p_t}} \boldsymbol{p_t q_t} = \boldsymbol{p_{t-2} q_t}\right]$$

where

m^k_{2020} is a vector of imports for 2020 in chained 2019 prices (k)
m^c_{2020} is a vector of imports for 2020 in current prices (c)
m^k_{2021} is a vector of imports for 2021 in chained 2019 prices (k)
m^c_{2021} is a vector of imports for 2021 in current prices (c)

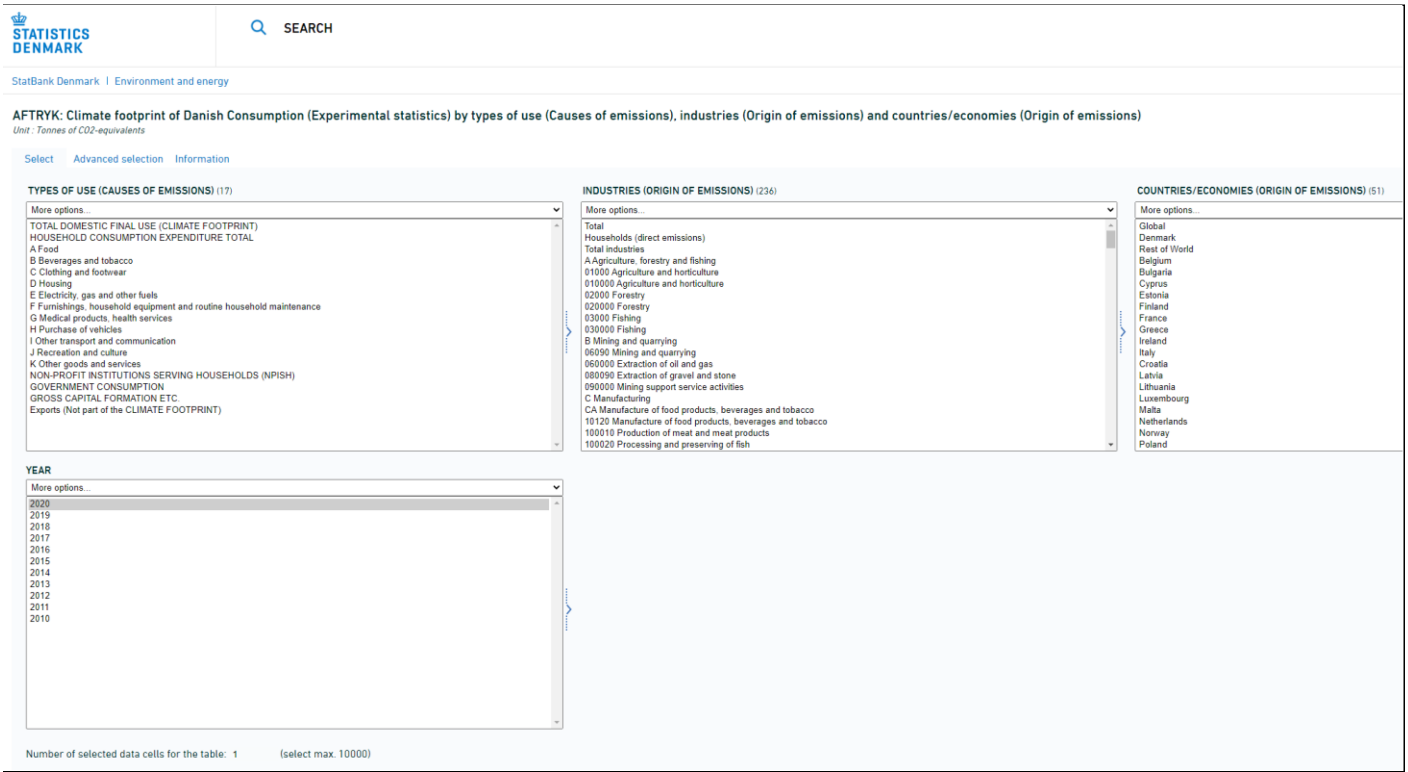
The equations in square brackets is only a supplement in order to better understand what is going on in terms of prices and quantities.

Thus, with the help of the price indices calculated in (19) we are able to deflate the 2020 and 2021 import vectors back to the 2019 price level.

4. Results

The results of the Danish footprint calculation was published for the first time in December 2021. It was decided that it could be published as an official table in the Statbank, but it was labelled “Experimental Statistics”. The results are to a large the outcome of a modelling exercise, which is normally not the case for official statistics. Therefore the Experimental Statistics label will probably stick to it in the years to come as well.

Figure 6. *Footprint results in the Danish Statbank.dk*



Source: www.statbank.dk/aftryk

The table shows the Danish Climate Footprint for the years 2010 to 2020. An update of the table with 2021 results are currently being prepared. At the same time an update back to 1990 is also being prepared.

