Environmental pressures from Swedish consumption –a hybrid multi-regional input-output approach

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Abstract

Sweden has a policy goal of solving major environmental problems in Sweden within a generation, without increasing environmental or health problems in other countries. Following up this goal requires indicators for domestic and external footprints of Swedish consumption. This paper presents such macro-level indicators for the years 2008–2014.

The new indicators are consistent with Swedish statistics from the System of Environmental-Economic Accounts. They combine a multi-regional input-output (MRIO) database, to capture the external components of Sweden's consumption, with national input-output, trade and environmental statistics. The hybrid MRIO-Sweden model provides a comprehensive environmental account for follow-up of the Generational Goal.

This paper presents impacts from household consumption, government consumption and capital formation, covering emissions of greenhouse gases, sulphur dioxide, nitrogen oxides, and particulate matter smaller than 2.5 micrometres (PM2.5), land use, materials consumption, and blue water consumption.

Except for land use, the majority (60% or more) of the environmental pressures due to consumption occurred outside Sweden in 2014; more than 90% of sulphur emissions and more than 80% of the water use fell abroad. The environmental pressures from consumption decreased over this period for all indicators (except materials consumption). This suggests an absolute decoupling between environmental pressure due to consumption and economic growth, which rose over the period. It is, however, too early to determine whether this is a genuine trend or a temporary stabilisation.

Key words: consumption; environment; Generational Goal; trade; multi-regional input-output; decoupling

1 Introduction

Products and services that are consumed in one country cause environmental impacts in many other countries, with complex globalized production chains (Hertwich and Peters, 2009; Peters et al., 2011b; Tukker et al., 2016). Production is increasingly fragmented across geographical space and firms (Gereffi et al., 2005; Wood et al., 2018) and Sweden, as a small country, is dependent on the rest of the world for trade to meet its population's consumption demands. At the same time, Sweden has an overarching environmental goal 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" (Swedish Environmental Protection Agency, 2012). While this ambition is laudable, it is also difficult to measure. How can Sweden's part in the global economy and its related environmental pressures be monitored?

Currently the Swedish Environmental Protection Agency (EPA) is using seven indicators to monitor the generation goal (Swedish Environmental Protection Agency, 2018). They cover waste, organic food, renewable energy, materials consumption, consumption-based greenhouse gas emissions and environmentally motivated subsidies. All these except consumption-based greenhouse gases focus on pressures in Sweden. In addition to the consumption-based greenhouse gases Statistics Sweden publishes annual consumption based accounts for air pollution. To calculate these environmental indicators of consumption, Statistics Sweden currently relies on input-output analysis (IOA), a tool emanating from the economical sciences, developed in the 1930s and 1940s (Leontief, 1936; Miller and Blair, 2009). In the past 10 years, environmentally-extended input–output modelling has become an increasingly popular tool for assessing the global environmental pressures of the consumption of a country as data have become more readily available and consistent over time (Tukker and Dietzenbacher, 2013; Wiedmann, 2009a).

At the core of an environmental input–output model is an input–output table describing the goods and services bought and sold between industries and finally sold to final consumers. The environmental extensions describe the resource use or emissions per industry, and a number of calculation steps can be performed in order to reallocate the resource use or emissions per industry, to resource use or emissions per consumed good or service. This can then be combined with data on the amount and type of consumption, to estimate the environmental pressures associated with the final consumption of goods and services by households, government, or also for capital formation for use in future years. Single-region input–output (SRIO) tables at the country level have been published regularly by statistical offices since the 1950s for some countries, and it is mandatory for EU countries to report these to the European Commission every five years (Eurostat, 2014). More recently, a number of multi-regional input–output (MRIO) models have been published by various research institutions. These MRIO models detail the exchanges between industries of different countries and provide greater details of international trade than domestic input-output tables alone. Examples of the latest MRIO models include WIOD (Erumban et al., 2011), GTAP (Peters et al., 2011a), Eora (Lenzen et al., 2013) and EXIOBASE (Wood et al., 2015). In terms of environmental indicators, consumption-based emissions of carbon dioxide (sometimes termed carbon footprints) have been studied extensively in the literature (Hertwich and Peters, 2009; Minx et al., 2009; Wiedmann, 2009b; Wiedmann et al., 2010), but similar studies using other kinds of environmental variables also exist, such as water and Ecological footprints (Ewing et al., 2012), material footprint (Giljum et al., 2016; Wiedmann et al., 2015) land use, material extraction, water use, and emission of acid substances, greenhouse gases and ozone precursors (Arto et al., 2012) as well as carbon, water, land and materials (Tukker et al., 2016).

The paper addresses four specific research questions on the macro-level: What are the environmental pressures in the form of greenhouse gas emissions, air pollution, land, materials and water used exerted by Swedish consumption in Sweden and abroad? How can they be monitored, and compared to similar pressures exerted inside Sweden, in a consistent and policy-relevant manner? How are these pressures divided between private consumption, public consumption and investments? How have the environmental pressures changed over time? The environmental results are also compared with the consumption based value added as an economic indicator. By including this economic indicator, it is possible to examine the change in economic activities in relation to the environmental pressures investigated. A final aim of the paper is to suggest ways to follow up on Swedish environmental policies in the light of these findings.

A core goal of the development of the indicator framework is to utilise existing Swedish data for the coverage of domestic environmental pressures and economic transactions, whilst adequately covering the international supply-chains of good and services imported into Sweden. To analyse the environmental impact from imported goods and services, the national statistics on environmental pressure and economic statistics on the production structure and volume and composition of the national consumption needs to be complemented with international data. Detailed and internationally harmonized reporting of trade statistics has a long tradition. However, detailed environmental and economic data for all countries has only recently become available in MRIO models. The MRIO database compilers have collected, processed and organized available statistics and where necessary, complemented missing data through estimates or other sources. As a result, globally consistent databases are available, but the harmonisation of data necessarily means that the databases differ in different ways to the original national data (Christis et al., 2017). A number of authors have identified such issues in calculating country specific footprints, and especially trade exposed countries like the Netherlands and Belgium. Edens et al. (2015) propose a new method of rebalancing MRIO tables in order to add consistency, which has been since implemented for Belgium (Hambÿe et al., 2018). Christis et al. (2017) in an analysis for Flemish consumption point to the specific need to have temporally updated data, as well as the need to avoid aggregation error where possible.

In this work, we have similar goals – the desire for accurate and consistent national data coupled with full coverage of global supply chains. Rather than rebalancing a MRIO database around national data as is suggested by Edens et al. (2015) we follow the analysis of Moran et al. (2018) on the insignificance of feedback effects between exports and imports on the final footprint calculations, and implement the suggestion of Wood and Palm (2016) in providing a simplified, linked model. This hybrid model is constructed such that domestic data – based on Sweden's own well-developed environmental monitoring, and retaining much of its detail – can be complemented directly with international data derived from a leading multiregional input-output (MRIO) model. By using MRIO, these consumption-based accounting results reflect environmental pressures along complex, multi-country supply chains.

2 Material and methods

2.1 Overall approach

MRIO approaches all represent a compromise of different countries' data, harmonised in a globally consistent model, which causes differences to a single countries data (Moran et al., 2017). In order to provide country specific accounts, fully respecting a countries' own environmental and economic data, a number of approaches have been suggested, from using the domestic data alongside the simplistic assumption that foreign technology is the same as domestic technology (as in Wood and Dey, 2009), to correcting for price differences (Tukker et al., 2013b) to integrating a domestic table and rebalancing a full MRIO model (Edens et al., 2015).

For this study, a new approach has been taken, using an environmentally extended hybrid MRIO-SRIO model to measure Sweden's environmental pressure due to final demand (consumption). This approach was outlined in Wood and Palm (2016) and Tukker et al. (2018) where it is called "simplified SNAC") , but is implemented into practise here for the first time.. The overall methodological approach is to combine national data from the Swedish System of Environmental and Economic Accounts (SEEA) and the System of National Accounts (SNA) (Brolinson et al., 2010) with international data a MRIO model. A number of recent studies have compared existing MRIO models, see Owen et al. 2014; Moran and Wood 2014, Dawkins et al., 2018 (this issue), and for this study we have chosen to use EXIOBASE (Stadler et al., 2018; Wood et al., 2015). Swedish Input-Output tables are used to describe the domestic production structure and are combined with the multi-regional input-output tables as follows. The Swedish input-output tables for domestic consumption and production (domestic and import coefficient matrices) are kept intact (i.e. used at their published level of product detail) and linked via bilateral trade data to the multi-regional-input-output tables, which supply detailed information about the environmental intensity of foreign production embodied in the imported goods. For environmental data, Swedish SEEA data are used for Sweden for air emissions by industry and including stationary emissions, mobile emissions and process emissions. EXIOBASE provides the equivalent data for countries of the rest of the world. For other environmental pressures and resource use, data from EXIOBASE are used for both Sweden and the rest of the world (due to lack of Swedish specific data in the SEEA) including: blue water use, land use and domestic materials extracted (including sand and gravel, metal ores, fossil fuels, wood products, and biomass (primary crops, fodder and grazing) all reported in tonnes).

