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Understanding GHG emissions from Swedish consumption- Current challenges in reaching the generational goal

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Abstract

The Swedish generational goal is a unique initiative governing all Swedish environmental policy, aiming at solving all major domestic environmental problems for the next generation without increasing environmental damage abroad. Without a good understanding of greenhouse gas (GHG) emissions from Swedish consumption, the formulation of efficient and well targeted policy initiatives to reach the generational goal is difficult. We have analysed the impacts of Swedish consumption in detail, investigating the impacts of different final consumers and different consumption clusters as well as the geographical location of where GHGs are emitted to satisfy Swedish demand. We use environmentally extended multi-regional input-output (EEMRIO) analysis and the database EXIOBASE3 to compute Swedish consumption-based (CB) GHG emissions over a time period of 20 years. Our study shows that total CB GHG emissions fluctuated but remained rather stable over the years. However, the origin of the emissions changed from within Sweden to outside Sweden's borders. CB emissions within Sweden have decreased substantially through a reduction of direct emissions associated with domestic heating and mobility, whereas GHG emissions outside Sweden have increased, especially in China and in the rest of Asia. We show that manufactured products are responsible for a large share of this development, displaying a strong trend toward future increases. This calls for policy measures targeting consumption, especially of manufactured products such as textiles, clothing and furniture that cause large impacts in other countries.

Keywords: CB accounting; generational goal; Sweden; GHG emissions; footprints; multi-regional input-output analysis

1 Introduction

"*The overall goal of Swedish environmental policy is to hand over to the next generation a society in which the major environmental problems in Sweden have been solved, without increasing environmental and health problems outside Sweden's borders.*" Generational goal (Riksdagen, 2010)

Many high income countries have managed to substantially increase the efficiency of industrial production at home and, with that, decrease domestic environmental impacts (Barbu et al., 2014; Weidner and Mez, 2008). Much too often this has occurred by outsourcing environmentally damaging and/or emission heavy production lines to low-wage countries with less strict environmental policy or by satisfying growing demand for consumer goods through imports from other countries (Wood et al., 2018). Like many other OECD countries, Sweden has successfully reduced greenhouse gas (GHG) emissions from domestic production (SCB, 2018). However, production emissions within Sweden are not the only impacts Sweden is responsible for. When taking a consumption perspective, the whole value chain of products and services consumed in Sweden needs to be measured, including impacts that happen during the production phase outside Sweden. Several studies have been conducted that focus on understanding how socio-economic factors influence energy use and emissions abroad from domestic households (Jones and Kammen, 2014; Lenzen et al., 2006; Ornetzeder et al., 2008). With its generational goal, Sweden is on the forefront in acknowledging this need to address the issue of displaced emission resulting from a country's consumption.

The question that arises is how well Sweden's climate policy measures align to this generational goal. Recent Swedish climate policy focus can be classified into three main areas (Isenhour and Feng, 2016):

1) policies that target emission intensity improvements in Swedish production
2) technology transfer programmes to countries that Sweden imports a lot from
3) improvement of easily understandable/accessible information about products environmental performance, in order to facilitate voluntary consumer choice

Emission intensity improvements have been part of Sweden's policy packages for a long time. In 1991, a green tax reform was initiated that explicitly targeted fossil fuels as a tax base (Sterner, 1995). Some of the taxes are on energy and others on emissions, making it more expensive to use fossil fuels and making biofuels more attractive. Subsidies or investment schemes urging households to change from fossil fuels to other energy systems are also part of these policies. The energy mix that was created in the wake of the oil crisis meant that hydropower and nuclear power are dominating the electricity generation in Sweden. For heating in urban areas, large scale solutions are common, and biofuels have surpassed oil as main fuel used. In the mobility sector, there are policies in place aiming to increase the use of biofuels and establish distribution systems for such fuels. Schemes for lowering the price of environmentally friendly cars have also been used. New proposals have been developed in order to reach a newly adopted target of reducing CO_2 emissions from transport in Sweden by 70 percent 2005–2030. (Nilsson, 2017). Furthermore, initiatives to get industry on board with voluntary energy efficient management are part of the work of the Energy Agency (2009).

Sweden has technology transfer programmes with several countries, its main target being China (Isenhour and Feng, 2016). The Centre for Environmental Technology (CENTEC) has been established with the specific goal to "contribute to the decrease of carbon dioxide emissions in China" (Froberg et al., 2013), in order to reduce Swedish consumption impacts in China.

On the consumer side, the biggest NGO in the country has established a system for the marking of green electricity so that consumers can purchase certified electricity, ensuring that the payment is allocated to renewable energy sources. Likewise, energy-marking schemes for energy-efficient electronic products (such as fridges and washing machines) aim to help consumers in reducing the use of electricity by households, and municipalities also provide information about how to best insulate houses as well as tips on how to save energy in the household (see e.g. Energy Agency (2009)). Furthermore, regulations require that all houses put for sale are accompanied with an energy declaration.

These initiatives show the pronounced interest by the government to tackle Swedish emissions. However to evaluate the effectiveness of the policies, especially regarding areas of major mitigation potential from a consumption viewpoint, it requires detailed knowledge and understanding of the supply chain impacts of consumer goods. Insights into who consumes what are crucial to develop future efficient and well target policies.

A comprehensive method for the evaluation of the global environmental impact of consumption is environmentally-extended multi-regional input-output (EE-MRIO) analysis (Energimyndigheten, 2016). As a top-down approach it is suited to assess impacts caused by a country's total consumption (Hertwich and Peters, 2009) in a given year. In contrast to product-specific environmental footprints calculated by life-cycle analyses, it is a macro-economic approach, which due to the global coverage, gets around the problem of truncation errors (Lenzen and Dey, 2000) and captures regionally specific technology in international supply chains. Using EE-MRIO framework, we can compute GHG footprints showing all the impacts of Swedish consumption, no matter where they occur.

The generational goal refers to environmental problems at a much larger scope than only climate impacts. Many more environmental pressures are related to consumption than only GHG emissions and tackling GHG emissions can result in problem shifting by creating other environmental problems, such as biodiversity loss or water scarcity. Hence, to avoid this, it is of utmost importance to assess the overall environmental impact before formulating policies.

In this study we focus on GHG emissions only, investigating how Sweden's consumption is driving those in Sweden and abroad, analysing the international sources of Sweden's CB emissions and the change over time. To better understand where policies targeting CB emissions have the highest impact, we investigate in detail which particular consumption clusters are causing large GHG emissions and where and which final consumer (households, governments, etc.) are mainly responsible for buying them. With the results of our study we discuss how well recent and planned Swedish environmental policy measures address the challenge of reducing GHG emissions not only in Sweden but also outside of Sweden for Swedish consumption.

