Quantification of Greenhouse Gas Emissions from Swedish Food Consumption

Consumption-Based Emission Trends using Input-Output Analysis

Master’s thesis in Circular Economy

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Abstract

This thesis quantifies the greenhouse gas (GHG) emissions associated with Swedish food consumption through input-output analysis (IOA) and structural decomposition analysis (SDA). Using the EXIOBASE database, the study provides a comprehensive overview of consumption-based emission trends of food consumption in Sweden from 1996 to 2021. The research examines in which sectors and regions the emissions occur and distinguishes between domestic production and imports. It identifies key drivers of changes in emissions. The results highlight significant patterns in food-related emissions. There is an overall downward trend in consumption-based emissions, which is driven by a significant decrease in GHG emissions in Sweden, whereas the emissions occurring outside of Sweden are slightly increasing. The sectors displaying the largest emission reductions are "hotel and restaurant services" and "dairy products". This is due to lower direct emissions in agriculture, particularly meat cattle and dairy products due to their high magnitude of emissions, and rice production, which points towards a reduction in methane emissions. For all specifications in the SDA, decreasing emission intensities are the main drivers for the downward trend in GHG emissions. The results of technological improvement are more visible in Sweden itself than in other countries where the total emissions are slightly increasing due to a higher final demand in Sweden and unfavorable changes in the supply chain. These findings provide guidance for policy makers aiming to develop strategies to reduce the carbon footprint of food consumption in Sweden and prevent carbon leakage of emissions. The thesis presents several opportunities for future research, such as more in-depth analysis in the IOA and SDA, the combination or comparison with other databases and provides a starting point for a comparative analysis with LCA.

Keywords: multi-regional input-output analysis, Swedish food consumption, EXIOBASE, carbon footprint, animal agriculture

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List of Abbreviations

CO_2	carbon dioxide
GHG	greenhouse gases
IOA	Input-Output Analysis
kg CO_2 eq.	kilogram of CO_2 equivalent
LCA	Lifecycle assessment
MR-IOT	Multi-regional input-output table
nec	not elsewhere classified
RoW	Rest of the World
SDA	Structural Decomposition Analysis

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1. Introduction

1.1 Background

The thesis addresses the urgent need to reduce emissions of carbon dioxide (CO_2) and other greenhouse gases (GHG) in the context of climate change. This is necessary to reach internationally agreed climate targets, such as the Paris Agreement. The global food production and consumption system is a major contributor to the climate crisis. According to Pinero et al. (2022), understanding food system emission sources and trends is vital to address these environmental issues. Challenges include the risk of carbon leakage induced by the complexity of food supply chains, i.e. emissions are mitigated in one country but occur as a result in another, thus hampering policies (Pinero et al., 2022).

The Swedish "Generational goal" is one out of 17 environmental quality goals which aim to reduce the environmental impacts in Sweden and should be reached within one generation. It calls for consumption patterns that minimize this impact without shifting the environmental burdens abroad. The focus in this thesis is on the carbon footprint of Swedish food consumption. In this thesis, due to the concept of "carbon footprint", carbon emissions relate to the emissions of all GHG. Studies show that the carbon footprint of food consumption in Sweden is decreasing over time (Statistics Sweden, 2023). To support this trend with policies, further research into the causes is needed. The observed trends can be attributed to several factors. First, there could be a reduction in emission intensity, driven by improvements in efficiency and yields. Second, shifts in dietary habits may alter the amount and type of food consumed, affecting the overall carbon footprint. In addition, changes in the product sourcing and supply chain dynamics could lead to variations in emissions. For general policy implications, it is useful to examine which categories are currently showing the largest reductions in their overall carbon footprint.

Sweden imports about one third of its food by weight (FAOSTAT, 2023). To account for this fact, previous studies based on the principle of consumption-based accounting have used different methodologies. For instance, Moberg et al. (2020) used life cycle assessment (LCA) and calculated the carbon footprint of food consumption in Sweden to be 2200 kilograms of CO_2 equivalent (kg CO_2 eq.) per person per year, while Statistics Sweden (2023) used input-output analysis (IOA) and reported approximately 1400 kg CO_2 eq. per person per year. These differences highlight the variability in results depending on the methodology used and the need for a consistent approach in future research. In assessing the impact of Danish food consumption, Osei-Owusu et al. (2021) found that food-related GHG emissions decreased by 30% between 1995 and 2014 with a carbon footprint of 1874 kg CO_2 eq. per person in the year 2014. This thesis builds on these studies by using IOA to investigate the trends in Swedish food consumption emissions and by using structural decomposition analysis (SDA) to assess the underlying drivers.

1.2 Problem statement and research questions

Sweden's environmental goals emphasize the need to reduce climate impacts, which requires a detailed understanding of the factors influencing food-related emissions. This understanding is crucial for formulating effective environmental policies. Despite existing research, there is a gap in identifying the factors that drive the changes in emissions over time. This thesis aims to fill this gap by focusing on the Swedish food consumption context. The main objective is to investigate the trend of the carbon footprint using IOA. Furthermore, this trend is analyzed in detail using SDA based on changes in consumption patterns, the sourcing in the supply chain and the emission intensity over time. Therefore, the research questions are:

1. *What are the trends in consumption-based emissions from Swedish food consumption?*
2. *How are these changes in emissions driven by changes in the emissions intensities, the sourcing, and the final demand of food consumed in Sweden?*

1.3 Structure of the thesis

After introducing the thesis and presenting the research questions, chapter 2 explains the application of IOA and SDA in detail, describing the specific steps and approaches used in the analysis. Chapter 3 presents the data sources, including a detailed introduction and description of the database EXIOBASE, its structure, and issues encountered while using it. Next, chapter 4 presents and interprets the results of the IOA and SDA, providing a comprehensive examination of the trends and key factors influencing the carbon footprint of Swedish food consumption. Chapter 5 discusses the implications and limitations of the study and summarizes the results in the conclusion.

2. Methodology

In this chapter, the methods IOA and SDA will be described in connection to their application to the study of emissions from Swedish food consumption.

2.1 Input-Output Analysis

IOA is a method used to evaluate the relationships between different sectors of an economy and how they interact with each other. Traditional IOA focuses on assessing the economic interactions within a single region, detailing the flow of goods and services between sectors. Multi-regional IOA extends this framework by examining these interactions across different regions in a global context (Kitzes, 2013). It extends traditional IOA by detailing the flow of goods and services between sectors across different regions, allowing for a deeper understanding of global supply chains. IOA is particularly relevant for evaluating the environmental impacts and resource use associated with international trade. This method allows to trace the origins and destinations of economic flows and to assess the direct and indirect effects on the environment globally.

2.1.1 Mathematical background

The direct requirements matrix A is essential for understanding economic interdependencies between the sectors in each region. This matrix represents the input components from each other sector for each unit of output in a given sector.

This matrix is derived by normalizing the inputs to the output of each sector, i.e. dividing the intermediate consumption matrix Z, which records transactions between sectors, by the vector of total outputs x. To be able to divide by a vector and keep the dimensions, it is used as a diagonalized and inversed matrix:

$$\mathbf{A} = \mathbf{Z}\,\hat{\mathbf{x}}^{-1} \tag{2.1}$$

In general, the matrix A is crucial for evaluating how sectoral changes can impact the broader economy and for assessing the environmental footprints of production processes. By tracing the direct and indirect inputs required for production, it allows identifying key areas in the supply chain for reducing resource use, emissions, and waste.

The final demand matrix Y contains the consumption of products by sector and region by final consumers, such as households, governments, and for capital formation, across different regions. The relevant region in this case is Sweden. Aggregating the final consumers, the final demand matrix Y becomes the final demand vector y.

The emission intensity matrix S details the environmental extension by including additional environmental data, such as GHG emissions, extraction of resource, energy use, water consumption, and other material flows. Relevant for the carbon footprint is the data on GHG emissions.

The following calculations are based on Leontief (1936) and the expansion of IOA in Miller & Blair (2009). The matrix I is an identity matrix with the same dimensions as the direct requirement matrix A, containing only 1s in the diagonal and 0s in all other cells. The Leontief inverse including the inter-industry flows is then given by subtracting the direct requirement matrix A from the identity matrix I and calculating the inverse of this:

$$\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1} \tag{2.2}$$

Extending the economic data with environmental metrics, the matrix including the emission coefficients S is given by multiplying the vector of total GHG emissions e with the inverse of the diagonalized industry output x. This operation normalizes the emission and S shows the emissions per unit output:

$$\mathbf{S} = \mathbf{e}\,\hat{\mathbf{x}}^{-1} \tag{2.3}$$

The final demand matrix Y includes the input sectors across all regions in the rows and the consumer groups for all regions in the columns, which will be aggregated to one column per country. This will be adjusted later for food consumption in Sweden as well as different cases for more specific analysis and the SDA. The total emissions matrix of the consumption-based accounts D_{cba} is calculated as the product of the emission coefficients S, the Leontief inverse L and the final demand vector y, resulting in the following formula:

$$\mathrm{D}_{\mathrm{cba}} = \mathbf{S}\,\mathbf{L}\,\mathbf{y} \tag{2.4}$$

The matrix D_{cba} provided in the database used for this research already contains the emissions of consumption-based accounts by consumption sector and region. However, analyzing the trends of emissions requires a higher resolution, i.e. from which sectors and regions the emissions are originating. Therefore, this matrix is not of use and the emissions of consumption-based accounts need to be calculated. For this detailed analysis, D_{cba} must be available as a matrix rather than as a vector or scalar. This matrix format enables the examination of how emissions from consumption sectors, input sectors, or input regions change over time. To calculate this, the principle of diagonalization is being used: A vector is diagonalized by transforming it into a matrix where the values of the original vector are in the diagonal of the matrix while all other values are 0. Since the resulting diagonalized vector is squared, indices and headers are equal. This vector is used in the following subchapter and adjusted for specific cases, i.e. setting certain rows, columns, or blocks from the larger matrices to 0.

To analyze the food consumption in Sweden, in the diagonalized final demand vector y_t, all values that are not in the column corresponding to Sweden and whose row indices are not in the list of food sectors (Appendix: *List of food sectors*) are set to 0. Here, it is to note that the list of food sectors includes the primary food sectors, processed food and hotel & restaurant services. While Osei-Owusu et al. (2021) do not include hotel and restaurant services in their research, for this study the sector is adjusted to only include inputs from the other food sectors to exclude non-food related services. To do so, the inputs from all sectors that are not included in the list of food sectors (Appendix: *List of food sectors*) are set to zero. The vector s_t represents a single row of GHG emissions from the emission coefficient matrix S, which includes emissions of other substances, whereas all other rows are excluded. This enables the analysis of GHG emissions. In the following calculations the results for all years of analysis will be combined into the matrix of emissions of consumption-based accounts of food consumption in Sweden over time $D_{cba,t}$, where “cba” stands for consumption-based accounts and “t” for the time series. All results have the unit of kg CO_2 eq.

2.1.2 Change in total emissions of food consumption in Sweden

The total carbon emissions for each year $D_{cba,t}$ can be obtained by multiplying the GHG emission coefficients vector s_t, the Leontief inverse L_t, and $y_{food,t}$, a version of the final demand vector y_t only including the food consumption in Sweden. The mathematical formula for this is the following:

$$\mathrm{D}_{\mathrm{cba,t}} = \mathbf{s}_{\mathrm{t}}\, \mathbf{L}_{\mathrm{t}}\, \mathbf{y}_{\mathrm{food,t}} \tag{2.5}$$

To calculate the carbon footprint per person per year, this scalar is divided by the population of Sweden for that year P_t:

$$carbon\ footprint\ per\ capita = \frac{\mathrm{D}_{\mathrm{cba,t}}}{\mathrm{P}_{\mathrm{t}}} \tag{2.6}$$

The trend is then obtained by plotting these for each year as shown in the results. The absolute change per year indicates the trend of the carbon footprint.

2.1.3 Change in emissions by consumption sector over time

To calculate the change in emissions by consumption sector over time the final demand vector of food consumption in Sweden $y_{food,t}$ is diagonalized to obtain the squared matrix $\hat{y}_{food,t}$. The adjusted final demand matrix $\hat{y}_{food,t}$ contains the time series of the final demand for food consumed in Sweden divided into the different consumption sectors. To analyze how the emissions in the food consumption sectors have changed over time, the matrix $D_{cba,food,t}$ is calculated using the time series of the vector s_t as well as the matrices L_t and $\hat{y}_{food,t}$.

$$\mathbf{D}_{\mathrm{cba,food,t}} = \mathbf{s}_{\mathrm{t}}\ \mathbf{L}_{\mathrm{t}}\ \hat{\mathbf{y}}_{\mathrm{food,t}} \tag{2.7}$$

$D_{cba,food,t}$ now enables the analysis of the emissions of all sectors of food consumption in Sweden, which are displayed in the columns of the matrix whereas the rows only show the emissions per sector as a scalar.