To quantify the environmental pressure associated with production in Sweden, the resource use and direct emissions from each industry are calculated. The same calculation is performed in EXIOBASE for the import data. These production-based environmental pressure data are then reallocated from the industries of production to the products and services produced, using an input-output approach and the Leontief inverse. This was done for the years 2008-2014, with EXIOBASE extrapolating data from 2011 until 2014. Lastly, by combining this with Swedish final demand for each year, the total Swedish footprints for the various environmental pressures can be calculated.

2.1.1 Economic data and Environmental data

The size and composition of final demand is calculated in the National Accounts at Statistics Sweden (Statistics Sweden, 2018a). Final demand is broken down into the following categories: household (private) consumption, governmental (public) consumption, capital formation (investments) and exports. The latter is however not included as part of the national consumption of Sweden (which is the focus of this study). Statistics on the quantity and products of trade are also available (Statistics Sweden, 2018b) and these data are combined with the modelled value-added chains as given in the multiregional input output framework. Data on emissions on air pollution and climate change from burning of fossil fuels and other stationary and industrial processes are taken from Swedish environmental-economic accounts for Sweden (Statistics Sweden, 2017), and EXIOBASE for the international data (Stadler et al., 2018). EXIOBASE in turn base their data on the international reporting conventions stipulated by the Intergovernmental Panel on Climate Change (IPCC) and the Convention for Long-Range Transboundary Pollutants (CLRTAP).

The emissions included in this study are greenhouse gases expressed in CO_2-equivalents (CO2eq_GHG), including carbon dioxide with fossil origin (CO2Foss), methane (CH_4), nitrous oxide (N_2O) and f-gases (CO2eq_fgas). Other emissions that have other environmentally harmful properties are particulate matter smaller than 2.5 micrometers, (PM2.5), Sulphur dioxide (SO_2), and nitrogen oxides (NOx). Greenhouse gases from biofuels and from land use change are not included in these analyses.

As well as emissions to air, the use of natural resources is also included in the study. These are land use, direct water consumption (blue water) and material consumption (including sand and gravel, metal ores, fossil fuels, wood products and biomass (primary crops, fodder and grazing). These resource use data are taken from EXIOBASE to ensure that the industry allocation and system boundaries are the same in the analysis (Stadler et al., 2018). For land use, the land use categories included crop land, land for forestry, permanent pasture and infrastructure land.

For a full description of the methods and data sources of EXIOBASE see: Tukker et al. (2009 and 2013); Wood et al. (2015) and Stadler et al. (2018).

2.1.2 Data harmonization

The common denominator to link the national accounts data with the environmental data is the international classification called International Standard Industrial Classification of All Economic Activities (ISIC Rev 4) (United Nations Statistics Division, 2018). This classification is then adapted to regional uses and it is then known as NACE in Europe or SNI in Sweden, but the main structure is harmonized. The classification covers every economic activity from agriculture, fishing, forestry, mineral extraction, through manufacturing, energy conversion to the transport industries and services. By using the industrial classification, the industrial economic statistics become internationally comparable. It is important to note that for energy and environmental statistics there are also other ways to report on economic activities using a sector based approach and that some care must be taken to align these statistics with the economic data. For example, in energy statistics and climate reporting to the IPCC, a broader classification of sectors is used, therefore allocating the emissions slightly differently. Most notably, according to the ISIC classification the transportation sector and housing sector will be allocated to the industries that own the vehicles and houses in line with the national accounts definitions and guidelines. This means that the agricultural industry has higher emissions in the environmental accounts than in the IPCC reporting for example. By following the same classification as the economic data we are able to reallocate the direct emissions from the industries to the resulting consumption of the products and services from economic production using the input-output approach.

2.2 The use of an input–output model for assessing environmental pressure and resource use from consumption

In environmentally extended input output analysis, the purpose is to track the resource use or emissions occurring in each step of the supply chain, due to the consumption of a given good or service (or any vector of goods and services). This can be expressed mathematically as:

$$\mathbf{f} = \mathbf{S}\left(\mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \cdots\right)\mathbf{y} = \mathbf{S}(\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{y} = \mathbf{S}\,\mathbf{L}\,\mathbf{y}$$

where **f** is the resource use or emissions occurring due to the final consumption **y, S** is the environmental extension matrix expressed as resource use or emissions per dollar (or other currency) output and ($\mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \ldots$) = $(\mathbf{I}–\mathbf{A})^{-1}$ = **L** describes the supply chain, also known as the Leontief inverse. **I** in the supply chain is the identity matrix, and **A** is the main square of the input–output table, expressed as the shares of inputs per total input per industry (i.e., per column). This means that **A** describes per industry the production recipe of inputs needed to produce one unit of output, i.e., one unit of a certain good or service (similarly, $\mathbf{A}^2$ describes the inputs of the inputs, i.e., the second step of the supply chain). Thus, **SA** is the resource use or emissions in the first step of the supply chain for producing one dollar of each good and service, and **S A y** the resource use or emissions in the first step of the supply chain due to the actual consumption *y* (the term **S L y** can be regarded as the direct resource use or emissions before the supply chain has started). In the context of a MRIO, the supply chain is global, incorporating not only imports, but also the imports of the imports, and so on. For a more detailed description of input–output analysis, see (Miller and Blair, 2009), and for applications to MRIO, see (Murray and Lenzen, 2013).

In this project we have developed a hybrid model that combines an MRIO model (EXIOBASE) with a single regional input-output (SRIO) model for Sweden (from the Swedish national accounts). The resource use and direct emissions in Sweden due to the Swedish final demand are calculated based on the SRIO part of the model, and the resource use and emissions outside Sweden due to the Swedish final demand are calculated with the MRIO part of the model. Full details of the derivation of the model are described in (Wood and Palm, 2016), and relevant equations for the Swedish specific case are shown below. We use product by product tables for both Sweden and EXIOBASE (Majeau-Bettez et al., 2014).

The model can be described mathematically as the Swedish footprint calculated as the sum of impacts from the domestic SRIO model and the impacts abroad from the MRIO model, due to the Swedish final demand. The domestic part of the model can be described by:

$$\mathbf{f}^{d} = \mathbf{S}^{d}\left(\mathbf{I} - \left(\mathbf{A}^{\mathrm{d}}\right)\right)^{-1}\mathbf{y}^{d} + \mathbf{f}^{h}$$

where superscript d denotes domestic, $\mathbf{f}^{d}$ is the domestic environmental impact due to domestic final demand (excluding exports), $\mathbf{f}^{h}$ is the direct household environmental impact (such as from driving a car), $\mathbf{S}^{d}$ is the environmental intensity of goods produced in Sweden (e.g. kg of CO_2 per million SEK), $\mathbf{A}^{\mathrm{d}}$ is the component of the coefficient matrix A that describes domestically produced goods used in Swedish production and $\mathbf{y}^{d}$ is the Swedish demand for domestically produced goods (excluding exports). The domestic Leontief inverse $\mathbf{L}^{d}$ is calculated as $\mathbf{L}^{d} = \left(\mathbf{I} - \left(\mathbf{A}^{\mathrm{d}}\right)\right)^{-1}$ which gives us the domestic emissions from the supply chain of products as $\mathbf{f}^{d} = \mathbf{S}^{d}\mathbf{L}^{d}\mathbf{y}^{d}$.

The impacts embodied in imports from the MRIO model, can be described by:

$$\mathbf{f}^{\boldsymbol{m}} = \mathbf{Q}^{\boldsymbol{t}}\mathbf{m}$$

where $\mathbf{f}^{\boldsymbol{m}}$ is the emissions abroad due to domestic final demand (excluding exports) per finally demanded product and $\mathbf{Q}^{\boldsymbol{t}}$ is the multiplier matrix of environmental impact per the monetary value of goods or service imported, $\mathbf{m}$.