Our study is structured as follows: In the following section, we provide an overview of the model and data used as well as the methods for calculating CB footprints, detailed on source country and consumption cluster, and the structural decomposition analysis (SDA). In the result section, we present Sweden's GHG CB footprints, their development over time and space, analysing in detail how different consumption clusters' impacts differ. In section 4, we discuss our findings within the context of Swedish recent and future environmental policy. In the last section we conclude with a remark on challenges and opportunities for Sweden to reach its generational goal.

2 Consumption-based accounting

In order to identify the areas of consumption in Sweden that are causing most GHG emissions, we use an EE-MRIO approach, which provides regional differentiated production of goods and services, reasonably high product detail, and temporal data on changes in production and consumption. MRIO approaches have been used extensively in the last decade to calculate CB impacts. Some of the earlier work focussed on GHG emissions embodied in trade (Peters and Hertwich, 2008), but since then it has been used for a variety of applications, such as analysing material use (Wiebe et al., 2012), biodiversity threats (Lenzen et al., 2012) and European footprints across a range of indicators (Tukker et al., 2016). The importance of using MRIO databases to capture the trade dynamics has increased over time, as both trade and environmental impacts embodied in trade have increased (Wood et al., 2018).

2.1 Data

We use version 3.4 of the EXIOBASE database (Stadler et al., 2018); an EE-MRIO describing inter-industry monetary transactions of 44 countries and 5 rest-of-the-world regions, constructed on a 200-product and 163-industries resolution. Sweden is represented individually in EXIOBASE and all our analysis is based on Swedish final demand (FD) only. EXIOBASE3 includes time series data from 1995 to 2011, nowcasted data for 2012-2015 and comes with 985 different environmental stressors, including emissions, water, material and land accounts. These extensions cover the stressors associated with each industry/product across all countries/regions as well as direct impacts associated with final consumption/demand. We use product-by-product tables and aggregate the detailed product information into six different consumption clusters: food, shelter, manufactured products, construction & materials, services, mobility and one “other” category, containing products that only constitute residual flows in final consumption or which do not fit any of the consumption clusters (see SI for the product to consumption cluster concordance). The “other” category is responsible for around 1% of the GHG emissions and is hence not analysed further in this study.

GHG emissions are calculated using 100-year global warming potential (GWP 100, (IPCC, 2014)) of the greenhouse gases CO2, CH4, N2O, SF6, HFC and PFC. EXIOBASE3.4 accounts include emissions from combustion, non-combustion, agriculture and waste, but exclude emissions from land use, land use change and forestry. Footprints are calculated using EXIOBASE3.4 extensions that have been adjusted with updated data for CO_2 combustion emissions that is more consistent with monetary accounts (Schmidt et al., 2018). Note that the emission factors used here are zero for biofuels, resulting in no CO2-combustion emissions for these products.

2.2 Footprints

Footprints are calculated using standard MRIO methodology (see Miller and Blair (2009) for an overview) for Swedish FD. In the following equations, bold uppercase letters indicate a matrix, bold lowercase letters indicate a vector, ˆ symbolises the diagonalization of a matrix, i, j, k refer to the first, second and third dimension of the respective matrix. Table 1 describes the IO variables used and their dimensions.

Table 1 – Input-output variables used to compute footprints

Symbol	Dimension	Description
	c	Number countries/region
	p	Number of products in each country/region
	d	Number of FD categories
	s	Number of stressors
$\boldsymbol{L}$	cp x cp	Leontief inverse
$\boldsymbol{Y}$	cp x d	Swedish FD
$\boldsymbol{F}$	s x cp	Environmental stressor matrix
$\boldsymbol{S}$	s x cp	Environmental coefficient matrix
$\boldsymbol{c}$	1 x s	GWP characterization vector
$\boldsymbol{F}^{hh}$	s x p x d	Direct impact from Swedish FD
$e, \boldsymbol{e}, \boldsymbol{E}$		Footprints

The total Swedish GHG footprint is computed according to:

$$e = \boldsymbol{c}(\boldsymbol{SL}\sum_j \boldsymbol{Y}_{ij} + \sum_i \sum_j \sum_k \boldsymbol{F}_{ijk}^{hh}) \quad (1)$$

The source of impacts (i.e. the country and sector in which they occur) caused by total Swedish consumption, (excluding direct emissions as they are not occurring in any specific sector but during the use phase) is calculated as such:

$$\boldsymbol{e} = \widehat{\boldsymbol{c}\boldsymbol{S}}\boldsymbol{L}\sum_j \boldsymbol{Y}_{ij} \quad (2)$$

and detailed for each of the FD categories as:

$$\boldsymbol{E} = \widehat{\boldsymbol{c}\boldsymbol{S}}\boldsymbol{LY} \quad (3)$$

Sweden's total impact on each country is then obtained by summing over all sectors in the respective country and, in the case for Sweden itself, adding $\boldsymbol{c}\sum_k \sum_j \boldsymbol{F}_{ijk}^{hh}$ and $\boldsymbol{c}\sum_k \boldsymbol{F}_{ijk}^{hh}$, respectively.

To investigate the impacts associated with different types of products, we aggregate the 200 EXIOBASE products into six consumption clusters: food, shelter, manufactured products, construction&materials, services, and mobility. Products that do not fit any of the consumption clusters are collected in a sevenths category "other". The concordance matrix $\boldsymbol{P}$ that groups the products into consumption clusters is provided in SI.

The calculated final consumption footprints do not include impacts associated with infrastructure and machinery used during the production processes, but instead capture capital goods within Sweden as the separate FD category "investments" (GFCF) (Minx et al., 2011; Södersten et al., 2018b). Capital requirements are therefore not allocated to industries using them, despite that there may be large emissions stemming from the production of them. In 2015, the GHG emissions associated with production of capital goods constituted 30% of total emissions from FD, and allocating these emissions to industry may lead to major increases in individual product footprints (up to 200% increase for some service sectors), whereas the effect of endogenising capital on the total Swedish footprint is very low (Södersten et al., 2018a).