Next and for all following calculations, the absolute change per year is obtained by calculating the difference between the scalars of the emissions of consumption-based accounts from the last year of analysis $D_{cba,max}$ and the first year of analysis $D_{cba.min}$ and dividing it by the total number of years t:

$$\frac{\Delta}{\mathrm{t}} = \frac{\mathrm{D}_{\mathrm{cba,max}} - \mathrm{D}_{\mathrm{cba,min}}}{\mathrm{t}} \tag{2.8}$$

Furthermore, the rate of change, expressed as the percentage of change in emissions per year, is calculated using the following formula:

$$\mathit{Rate\ of\ change} = \left(\left(\frac{\mathrm{D}_{\mathrm{cba,max}}}{\mathrm{D}_{\mathrm{cba,min}}}\right)^{\frac{1}{\mathrm{t}}} - 1\right) * 100 \tag{2.9}$$

The absolute change is more informative regarding the total influence of an input or consumption sector, category, or region since it is similar to the annual change over the years. However, the rate of change indicates the relative change for each sector, category, or region and can aid in the analysis.

2.1.4 Change in emissions by input sectors over time

To gain insight into the change in emissions by input sectors over time the vector of GHG emission coefficients s is diagonalized for all years resulting in $\hat{\mathrm{s}}_{\mathrm{t}}$. Summing all regions of this GHG emission coefficient matrix $\hat{\mathrm{s}}_{\mathrm{t}}$ by the 200 sectors results in $\hat{\mathrm{s}}_{\mathrm{sectors,t}}$. Again, this is multiplied by the Leontief inverse and the final demand for food consumed in Sweden $\mathrm{y}_{\mathrm{food,t}}$:

$$\mathbf{D}_{\mathrm{cba,sectors,t}} = \hat{\mathbf{s}}_{\mathrm{sectors,t}}\, \mathbf{L}_{\mathrm{t}}\, \mathbf{y}_{\mathrm{food,t}} \tag{2.10}$$

Here, $\mathrm{D}_{\mathrm{cba,sectors,t}}$ contains all 200 input sectors regardless of the region in the rows. Diagonalizing $\mathrm{y}_{\mathrm{food,t}}$ as well would allow for the columns to be aggregated to obtain the total emissions by input sectors.

2.1.5 Change in emissions by input categories over time

In the next step, the concordance matrix **C** is used that aggregates the input sectors in which the direct emissions occur to categories (Appendix B: Concordance matrix). $\mathrm{D}_{\mathrm{cba,sectors,t}}$ is being multiplied with the concordance matrix **C** from the left to obtain this categorization:

$$\mathbf{D}_{\mathrm{cba,categories,t}} = \mathbf{C}\, \mathrm{D}_{\mathrm{cba,sectors,t}} \tag{2.11}$$

$\mathrm{D}_{\mathrm{cba,sectors,t}}$ shows the categorized sectors in the rows while still showing the food consumption sectors in the columns. This allows for a better overview when analyzing the inputs. Each category consists of a different number of sectors. Therefore, the absolute emissions differ significantly and normalizing the emissions per category makes them more comparable.

2.1.6 *Change in emissions by input regions over time*

Grouping the resulting emissions by input country allows for analysis on a geographical level. To calculate this step, $\hat{s}_t$ is now aggregated by regions which gives $\hat{s}_{regions,t}$. The calculation is carried out as follows:

$$\mathbf{D}_{\mathrm{cba,regions,t}} = \hat{\mathbf{s}}_{\mathrm{regions,t}}\, \mathbf{L}_{\mathrm{t}}\, \mathbf{y}_{\mathrm{food,t}} \qquad (2.12)$$

The rows of the matrix $D_{cba,regions,t}$ contain the 49 regions where the emissions occur. As before when analyzing the input sectors, if $y_{food,t}$ is diagonalized, the columns can be aggregated resulting in the total emissions by input region. This allows for a division between a domestic component of the food consumed in Sweden being produced in Sweden and a foreign component produced overseas.

2.2 Structural Decomposition Analysis

SDA is a quantitative method used in the field of input-output economics to analyze changes over time. These changes are mathematically decomposed to isolate the impact of specific components (Dietzenbacher & Los, 2000). It is useful for examining the driving factors behind these changes in economic indicators, such as output, wealth, energy consumption, or environmental impact. The technique is widely used in environmental economics, industrial ecology, and sustainable development studies.

2.2.1 *Mathematical background*

Applying the SDA according to Dietzenbacher & Los (2000), the average of two polar decomposition analysis is used to systematically investigate the drivers behind the changes in GHG emissions associated with food consumption in Sweden from 1996 to 2021.

The change in total emissions ΔD_{cba} is calculated over the period analyzed, where the subscript “0” for each variable denotes the year 1996, while the subscript “1” denotes the year 2021. With the vector of emission coefficients s containing the GHG emissions per output, the Leontief inverse L representing the supply chain and the vector of final demand for food consumption in Sweden, hereafter simplified as y, ΔD_{cba} is calculated as follows:

$$\Delta \mathrm{D}_{\mathrm{cba}} = \mathbf{s}_1 \mathbf{L}_1 \mathbf{y}_1 - \mathbf{s}_0 \mathbf{L}_0 \mathbf{y}_0 \tag{2.13}$$

The incremental changes in each component are defined as follows:

- $\Delta \mathbf{s} = \mathbf{s}_1 - \mathbf{s}_0$ for changes in emission coefficients,
- $\Delta \mathbf{L} = \mathbf{L}_1 - \mathbf{L}_0$ for changes in the supply chain,
- $\Delta \mathbf{y} = \mathbf{y}_1 - \mathbf{y}_0$ for changes in final demand.

These equations are transformed to:

- $\mathbf{s}_1 = \mathbf{s}_0 + \Delta \mathbf{s}$,
- $\mathbf{L}_1 = \mathbf{L}_0 + \Delta \mathbf{L}$,
- $\mathbf{y}_1 = \mathbf{y}_0 + \Delta \mathbf{y}$.

Inserting these equations in (2.13) once starting with s_1, then L_1, and last y_1, and once in the opposite order gives the first polar $\Delta D_{cba,1}$ and the second polar $\Delta D_{cba,2}$:

$$\Delta \mathrm{D}_{\mathrm{cba,1}} = (\Delta \mathbf{s}) \mathbf{L}_1 \mathbf{y}_1 + \mathbf{s}_0 (\Delta \mathbf{L}) \mathbf{y}_1 + \mathbf{s}_0 \mathbf{L}_0 (\Delta \mathbf{y}) \tag{2.14}$$

$$\Delta \mathrm{D}_{\mathrm{cba,2}} = (\Delta \mathbf{s}) \mathbf{L}_0 \mathbf{y}_0 + \mathbf{s}_1 (\Delta \mathbf{L}) \mathbf{y}_0 + \mathbf{s}_1 \mathbf{L}_1 (\Delta \mathbf{y}) \tag{2.15}$$

The final formula for ΔD_{cba} is derived by taking the average of the corresponding terms from both polars. Each component from both polar scenarios is summed and then divided by two to compute the mean to balance the polars:

$$\begin{aligned}\Delta \mathrm{D}_{\mathrm{cba}} = {} & \frac{(\Delta \mathbf{s}) \mathbf{L}_0 \mathbf{y}_0 + (\Delta \mathbf{s}) \mathbf{L}_1 \mathbf{y}_1}{2} + \frac{\mathbf{s}_1 (\Delta \mathbf{L}) \mathbf{y}_0 + \mathbf{s}_0 (\Delta \mathbf{L}) \mathbf{y}_1}{2} \\ & + \frac{\mathbf{s}_1 \mathbf{L}_1 (\Delta \mathbf{y}) + \mathbf{s}_0 \mathbf{L}_0 (\Delta \mathbf{y})}{2}\end{aligned} \tag{2.16}$$

Each term of this sum represents the changes due to the three components emission coefficients s, Leontief inverse L and final demand y. This analytical method allows for a detailed attribution of emission changes to specific driving factors.

The first term represents changes due to changes of the emission coefficients s, reflecting varying GHG emissions per unit of output due to improvements in the technology that is applied in the production process. The second term stands for changes due to the Leontief inverse L, which indicates the effect of changes within the supply chain. A different sourcing or material use of the final product can influence the overall emissions. The third term captures change due to changes in the final demand. Therefore, changes in the amount and composition of food products consumed have an impact on the total emissions of food consumption in Sweden.

The change in emissions due to changes in emission coefficients, $\Delta D_{cba,s}$,is calculated as follows:

$$\Delta \mathrm{D}_{\mathrm{cba,s}} = \frac{(\Delta \boldsymbol{s})\boldsymbol{L}_0\boldsymbol{y}_0 + (\Delta \boldsymbol{s})\boldsymbol{L}_1\boldsymbol{y}_1}{2} \tag{2.17}$$

The changes in emissions based on changes in the supply chain represented by the Leontief inverse L are given by $\Delta D_{cba,L}$:

$$\Delta \mathrm{D}_{\mathrm{cba,L}} = \frac{\boldsymbol{s}_1(\Delta \boldsymbol{L})\boldsymbol{y}_0 + \boldsymbol{s}_0(\Delta \boldsymbol{L})\boldsymbol{y}_1}{2} \tag{2.18}$$

The effect due to changes in final demand Δy results in $\Delta D_{cba,y}$, which is calculated as:

$$\Delta \mathrm{D}_{\mathrm{cba,y}} = \frac{\boldsymbol{s}_1\boldsymbol{L}_1(\Delta \boldsymbol{y}) + \boldsymbol{s}_0\boldsymbol{L}_0(\Delta \boldsymbol{y})}{2} \tag{2.19}$$

To analyze the consumption of certain products, sectors in which direct emissions occur or specific regions, the final demand will be adjusted in the following, creating specific cases based on the IOA results.

2.2.2 Definition of cases by specifying the final demand

The most significant results from the IOA will be examined in depth in the SDA. Therefore, the final demand will be specified to analyze the drivers for these cases. First, this encompasses the change in total emissions due to the overall food consumption in Sweden. Then, the direct emissions occurring in Sweden are compared with direct emissions occurring overseas. Last, the direct emissions of the three consumption sectors that are contributing the most will be analyzed: Hotel and restaurant services, products of meat cattle and dairy products. By utilizing SDA, this provides a nuanced understanding of how each factor contributes to the environmental footprint of Sweden's food sector and the different cases, enabling the identification of effective strategies for reducing national GHG emissions. For the various cases the final demand vector y is represented differently:

- Total emissions: The final demand corresponds to the total food consumption in Sweden.
- Sweden (Domestic): Elements of the region Sweden across all sectors are non-zero.
- Other regions (Overseas): Elements of the region Sweden across all sectors are zero.
- Hotel and Restaurant Services: Elements of the hotel and restaurant services are non-zero.
- Products of Meat Cattle: Elements of the products of meat cattle sector are non-zero.
- Dairy products: Elements of the dairy products sector are non-zero.

3. Data

This chapter first introduces the database, explains its structure and then deals with issues regarding the use of the database for this specific research.

3.1 Database

3.1.1 Introduction to EXIOBASE

EXIOBASE v3.8 is an input-output table time series compiled in monetary units with extensive sectoral and regional coverage and a specific focus on environmental impacts (Stadler et al., 2018). For the years after 2011, "now-casting" is being used, which means there is no update of the supply-use tables and therefore the flow matrix Z, which are statistics used in national accounting that include the data about the supply and use of products from all sectors. Therefore, for these years the EXIOBASE data relies on projections of the Gross Domestic Product and trade data. The multi-regional input-output tables (MR-IOT), forming the base of the Z matrix and therefore also the A matrix, are created by harmonizing of supply-use tables and adding information from other sources. The emissions and resource extraction are estimated. The supply-use tables of different countries and regions are then linked via trade to construct the MR-IOT. EXIOBASE contains the environmental impacts of international trade, allowing to analyze resource use and efficiency among different economies. These economies are represented as 49 regions, containing 32 European and 12 non-European countries with economies of global importance as well as 5 Rest of the World (RoW) regions comprising all other countries. In the flow matrix and the direct requirement matrix, which are explained below, the interconnection of economies is highlighted by illustrating how products and services flow between the 200 product sectors across different regions. The interconnection of sectors is crucial for analyzing the dependencies and impacts of economic activities on a global scale. In this work, it allows me to trace the origins of goods required for the food consumption in Sweden and to assess the environmental consequences. It should be noted that the resolution in EXIOBASE is higher than in most of the national statistics from which it is compiled, thereby compromising accuracy. However, Stadler et al. (2018) state to "plan to overcome this issue with the future development of EXIOBASE".