Imports (denoted by superscript *m*) are broken down into the imports going to intermediate demand $\mathbf{A}^{m}\mathbf{x}$ and those going to final demand $\mathbf{y}^{m}$. The imports going to intermediate demand are simply shown as the imports of goods per unit of production of goods $\mathbf{A}^{m}$ multiplied by the quantity of the production of goods $\mathbf{x}$, which gives us that:

$$\mathbf{m} = \mathbf{A}^{\boldsymbol{m}}\mathbf{x} + \mathbf{y}^{\boldsymbol{m}}.$$

Since the output $\mathbf{x}$ is the production of goods in Sweden due to the Swedish final demand $\mathbf{y}^{\boldsymbol{d}}$, it can be written as $\mathbf{x} = \left(\mathbf{I} - \left(\mathbf{A}^{\mathbf{d}}\right)\right)^{-\mathbf{1}}\mathbf{y}^{\boldsymbol{d}}$, which means that the impacts embodied in imports can be described by:

$$\mathbf{f}^{\boldsymbol{m}} = \mathbf{Q}^{\boldsymbol{t}}(\mathbf{A}^{m}\left(\mathbf{I} - \left(\mathbf{A}^{\mathbf{d}}\right)\right)^{-\mathbf{1}}\mathbf{y}^{\boldsymbol{d}} + \mathbf{y}^{\boldsymbol{m}}).$$

The multiplier matrix $\mathbf{Q}^{\boldsymbol{t}}$ is constructed as follows. From EXIOBASE data, we can extract the multi-regional input-output multiplier for emissions and resource uses $\mathbf{Q} = \mathbf{SL}$ where $\mathbf{S}$ is the environmental intensity matrix per million Euro of production in EXIOBASE, and **L** is the MRIO Leontief inverse. $\mathbf{Q}$ expresses the environmental impacts per unit of consumption. For the consideration of aspects of double counting and the application of the multipliers to intermediate trade, the reader is referred to (Wood and Palm, 2016).

The MRIO multipliers cannot be applied to the imports used in Swedish production and consumption directly because they are in a) different currency, b) different product classification and c) different country classification (Swedish IO data reports only total imports of each product per consuming sector, but not which country the products are imported from).

Hence, firstly we introduce a currency conversion *c*, based on market exchange rates (originally used in EXIOBASE to convert the Sweden table to Euro, see (Wood et al., 2014). Secondly, we introduce a product concordance $\mathbf{G}^{\boldsymbol{p}}$ which links the classification of the Swedish table to EXIOBASE products. $\mathbf{G}^{\boldsymbol{p}}$ is block diagonal, repeating the product concordance for the 49 EXIOBASE regions on the diagonal. This allows us to take a weighted average of the product level multipliers used in EXIOBASE, by re-calculating the multipliers in Swedish product classification through calculating the overall impact by product group for EXIOBASE ($\mathbf{SL\hat{y}}$**,** where **y** is global final demand by product for EXIOBASE), aggregating to Swedish classification by post-multiplying by $\mathbf{G}^{\boldsymbol{p}}$ and dividing that aggregated impact by an aggregation of global final demand ($\mathbf{yG}^{\boldsymbol{p}}$) $\mathbf{Q}^{\boldsymbol{g}}$ has thus a column dimension of 49 (EXIOBASE countries) x 59 (Swedish products)

$$\mathbf{Q}^{\boldsymbol{g}} = \mathbf{SL\hat{y}G}^{\boldsymbol{p}}\widehat{(\mathbf{yG}^{\boldsymbol{p}})}^{-\mathbf{1}}$$

Finally, we introduce a country concordance $\mathbf{G}^{\boldsymbol{c}}$ (a binary matrix, row dimension 59 products x 49 EXIOBASE countries; column dimension 59 products by 202 countries) that maps country or region of production multipliers from EXIOBASE to Swedish bilateral trade share data $\mathbf{B}$ (row dimension 59 products, column dimension 202 countries) that shows the country of origin of goods with products on rows and country of origin on columns, normalised to give percentages, as the summation of the bilateral trade data over country of export corresponds to total imports **m**. When also multiplying with the currency conversion *c* gives:

$$\mathbf{Q}^{c} = \mathbf{Q}^{g}\mathbf{G}^{c}c$$

$\mathbf{Q}^{c}$ thus denotes the multi-regional input–output multipliers for emissions and resource uses from EXIOBASE, aggregated to the published Swedish official 59 product groups and disaggregated to 202 countries to fit with the Swedish trade data (i.e. column dimension 59x202). As $\mathbf{G}^{c}$ is a binary matrix $\mathbf{Q}^{c}$ has the same multiplier for each sub-region (where 1 region in EXIOBASE maps to multiple countries in the Sweden bilateral trade data). In order to disaggregate the multipliers to individual countries, for ease of exposition, we proceed with a transformation for each row of the environmental pressure *i* such that $\mathbf{Q}^{ci} = mat(\mathbf{Q}^{c}_{i,:})$ is the stacked matrix (row dimension 59 products, column dimension 202 products) of the *i*-th row of $\mathbf{Q}^{c}$, which can then be multiplied using the Hadamard product (element by element multiplication) to the bilateral trade shares **B**, such that the *i*-th row of $\mathbf{Q}^{t}$ becomes

$$\forall \boldsymbol{i}, \qquad \mathbf{Q}^{t}_{i,:} = (\mathbf{Q}^{ci} \circ \mathbf{B})\mathbf{e}$$

where **e** is a simple summation vector over the countries of length 202. This completes the derivation of $\mathbf{Q}^{t}$, which represents the total global impact per unit of imports.Simplifying the above expressions, we have the total impact embodied in imports as:

$$\mathbf{f}^{m} = \mathbf{Q}^{t}\mathbf{A}^{\mathrm{m}}\mathbf{L}^{\mathrm{d}}\mathbf{y}^{d} + \mathbf{Q}^{t}\mathbf{y}^{m}.$$

Adding the impacts embodied in imports to the impacts of domestic production we have the total environmental footprint of the hybrid model as:

$$\mathbf{f}^{d+m} = \mathbf{S}^{d}\mathbf{L}^{d}\mathbf{y}^{d} + \mathbf{Q}^{t}\mathbf{A}^{\mathrm{m}}\mathbf{L}^{\mathrm{d}}\mathbf{y}^{d} + \mathbf{Q}^{t}\mathbf{y}^{m} + \mathbf{f}^{h}.$$

Following this method, the model was compiled and results run for the years 2008-2014. The model was run in current prices. For all physical environmental indicators, we compare the change in physical quantity over time. However, for the monetary value added, the effect of inflation (despite being low in Sweden in this period (Statistics Sweden, 2019) means that the direct interpretation of results reflects both volume and price effects. As it was not possible to have a consistent constant price hybrid model (neither EXIOBASE or the Swedish IO tables were available in constant prices), we adjust the final calculated value added indicators embodied in final demand. Here, we exploit the duality of the IO model in that total monetary factor inputs (value added) equal total final demand. As such, we use a dataset on constant price demand from Statistics Sweden, reported by final demand category (Supplementary material) to calculate the value added embodied in final demand in constant prices. From the constant price Swedish data, a deflator was calculated for each component of final demand as the ratio between constant and current price for each component for each year. This deflator was then multiplied by the respective current price demand from the hybrid model.

3 Results

3.1 Greenhouse gas emissions and air pollution, by component of final demand

Table 1 presents the calculated per capita emissions to air from the Swedish consumption in 2014 for the relevant components of the final demand. In 2014, the population in Sweden was approximately 9.7 million and it is slowly increasing over time.

The greenhouse gas emissions are mainly driven by household demand for goods and services, almost 7 tonnes per capita. It consists of household consumption of travel, food items, housing, clothing, medical purchases and other services. The size of the environmental pressure from household consumption and how to decrease this footprint should be an important part of the environmental policy in Sweden. The other components of final demand are also of interest. Investments is the second largest driver, about 2.6 tonnes per capita is generated through investments in long term capital. These investments include spending on maintaining and building infrastructure such as roads, industrial investments in industry and buildings. Aside from the yearly environmental pressure, they also are of interest because of the long-term nature of these installations.

General government spending consists of state, local governments, and social security funds. The consumption of the Swedish government (including activities that are paid for by taxes such as schools, hospitals, care, defence and infrastructure) accounts for 1.2 tonnes per capita. Also included here is public procurement, where the government has the possibility to influence the market for more sustainable products.

Some public expenditures are for household consumption (health care, housing, education, etc.), that reflect expenditures incurred by government on behalf of individual households. Notable is that both households and public sector purchase the same products like fossil fuels, food and building materials and therefore the same product impacts are high in both groups.

In terms of mass, the quantity of other emissions is small in comparison to the greenhouse gases, but similar patterns arise, for example the emissions of NOx (in total 32 Kg per capita) are mostly due to the demand from households. For all of the environmental indicators the pressures of private consumption are consistently larger than that of public consumption.