2.3 Structural decomposition analysis

SDA is a widely used tool to assess the contribution of changes in different determinants in the overall change in footprints. Studies of energy use and emissions have been some of the most frequent environmental applications of SDA in recent years. Most studies conclude that the main driver for increased energy use and GHG emissions in both developing and developed countries is the increase in expenditures, which often offsets important technological gains in energy efficiency and decarbonisation (Lenzen, 2016). A recent study for the United States found that the reduction in CO_2 emissions between 2007 and 2013, previously attributed to changes in the energy mix, was mostly due to economic recession (Feng et al., 2015). Other studies have identified that emission reduction due to technology improvements in developed economies was partly offset by increased imports from more carbon-intensive countries (Baiocchi and Minx, 2010; Hoekstra et al., 2016; Malik and Lan, 2016).

We use SDA to quantify the effects of the changes in individual drivers for the total change in footprints, by changing each variable in the equation in turn while maintaining the remaining parameters constant (Rose and Chen, 1991). The changes in the footprints between two years t-1 and t are calculated as such:

$$\Delta\mathbf{E} = \mathbf{E_t} - \mathbf{E_{t-1}} = \mathbf{C}(\Delta\mathbf{SLY} + \mathbf{S}\Delta\mathbf{LY} + \mathbf{SL}\Delta\mathbf{Y})$$

The characterisation matrix $\mathbf{C}$ remained constant during the analysed time period and is therefore not decomposed. We use a decomposition method based on the average of the extreme polar decompositions (Dietzenbacher and Los, 1998), decomposing the FD matrix $\mathbf{Y}$ into three factors: the composition of FD ($\mathbf{y_H}$), which describes the product mix purchased by final consumers; the origin of products consumed by FD ($\mathbf{y}_T$); the total expenditure per capita (y); and population size (p). We also split the Leontief inverse into technology and trade relationships based on the method described in Arto and Dietzenbacher (Arto and Dietzenbacher, 2014), decomposing the technical coefficient matrix (**A**) into production structure (**H**) and trade effects (**T**).

In order to decompose $\mathbf{A}$ into two components, we apply the calculation of changes in $\mathbf{L}$:

$$\Delta\mathbf{L} = \mathbf{L}_{t-1}\mathbf{A}\mathbf{L}_t = \mathbf{L}_{t-1}(\mathbf{H}\otimes\mathbf{T})\mathbf{L}_t$$

Here, ⊗ represents element-by-element multiplication. The footprint can then be decomposed as:

$$\Delta\mathbf{E} = \mathbf{C}(\Delta\mathbf{SLy}_{\boldsymbol{H}}\otimes\widehat{\mathbf{y}_{\boldsymbol{T}}}y\,p + \mathbf{SL}_{\boldsymbol{t-1}}\Delta\mathbf{H}\otimes\mathbf{TL}_{\boldsymbol{t}}\mathbf{y}_{\boldsymbol{H}}\otimes\widehat{\mathbf{y}_{\boldsymbol{T}}}yp + \mathbf{SL}_{\boldsymbol{t-1}}\mathbf{H}\otimes\Delta\mathbf{TL}_{\boldsymbol{t}}\mathbf{y}_{\boldsymbol{H}}\otimes\widehat{\mathbf{y}_{\boldsymbol{T}}}yp + \mathbf{SL}\Delta\mathbf{y}_{\boldsymbol{H}}\otimes\widehat{\mathbf{y}_{\boldsymbol{T}}}yp \\ + \mathbf{SLy}_{\boldsymbol{H}}\otimes\widehat{\mathbf{y}_{\boldsymbol{T}}}yp + \mathbf{SLy}_{\boldsymbol{H}}\otimes\widehat{\mathbf{y}_{\boldsymbol{T}}}\Delta y\,p + \mathbf{SLy}_{\boldsymbol{H}}\otimes\widehat{\mathbf{y}_{\boldsymbol{T}}}y\,\Delta p)$$

This gives us seven effects, in the order of the above equation, that drive the changes in emissions: GHG intensity (emission per unit of production), production structure, trade in intermediate inputs, product mix of final consumption, trade in final products, total volume of consumption per capita, and overall population growth. We further decomposed the change in stressor matrix $\mathbf{S}$ into two factors $\mathbf{S_{dom}}$and $\mathbf{S_{for}}$(domestic and foreign intensities) and aggregated trade of intermediates and trade in final products to a single “trade” effect, resulting in seven final drivers plus direct emissions by households. SDA involves cross-temporal decomposition, and EXIOBASE3 has a constant price estimate based on product specific price indices and rebalancing to macro-economic constant price data. We performed the SDA analysis for every pair of years from 1995 to 2014.

3 Results

Below, we present Sweden's production- and CB GHG emissions. The results are shown at an aggregated level, as well as broken down by country/region of origin and by FD sector and consumption clusters. For illustration purposes we have chosen to only present our main findings in the article. Results on the product and consumption cluster level for each year in the time range of the study (1995-2014) and source country/region for GWP 100 are presented in the SI.

3.1 GHG emissions due to Swedish demand

The results show that GHG emissions from Swedish production declined over the 20 year time period (1995-2014) analysed (black line, figure 1), while imports of embodied emissions increased (orange bars, figure 1). CB impacts are composed of direct, indirect domestic and indirect non-domestic impacts. Indirect domestic impacts are impacts occurring down the supply chain within Sweden due to Swedish demand, i.e. all the impacts occurring inside Sweden in the make phase of products bought by Swedes. Direct impacts of Swedish demand are impacts that are related to the use phase of the products purchased by Swedes. Indirect non-domestic impacts are all the impacts from the production of a purchased good that occur outside Sweden's borders.