For the IOA calculation in Cederberg et al. (2019) EXIOBASE 3.4 is used to calculate the carbon footprint of food consumption in Sweden. In their dataset, the authors us the "industry-by-industry" dimension and monetary units. The emission data consist of EXIOBASE v3.4 data as well as energy balances and emission coefficients provided by the International Energy Agency. To produce comparable results while analyzing results more in detail, EXIOBASE is used in this work as well.

3.1.2 Pymrio

Pymrio developed by Stadler (2014) is a tool developed at the Norwegian University of Science and Technology (NTNU) in Trondheim by researchers from the Department of Industrial Ecology (Stadler, 2014). It is intended to serve as an open-source tool to support the analysis of MR-IOTs. In this case, pymrio is being used to process the data from the EXIOBASE database. In particular, it contains the functions to parse the data sets as well as the mathematical background described in the previous chapter.

3.1.3 Database structure

EXIOBASE features a time series of several interconnected matrices that provide a comprehensive view of economic activities and their environmental impacts. The core of these connections is found in the MR-IOTs in the form of the flow matrix Z, which captures the economic transactions across various sectors and regions, and the final demand matrix Y, which details the consumption of goods and services. The database also includes a direct requirements matrix A, which shows the input required from each sector to produce one unit of output in another sector. Its calculation, which is based on the flow matrix Z and the vector of total outputs x (see Eq. 2.1). Environmental and resource extensions are directly tied to these economic matrices in the form of the S matrix. The emission coefficients are compiled using emission statistics and data provided by the International Energy Agency on combustion in different sectors. As there are disagreements in these statistics, the data can vary. Due to the higher aggregation in these data sources, inaccuracy is expected and change in specific sectors is not shown directly.

The EXIOBASE data is available in product-by-product as well as industry-by-industry dimensions. Product-by-product tables map the flows of specific products across sectors and regions in monetary units, detailing how each product is used as input and output. This format is used to track specific product impacts on the economy and environment. Industry-by-Industry tables focus on interactions between industries, showing the inputs and outputs among them. This approach is suited for analyzing economic structures and industry relationships. As the basis of the research focus on carbon footprints, product-by-product tables are used. This allows the analysis of certain food products and their domestic and foreign components. The product sectors will be referred to simply as “sectors” throughout the remainder of this thesis.

3.1.4 Concordance matrix

The concordance matrix **C** (Appendix B: Concordance matrix) allows the categorization of sectors from all countries and regions. This aggregation supports the overall analysis of GHG emissions from input sectors. The concordance matrix used for this research was obtained from the EXIOBASE folder (Stadler et al., 2018). In addition, the category “Manufacturing” was extended to “Food Manufacturing”, “Fertilizer” and “Other Manufacturing” in order to differentiate the rather broad category adapted to the research on food consumption. This allows to compare the influence of different parts of the manufacturing industry and analyze the magnitude for the category “Fertilizer” which includes only two sectors (nitrogen and phosphorus fertilizer). In addition, the “Agriculture” category differs from the food sectors used in the calculations in that it includes "Wool, silk-worm cocoon", "Manure (conventional treatment)", "Manure (biogas treatment)", "Products of forestry, logging and related services (02)” which are not part of the food industry but are part of the “Agriculture” category. The nine categories in the concordance matrix are:

- Agriculture
- Mining
- Food manufacturing
- Other manufacturing
- Fertilizer
- Electricity and utilities
- Construction
- Transport
- Services

3.1.5 Population data

To consider the carbon footprint per person per year, population data is required. The data for the Swedish population from 1996 to 2021 is obtained from FAOSTAT (FAOSTAT, 2023).

3.2 Limitations with the EXIOBASE data

3.2.1 Food-related emissions

The modelling of food-related emissions is generally considered highly uncertain due to the underlying complex biogeochemical processes. This is due to land-use change and its attribution to products as well as emissions from indirect inputs like energy or fertilizer (Pinero et al., 2022). Nutrient cycling and methane emissions from livestock are difficult to model precisely. Attribution of land-use change to specific products presents significant challenges and is therefore not included in EXIOBASE data. Differences in regional agricultural productivity as well as the impact on climate change complicate accurate emissions modeling.

Despite these challenges, using this data remains crucial for several reasons. Informed policies and regulations rely on the best available data to mitigate environmental impacts. Utilizing this data provides critical insights and supports efforts to reduce the environmental impact of food production and consumption on a global level. Compromising a certain level of accuracy for a high number of regions and sectors included, as in the EXIOBASE database, helps in directing resources and efforts towards areas with the highest potential for emission reductions.

3.2.2 Disaggregation level

The sectors in EXIOBASE consist of product groups that include many different products (Steubing et al., 2022). Thus, the emissions per unit output differs inside these product groups. According to Steubing et al. (2022), the geographical aspect is considered based on the countries and regions but might still deviate from the real emissions based on the origin.

Industry statistics often provide information on sales to industries, but not on the purpose and sector in which a product is consumed. Therefore, disaggregating emissions to the high level of resolution required in this work can lead to distorted results. However, EXIOBASE as a database is the best available data used by various institutions for environmental analysis due to its comprehensiveness. Therefore, it is appropriate to conduct this research using these data.

3.2.3 Monetary and units

There are disadvantages of using monetary units for carbon footprint analysis over time due to price changes and variations in the quality of goods, e.g. in exports and domestic consumption (Kastner et al., 2014). Here, it would be necessary to analyze the differences in product quality and emissions in each sector per monetary unit. This would require a combination with additional data on the composition of product quality in the consumption. In addition, the aggregation of different products into one sector would lead to distorted results (Kastner et al., 2014). This could be considered with more sector disaggregation. However, this would be necessary at the data collection level and can therefore not be carried out with EXIOBASE.

Hubacek & Feng (2016) suggest using physical trade flows, which contain the MR-IOT in hybrid units, i.e. physical as well as monetary, to avoid the issue of different prices for domestic consumption and export. However, there are significant compromises in the supply chain, where physical trade flows do not distinguish between intermediate and final products and the supply chain is not traced back further than the first importing country (Hubacek & Feng, 2016). Therefore, and since monetary units are used in previous research, this analysis will be carried out using monetary units as well.

3.2.4 Modeling

Furthermore, certain sectors like fertilizer are not adequately modeled, likely to be heavily underestimated, and therefore lead to lower emissions than in reality (Pinero et al., 2022). Changes in the classification of products and sectors will look like the demand changed and distort the results as well. Considering the comprehensiveness of EXIOBASE, this is likely to be the case for other sectors. In addition, EXIOBASE is compromising data for individual regions to harmonize the interconnections between economies which changes the regions consumption data (Moran et al., 2018). This would have a higher impact on smaller economies like Sweden.

Additionally, it is important to note that EXIOBASE does not include GHG emissions from land-use changes and only links transport emissions to sectors for transport between industries, from processing to retail, but not from retail to the consumer. This results in lower reported carbon emissions compared to reality. However, it should be noted that other methods like Life Cycle Assessment (LCA) typically do not include the transport from retail to consumer either.

4. Results

This chapter first describes and then interprets the results of the different calculations based on the level of disaggregation in the IOA and based on the specific cases in the SDA. The IOA results highlight sectors and regions with the most significant absolute changes in emissions, focusing on trends over the analyzed period. However, sectors or regions with the highest total emissions are mostly included as they typically experience considerable changes due to their magnitude.

4.1 Trends of food-related consumption-based emissions

4.1.1 Change in total emissions and carbon footprint of the food consumption in Sweden

Figure 1 illustrates the carbon emissions of food consumption in Sweden from 1996 to 2021, measured in kg CO_2 eq. The emissions start at approximately 18.5 billion kg CO_2 eq. in 1996 and demonstrate a gradual decline with minor fluctuations until it reaches 15.8 billion kg CO_2 eq. in 2021. The year 2009 is notable for having the lowest emissions within the observed period. The emissions dipped to approximately 14 billion kg CO_2 eq., marking a significant reduction compared to earlier as well as later years. The trend suggests a period of reduction followed by a recent stabilization in the carbon emissions associated with food consumption in Sweden over the 25-year period.

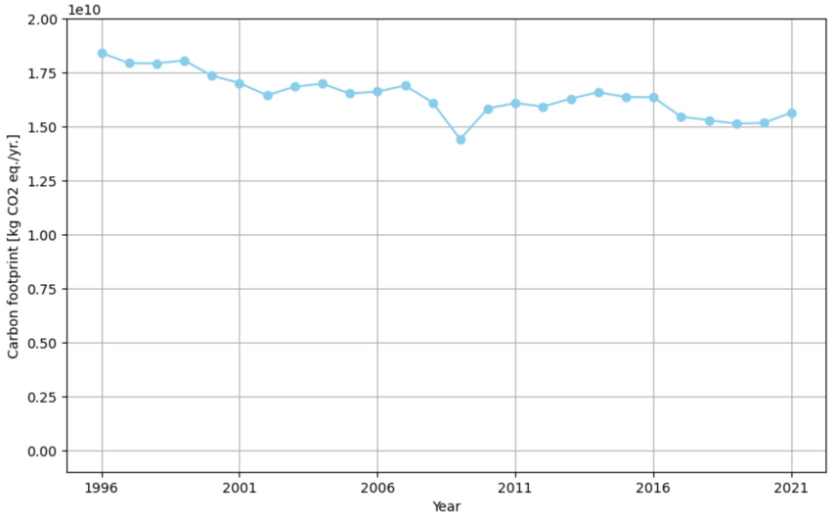


Figure 1: Annual Carbon Emissions from Food Consumption in Sweden (1996-2021).

Figure 2 depicts the Swedish per capita carbon footprint of food consumption from 1996 to 2021. This data correlates to the total carbon emissions in Figure 1, normalizing it by the population which adds the influence of population change over time. At the beginning of the timeline, in 1996, the graph shows that carbon emissions were approximately 2100 kg CO_2 eq. per person per year. This point reflects the initial state of carbon emissions related to food consumption for that period. After a constant decline, the graph indicates a noticeable dip in carbon emissions in 2009. The emissions reduced to about 1500 kg CO_2 eq. per person per year. This year stands out due to the significant decrease of emissions with an immediate increase afterwards. By the end of the timeline, the emissions reach their lowest point at slightly less than 1500 kg CO_2 eq. per person per year. This indicates an overall reduction compared to the start of the period.

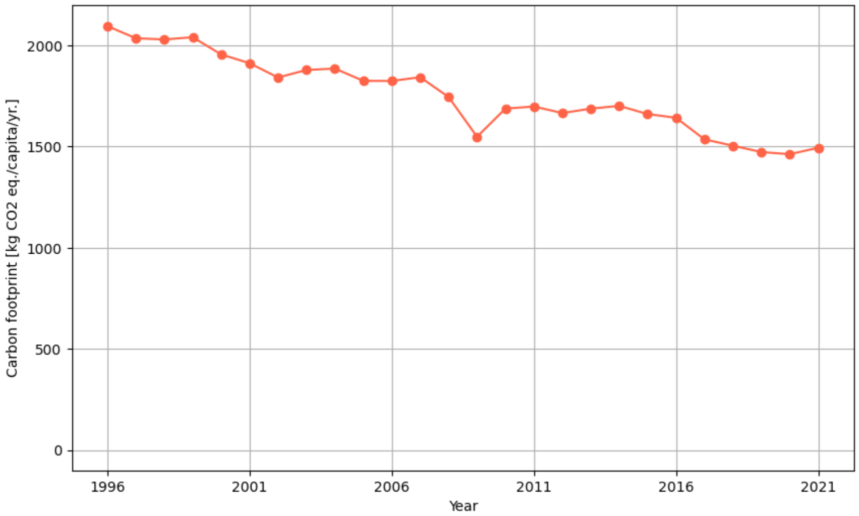
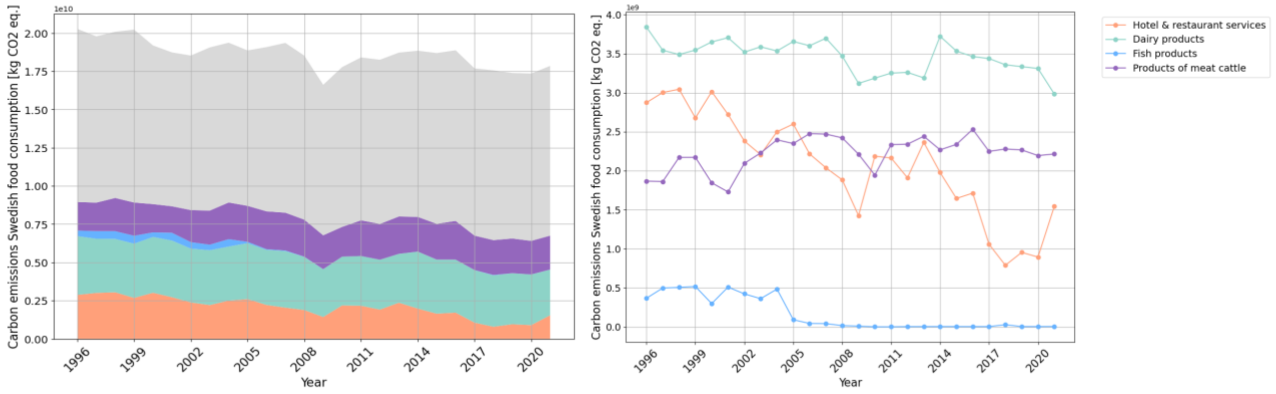


Figure 2: Carbon Footprint from Food Consumption in Sweden per capita and year (1996-2021).