However, consumption based value added is more evenly spread between private consumption, public consumption and investments. Value added from a consumption perspective is calculated in the same way as the environmental pressures. This means that just as CO2 emissions is generated in each step of the production chain, also value added is generated in each step of the production chain.

Table 1: Environmental pressure from final demand and the consumption based value added it generates. Tonnes per capita, SEK (2014) per capita, 2014. Population in 2014 was 9 747 355 persons.

	Households	**Government**	**Investments**	**Total**
Greenhouse gases, CO_2eq-ghg	6,59	1,22	2,64	10,45

Greenhouse gases, fossil CO_2.	4,72	0,93	2,12	7,77
CH4	0,044	0,007	0,011	0,062
N20	0,002	0,000	0,000	0,002
SO2	0,008	0,002	0,007	0,018
NOx	0,019	0,005	0,008	0,032
PM2.5	0,002	0,000	0,001	0,004
NMVOC	0,011	0,001	0,001	0,013
Value added (SEK/capita)	144 970	102 964	80 141	328 074

Figures 1 to 4 show the change over time in the footprints of Sweden (2008-2014), including GHG emissions, sulphur and nitrogen emissions and particulate matter. The changes over time can be attributed to economic cycles but also to gradual societal changes in, for example, the energy fuel mix of Sweden. The investment category is more variable than household and public consumption, which is a normal pattern due to the economic investments being more volatile from year to year.

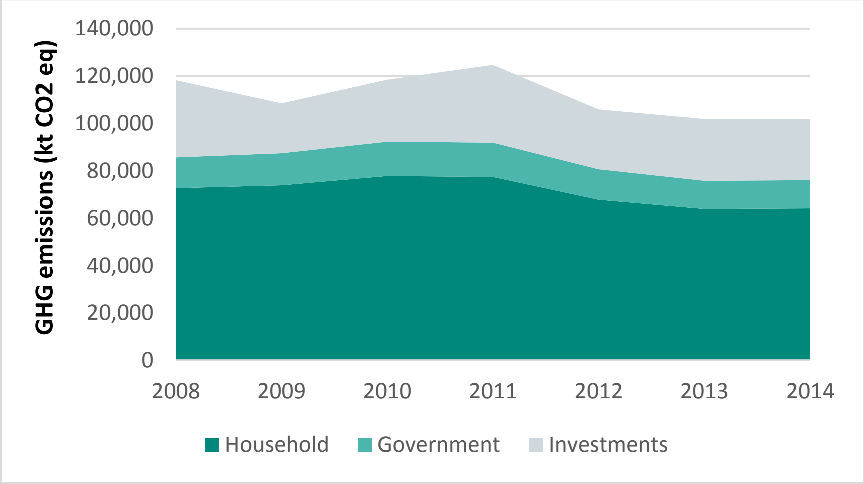

Figure 1: Greenhouse gas emissions, by component of final demand, 2008-2014, kilotonnes CO_2-equivalents

Sweden has low sulphur emissions within its territorial borders, due to an active environmental policy that has led to fuel changes and cleaning filters that decreased emissions. The emissions of sulphur are largely connected to the burning of fossil fuels and depending on the sulphur content of the fuels and the cleaning equipment of the processes these emissions vary between countries. However, it is seen that the emissions in the Swedish sulphur footprint, emanating from production abroad, are decreasing. Fuel switches away from fossil fuels could drastically change the footprint.

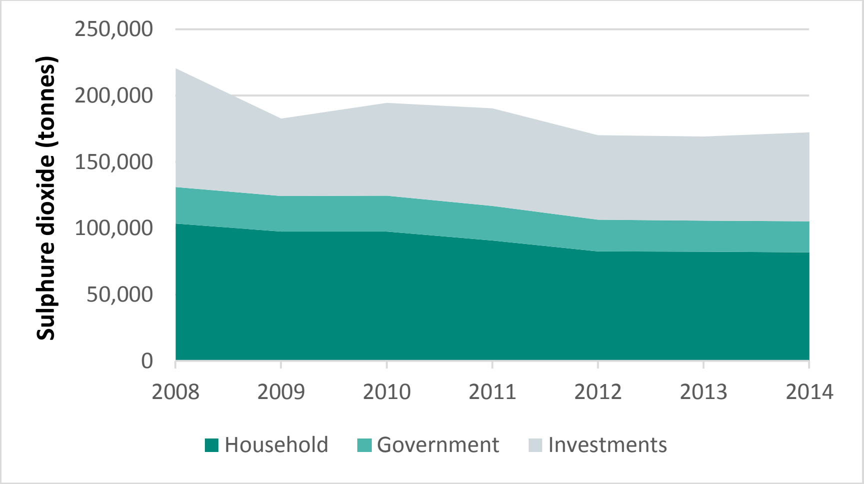

Figure 2: Sulphur dioxide emissions by component of final demand, 2008-2014, tonnes

The nitrogen oxide emissions to air are also decreasing with time. These emissions are connected to emissions from vehicles and even though the catalytic converters where introduced the volume of transportation has still prevented these emissions from decreasing quickly.

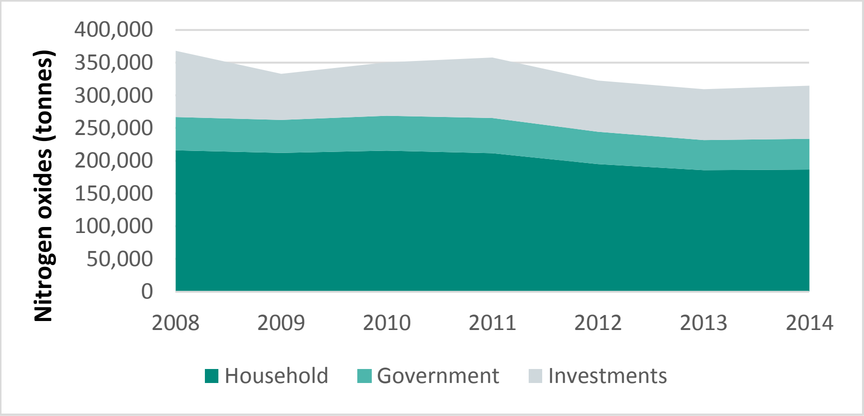

Figure 3: Nitrogen oxide emissions by component of final demand, 2008-2014, tonnes

Particle emissions have been decreasing over time. They are also connected to emission from transportation, both from engines and from roads. They are a health problem that could benefit from switches to cleaner transportation.

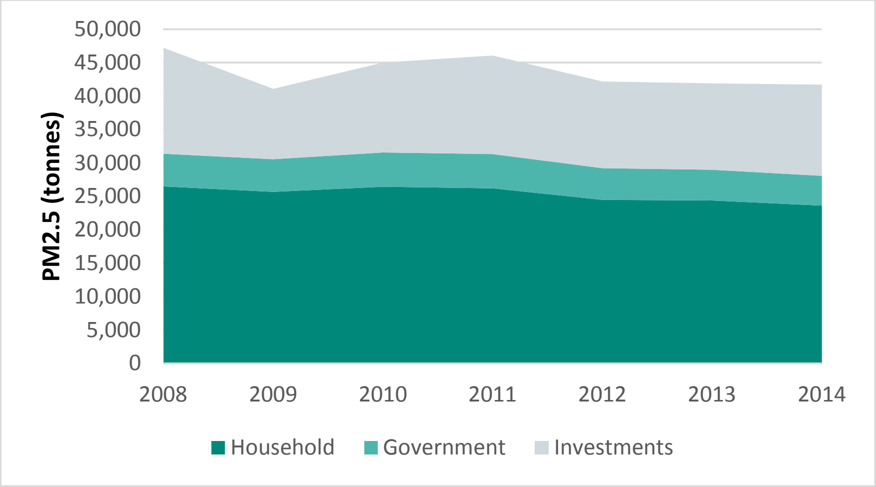

Figure 4: Particle emissions (PM2.5) by component of final demand, 2008-2014, tonnes

In figure 5 the value added generated by Swedish consumption (in 2008 prices, calculated based on Swedish data) is pictured and we see a small gradual increase since 2009 of household and government generated value added. Fortunately, this increase of activity has not resulted in a similar increase of environmental pressure, which indicates that some changes either in the emission intensity of the production activities or a change in the types of goods and services purchased has occurred.