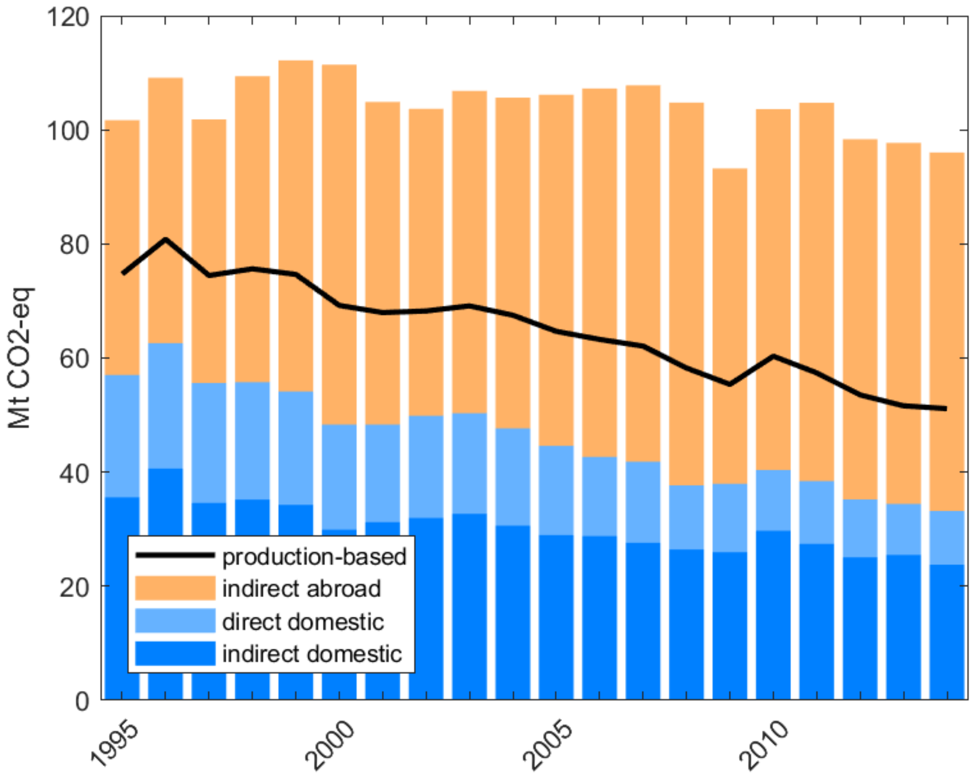

Figure 1 – The bars show the GHG footprints (GWP100) of Swedish total FD from 1995-2014. The blue bars show the domestic impacts (light blue – direct impact, dark blue – indirect impact), the orange

bars show the impact occurring outside Sweden's borders. The black line indicates GHG emissions within Sweden according to the production-based accounting framework.

CB GHG emissions due to Swedish FD have remained around 100 Mt CO2-eq the last 20 years (total size of bars in Figure 1, suggesting a slight decreasing trend in the last years. Over the time period investigated, the total amount as well as the share of domestically emitted GHGs due to Swedish demand have dropped; in 1995 57Mt CO2-eq (56% of the total footprint) were emitted within Sweden, in 2014 this had changed to 33 Mt CO2 (35%).

To investigate the driving factors of the change in CB GHG emissions, we have decomposed the indirect domestic and indirect foreign emissions into technology, trade and consumption factors (Figure 2), as per the methods. The decrease in GHG intensity of production (dark blue lines), both in Sweden and in other countries, together with a significant decrease in direct emissions (red line) was able to offset the increase in emissions due to the growth of expenditure per capita (green line), change in product mix and intermediate inputs (purple and orange lines). The sourcing of final products resulted in increased emissions because a growing share of products are being sourced from developing economies, especially in Asia, where energy and GHG productivity is lower than in Europe. Changes in the trade structure (intermediate and final goods combined) (yellow line) and in population (cyan line) proved to only have weak effects that counterweighed each other.

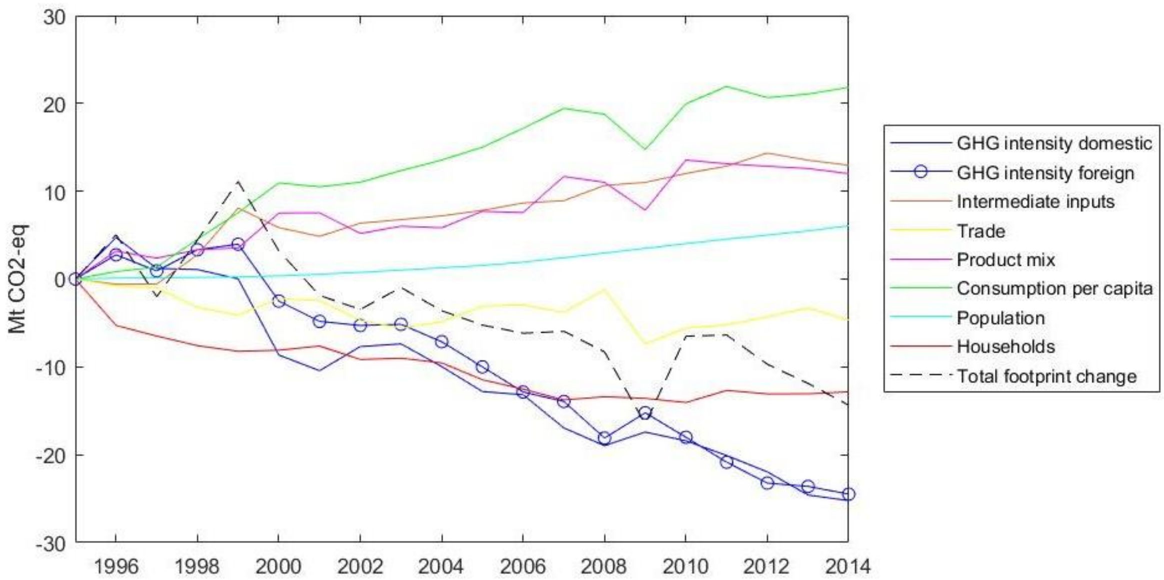

Figure 2 – Changes in GHG footprint - Decomposition of the cumulative changes in total Swedish GHG footprints from 1995 to 2014, broken down in eight different drivers. The dashed line represents total cumulative change, in Mt CO_2-eq, and the solid lines represent the contribution of each of the drivers.

Sweden's trade and consumption patterns have changed over time and thereby also the origin of emissions embodied in Swedish FD (figure 3). In 1995, less than half of the GHGs emitted to satisfy total Swedish FD, occurred outside Sweden, mainly in Europe including Germany (17%) and Russia (9%). By 2014, the emissions outside Sweden were emitted to a larger extent in China and RoWA (21% combined). The share of value added created has shifted very little compared to the changes in GHG footprints, with Sweden's share decreasing slightly. With 70%, the most value creation was still in Sweden in 2014. The rest of the value created was 2014 mainly happening in Europe including Germany (19 %) and to a comparatively small extent in and China and RoWA (6% combined).