The fluctuations and trends in carbon emissions from food consumption in Sweden likely result from a complex interplay of economic, technological, behavioral, and regulatory factors. While significant progress in reducing the total emissions was made around the year 2000 and stable overall emissions paired with a steady population growth led to a lower per capita carbon. It is important to note that price effects are considered with the emission coefficients changing over time. To identify potential regarding the sourcing and consumption patterns, certain cases are analyzed in the following. In 1996, both graphs start with high carbon emissions. Possible reasons for these elevated levels could include traditional agricultural practices which are more energy and resource intensive, a higher dependency on fossil fuels or a lack of environmental regulatory frameworks aimed at reducing carbon emissions in the food sector. This needs to be analyzed more in detail. A major reason for the reduction of carbon emissions in the year 2009 is the global financial crisis. This period marked economic slowdowns, which likely led to reduced production volumes and consumption patterns, indirectly lowering emissions.

4.1.2 Change in emissions by consumption sector over time

Figure 3 illustrates the changes in total emissions by consumption sectors over time. Figure 3 (a) presents a stacked chart showing the total emissions, highlighting the four sectors with the most significant changes in emissions in Swedish food consumption between 1996 and 2021: Hotel and restaurant services, dairy products, fish products, and meat cattle products. To provide a complete picture, all other sectors are aggregated into a single category, represented in grey, which sums up to the total carbon footprint of Swedish food consumption. Figure 3 (b) shows the changes in these four major consumption sectors using colored lines for clear comparison.



(a) Stacked chart *(b) Line chart*

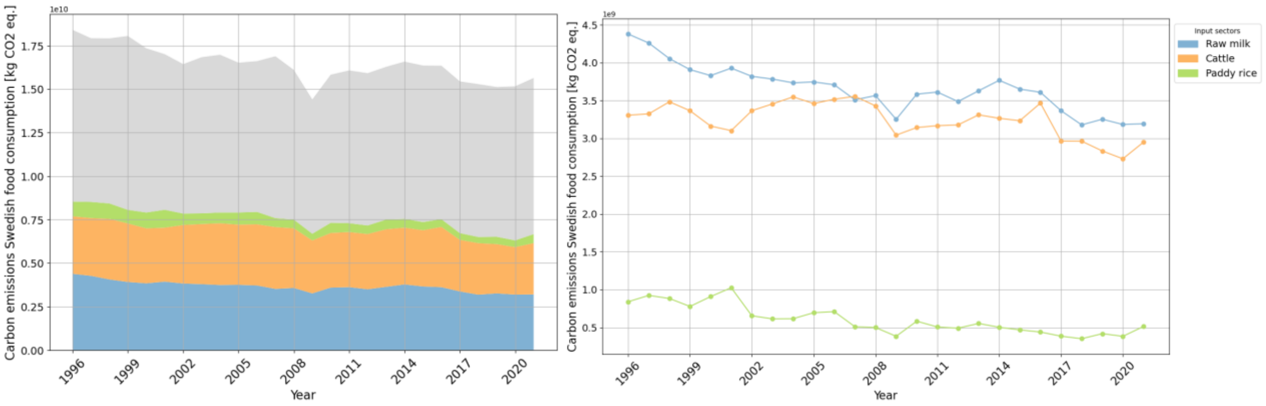
Figure 3: Carbon Emission Trends by Consumption Sector in Swedish Food Consumption (1996-2021), as (a) stacked chart showing the total carbon footprint and as (b) line chart highlighting the sectors with the biggest change.

Key observations include significant fluctuations in hotel and restaurant services with peaks in 1998 and 2014 followed by a sharp decline after 2015 and a spike for the last year of observation. In addition, the emissions from hotel and restaurant services sector are at a low point in 2009, indicating that there was less food consumed away from home. A steady decline in the consumption of dairy products is noticed. The emissions attributed to meat cattle products show a noticeable increase in the early 2000s, while the emissions attributed to fish products decrease significantly at the same time. While the trend in emissions from meat cattle products contradicts studies by Osei-Owusu et al. (2021) assessing the carbon footprint of food consumption in Denmark, a decrease in emissions from fish products is consistent with them. However, according to Statistics Sweden (2023), the emissions in the sector “fish and seafood” only decreases from 130 million kg CO_2 eq. in 2008 to 120 million kg CO_2 eq. in 2021. It is important to emphasize that EXIOBASE distinguishes between the sectors “Fish products” and “Fish and other fishing products; services incidental of fishing (05)”. Summing both sectors the emissions decline from 80 million kg CO_2 eq. in 2008 to 68.45 million kg CO_2 eq.

in 2021. This shows a similar trend as the data from Statistics Sweden. The different levels in emissions can be explained by differences in the classification. The graphs reveal varying carbon impact trends across food sectors, suggesting improvements in production efficiency or changes in sourcing and consumption patterns. The increase of meat cattle products should be monitored and analyzed in depth to suggest mitigating policies. To gain more insight into these effects, the sectors with the highest emissions “hotel and restaurant service”, “products of meat cattle” and “dairy products” are object of further analysis in the SDA.

4.1.3 Change in direct emissions by input sectors over time

Figure 4 (a) shows the direct emissions as a stacked chart. The emissions from cattle and raw milk have consistently been the highest among the analyzed sectors, both declining over the years but maintaining relatively high levels compared to other sectors. In contrast, emissions from the paddy rice sectors have been considerably lower but decrease steadily during the observed period. The graphs in Figure 4 (b) display the direct carbon emissions from the input sectors contributing most to changes in emissions of Swedish food consumption from 1996 to 2021. Notably, there is a visible decline in emissions from all sectors around 2008. Raw milk as the sector with the highest direct emissions as well as the highest absolute change and paddy rice as the sector with the highest rate of change will be analyzed more in detail below.



(a) Stacked chart *(b) Line chart*

Figure 4: Direct Carbon Emission Trends by Input Sector in Swedish Food Consumption (1996-2021), as (a) stacked chart showing the total carbon footprint and as (b) line chart highlighting the sectors with the biggest change.

Figure 5 describes the direct emissions attributed to input from the raw milk sector by region. The countries that influence the trends the most are displayed. The domestic component of direct emissions due to raw milk produced in Sweden demonstrates a significantly higher magnitude. It is noticeable that the emissions due to raw milk from Sweden and the RoW Asia region are decreasing by more than half, whereas the emissions from other countries, here in particular from Denmark and the Netherlands are increasing.

Figure 5: Direct Carbon Emissions in the Raw Milk Sector by Region of Origin (1996-2021).

In Figure 6 the direct emissions of raw milk in the supply chain based on the sectors in which it is consumed most are displayed. The major impact occurs in the sectors “dairy products”, “hotel and restaurant services” and “food products nec (not elsewhere classified)”. The latter is a sector in EXIOBASE whereas the sector “Other” is summing up all other sectors for this study in particular. The emissions due raw milk in the consumption sector “raw milk” declined sharply in the year 1998 and remained non-existent for the following years. This could be due to a change in classification. In general, the emissions are decreasing in “dairy products” and “hotel and restaurant services” while they are slightly increasing in the sector “food products nec”. The latter can be explained by a rise of processed food over time.

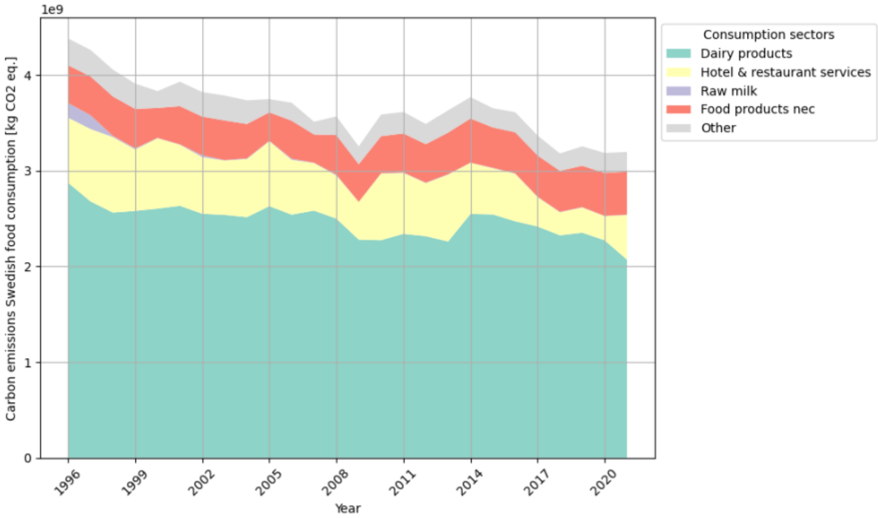


Figure 6: Direct Carbon Emissions in the Raw Milk Sector by Consumption Sector (1996-2021).

Figure 7 illustrates the GHG emissions in the paddy rice sector categorized by regions with the highest impact, over the period from 1996 to 2021. The data indicate that direct carbon emissions occurring in the region “RoW Asia” have experienced a significant decline over the analyzed period. Initially, emissions peaked at nearly 800 million kg CO_2 eq. following a noticeable downward trend, resulting in emissions of approximately 300 million kg CO_2 eq. by 2020. With an overall declining trend, emissions of paddy rice from India experience a notable peak around 2002, where emissions reached approximately 350 million kg CO_2 eq. Turkey’s impact on carbon emissions due to paddy rice has been consistently rising over the time of observation but remains low in comparison. In contrast, carbon emissions from Indonesia have fluctuated with longer periods of less effect on the emissions due to paddy rice around the years 2006 and 2018 and reached a low by the end of the 2010s.

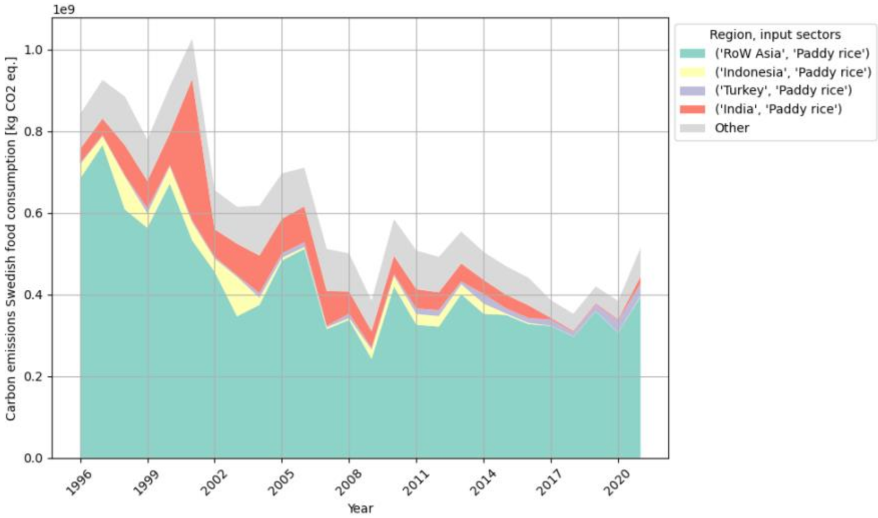


Figure 7: Direct Carbon Emissions in the Paddy Rice Sector by Region of Origin (1996-2021)

Figure 8 shows a stacked chart describing the direct carbon emissions in the paddy rice sector in Swedish food consumption from 1996 to 2021, categorized by the most influential consumption sectors. The emissions due to paddy rice consumed in hotel and restaurant services are the highest but have significantly declined from around 600 million kg CO_2 eq. in the end-1990s to about 200 million kg CO_2 eq. by 2021, with notable fluctuations. Food products nec and processed rice have much lower and moderately increasing emissions from slightly under to slightly over 100 million kg CO_2 eq.