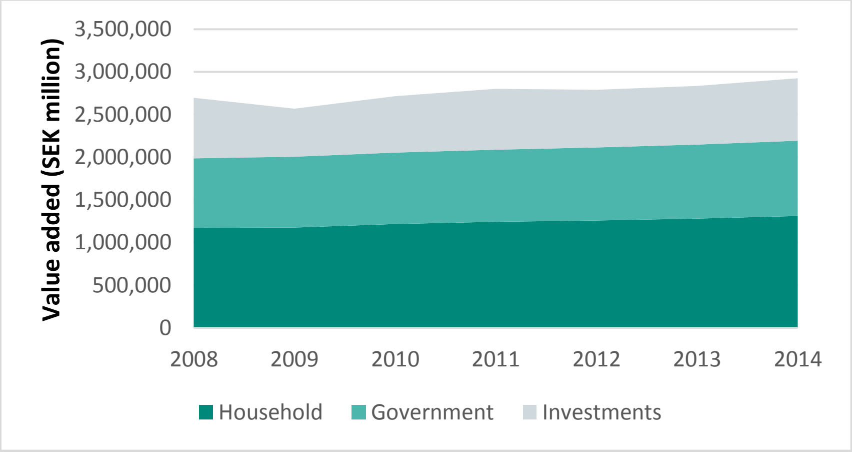

Figure 5: Consumption-based value added generated by component of final demand, 2008-2014, SEK Million. 2008 prices calculated based on Swedish data.

Figure 6 shows the change in intensity of the GHG footprint by value added. A key finding is that the environmental pressure has decreased for all indicators between 2008 and 2014, whilst the value added created through the demand has increased during this time period. As a result, the intensity indicator (figure 6) shows a decoupling of consumption-based greenhouse gas emissions and value added.

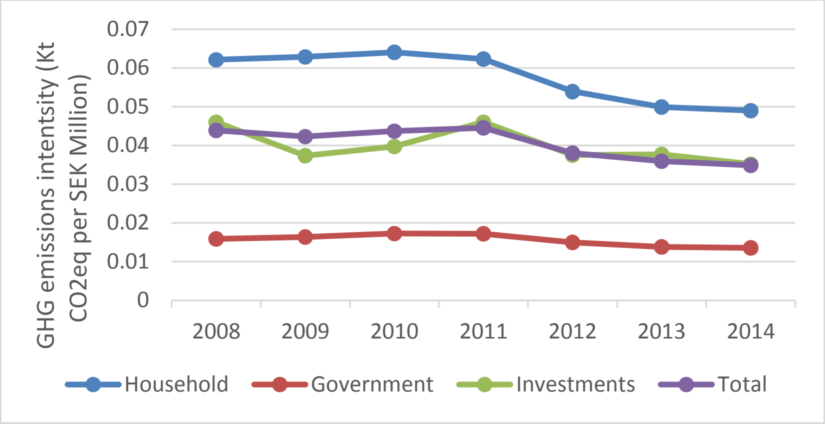

Figure 6: Intensity of greenhouse gas emissions by consumption based value added, generated by component of final demand, 2008-2014, kilotonnes CO_2eq per SEK Million. 2008 prices calculated based on Swedish data

3.2 The GHG emissions and air pollution occurring abroad due to Swedish final demand

Within the hybrid MRIO-SRIO model of this study is it possible to distinguish between environmental pressures occurring in Sweden for Swedish consumption and those occurring abroad. This is the main issue relevant to following up on the Generational Goal in Sweden, – have the environmental improvements in Sweden been possible without increasing the environmental pressure in other countries? The change in GHG emissions and air pollution generated in Sweden versus those occurring abroad are presented in Figures 7 to 11. For all emissions to air as well as for water and materials consumption, the environmental pressure is larger abroad than in Sweden, but it has not increased over time. Thus, the Generational Goal is being attained. For all of the GHG and emissions to air indicators, the split between domestic pressures and those originating abroad has remained relatively stable over the time period.

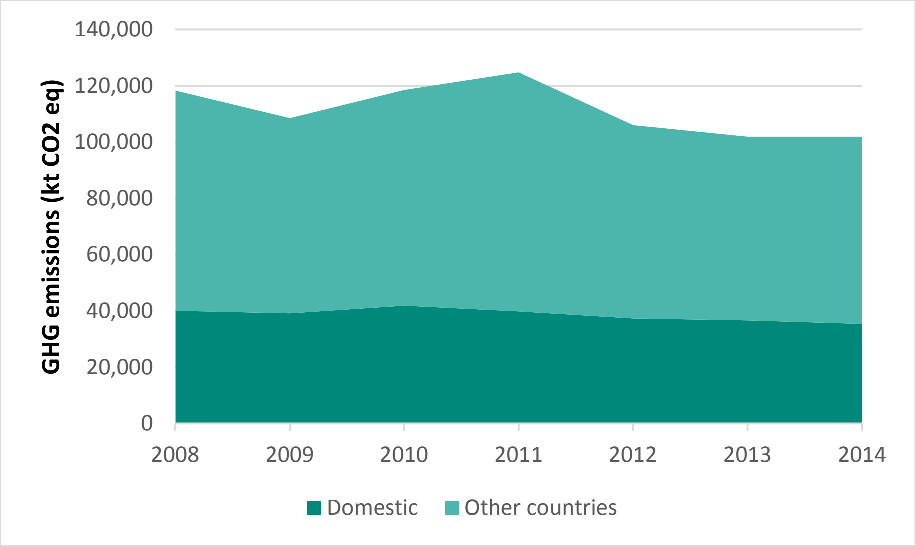

Figure 7: Greenhouse gas emissions, domestic vs external, 2008–2014, kilotonnes CO_2-equivalent

For sulphur dioxide emissions (Figure 8) almost all of the impacts occur abroad. The sulphur content for fossil fuels are the main source of sulphur emissions and it has been a successful part of European environmental policy to decrease the emissions so that in 2011 they were only 20% of what they were in 1990 (EEA, 2015).

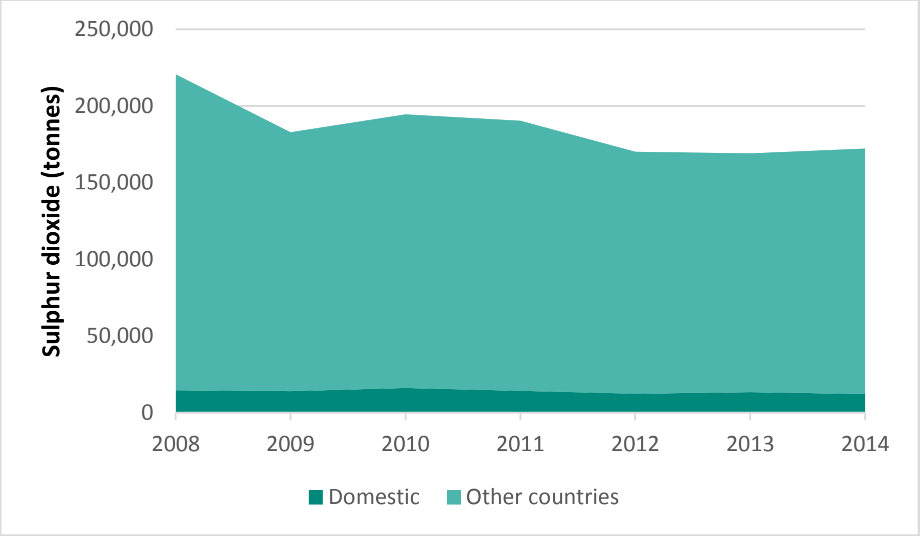

Figure 8: Sulphur dioxide by domestic and from other countries, 2008-2014, tonnes

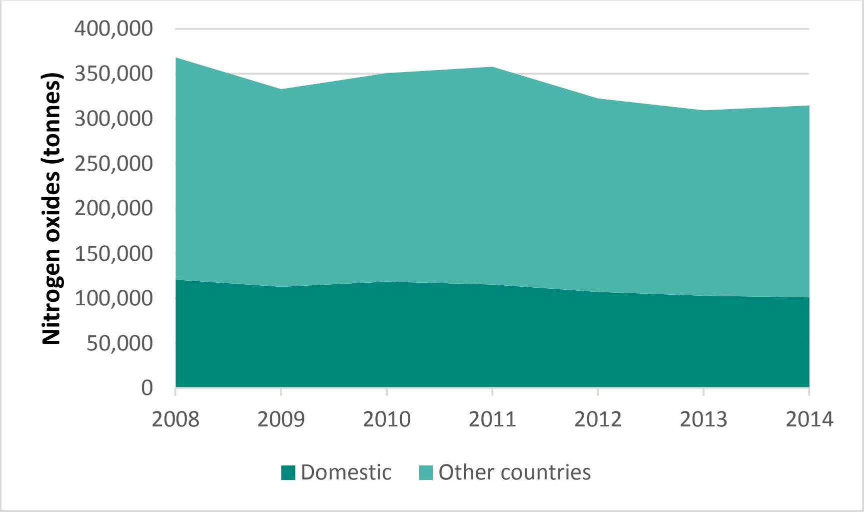

Figure 9: Nitrogen oxides by domestic and from other countries, 2008-2014, tonnes

Figure 10: Particles (PM2.5) emissions by domestic and from other countries, 2008-2014, tonnes

The value added generated by Swedish consumption is presented in Fig. 11. The value added has increased mainly in Sweden, while that from imports dropped most after 2008, and recovered in a similar fashion to domestic value added. The value added data has been deflated with the help of Swedish deflators, to receive a time series in constant prices. For value added generated outside Swedish borders the price indices of imports may be different to the price index of domestically produced goods, but the effect of such differences would be expected to be small.