Apart from the time period there are three variables that must be decided upon when drawing from the database.

(1) **Types of use**. Here it is possible to choose various sub-components of total domestic final use. Thus, the Climate Footprint is decomposed into the four main categories

- Consumption by Households
- Consumption by Non-profit institutions (NPISH)
- Consumption by Government
- Gross Capital Formation etc.

Moreover it is possible to get the footprints of 11 subcategories of Household Consumption.

Finally, as mentioned previously, there is also a possibility to draw the Climate Footprint of the Danish exports, although it is not part of the official Climate Footprint, since it completes the picture for many users.

(2) **Industry of origin**. Here it can be chosen either to see the total (= an aggregation over all industries) or specific industries or aggregation of industries. The industry of origin is where emissions actually appear as a consequence of Danish final demand travelling through the global value chains.

(3) **Country of origin**. Here it can be chosen either to see the total (= an aggregation over all countries) or specific countries. The country of origin is where emissions actually appear as a consequence of Danish final demand travelling through the global value chains. When Denmark is chosen, one gets the domestic emissions in Denmark as a consequence of Danish final use.

As an example; when there is consumption of e.g. a German car by Danish households the number in the cell "Car manufacturing industry" + "Germany" only contains the emissions actually generated in the German car manufacturing plants. The steel that is used in the car may have been produced in China and the tyres in the Czech Republic and so on. So for the subcategory "H Purchase of vehicles" there will be emissions in the steel industry in China and rubber industry in the Czech Republic, and in many other industries and in many other countries all over the world.

The result for 2020 showed that the Climate Footprint for Denmark was 65.4 mill. tons of CO_2-equivalents. That is an equivalent of 11 tons per capita.

A query from the AFTRYK table shows that in 2020 around 24.6 of the 65.4 mill. tons are emitted in Denmark which amounts to 38 percent. The remaining 62 percent or 40.8 mill. tons are emitted in Rest of The World.

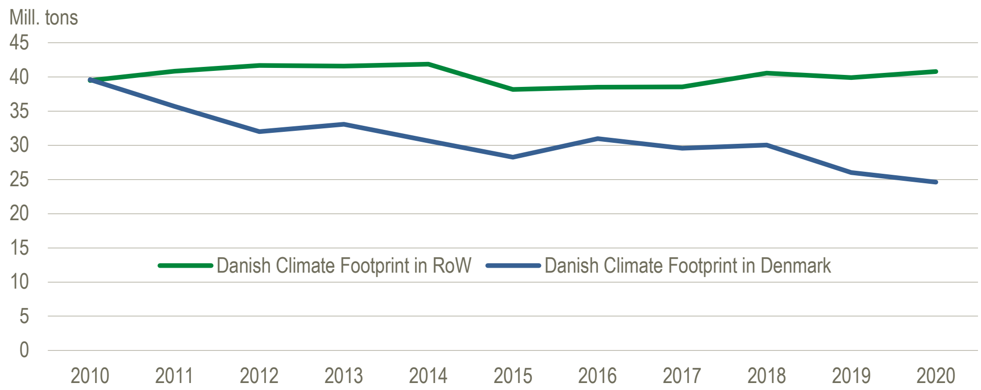
	Total	Households (direct emissions)	Total industries
2020			
TOTAL DOMESTIC FINAL USE (CLIMATE FOOTPRINT)			
Global	65 372 184	6 925 137	58 447 046
Denmark	24 608 729	6 925 137	17 683 591
Rest of World	40 763 455	0	40 763 455

Only in Danish

Unit : Tonnes of CO2-equivalents

Thus, a huge share of emissions attributable to the Danish domestic use is emitted outside of the Danish borders. Now we could test if this has developed over time which was indicated in figure 1 in the introduction to this document.