Figure 8: Direct Carbon Emissions in the Paddy Rice Sector by Consumption Sector (1996-2021)

It is notable that raw milk, cattle and paddy rice sectors are all representing intermediate products connected to high methane emissions. The observed changes in direct emissions across these input sectors can be attributed to several key factors. The reason why the emissions trend for paddy rice from RoW Asia closely matches that of paddy rice consumed in hotel and restaurant services is still unclear. Despite the analysis, there is no clear link, indicating that there might be unknown factors in the data at play that need more investigation. In the raw milk and cattle sectors, technological advancements such as improved feed efficiency, manure management, and optimized livestock practices have reduced methane emissions while policy changes promoting sustainable farming and offering incentives for methane reduction have also contributed (Key & Tallard, 2012). According to Martin & Brandão (2017), a shift in consumer preferences towards plant-based alternatives, have reduced production, further lowering emissions. This environmental awareness has encouraged more sustainable practices and reduced consumption of dairy and beef products. For paddy rice, technological advancements like water-saving irrigation techniques have helped to reduce methane emissions from rice paddies (Jiang et al., 2019). Which effect these different components have quantitatively, is to be evaluated in the SDA.

4.1.4 Change in emissions by input categories over time

Figure 9 illustrates the absolute direct GHG emissions in categories of input sectors associated with Swedish food consumption from 1996 to 2021. The emissions of the Swedish food consumption occurring in the agriculture category are significantly higher, starting at around 13 billion kg CO_2 eq. in 1996 and gradually decreasing to approximately 11 billion kg CO_2 eq. by 2021. Considering the magnitude, there is a noticeable decline over the period with some fluctuations. Here, the dip in 2009 shown in Figure 1 and Figure 2 can clearly be attributed to activities in the agriculture sector.

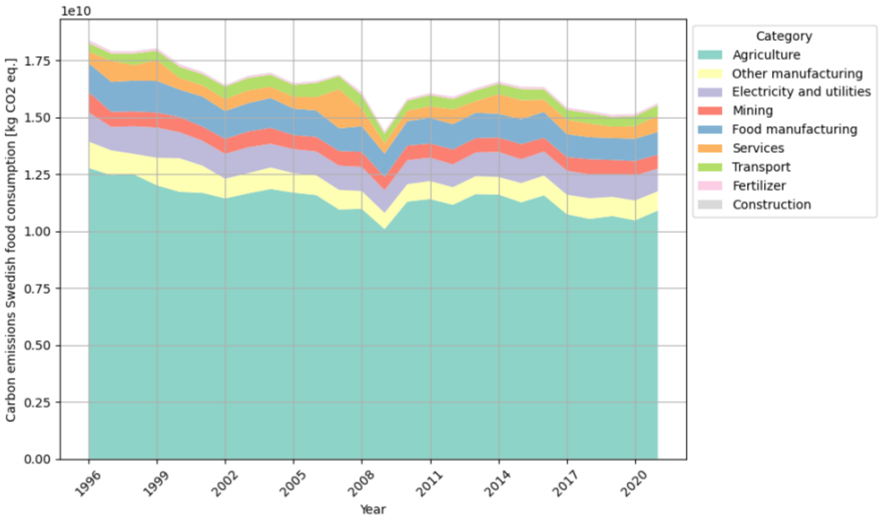


Figure 9: Absolute Direct Carbon Emissions from Swedish Food Consumption by Category (1996-2021).

The emissions from other categories, including other manufacturing, electricity and utilities, mining, food manufacturing, services, transport, fertilizer, and construction, are significantly lower, generally below 2 billion kg CO_2 eq. Overall, the agriculture sector dominates as a source of GHG emissions in the Swedish food consumption, with a decreasing trend over time. Other categories contribute much less to the total emissions and remain relatively stable throughout the period. Given the overwhelming dominance of agriculture in carbon emissions, it becomes necessary to show the emissions from other sectors separately in Figure 10 for better clarity.

This leads to Figure 10, allowing for a clearer view and comparison of the emissions from the remaining categories. Electricity and utilities and food manufacturing show the highest emissions over the period, with a steady decline. Other manufacturing also contributes significantly to the declining trend, showing a peak around the year 2000 followed by a drop and a stable emission level. Mining, services, and transport display contribute moderately, with the service sector experiencing a notable peak in 2007. Fertilizer and construction have the lowest emissions, maintaining relatively steady levels throughout the years. The chart indicates that electricity and utilities, food manufacturing, and other manufacturing decreased less than agriculture but contributed noticeably to the trend of emissions of the food consumption in Sweden.

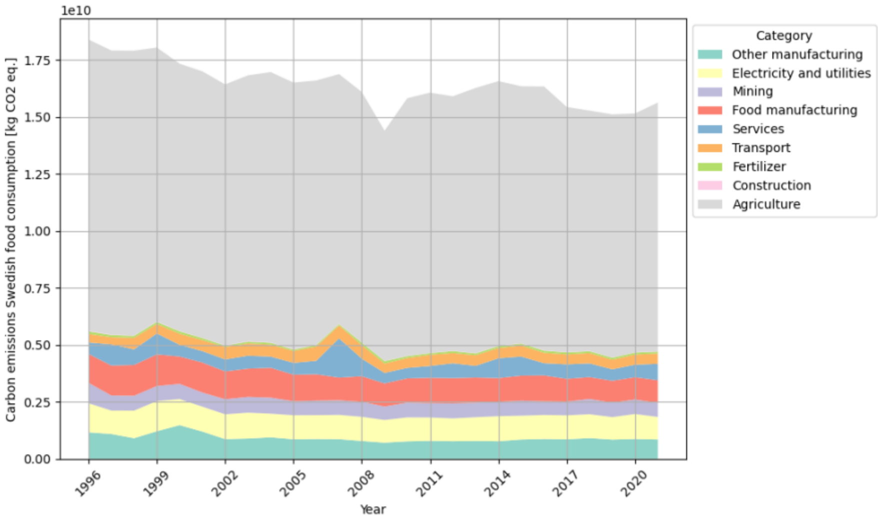


Figure 10: Absolute Direct Carbon Emissions from Swedish Food Consumption by Category, excluding Agriculture (1996-2021).

To analyze the categories not just by absolute change but also regarding their rate of change, Figure 11 illustrates the direct carbon emissions from categories associated with Swedish food consumption from 1996 to 2021 normalized with the base year 1996. Most categories exhibit stable emissions around the normalized value of 1 with minor fluctuations or trends. Agriculture, other manufacturing, electricity and utilities, mining, food manufacturing, fertilizer, and construction sectors all maintain slightly decreasing emission levels throughout the period. In contrast, the services sector shows significant variability, with notable peaks, where emissions reach as high as 3.5 times the base year value. The transport sector also displays some variability and an increase, fluctuating between 1 to 1.5. Overall, while most sectors maintain stable emission levels, the services sector experiences occasional spikes.

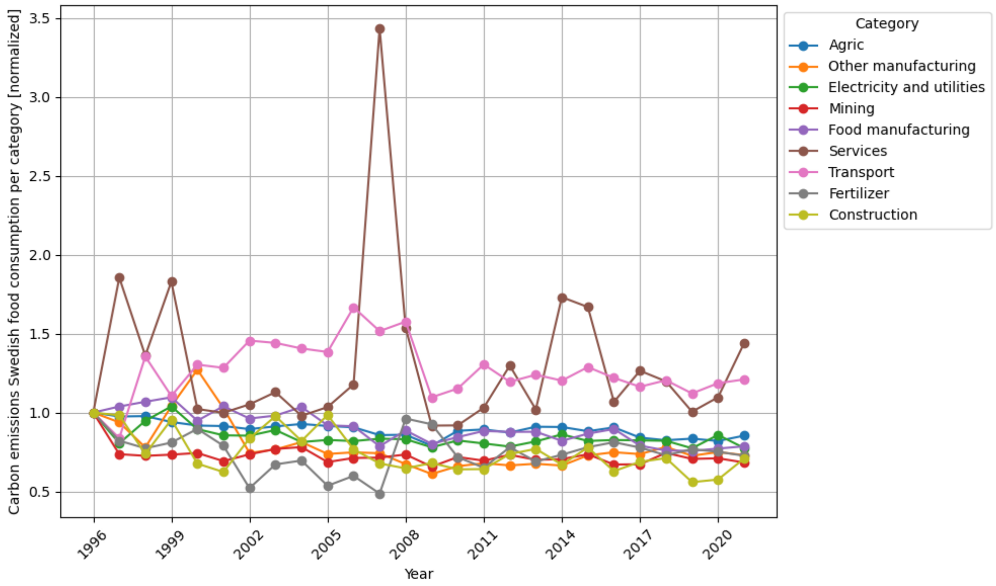
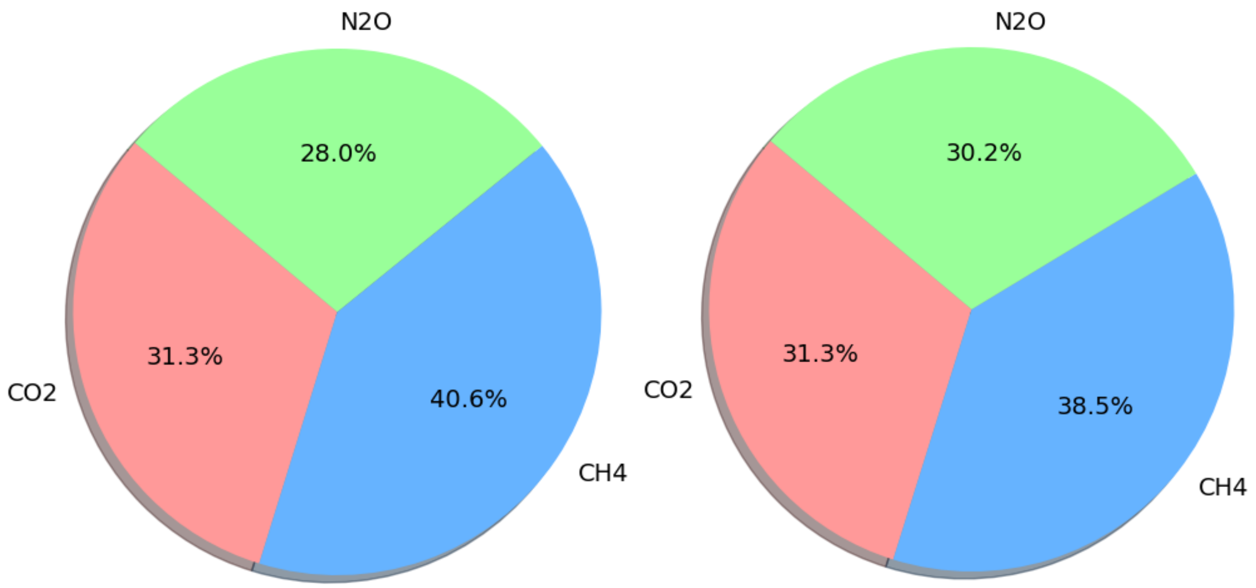


Figure 11: Normalized Direct Carbon Emissions from Swedish Food Consumption by Category (1996-2021).

The shift towards renewable energy sources significantly cuts emissions in the category “Electricity and Utilities”. Food manufacturing shows higher emissions than other manufacturing sectors. The emissions change in a similar pattern due to the adoption of cleaner technologies and environmental regulations. The category “Transport” is subject to increased efficiency and better fuel standards during the analyzed period. However, it appears that these improvements might be offset due to an increase in trade activities that require transportation. The amount of food that is imported from overseas is generally increasing (Pinero et al., 2022). The spike in the category “Services” in the year 2007 requires a special analysis but could be due to an error. Since data about services activities are harder to collect and not connected to material flows, data sources for service sectors could be more inaccurate. The emissions from fertilizer input are of lower magnitude than the most significant sectors and therefore do not change considerably. In general, this level of disaggregation shows that the reduction of the total emissions by the Swedish food consumption shown in Figure 1 and Figure 2 is mainly due to declining direct emissions from agricultural activities. These decreasing direct emissions are likely to be methane emissions. To confirm this hypothesis, the pie chart in Figure 12 shows the ratio of different GHG in 1996. While the share of CO_2 emissions remains constant, the share of methane emissions is shifting towards nitrous oxide.