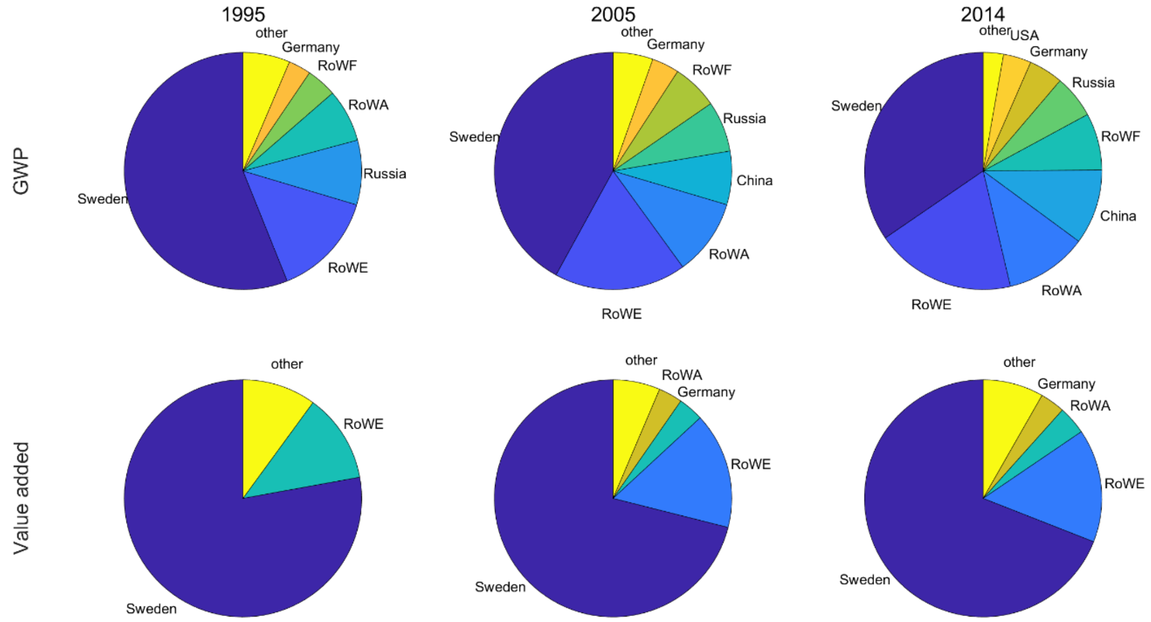

Figure 3 – Geographic location of Sweden's GHG footprint (first row) and the creation of value added from Swedish consumption (second row) for 1995, 2005 and 2014.

3.2 Who is responsible for what - analysing Swedish consumption clusters

Analysing Swedish consumption in detail, we can distinguish between 1) which FD category the impacts are associated with (who is consuming) and 2) which consumption clusters cause the impact (what is consumed).

Total FD can be divided into household consumption; consumption from non-governmental organisations serving households (NPISH), government consumption, investments (GFCF) and changes in inventories. Household consumption shows by far the largest contribution to the total Swedish footprint, decreasing from 71% in 1995 to 64% in 2014, compare Ivanova et al. (2016). It is also the largest category of expenditure (decreasing from 44% to 40% of total FD by 2014). Investments are the second largest contributor to Swedish GHG emissions and that impact has significantly increased. In monetary terms, government spending constitutes about one third of all Swedish demand, but is associated with a rather small impact in terms of GHG emissions. One dollar household spending hence has a much larger footprint associated with it than either, investments and government spending (table 1).

Table 1 – CB GHG emissions shares and expenditure shares (Mon share) across different FD categories (1995-2014) for Sweden

	1995		2000		2005		2010		2014	
	GHG share	Mon share	GHG share	Mon share	GHG share	Mon share	GHG share	Mon share	GHG share	Mon share

Households	71 %	44 %	68 %	43 %	68 %	42 %	66 %	42 %	64 %	40 %
GFCF	16 %	18 %	19 %	20 %	20 %	21 %	21 %	22 %	23 %	23 %
Government	9 %	31 %	9 %	30 %	8 %	31 %	9 %	31 %	9 %	31 %
NPISH	3 %	6 %	2 %	5 %	2 %	5 %	2 %	5 %	2 %	5 %
Inventory changes	2 %	2 %	2 %	1 %	2 %	1 %	1 %	1 %	2 %	1 %

Combining the information on who is the consumer (which FD category) with the information on consumption cluster detail, shows that households, as the largest overall consumer, are responsible for almost all impacts from food, shelter and mobility (figure 4). Impacts from services and manufactured products are split almost equally between households and governments. Impacts from the consumption cluster construction & materials are mainly due to investments.