Figure 7. Danish Climate Footprint 2010 to 2020

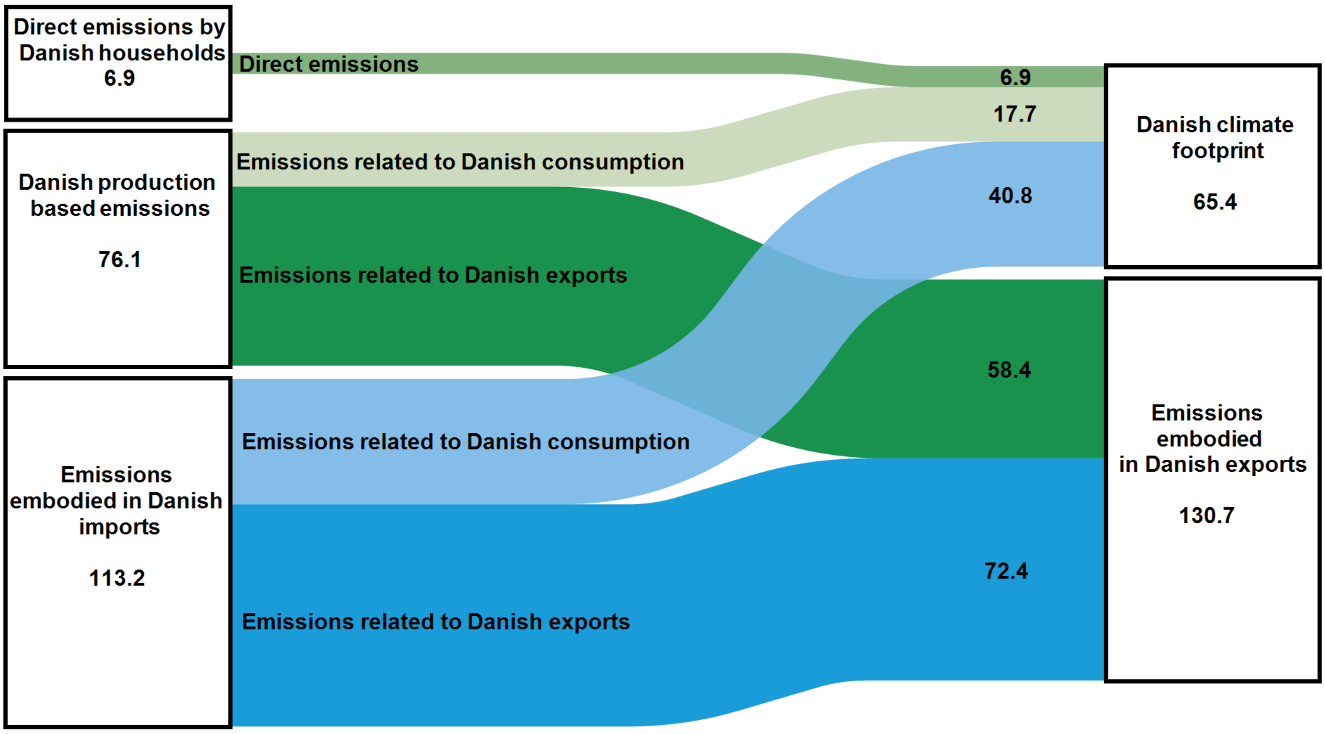


This figure shows a result that was somewhat expected based on figure 1 in the introduction. Despite the fact that industries in RoW have made improvement in their emission intensities from 2010 to 2020 the Danish imports have increased at the same pace which has led to a completely constant footprint contribution in RoW from Danish imports at around 40 mill. tons. In the same span of years, the domestic emissions contribution to the Danish Climate Footprint decreased from around 40 mill. tons in 2010 to around 25 mill. tons in 2020 which is a 38 percent decrease.

While the Danish economy has grown in terms of GDP there has been a decoupling meaning that at the same time emissions have fallen quite rapidly. The finding in figure 7 contributes to a general understanding that this decoupling to a certain extent has been facilitated by an increasing imports of GHG intensive products.

When the results from the footprint calculations are put in a Sankey diagram together with footprint of exports the overview of the connection between the production- and consumption based emissions improves considerably.

Figure 8. *Connection between production and consumption based emissions, mill. tons CO_2e, 2020*



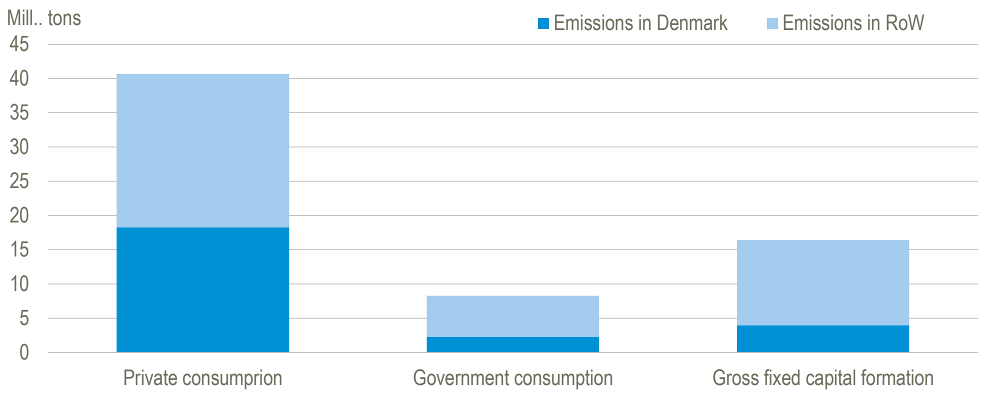
It is evident that the Danish export production is responsible for a considerable share of Danish production based emissions. Thus 58.4 out of 76.1 mill. tons of emissions can be attributed to exports. This is due to the relatively very large sea transport industry that is operated from Copenhagen and therefore is a part of the resident economy and therefore also resident emissions. Thus, only around 23 percent of the resident emissions in Denmark can be related to domestic consumption.