(a) 1996 *(b) 2021*

Figure 12: Ratio of CO_2, Methane (CH_4) and Nitrous Oxide (N_20) in the years (a) 1996 and (b) 2021.

4.1.5 Change in emissions by input regions over time

Figure 13 displays the direct carbon emissions associated with Swedish food consumption from 1996 to 2021 aggregated by the region of origin. Emissions occurring in Sweden are the highest throughout the period, with a noticeable decreasing trend from over 8 billion kg CO_2 eq. in 1996 to about 5 billion kg CO_2 eq. in 2021. The region “RoW Asia” follows with significantly lower emissions than Sweden, showing a slightly declining trend with fluctuations from 2 to 1.5 billion kg CO_2 eq. Other countries, including Germany, RoW America, Denmark, Russia, and Poland, have emissions clustered closely together at a much lower level and require a different visualization, which follows next. The chart shows that Sweden is the main source of carbon emissions from Swedish food consumption, with other countries contributing much less. However, emissions reductions in Sweden exceed the overall reduction discussed in chapter 4.1.1, indicating that increasing emissions in other regions offset some of Sweden's reductions. This carbon leakage contradicts Sweden’s “Generational Goal” to minimize environmental impacts without shifting them overseas.

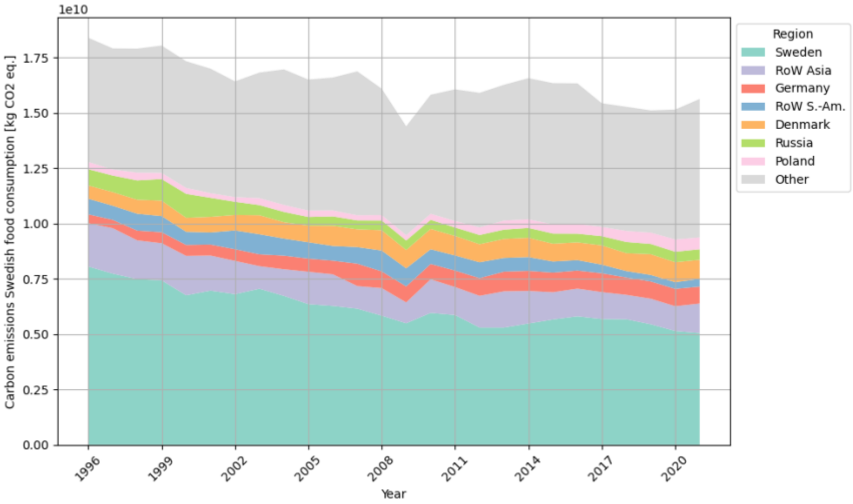


Figure 133: Direct Carbon Emissions from Swedish Food Consumption by Region of Origin (1996-2021).

Figure 14 illustrates the direct carbon emissions associated with Swedish food consumption from other regions that contribute the most from 1996 to 2021. Excluding Sweden allows for a more detailed observation of other regions. RoW Asia shows the highest emissions throughout the period, with a noticeable decreasing trend. While the emissions from RoW America as well as Russia are decreasing over time, other countries like Germany, Denmark and Poland have an inclining trend. The change in emissions occurring in Germany and Denmark show the biggest total increase, the one in Poland on the other hand represents a high relative change by doubling from 1996 to 2021. The source of direct emissions in Germany and Denmark will be analyzed based on the input sectors that contribute the most to these effects.

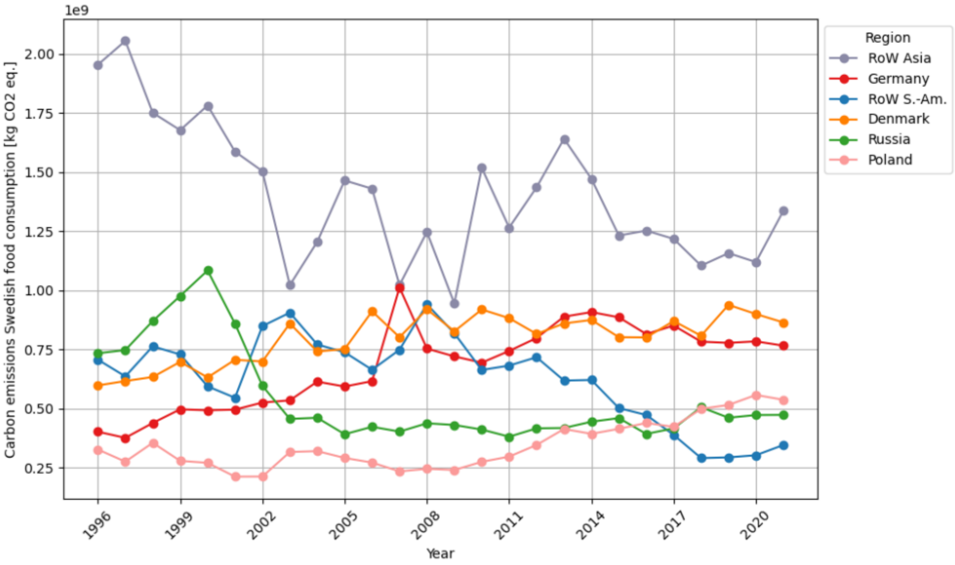


Figure 144: Direct Carbon Emissions from Swedish Food Consumption by Region of Origin, excluding Sweden (1996-2021).

Figure 15 shows the direct carbon emissions from food consumed in Sweden for the two input sectors from Germany and Denmark that experienced the greatest increase from 1996 to 2021. Emissions by the cattle products from Germany consumed in Sweden increased fourfold from 35 million kg CO_2 eq in 1996 until 2013 when stabilizing between 160 and 175 million kg CO_2 eq. In the raw milk input from Germany the emissions more than doubled, while peaking at 200 million kg CO_2 eq. in 2014. The direct emissions due to raw milk from Denmark increased dramatically from 140 million kg CO_2 eq. in 1996 to 350 million kg CO_2 eq. by 2021. The rise of direct emissions in the water transportation services sector is slightly contributing to the increasing emissions from Denmark.

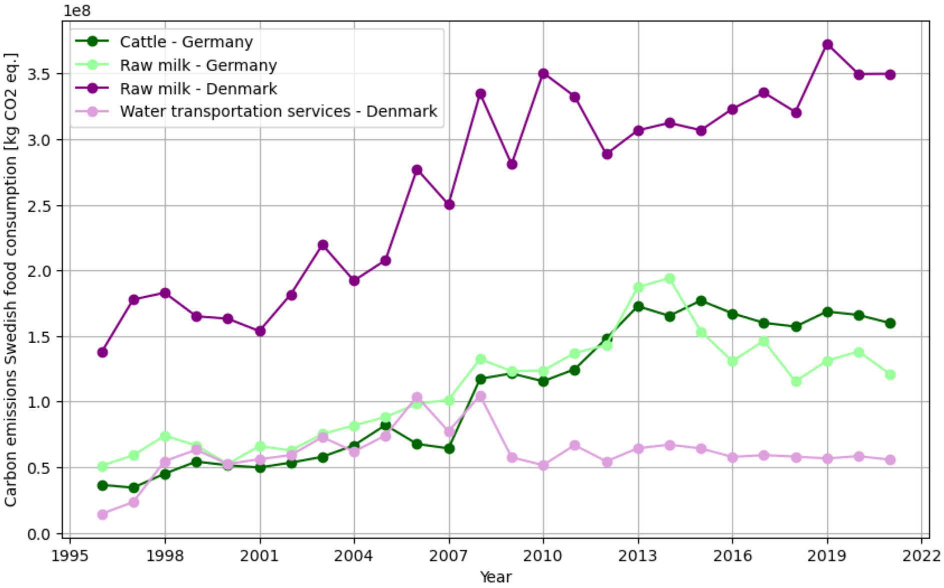


Figure 155: Direct Emissions from Swedish Food Consumption in Denmark and Germany by Input sector (1996-2021).

4.2 Drivers of the change in consumption-based emissions

The bar chart in Figure 16 breaks down the contributions of changes in emission intensity Δs, supply chain ΔL, and final demand Δy, to the total change in emissions ΔD_{cba} for various specifications of the food consumption in Sweden. The y-axis represents the emissions due to the Swedish food consumption in kg CO_2 eq., while the x-axis lists the different specifications of the final demand as explained in chapter 2.2.2. The chart illustrates the different key factors of emissions changes in Swedish food consumption across various sectors and regions, driven by technological, economic, and policy factors.

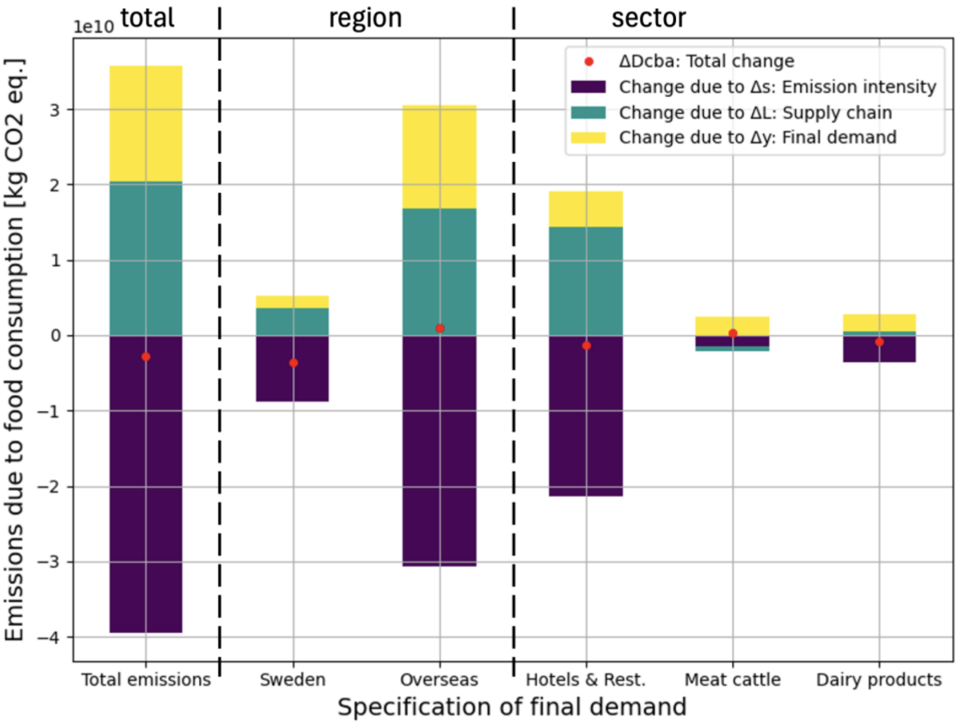


Figure 166: Contribution of Changes in Emission Intensity s, Leontief inverse L, and Final Demand y to Total Change in Emissions ΔC for Specifications of Swedish Food Consumption

4.2.1 Total emissions

As already presented in the IOA, the total change of emissions due to the food consumption in Sweden (red dot) is negative. The largest quantitatively positive contribution to the change of total emissions of the Swedish food consumption comes from changes in supply chain (teal) and final demand (yellow) to a similar extent. However, the emission intensity (purple) has a higher negative impact on the total emissions.

The increase in total emissions due to changes in the supply chain ΔL and final demand Δy indicates an expansion in food consumption and a shift of sourcing in the supply chain leading to higher emissions. The reduction in emission intensity Δs has a substantial negative impact on the emissions. As shown in Figure 9 in chapter 4.1.4, this is mainly due to improvements in the agriculture sector. According to Clark & Tilman (2017), the reasons for changes in emissions due to the food consumption are technological advancements and efficiency improvements: Reductions in emission intensity across different sectors suggest significant improvements in sustainable farming practices leading to lower emissions per unit of food produced. Technological advancement in manufacturing processes as well as a shift towards renewable energy sources have effectively reduced overall emissions contribute as well.

4.2.2 Domestic emissions

For the emissions generated domestically, there are small contributing effects on the change of emissions by supply chain and final demand changes. These indicate increases due to a change in the sourcing of food as well as the higher demand. The latter can be explained by a population growth in Sweden from 8.8 million people in 1996 to 10.5 million people in 2021 (FAOSTAT, 2023). The direct emissions in Sweden are substantially decreasing due to improvements in emission intensity, which highlights successful implementation of sustainable practices and technologies within Sweden's domestic food supply chain. This has been incentivized by stricter environmental regulations and policies in Sweden and the EU (Key & Tallard, 2012). These findings align with the significant decline of emissions due to consumption of domestically produced food in Denmark (Osei-Owusu et al., 2021).