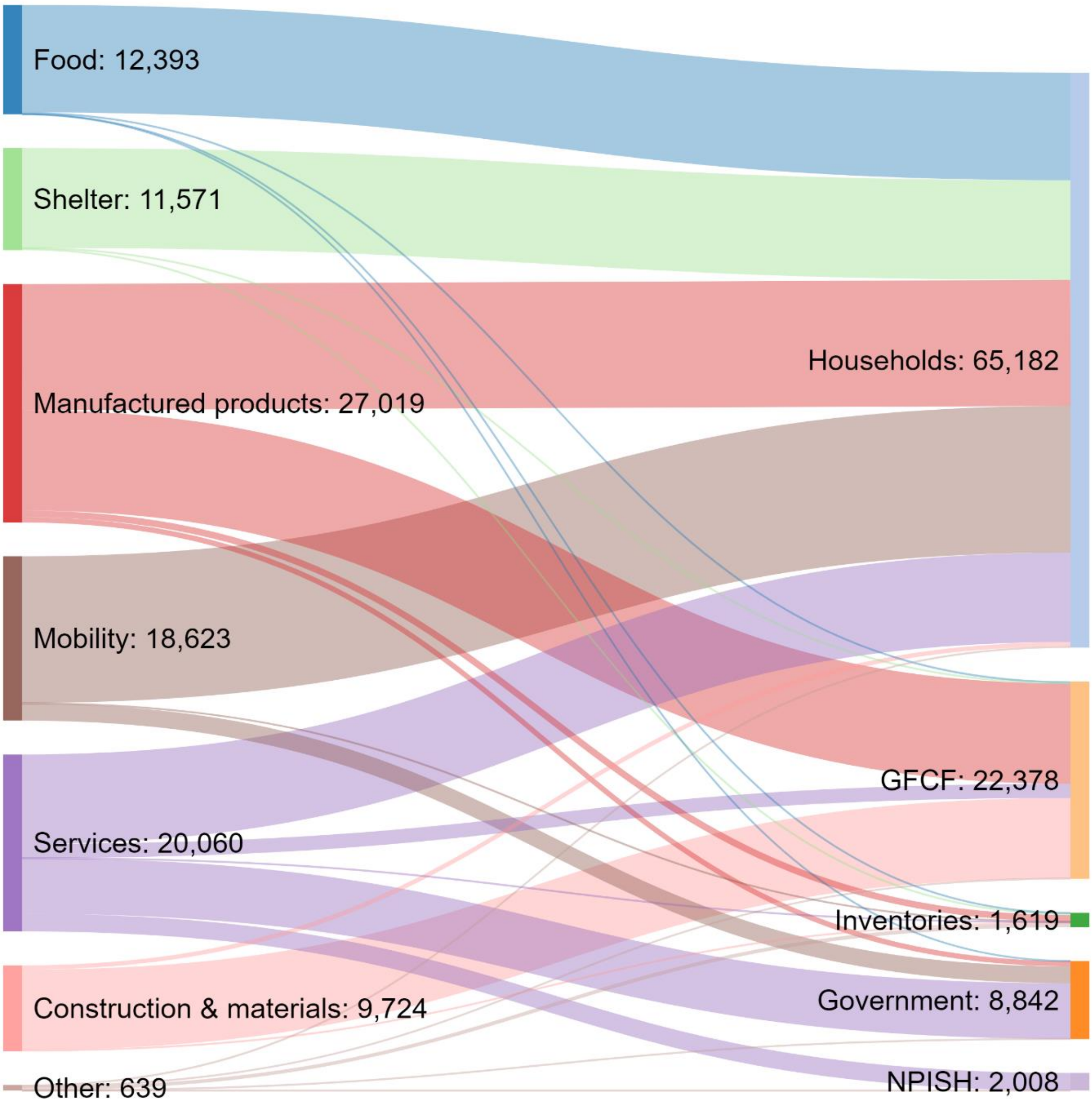

Figure 4 – Swedish CB GHG emissions detailed by FD category and consumption cluster (2014)

Breaking down Swedish FD into six different consumption clusters, the largest GHG footprint are due to the purchase of manufactured products, mobility and services (figure 4 and 5). Between 1995 and 2014, only shelter and mobility show a significant decrease in absolute GHG emissions. Emissions associated with services show a minor decrease and the consumption clusters food, construction & materials and manufactured products all show an increase, the largest one (in absolute numbers) being from manufactured products.

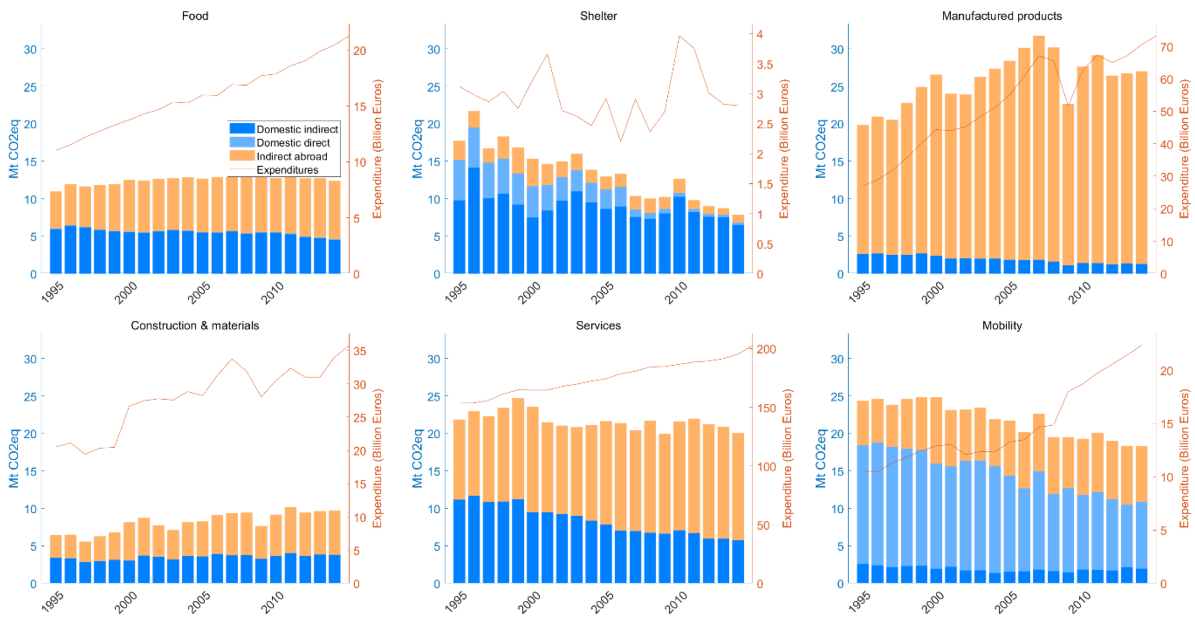

Figure 5 - GHG emissions associated with Swedish demand of different consumption clusters over a 20-year time period, divided into indirect impacts occurring in Sweden, indirect impacts occurring outside Sweden and direct impacts associated with the use of the respective products.

In 1995, 24% of the total footprint was related to mobility, 22% to services, 20% to manufactured goods, followed by shelter 17%, food 11% and construction 6%. In 2014 manufactured products was the consumption cluster with the largest footprint (28%), followed by services (21%), mobility (19%), food (13%), construction (10%) and shelter (8%). Only the consumption clusters mobility and shelter contained a significant amount of direct emissions, with direct emissions from shelter almost disappearing over the analysed time period. About 80% of all GHG emissions were associated with the consumption clusters manufactured products, mobility, services and shelter, which are analysed in detail below. For a short analysis on the consumption clusters construction &materials and food, see SI. A more detailed analysis of the consumption of food in Sweden has been done by Cederberg (2018-this issue).

3.2.1 Manufactured products

This consumption cluster showed the largest differences between impacts happening inside and outside Sweden. It also has the smallest absolute impact within Sweden (1,3 of total 27 Mt CO_2-eq from manufactured products in 2014), indicating that their GHG emission intensive production is almost exclusively happening outside Sweden's borders. The value they create however, is to a large extent in Sweden 35% (2014). Germany and China received only 12% and 6% of the value added respectively that year.

The GHG footprint increase follows roughly the increase in spending (constant prices – adjusted for inflation), suggesting that an increase in the amount of products consumed is the main reason for the increasing impact. Manufactured goods were mainly consumed by private households and investments, with the absolute largest amount of emissions occurring in China (an increase from 5% to 25% equalling 6,7 Mt CO_2-eq) and Germany (8% increase equalling 2,3Mt CO_2-eq).