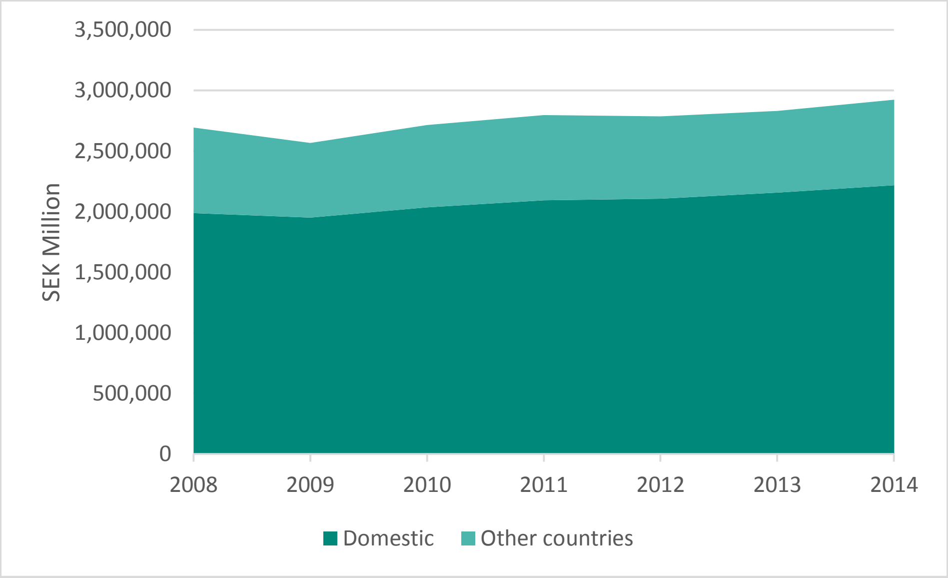

Figure 11: Consumption-based value added by domestic and from other countries, 2008-2014, SEK Million. Constant 2008 prices assuming inflation in export countries is the same as in Sweden.

By studying the value added due to Swedish demand in Sweden and abroad we can also calculate the environmental pressure intensity of the value chain. The intensity of greenhouse gas emissions by value added are much higher for products and services imported, than for those produced in Sweden (see figure 12). The intensity is falling, both abroad and in Sweden.

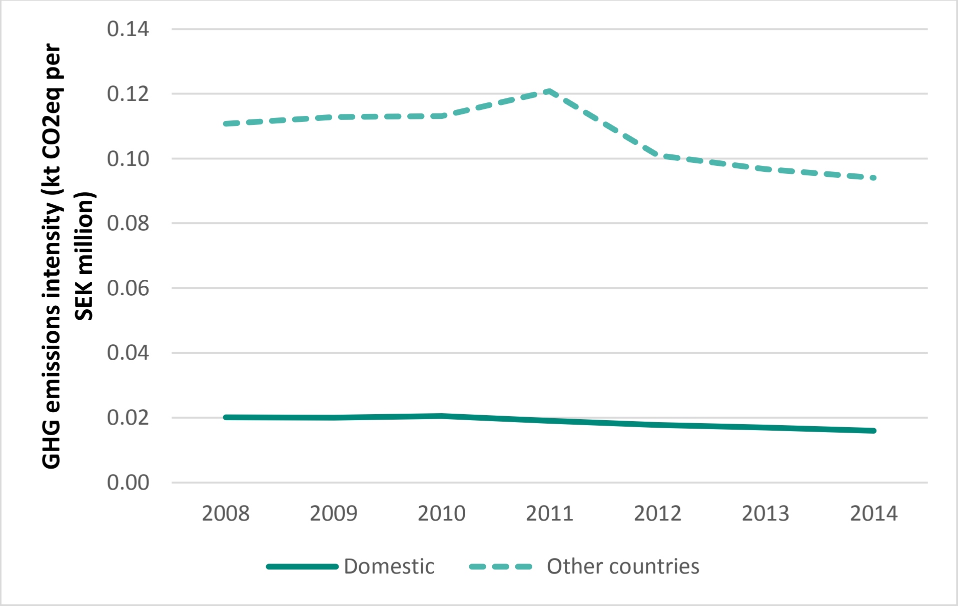

Figure 12: Intensity Greenhouse gas emissions by consumption-based value added. Domestic and from other countries, 2008-2014, kilotonnes CO_2eq per SEK Million. 2008 prices assuming inflation in export countries is the same as in Sweden.

3.3 Natural resources by components of final demand and impact abroad

Table 2 presents land use and use of natural resources pressures per capita for household consumption, public consumption and investments for the year 2014. For land use, the pressures due to households and investments are almost equal in size. For households the land use is principally for food, dwellings and fuel, while the investments are for construction and products from forestry. For the materials consumption the households and investments categories also dominate.

Table 2 Size of land use and material use from Swedish consumption per capita 2014 by relevant component of final demand. m2 per capita, kilotonnes per capita, Million cubic meters per capita

	Household	**Government**	**Investments**	**Total**
Land (m2/capita)	10 083	1 548	11 241	22 872
Material (kt/capita)	12,30	2,46	9,15	23,91
Water use (Mm3/capita)	0,09	0,01	0,02	0,12

Figures 13-16 show the change in land use, material and water use for Swedish consumption between 2008-2014 and where this pressure originates (either domestically in Sweden or abroad).

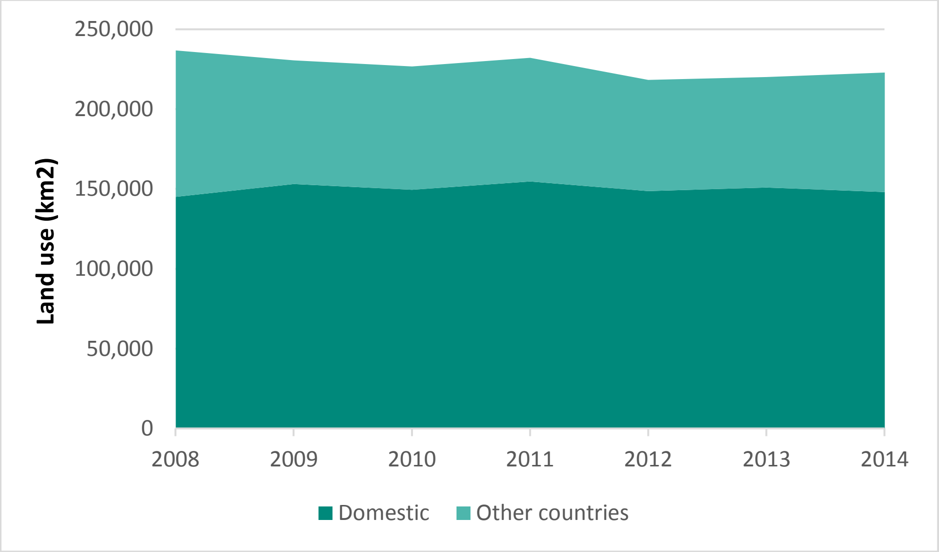

Figure 13: Land use by domestic and from other countries, 2008-2014, Square km

The land use for Swedish consumption have remained fairly stable over time. There is a slight increase in the proportion of pressure occurring domestically compared to abroad. For land use, which includes crop land, land for forestry, permanent pasture and infrastructure land, over 50% of the pressure occurs domestically, largely due to the use of forestry products for houses and for fuel.