4.2.3 Emissions occurring overseas

In the case of GHG emitted outside of Sweden, the rise in emissions can be attributed to the change in final demand as well as changes in the supply chain. This increase points to higher imports and the globalization of food production. The effect of emission intensity changes is significant, indicating improvements in emission intensity. However, this effect is outweighed leading to an overall increase in emissions overseas.

The rise in emission-intensive food consumption in Sweden, driven by population growth, dietary shifts, and economic factors, contributes to the positive changes in final demand (Geeraert, 2013). Supporting the observations made, Pinero et al. (2022) found, that the global food-related emissions generated overseas increased by 75% from 1986 to 2013 due to more international trade.

4.2.4 Hotel and restaurant services sector

The case of hotel and restaurant services is comparable to cases of total emissions and domestic emissions: There is a significant contributing impact on the total emissions from supply chain and final demand changes, with a notable overall decrease in emissions due to the reduction emission intensity. The GHG emitted due to changes in supply chain and final demand suggest higher activity in the hotel and restaurant sector and a more carbon intensive supply chain. This aligns with previous research on the increasing trend of eating out and the resulting need to focus on environmental sustainability (Dai et al., 2020).

4.2.5 Products of meat cattle sector

For products of meat cattle, the changes in emission intensity and the supply chain show a small negative effect whereas the final demand contributes to the emissions, explaining the overall rise. However, this rise is of a lower magnitude than the previous cases. In contrast to all other cases, the changes of the Leontief inverse reduce the emissions. Nevertheless, the change of final demand outweighs this effect as well as the improvements regarding the emission intensity. Furthermore, this increase is higher in relative terms than the increase of population, i.e., the per capita consumption increase. Thus, the higher demand for products of meat cattle leads to an increase of emissions over time. However, it is possible that this reason has been more prominent at the beginning of the analyzed period and decreased because of a rising awareness of the environmental impact and consecutively a shift of diets. This could be analyzed by splitting the period of observation for the SDA in multiple time periods.

4.2.6 Dairy products

The rise in final demand and changes in the supply chain contribute to emissions in the dairy sector. Overall, the dairy sector has a negative trend of emissions due to the consumption in Sweden. As in all previous cases, this is driven by improvements in the emissions intensity. It is to be noted that the improvements in the emission intensity are more than twice as big as for meat cattle, suggesting that the focus for improvement was on dairy products. The key difference lies in production efficiency, which has significantly improved for dairy products, resulting in a reduced environmental impact compared to meat cattle products (Hessle et al., 2017).

5. Conclusive remarks

5.1 Discussion

This chapter points out the limitations of the study, examines the implications for environmental policy and highlights potential for future research in the field.

5.1.1 Limitations of the study

There are limitations of EXIOBASE as a data source which will be discussed as follows. As indicated by Sandström et al. (2018), one-third of the carbon footprint of food is related to land-use change in agriculture. Cederberg et al. (2019) found that the land-use change emissions due to Swedish food consumption are approximately one tenth of the total food-related GHG emissions. However, emissions data in EXIOBASE does not include land-use change (Merciai & Schmidt, 2018). In addition, although subsistence agriculture is highly important in the food production and consumption system, data on its environmental impact is either not included or inaccurate (Stadler et al., 2018). This is less likely to have a noticeable impact in the case of Sweden due to less subsistence agriculture but should be considered when analyzing the carbon footprint in other countries or regions. Furthermore, the system boundaries for the EXIOBASE database are set. There is no adjustment possible, e.g. for land use change. Thus, the emissions might be underestimated and for the detailed analyses, disaggregation of the data in both methodologies is only possible based on the data provided. For IOA databases there is a considerable delay of 3 to 9 years in the data (Owen, 2017). Owen (2017) also notes that these databases rely on national data for environmental impacts, potentially containing errors depending on the accuracy of national statistical agencies in calculation and reporting. For countries with smaller economies like Sweden, harmonizing of national statistics and trade data as well as the adjustment of EXIOBASE data might lead to additional inaccuracies.

5.1.2 Implications for environmental policy

Linking mitigation policies to the variables in the IOA and SDA, emission intensities are influenced by production-side policies, final demand is influenced by consumption-side policies, while supply chain impacts are subject to market dynamics and trade policies (Pinero et al., 2022).

The results show the significant impact of livestock products, such as meat cattle and dairy products. “Halving the consumption of meat, dairy products and eggs in the European Union would achieve a

[…] 25–40% reduction in greenhouse gas emissions" (Westhoek et al., 2014). Herrero et al. (2016) emphasize that the livestock sector could contribute significantly to global mitigation efforts, but this potential is largely untapped due to the low adoption of practices and challenges in reducing consumption of livestock products. According to Herrero et al. (2016), "public and private incentives [are] necessary" to reduce emissions from animal agriculture. To do this on the supply side, positive incentives could reduce emissions without causing carbon leakage. Awareness of possible rebound effects is also important. To reduce the impact on the demand side, policies need to prevent the additional production abroad, as this increases the carbon footprint overseas in the short term but would not be accounted for in consumption-based accounts.

5.1.3 Future research

Potential areas for future research will be highlighted that were beyond the scope of the present study. The consumption-based emissions for different GHGs shown in chapter 4.1.4 in Figure 12 should be disaggregated to analyze the most influential sectors. This allows a specific analysis of the direct emissions based on livestock and rice production driving methane emissions as well as manufacturing processes and other energy intense sectors being responsible for CO_2 emissions. This might help in understanding how improved agricultural practices and energy or production efficiencies are driving the decreasing emission trends.

In future research, the SDA can be extended with more variables. Including the change in population allows to differentiate between increasing final demand due to population growth and higher consumption per capita. In addition, the period of observation for the SDA can be split in multiple time periods to allow for more detail. Investigating particular years, such as 2009, for effects in emissions data due to events like the global financial crisis could provide insights into short-term trends and their underlying drivers.

The influence of financial parameters on IOA using monetary units can be mitigated by using hybrid unit supply-use tables. E.g., Merciai & Schmidt (2018) follow the "Goal of creating a multipurpose tool for country, sector, and product group-specific analyses". This would create potential for the quantification of GHG emissions from Swedish Food Consumption. Furthermore, the reliability of the data and results can be verified, and the analysis extended by using or combining different data sources. This requires sector matching as done in Steubing et al. (2022) or the use of concordance matrices supplied in the EXIOBASE database. In addition to other data sources, a comparative analysis of methodologies between IOA and LCA can lead to more clarity in the calculation.

LCA, as carried out in Moberg et al. (2020), evaluates environmental impact throughout a product's lifecycle and focuses on reducing ecological footprints in industries, whereas IOA analyzes economic interdependencies between regions or sectors globally to explore economic relationships for trade analysis and policymaking, but both can be applied to calculate a carbon footprint. Differences in the methodology and data itself lead to varying results in the carbon footprint and IOA results appear to be lower than LCA results in most cases (Steubing et al., 2022). Non-matching results can be due to different levels of aggregation: For the sector "*vegetables, fruits, nuts*, for which [the LCA database] Ecoinvent covers 70 different crop products" (Steubing et al., 2022). According to Merciai & Schmidt (2018), the results from EXIOBASE for dairy products are considerably lower than those from Ecoinvent. Comparing these differences can enhance comprehension and emphasize which sectors have the highest deviation. However, Steubing et al. (2022) also states that it is not possible to verify in which methodology the supply chains are the most accurately modelled and which results are correct. Additional limitations of LCA are the choice of system boundaries, a limited coverage of environmental impacts along supply chains as well as missing temporal and geographical detail (Osei-Owusu et al., 2021). While it is more difficult to compare certain sectors, the best fits are such as the agricultural sector, which is the most important sectors for this research (Steubing et al., 2022). According to the results of this research, emission intensities are the main drivers for the decreasing trend in carbon emissions due to the Swedish food consumption. This highlights the importance of up-to-date data. However, these emissions intensities are modelled based on a different aggregation level than the one of EXIOBASE and in LCA they are not updated as frequently. Thus, it might be possible that in LCA only the consumption data changes over time.

Exploring these potentials for future research could contribute to a deeper understanding of the complexities underlying environmental impacts and provide valuable insights for policy formulation and decision-making in sustainability.

5.1.4 Ethical Considerations

From a sustainable development perspective, the chosen methods facilitate the identification of sectors with the highest emissions, thereby enabling targeted interventions to reduce carbon footprints.

This approach aligns with the principles of sustainable development by promoting informed decision-making to enhance environmental sustainability.

Ethically, the research conforms to principles of accuracy and transparency. The use of established databases like EXIOBASE ensures the reliability of the data, although it is acknowledged that there are inherent limitations and potential inaccuracies in these sources. Addressing these limitations transparently underscores the commitment to ethical research practices.

The focus on reducing emissions in the food sector also highlights the ethical responsibility to contribute to the global effort against climate change. However, it is also important to consider the potential socioeconomic impacts, such as changes in employment within certain sectors. Ethical research must balance environmental benefits with the social consequences of proposed changes, ensuring that all stakeholders are considered in the transition towards sustainability.

5.2 Conclusion

This research aimed to assess consumption-based emission from Swedish food consumption using IOA and to identify to which extent changes in emissions intensities, sourcing and final demand drive these trends. Disaggregating the matrices allowed for quantitative comparison of different regions and sectors in which the emissions occur. Mathematically isolating the components of the change in consumption-based emissions by using the average of two polars in the structural decomposition analysis enabled the analysis of key drivers.

The study identifies a significant overall decrease in consumption-based emissions from Swedish food consumption. This decline is primarily driven by a reduction in GHG emissions within Sweden, despite a slight increase in emissions from imported goods.

The findings indicate that technological advancements and improved emission intensities are the main drivers for the downward trend in carbon emissions. These improvements are more pronounced within Sweden compared to other countries where an increasing final demand and changes in sourcing leads to emissions. Notable food sectors contributing to the reduction include “hotel and restaurant services” and “dairy products.” These sectors have seen substantial declines in direct emissions, particularly from meat cattle and dairy products, reflecting improved agricultural practice and efficiency. Thus, the driver behind this reduction is the improvement of emission intensity which outweighs the increasing impact of sourcing and final demand.

By identifying the key drivers of emission changes, the study enhances the understanding of factors influencing food-related emissions, which is essential for formulating effective mitigation strategies. The thesis contributes to the existing body of knowledge by providing a detailed analysis of long-term emission trends and their drivers within the context of Swedish food consumption based on one of the most comprehensive databases for IOA. EXIOBASE does not take emissions due to land-use change into consideration and due to its comprehensiveness, there might be inaccuracies in the data which leads to the assumption that the emissions are underestimated. This highlights the potential for future research through the use of alternative databases, a more comprehensive analysis with IOA and SDA, and comparative studies with previous LCA results. By articulating these findings and their implications, the thesis underscores the importance of continued efforts to improve the sustainability of food systems.