For household consumption, the GHG footprint has increased by 46%, equalling a total increase of 4,5 Mt CO_2-eq, which is due to a big increase in GHG emissions related to furniture, chemicals, wearing apparel and leather (0,6-0,7 Mt CO_2-eq increase each). In absolute numbers the biggest impacts were associated with the products chemicals, furniture and motor vehicles (2,5 Mt CO_2-eq, 2 Mt CO_2-eq and 2 Mt CO_2-eq respectively in 2014), with the largest share being emitted in China (motor vehicles 17%, chemicals 20%, furniture 28%, textiles 35%, clothing 53%).

In 2014, 42% of the total footprint of from manufactured products were due to investments and three products made up 75% of the total investment footprint: Machinery and equipment (increased from 36% in 1995 to 44% in 2014 (total in 2014 is 5,0 Mt CO_2-eq)), motor vehicles (increased from 15% to 21% (total in 2014 is 2,4 Mt CO2-eq)) and metal products (decreased from 12% to 10% (total in 2014 is 1,2 Mt CO_2-eq)). The most drastic increase has been in China (13-fold impact increase for machinery and equipment).

3.2.2 Mobility

The consumption cluster mobility contains transport fuels (excluding electricity, since the amount of electric vehicles is negligible in Sweden (see SI for details)) and transport services. Vehicles are not included here but in manufactured products. Impacts from transport in industry are allocated to the product they are helping to produce. The largest share of the impacts associated with mobility showed to be due to demand by private households (figure 4) with the largest part being direct emissions, 99% dominated by CO_2 from combustion. These show a significant decrease (44 %) over the time period analysed. All direct emissions were basically from road transport, specifically from the combustion of the fuels motor gasoline and gas/diesel oil (combined over 97%). The decrease in these emissions can be attributed to almost only motor gasoline, which has more than halved. Swedish statistics on the supplied volume of motor gasoline to gas stations shows a similar decrease, explained by an increased share of motor gasoline being mixed with biofuels and a total decrease in motor gasoline sold (SPBI 2018). The distance driven per year has increased by 15% for passenger cars from 1999 to 2015 (Trafik Analys2018), so the observed decrease in direct GHG emissions from mobility can be attributed to large efficiency increases in gasoline cars and to a switch to cleaner fuels (bio, electricity).

Indirect emissions have fluctuated with no clear trend observable in the time frame analysed. The indirect impacts associated with mobility were due the emissions from the production of the fuels used directly and to the purchase of transport services, i.e. the emissions caused to provide those. Emissions from air transport (through the purchase of air travel services) were almost exclusively indirect and have drastically increased from 2,4 to 4,8 Mt CO2–eq, from only 28% to 51% (2014) of the indirect CO2 emissions associated with mobility. Indirect emissions from marine transport have decreased in absolute numbers as well as share-wise (from 8% to 2% over the time period analysed), the decrease coinciding with the opening of the bridge (for rail and road transport) between Denmark and Sweden.

Until 2011, emissions from land transport have constituted the major part of indirect emissions related to mobility. Constantly declining, they were only 47% in 2014.

3.2.3 Services

Impacts associated with service consumption have slightly decreased (8%) and were in 2014 mostly due to the consumption from private households and government. All GHG emissions from service consumption are indirect. The composition of where the impacts occurred changed from 51% happening within Sweden (1995) to 71% in other countries in 2014. In 1995 the emissions outside Sweden occurred mainly in WWA (10%), Russia (7,9%) and China (2,4%). In 2014 they were distributed amongst many more countries, with WWA (9%) and China (8%) being the major emitters. In total numbers, the impacts occurring in Sweden have halved over the time period analysed and show a continued decreasing trend, counterweighted by a continued increase outside of Sweden.

Impacts from household consumption (10,1 Mt CO_2-eq in 2014) were throughout the time period analysed mainly due to consumption of real estate services (construction of the buildings not included) and hotels and restaurants (4,3 and 2 Mt CO_2-eq respectively). For real estate services, impacts have shifted from 58% in 1995 to only 35% in 2014 in Sweden. At the same time, impacts have increased in China, WWM and USA. For hotels & restaurants, the share of impacts happening in Sweden has decreased from 47% in 1995 to 27% in 2014, with the impacts occurring outside Sweden spreading across more and more countries over the period analysed.

Government consumption's footprint (total 6,3 MT CO_2-eq) was mainly due to health and social work services, public administration and defence services, and education services (2,1 Mt CO_2-eq 2,0 Mt CO_2-eq, 1,5 Mt CO2-eq respectively). Even here the impacts have shifted from Sweden (50% in 1995 to 25% in 2014) to a variety of other countries/regions such as China, WWA, WWM (8-9% each in 2014).

3.2.4 Shelter

The consumption cluster shelter contains fuel products used for heating (like coal, heating oil and wood) as well as electricity and waste. Distinguishing features of the footprint of this consumption cluster are that CB GHG emissions associated with it were mainly occurring in Sweden (figure 5), were almost exclusively due to household demand (figure 4) and have shown a significant drop of 56% over the 20 year time period analysed. This drop can almost solely be attributed to the substantial decrease in direct emissions (from 5,4 to 0,30 Mt CO_2-eq), its share being reduced from 30% and 4% of the total GHG emissions due to shelter.

This can be explained by a substantial drop in the use of gas/diesel oil for heating, resulting in a GHG emissions decrease of 95% associated with it. Energy use for shelter shows that the drop is not due to less energy being required but to a shift in how houses were heated (from heating oil to district heating and electricity) (Energimyndighet, 2015). The total amount of energy used for shelter by households has fluctuated but remained rather stable. In 2014, direct energy use of households for shelter shows the use of 38 PJ (13%) of biofuels (wood), which we consider carbon neutral in this study. This assumption might have to be revised in the future to yield a more realistic picture of the direct climate impact of according to new Arvesen et al. (2018), which find that heating with wood at home affects the climate more and in more different ways than assumed until now.

The indirect GHG emissions mostly happened within Sweden and were dominated by emissions from the production of steam and hot water used in district heating (78% - 5,9 Mt CO_2-eq in 2014), and electricity production (average 18%).

4 Discussion

The generational goal set by Sweden's government to guide their environmental policies takes on the challenge of addressing consumers' responsibility for impacts beyond the nation state. An understanding of Swedish CB GHG emissions is the basis for informed environmental policy aiming to reach the generational goal. In this study, we have analysed GHG emissions from Swedish consumption from different perspectives. We have assessed the impacts associated with the demand of different final consumer categories, the impacts associated with the consumption of different consumption clusters as well as where GHGs are emitted to satisfy Swedish demand.