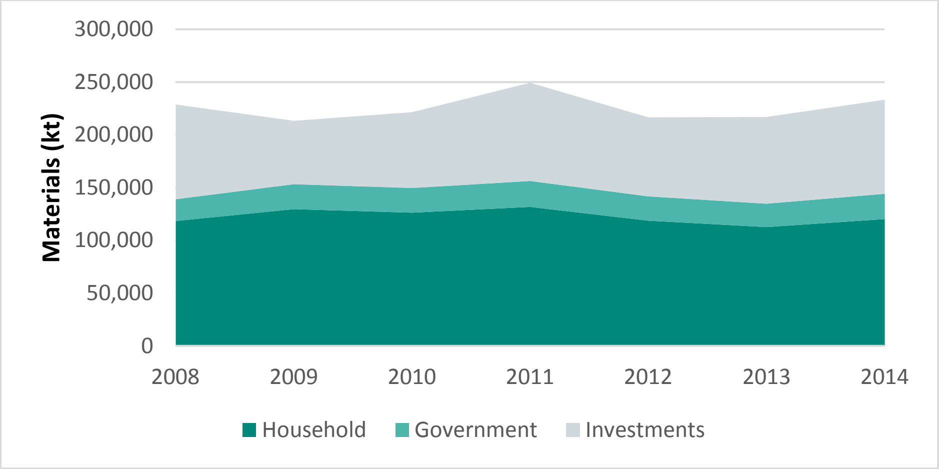

Figure 14: Materials consumption by components of final demand, 2008-2014, kilotonnes

The materials consumption shows a typical business cycle pattern in the investment component (Figure 14).

It has remained fairly stable over the time period. The domestic part is about a third of the materials consumption (Figure 15).

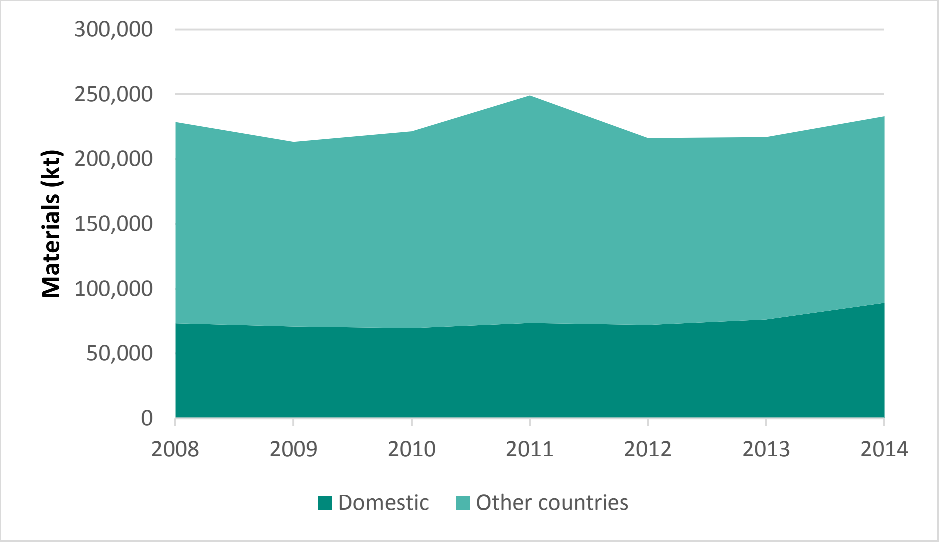

Figure 15: Materials consumption by domestic and from other countries, 2008-2014, kilotonnes

Water use from the Swedish consumption abroad has declined slightly over the period (Figure 16). For water use it is expected that the contribution from abroad is larger as Sweden uses very little water for irrigation in agricultural production. Water use is typically connected to food production.

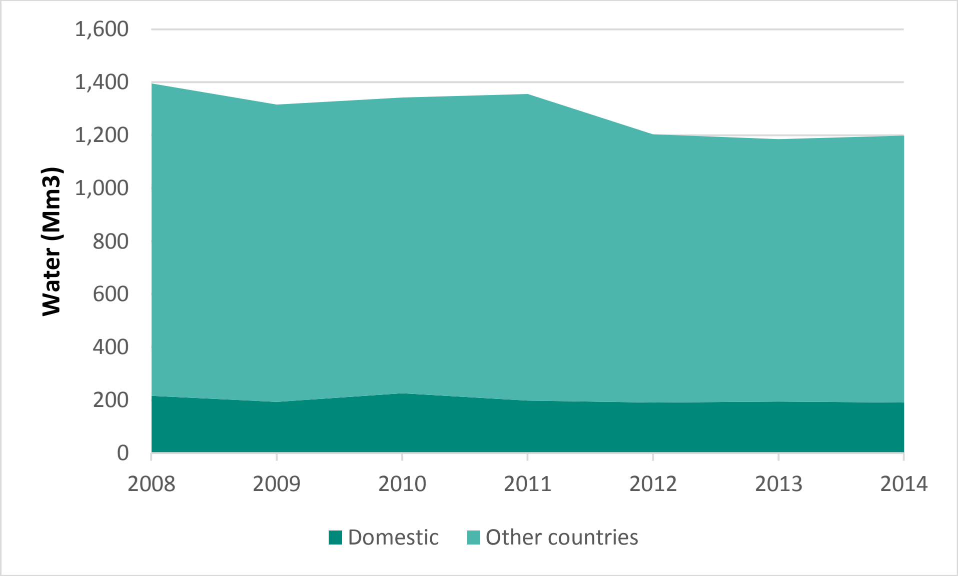

Figure 16: Water use (blue water) by domestic and from other countries, 2008-2014, Million Cubic meters

4 Discussion

There are three ways to look at greenhouse gas emissions in environmental statistics. The first is looking at it from a national, territorial perspective; the second is to view it from an economic production perspective and a third to approach the emissions from the economic perspective of demand of goods and services. In Sweden, from the national, territorial perspective, from 2008, the emissions of greenhouse gas emissions are declining, but levelling off; from the production perspective they are showing the similar pattern (Naturvårdsverket, 2017; Statistics Sweden, 2017). Our results confirm that, internationally and nationally, greenhouse gas emissions due to Swedish consumption have also been falling since 2008. This trend is also reflected in the other environmental indicators, with the exception of materials consumption. The fact that these decreases have happened even as consumption based value added, which is related to economic activity, has increased, suggests that for this period Sweden has achieved an absolute decoupling of environmental pressures and economic growth[1]. It can also be noted that the decrease in pressures in Sweden, does not seem to have come at the expense of increased pressure in other countries, with little change in the proportion of pressures exerted domestically in Sweden compared to abroad.

Absolute decoupling is a central aim of global policy on sustainable consumption and production, and is essential to the concept of sustainable economic growth. Sustainable Development Goal 8, to which Sweden is a signatory, includes among its targets “endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes (10YFP) on sustainable consumption and production, with developed countries taking the lead” (United Nations General Assembly, 2015). Similarly, the 10YFP includes among its aims “Contributing to resource efficiency and decoupling economic growth from environmental degradation and resource use, while creating decent jobs and economic opportunities and contributing to poverty eradication and shared prosperity” (UNEP, 2017).

Whilst the results from this study show that Sweden may be on an encouraging pathway towards these international goals, many of the pressures still remain high above what is required to meet the environmental targets (c.f. Swedish Environmental Protection Agency, 2012) or the international targets for reducing climate change, which requires approximately halving emissions per decade (Rockström et al., 2017). Research also uses calculations where the starting point is per capita consumption in the world, and the Paris agreement: to aim at 1.5 degree warming means that emissions by 2050 should be 0.82 tonnes per capita globally (Fauré et al., 2016). Climate change is unique in that there is a global target that can be related to decreases of emissions. For the other topics under investigation in this paper it is more difficult to find global or national targets to compare with. The use of natural resources and water for example does not translate directly to environmental impacts in the same was as GHG emissions do, as any impacts or material or water extraction are locally specific and therefore depend on local conditions, resource availability and management practices.

For all of the emissions to air as well as materials consumption and water use (but not land use), the environmental pressures from Swedish consumption fall predominantly outside Swedish territory. The reason for the dominant land use within Swedish borders is for example forest products that are used for building houses and as biofuels. The majority of the consumption-based value added is also generated within Sweden. Domestically, environmental pressures are lower for a number of structural and policy reasons. For example, Sweden’s electricity is mostly generated by hydro power and nuclear power, which reduces the greenhouse gas emissions, but also for air quality. Fossil-based

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[1] Absolute decoupling is distinct from relative decoupling, in which environmental pressures increase, but at a slower rate than economic growth.

heating sources are mainly only used as extra fuel during cold spells. Another aspect is policies that have shifted the use of fossil-based sources through taxation on fossil fuels and subsidies for renewable energy sources in Sweden. For Sulphur emission the EU Sulphur directive (European Union, 2012) has been an important policy to decrease sulphur in fuels. This has reduced the sulphur dioxide emissions from the industry considerably since 1990s levels.