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Appendix

A. List of food sectors

- Paddy rice
- Wheat
- Cereal grains not elsewhere classified
- Vegetables, fruit, nuts
- Oil seeds
- Sugar cane, sugar beet
- Plant-based fibers
- Crops nec
- Cattle
- Pigs
- Poultry
- Meat animals not elsewhere classified
- Animal products not elsewhere classified
- Raw milk
- Fish and other fishing products; services incidental of fishing
- Products of meat cattle
- Products of meat pigs
- Products of meat poultry
- Meat products not elsewhere classified
- Products of vegetable oils and fats
- Dairy products
- Processed rice
- Sugar
- Food products not elsewhere classified
- Fish products
- Hotel and restaurant services

B. Concordance matrix

Sectors	Agriculture	Mining	Food manufact.	Other manufact.	Fertilizer	Electr. & utilities	Construction	Transport	Services
Paddy rice	1	0	0	0	0	0	0	0	0
Wheat	1	0	0	0	0	0	0	0	0
Cereal grains nec	1	0	0	0	0	0	0	0	0
Vegetables, fruit, nuts	1	0	0	0	0	0	0	0	0
Oil seeds	1	0	0	0	0	0	0	0	0
Sugar cane, sugar beet	1	0	0	0	0	0	0	0	0
Plant-based fibers	1	0	0	0	0	0	0	0	0
Crops nec	1	0	0	0	0	0	0	0	0
Cattle	1	0	0	0	0	0	0	0	0
Pigs	1	0	0	0	0	0	0	0	0
Poultry	1	0	0	0	0	0	0	0	0
Meat animals nec	1	0	0	0	0	0	0	0	0
Animal products nec	1	0	0	0	0	0	0	0	0
Raw milk	1	0	0	0	0	0	0	0	0
Wool, silk-worm cocoons	1	0	0	0	0	0	0	0	0
Manure (conventional treatment)	1	0	0	0	0	0	0	0	0
Manure (biogas treatment)	1	0	0	0	0	0	0	0	0
Products of forestry, logging and related services (02)	1	0	0	0	0	0	0	0	0
Fish and other fishing products; services incidental of fishing (05)	1	0	0	0	0	0	0	0	0
Anthracite	0	1	0	0	0	0	0	0	0
Coking Coal	0	1	0	0	0	0	0	0	0
Other Bituminous Coa	0	1	0	0	0	0	0	0	0
Sub-Bituminous Coal	0	1	0	0	0	0	0	0	0
Patent Fuel	0	1	0	0	0	0	0	0	0
Lignite/Brown Coal	0	1	0	0	0	0	0	0	0
BKB/Peat Briquettes	0	1	0	0	0	0	0	0	0
Peat	0	1	0	0	0	0	0	0	0
Crude petroleum and	0	1	0	0	0	0	0	0	0
Natural gas and serv	0	1	0	0	0	0	0	0	0
Natural Gas Liquids	0	1	0	0	0	0	0	0	0
Other Hydrocarbons	0	1	0	0	0	0	0	0	0
Uranium and thorium	0	1	0	0	0	0	0	0	0

Iron ores	0	1	0	0	0	0	0	0	0
Copper ores and conc	0	1	0	0	0	0	0	0	0
Nickel ores and conc	0	1	0	0	0	0	0	0	0
Aluminium ores and c	0	1	0	0	0	0	0	0	0
Precious metal ores	0	1	0	0	0	0	0	0	0
Lead, zinc and tin o	0	1	0	0	0	0	0	0	0
Other non-ferrous me	0	1	0	0	0	0	0	0	0
Stone	0	1	0	0	0	0	0	0	0
Sand and clay	0	1	0	0	0	0	0	0	0
Chemical and fertili	0	1	0	0	0	0	0	0	0
Products of meat cat	0	0	1	0	0	0	0	0	0
Products of meat pig	0	0	1	0	0	0	0	0	0
Products of meat pou	0	0	1	0	0	0	0	0	0
Meat products nec	0	0	1	0	0	0	0	0	0
products of Vegetabl	0	0	1	0	0	0	0	0	0
Dairy products	0	0	1	0	0	0	0	0	0
Processed rice	0	0	1	0	0	0	0	0	0
Sugar	0	0	1	0	0	0	0	0	0
Food products nec	0	0	1	0	0	0	0	0	0
Beverages	0	0	1	0	0	0	0	0	0
Fish products	0	0	1	0	0	0	0	0	0
Tobacco products (16	0	0	0	1	0	0	0	0	0
Textiles (17)	0	0	0	1	0	0	0	0	0
Wearing apparel; fur	0	0	0	1	0	0	0	0	0
Leather and leather	0	0	0	1	0	0	0	0	0
Wood and products of	0	0	0	1	0	0	0	0	0
Wood waste to recycl	0	0	0	1	0	0	0	0	0
Pulp	0	0	0	1	0	0	0	0	0
Paper waste to recyc	0	0	0	1	0	0	0	0	0
Paper and paper prod	0	0	0	1	0	0	0	0	0
Printed matter and r	0	0	0	1	0	0	0	0	0
Coke Oven Coke	0	0	0	1	0	0	0	0	0
Gas Coke	0	0	0	1	0	0	0	0	0
Coal Tar	0	0	0	1	0	0	0	0	0
Motor Gasoline	0	0	0	1	0	0	0	0	0
Aviation Gasoline	0	0	0	1	0	0	0	0	0
Gasoline Type Jet Fu	0	0	0	1	0	0	0	0	0
Kerosene Type Jet Fu	0	0	0	1	0	0	0	0	0
Kerosene	0	0	0	1	0	0	0	0	0
Gas/Diesel Oil	0	0	0	1	0	0	0	0	0
Heavy Fuel Oil	0	0	0	1	0	0	0	0	0
Refinery Gas	0	0	0	1	0	0	0	0	0

Liquefied Petroleum	0	0	0	1	0	0	0	0	0
Refinery Feedstocks	0	0	0	1	0	0	0	0	0
Ethane	0	0	0	1	0	0	0	0	0
Naphtha	0	0	0	1	0	0	0	0	0
White Spirit & SBP	0	0	0	1	0	0	0	0	0
Lubricants	0	0	0	1	0	0	0	0	0
Bitumen	0	0	0	1	0	0	0	0	0
Paraffin Waxes	0	0	0	1	0	0	0	0	0
Petroleum Coke	0	0	0	1	0	0	0	0	0
Non-specified Petrol	0	0	0	1	0	0	0	0	0
Nuclear fuel	0	0	0	1	0	0	0	0	0
Plastics, basic	0	0	0	1	0	0	0	0	0
Recycled waste plast	0	0	0	1	0	0	0	0	0
N-fertiliser	0	0	0	0	1	0	0	0	0
P- and other fertili	0	0	0	0	1	0	0	0	0
Chemicals nec	0	0	0	1	0	0	0	0	0
Charcoal	0	0	0	1	0	0	0	0	0
Additives/Blending C	0	0	0	1	0	0	0	0	0
Biogasoline	0	0	0	1	0	0	0	0	0
Biodiesels	0	0	0	1	0	0	0	0	0
Other Liquid Biofuel	0	0	0	1	0	0	0	0	0
Rubber and plastic p	0	0	0	1	0	0	0	0	0
Glass and glass prod	0	0	0	1	0	0	0	0	0
Recycled glass waste	0	0	0	1	0	0	0	0	0
Ceramic goods	0	0	0	1	0	0	0	0	0
Bricks, tiles and co	0	0	0	1	0	0	0	0	0
Cement, lime and pla	0	0	0	1	0	0	0	0	0
Recycled ash	0	0	0	1	0	0	0	0	0
Other non-metallic m	0	0	0	1	0	0	0	0	0
Basic iron and steel	0	0	0	1	0	0	0	0	0
Recycled steel scrap	0	0	0	1	0	0	0	0	0
Precious metals	0	0	0	1	0	0	0	0	0
Recycled pecious met	0	0	0	1	0	0	0	0	0
Aluminium and alumin	0	0	0	1	0	0	0	0	0
Recycled aluminium w	0	0	0	1	0	0	0	0	0
Lead, zinc and tin a	0	0	0	1	0	0	0	0	0
Recycled lead, zinc	0	0	0	1	0	0	0	0	0
Copper products	0	0	0	1	0	0	0	0	0
Recycled copper wast	0	0	0	1	0	0	0	0	0
Other non-ferrous me	0	0	0	1	0	0	0	0	0
Recycled other non-f	0	0	0	1	0	0	0	0	0
Foundry work service	0	0	0	1	0	0	0	0	0

Fabricated metal pro	0	0	0	1	0	0	0	0	0
Machinery and equipm	0	0	0	1	0	0	0	0	0
Office machinery and	0	0	0	1	0	0	0	0	0
Electrical machinery	0	0	0	1	0	0	0	0	0
Radio, television an	0	0	0	1	0	0	0	0	0
Medical, precision a	0	0	0	1	0	0	0	0	0
Motor vehicles, trai	0	0	0	1	0	0	0	0	0
Other transport equi	0	0	0	1	0	0	0	0	0
Furniture; other man	0	0	0	1	0	0	0	0	0
Secondary raw materi	0	0	0	1	0	0	0	0	0
Glass bottles direct	0	0	0	1	0	0	0	0	0
Electricity by coal	0	0	0	0	0	1	0	0	0
Electricity by gas	0	0	0	0	0	1	0	0	0
Electricity by nucle	0	0	0	0	0	1	0	0	0
Electricity by hydro	0	0	0	0	0	1	0	0	0
Electricity by wind	0	0	0	0	0	1	0	0	0
Electricity by petro	0	0	0	0	0	1	0	0	0
Electricity by bioma	0	0	0	0	0	1	0	0	0
Electricity by solar	0	0	0	0	0	1	0	0	0
Electricity by solar	0	0	0	0	0	1	0	0	0
Electricity by tide,	0	0	0	0	0	1	0	0	0
Electricity by Geoth	0	0	0	0	0	1	0	0	0
Electricity nec	0	0	0	0	0	1	0	0	0
Transmission service	0	0	0	0	0	1	0	0	0
Distribution and tra	0	0	0	0	0	1	0	0	0
Coke oven gas	0	0	0	0	0	1	0	0	0
Blast Furnace Gas	0	0	0	0	0	1	0	0	0
Oxygen Steel Furnace	0	0	0	0	0	1	0	0	0
Gas Works Gas	0	0	0	0	0	1	0	0	0
Biogas	0	0	0	0	0	1	0	0	0
Distribution service	0	0	0	0	0	1	0	0	0
Steam and hot water	0	0	0	0	0	1	0	0	0
Collected and purifi	0	0	0	0	0	1	0	0	0
Construction work (4	0	0	0	0	0	0	1	0	0
Construction waste t	0	0	0	0	0	0	1	0	0
Sale, maintenance, r	0	0	0	0	0	0	0	0	1
Retail trade service	0	0	0	0	0	0	0	0	1
Wholesale trade and	0	0	0	0	0	0	0	0	1
Retail trade servic	0	0	0	0	0	0	0	0	1
Hotel and restaurant	0	0	0	0	0	0	0	0	1
Railway transportati	0	0	0	0	0	0	0	1	0
Other land transport	0	0	0	0	0	0	0	1	0

Transportation servi	0	0	0	0	0	0	0	1	0
Sea and coastal wate	0	0	0	0	0	0	0	1	0
Inland water transpo	0	0	0	0	0	0	0	1	0
Air transport servic	0	0	0	0	0	0	0	1	0
Supporting and auxil	0	0	0	0	0	0	0	0	1
Post and telecommuni	0	0	0	0	0	0	0	0	1
Financial intermedia	0	0	0	0	0	0	0	0	1
Insurance and pensio	0	0	0	0	0	0	0	0	1
Services auxiliary t	0	0	0	0	0	0	0	0	1
Real estate services	0	0	0	0	0	0	0	0	1
Renting services of	0	0	0	0	0	0	0	0	1
Computer and related	0	0	0	0	0	0	0	0	1
Research and develop	0	0	0	0	0	0	0	0	1
Other business servi	0	0	0	0	0	0	0	0	1
Public administratio	0	0	0	0	0	0	0	0	1
Education services (	0	0	0	0	0	0	0	0	1
Health and social wo	0	0	0	0	0	0	0	0	1
Food waste to incine	0	0	0	0	0	0	0	0	1
Paper waste to incin	0	0	0	0	0	0	0	0	1
Plastic waste to inc	0	0	0	0	0	0	0	0	1
Inert/metal waste to	0	0	0	0	0	0	0	0	1
Textiles waste to in	0	0	0	0	0	0	0	0	1
Wood waste to incine	0	0	0	0	0	0	0	0	1
Oil/hazardous waste	0	0	0	0	0	0	0	0	1
Food waste to bioga	0	0	0	0	0	0	0	0	1
Paper waste to bioga	0	0	0	0	0	0	0	0	1
Sewage sludge to bio	0	0	0	0	0	0	0	0	1
Food waste to compos	0	0	0	0	0	0	0	0	1
Paper and wood to co	0	0	0	0	0	0	0	0	1
Food waste to waste	0	0	0	0	0	0	0	0	1
Other waste to waste	0	0	0	0	0	0	0	0	1
Food waste to Landfi	0	0	0	0	0	0	0	0	1
Paper waste to Landf	0	0	0	0	0	0	0	0	1
Plastic waste to Lan	0	0	0	0	0	0	0	0	1
Inert/metal/hazardou	0	0	0	0	0	0	0	0	1
Textiles waste to La	0	0	0	0	0	0	0	0	1
Wood waste to Landfi	0	0	0	0	0	0	0	0	1
Membership organisat	0	0	0	0	0	0	0	0	1
Recreational, cultur	0	0	0	0	0	0	0	0	1
Other services (93)	0	0	0	0	0	0	0	0	1
Private households	0	0	0	0	0	0	0	0	1

DEPARTMENT OF SPACE, EARTH AND ENVIRONMENT
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