Sweden's GHG emissions footprint has, despite a significant decrease of domestic emissions and a significant drop in emission intensity, remained rather stable, with no clear trend over the 20-year time frame analysed. A major change in the location of the impacts has occurred, impacts shifting from occurring mainly inside Sweden to outside its borders. This is coherent with other findings (Energimyndigheten, 2016; Palm et al., 2018- this issue).

The analysis at consumption cluster detail reveals that Sweden has been very successful in decreasing CB GHG emissions occurring on their territory, mainly through efficiently decreasing direct emissions from domestic heating and mobility. However, our results show that this decrease in CB emissions is offset by the development of emissions from manufactured products. This consumption cluster is responsible for both the largest impact of all consumption clusters as well as the largest total increase in emissions. Furthermore, the emission increase is solely happening outside Sweden's borders. This increase could be traced to the rapidly increasing consumption by private households of wearing apparel, textiles, furniture and chemicals. This has resulted in an emissions increase occurring mostly in Asia, especially China.

Our findings compare well to a study conducted on impacts from Norwegian household consumption by Steen-Olsen et al. (2016). They evaluate household carbon footprint development from 1999 to 2012 and find a per household increase over that time period of 26% alongside a household expenditure increase of the same magnitude (same trend as we observe in the SDA). Their findings on the distribution and location of where value is created compared to where carbon is emitted are also highly similar to what has been found in this study. A similar analysis has been conducted on China's carbon footprint development (Zheng et al., 2017) showing that the total CB emissions from Chinese FD are increasing and that GFCF is mainly responsible for that. Even here it is found that consumption level increases more than counterweigh all emission intensity improvements.

The generational goal requires not to increase the environmental problems neither in nor outside Sweden's borders. All consumption clusters show a decrease in domestic emissions, from both a production-based and a consumption-based perspective. However, all consumption clusters, except shelter, show an increase in foreign GHG emissions. This shows that the major challenge in reaching the generational goal is currently to halt and in the future decrease GHG emitted abroad for Swedish consumption. A further challenge identified is the trend of increasing overall consumption levels, which, if not halted or altered, will rather sooner than later compromise the chance to meet the generational goal.

Swedish policy initiatives are heavily focused on emissions happening in Sweden. To reach the generational goal a climate policy framework was implemented in order to create coherent long term climate policies to reach a set of climate goals. However, a major drawback of this initiative is its narrow focus on territorial emissions, with no consideration of Swedish consumption impacts abroad. Also the policies implemented to encourage the use of electricity for domestic heating and the introduction of biofuels into conventional gasoline have targeted, although seemingly efficient, only domestic emissions. The domestic emission reduction achieved have been sufficient to counterweigh the increase happening abroad. If the generational goal is to be met, however, policies need to be implemented that halt the increase in foreign emissions. One such initiative is Sweden's technology transfer program to China. It is well targeted, as Swedish increased consumption of manufactured products has resulted in major emission increases in China. The main contributor here is the coal electricity, which is used in the production processes and the program partly aims at transferring knowledge for the implementation of renewable energy into the electricity sector.

Based on our finding that identify the increase in overall consumption levels, specifically in the consumption cluster manufactured goods, as the major determinant in explaining increasing foreign emissions, future policies need to either target the consumption level itself or the production processes to efficiently turn the trend of increasing foreign emissions. Both is politically very challenging as measures to limit consumption tend to be highly unpopular and influence on other countries' production processes and electricity system are limited (Wiebe, 2016). Furthermore, policies targeting consumption levels bear the risk of affecting the economically most vulnerable unproportionally.

In this study we have focused solely on GHG emissions. The generational goal is about the environment as a whole, however, and there are other environmental pressures that need to be considered as well. While having identified manufactured products as a key consumption cluster that policies should aim at to reduce GHG emissions, when focusing on land and water footprints food has shown to be the consumption cluster with the highest impacts (in the EU) (Usubiaga et al., 2018). With land use furthermore having been identified as the main contributor to biodiversity loss (Mace et al., 2005), targeting the consumption cluster food becomes highly important in reaching the generational goal. This example indicates the need to carefully assess trade-offs when formulating sustainable and successful environmental policy.

A full assessment of uncertainty has not been done, but national level footprints have errors in the order of 10% (Moran and Wood, 2014; Rodrigues et al., 2018). Owen et al. (2014) found that the major part of the differences in footprint results calculated with the various global MRIOs is due to the differences in the environmental extensions. The next step is to validate the results of this paper specifically and the footprint results of all MRIOs in general, is to use the same environmental extensions and methodology to allocate these to the industries at country level for all the MRIOs and compare the resulting footprints.

Finally, the level of detail of CB impacts also has an impact on the uncertainty of the obtained results (Lenzen et al., 2010; Owen et al., 2016; Wieland et al., 2018). When an analysis is conducted on a high level of detail, uncertainty increases at higher levels of detail. This limitation was circumvented in our study by assessing the impacts associated with aggregated consumption clusters. For an evaluation of uncertainty of footprint results for Sweden from available MRIO results, the reader can refer to Moran and Wood (2014) or www.environmentalfootprints.org/infographics, whilst Rodrigues et al. (2018) provide consumption cluster results and insights into the effect of correlations in data used in calculations.

5 Conclusions

From the results in this paper, we can conclude that Sweden's CB emissions remained more or less constant between 1995 and 2014, while the total volume of consumption has increased significantly. This development can be described as a weak decoupling of consumption from GHG emissions.

Our detailed results offer insights that can help inform and facilitate the formulation of environmental policies to efficiently target Swedish CB impacts both inside and outside Sweden's borders, as the generational goal requires. Our findings suggest that targeting the impacts due to the consumption of manufactured products is key to decreasing Sweden's footprint abroad. To be efficient, policies need to address either the absolute increase of consumption of these products or their GHG emission-intensive production.

In the last years, Sweden has put policies into place targeting direct emissions from heating and transport. A sharp decrease in these emissions has been observed, suggesting a link between these policy initiatives and the obtained results. Further research investigating this link and the causality is needed to be able to inform future effective domestic policy measures to further reduce Swedish CB emission of domestic origin.

The major challenge that remains to meet the generational goal is to halt or better decrease GHG emissions that happen abroad due to Swedish consumption. Most policy initiatives so far have targeted and lead to reduced emissions on Swedish territory. To efficiently halt or decrease foreign emissions, new policies have to be developed targeting especially the impacts due to increased consumption of manufactured goods.

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