In this paper, results are presented for a larger range of environmental pressures than is normally covered by consumption-based accounting. Although the general trends are rather similar for most indicators, there are also differences. The indicator for materials consumption does not, for example, show the same decoupling pattern as the other indicators, but is more sensitive to the business cycle, possibly because the large amounts of building materials in the indicator. Also some indicators, most notably SO_2 and water use show a significantly lower share of environmental pressure in Sweden compared to abroad. In an accompanying paper, results are also shown for a new set of indicators for chemicals use, pressure and potential impacts for the year of 2013 (Persson et al., 2018).

Another major output of this study has been the development of a unique hybrid MRIO-SRIO model for Sweden which allows detailed monitoring of the various environmental pressures, utilizing existing national statistics, in combination with a global MRIO. For some indicators, this model can already provide a historical time series, revealing trends and giving insight into the central question for monitoring the Generational Goal: Is Sweden performing equally well in terms of its international and domestic environmental footprints? For other indicators, due to scarcity of data, the model can only provide a first estimate of the size of the issue that can also serve as a baseline for future monitoring.

The model is closely connected to Swedish economic statistics within the framework of the System of Economic and Environmental Accounts. There are strengths and drawbacks of basing the model on current economic statistics. Without the economic statistics, this type of analysis would not be possible. The economic data are rich in comparison to the environmental data, as it is legislated reporting in most countries. Since the economic statistics cover the resource use and the buying and selling of products between economic industries within and between countries it gives thus the "production recipes" of the production and consumption activities. In that way, the national accounts data shows the main driving force for the production patterns that we are studying here. Over time, it is also possible to see how trade partnerships are changing, as Swedish consumption relies more or less on goods imported from different regions of the world. Since such changes can be relevant for the problem we are studying, the economic data describing the value chains are relevant. However, the simplifications needed to be able to follow such a complex system do have some side-effects that should be recognized. First, what economists refer to as "volume changes" in consumption or trade of a good are generally measured in monetary terms. But as prices of the same good vary over time, changes in monetary value may not reflect similar changes in the number of items or physical quantities – making it sometimes a poor proxy of the associated environmental pressures, but a good measure of the driving forces.

The indicators assessed here can be seen as macro indicators. Their purpose is to provide an overall picture of the national situation and place the broader perspective in focus. The macro indicators can capture the overall size of environmental pressures and change over time. However, if we want to know more details on product level to compare between different product methods or design of similar products, more detailed analysis using for example process life cycle assessments are necessary. Macro indicators give the overall result of different activities by combining information on overall consumption, the types of products and services bought, and their environmental pressure. Consumption can be a strong driving force for environmental pressure, specifically when the production of the goods consumed is resource intensive and depend on fossil fuels and changes the terrestrial or marine habitats. Lowering the environmental pressures of consumption and finding better production methods is necessary. In order to monitor that progress, macro indicators of the type suggested here are needed.

5 Conclusions

A new hybrid MRIO-SRIO approach for calculating the global environmental pressures due to a country's consumption has been developed, and the method applied to the Swedish case using a number of emission and resource use indicators.

The results show that total environmental pressures for most indicators decreased both in Sweden and abroad between 2008 and 2014 (in most cases declining steadily from 2010 or 2011, after a rise between 2009 and 2010). Material consumption remained fairly stable during this period. This means that developments have been in line with this aspect of the Generational Goal (addressing environmental problems inside Sweden without increasing environmental problems outside its borders).

The results also show that the decreases in emissions of greenhouse gases, several air pollutants (nitrogen oxides, particulate matter and sulphur dioxide), along with land use and blue water use, happened during a period when consumption-based value added increased, indicating an absolute decoupling between economic activity and environmental pressures. The recorded decoupling is, however, not long enough to say whether it is an established pattern or a temporary stabilisation. Also, the decrease in greenhouse gas emissions is far from large enough in order to reach the Paris Agreement goals. This has important policy implications, since it means that more efforts are needed to reduce the environmental pressures from Swedish consumption.

Although Sweden's international footprints decreased slightly over the period, they remained large in comparison to the domestic footprint. The majority (60% or more) of environmental pressures due to Swedish consumption occurred outside Sweden, with exception of land use. More than 90% of the sulphur emissions and more than 80% of the water use footprints were abroad. In contrast, the majority of consumption-based value added occurred inside Sweden.

We suggest that Sweden could use the method presented here for continued monitoring of emissions of greenhouse gases and the studied air pollutants. The method could also be used for developing other relevant environmental indicators, for example for hazardous chemicals. Based on this method, further studies can also be made to identify important product groups and countries in Sweden's consumption-based footprints, which in turn can be used in the development of product- and sector-specific environmental policies. While the model developed in this study was tailored for Sweden, the same approach could also be considered and adapted for other countries, for example to support policy for sustainable production and consumption.

Acknowledgements

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Environmental pressures from Swedish consumption – a hybrid multi-regional input-output approach

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Supplementary Information on deflation calculations

Table A presents the deflated value added in 2008 prices. Consumption-based value added from the model in Table B is deflated by the deflators in the Total domestic demand column from Table C, which results in the data presented in Table A, which is the actual data in Figure 11 in the paper. For example, Sweden, 2008 in Table B is divided by the deflator in Total domestic demand, 2008 in Table C; Sweden, 2009 in Table B is divided by the deflator in Total domestic demand, 2009 in Table C; and so on. Sweden, Other countries and Total all uses the same deflators, i.e., the Total domestic demand deflators from Table C.

The deflators in Table C are calculated by dividing the final demand value in current prices, Table D, with the final demand value in 2008 prices, Table E. Total domestic demand in Table D is the sum of households, government and investments. The 2008 prices in Table E is calculated by chaining t-1 prices on the level of aggregation that is shown in Table E. For example, Total domestic demand is not the sum of households, government and investments, but rather the chaining of the sums of these components.

Source: Data in Table B comes from the model. Data in Table D and E comes from the national accounts, Statistics Sweden.

Table A: Value Added, MSEK, 2008 prices, deflated (actual data for Figure 11)

	Sweden	Other countries	Total
2008	1 987 479	705 708	2 693 187
2009	1 950 114	614 997	2 565 110
2010	2 034 074	678 427	2 712 502
2011	2 092 091	703 602	2 795 693
2012	2 105 208	680 070	2 785 278
2013	2 156 510	674 595	2 831 105
2014	2 216 484	706 950	2 923 434

Table B: Value Added, MSEK, current prices, data from model of induced value added due to total Swedish final demand minus exports

	Sweden	Other countries	Total
2008	1 987 479	705 708	2 693 187
2009	1 989 610	627 452	2 617 062
2010	2 103 337	701 528	2 804 865
2011	2 199 807	739 829	2 939 636
2012	2 238 061	722 987	2 961 048
2013	2 319 892	725 704	3 045 595
2014	2 424 543	773 311	3 197 854

Table C: Deflators

	Households	Government	Investments	Exports	Total domestic demand
2008	1,00	1,00	1,00	1,00	1,00
2009	1,02	1,01	1,03	1,01	1,02
2010	1,04	1,03	1,04	1,01	1,03
2011	1,05	1,06	1,04	1,00	1,05
2012	1,06	1,09	1,04	0,99	1,06
2013	1,07	1,11	1,04	0,96	1,08
2014	1,08	1,14	1,07	0,98	1,09

Table D: Value Added, MSEK Purchaser's prices, current prices

	Households	Government	Investments	Exports	Total domestic demand
2008	1 461 553	883 115	684 650	1 687 468	3 029 318
2009	1 499 808	911 147	592 594	1 461 818	3 003 549
2010	1 583 426	937 586	629 675	1 625 716	3 150 687
2011	1 640 068	973 645	673 661	1 706 996	3 287 374
2012	1 660 763	1 009 176	672 604	1 706 915	3 342 543
2013	1 703 908	1 048 030	679 831	1 651 246	3 431 769
2014	1 758 938	1 088 750	740 533	1 772 883	3 588 221

Table E: Value Added, MSEK Purchaser's prices, 2008 prices

	Households	Government	Investments	Exports	Total domestic demand
2008	1 461 553	883 115	684 650	1 687 468	3 029 318
2009	1 468 145	900 618	575 162	1 443 035	2 943 925
2010	1 527 351	911 630	607 954	1 615 369	3 047 242
2011	1 556 409	919 127	650 868	1 713 929	3 126 823
2012	1 568 589	929 260	646 279	1 730 750	3 144 722
2013	1 598 834	940 474	650 774	1 717 377	3 190 709
2014	1 632 968	954 886	692 449	1 807 664	3 279 941