The emissions contained in Danish imports amounts to 113 mill. tons of which only 36 percent or 40,8 mill. tons is attributable to domestic consumption and investment. The main part or 64 percent of the import related emissions was related exports in 2020.

This means that Danish economic activity resulted in almost 200 mill. tons of emissions globally, but only one third hereof can be said to be the responsibility of Danish consumers.

Out of the emissions related to domestic consumption the consumption by households makes up the major part

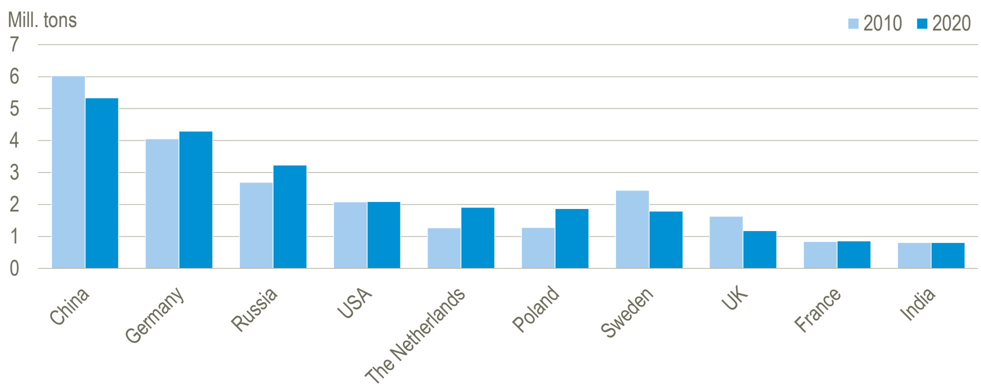
***Figure 9**. Denmark's Climate Footprint by final demand category, 2020*



The figure shows that private consumption amounts to approximately 40 mill. tons of emission of which a little bit more than half (55 percent) are footprints in RoW. Although government consumption contributes only 8 mill. tons to the footprint it is a little surprising that approximately two thirds of the footprint lies outside the Danish borders.

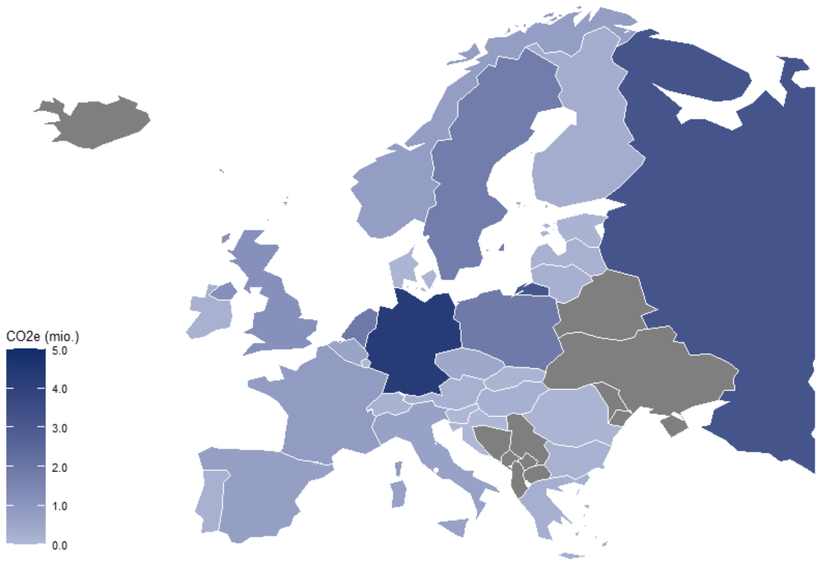
Gross fixed capital formation puts not so surprisingly a lot more pressure on RoW than Denmark. A large part of machinery, transport equipment, steel etc. either is imported directly or imported through intermediate consumption.

***Figure 9**. Denmark's Climate Footprint by country of origin, 2020*



The figure show that like in many other western countries Denmark imposes its largest footprint outside of Denmark on China. But the footprint actually decreased a bit between 2010 and 2020 which is a little surprising. On the contrary, many of the import markets closer to Denmark had an increasing footprint caused by Danish domestic final consumption.

***Figure 10**. Denmark's Climate Footprint by European countries*



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