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Environmental pressure from Swedish consumption – the largest contributing producer countries, products and services

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1. Introduction

In 2010, Sweden adopted the Generational goal (Government of Sweden, 2010), stating that "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". However, Palm et al. (2019) and Dawkins et al. (2019) show that for many indicators, the largest part of the environmental pressure from Swedish consumption occurs not in Sweden, but in other countries. These results open up a number of new questions. This study attempts to answer three of them: In which countries or regions do the environmental pressures resulting from Swedish consumption occur? Which product groups cause the largest environmental pressures? And are those high pressures due to the pressure intensity of the product groups or the volume demand for that particular product group, or a combination of the two? These questions are of interest to consumers and governments in order to better understand how to reduce the environmental impacts.

To answer these questions, we employ input-output analysis (IOA). Input-output analysis is an analytical framework developed by Leontief in the late 1930s (Leontief, 1987), and in its most basic form is a system of linear equations which describe the distribution of an industry's product through the economy, and hence the flows of products from each industrial sector of an economy to each of the other sectors (Miller and Blair, 2009). By applying the Leontief inverse it is possible to determine the required output for given levels of consumption (final demand), and by extending this with environmental information it is possible to calculate environmental pressures associated with final demand, reallocating the pressures from the point of production to final consumption. This is termed environmentally-extended input-output analysis EE-IOA. EE-IOA has become a prominent tool for analysing environmental pressures resulting from a country's consumption (Ivanova et al., 2016). Results can be presented for countries, sectors or broad product groups including both goods and services (Minx et al., 2009; Peters and Hertwich, 2009; Toller et al., 2011).

There are different methods to estimate the emissions and resource use embodied in trade (Tukker et al., 2018b). Early studies using EE-IOA to identify the most important product groups in terms of a country's consumption-based environmental pressures (Palm et al., 2006; Tukker and Jansen, 2006), used single region input-output analysis. Single region models provide detailed data on the interactions between domestic sectors of the economy, but do not distinguish between domestic and foreign production technology (Wiedmann, 2009). Such analyses can therefore answer the question of which product groups have the largest environmental pressure, but under the assumption that imported products have the same environmental pressure as the region under study. In the case of countries such as Sweden, single region IOA runs the risk of underestimating the environmental pressure from consumption when the environmental intensities are lower in the country under study, compared to other countries in the world. Further to this, single region IOA cannot reveal in which countries the environmental pressure occurs. Other studies (e.g. Lenzen et al., 2004; Nijdam et al., 2005) incorporated some assumptions on foreign production technologies but only took into account bilateral trade. In order to account for foreign production technology and value chain perspective (Tukker et al., 2018b) (i.e. that one specific product may have been manufactured in several countries before reaching the final consumer), a multi-regional input-output (MRIO) model is needed. Such a model incorporates the environmental and economic data of multiple countries and country groupings (Wiedmann et al., 2010). By using an MRIO model, trade between different regions as well as geographic differentiation of environmental and economic aspects can be analysed (Tukker and Dietzenbacher, 2013; Wiedmann et al., 2011).

Numerous MRIO models have been developed, with various environmental extensions (Erumban et al., 2011; Lenzen et al., 2013; Malik et al., 2018; Tukker et al., 2018a; Wood et al., 2015). Many of the published studies based on these models and similar MRIO analyses have focused on emissions of greenhouse gases (GHGs) embodied in trade (Davis and Caldeira, 2010; Peters and Hertwich, 2009). However, several more recent studies using MRIO analyses have included other types of emissions or resource use such as NO_X and SO_2 emissions (Kanemoto et al., 2014), material resources (Giljum et al., 2016; Thomas O Wiedmann et al., 2015), biodiversity loss (Lenzen et al., 2012) or several types of pressures in combination such as carbon, land, material and water footprints (Ivanova et al., 2016; UNEP, 2016), carbon, land and water footprints (Steen-Olsen et al., 2012) or water, food and energy nexus showing interrelations between the indicators (Owen et al. 2018). These studies have looked at different geographical levels (EU, national, regional) and for different activities (household or total national consumption). Using an MRIO model, UNEP (2016) compiled the material footprint of countries in order to highlight the amount of materials needed for final consumption globally, per world region and for a selection of countries, thereby showing the trends in material consumption. Giljum et al. (2016) calculated the material footprints for EU 28 countries on a national level and included a sector level analysis. Tukker et al. (2016) explored how Europe's environmental footprints (for GHG, water, land and material) compared to other countries and their respective reliance on embodied emissions or resources. Wood et al. (2018) looked at the growth in environmental footprints, the growth of trade and the level of decoupling observed. Dawkins et al.(2019) compared results for several MRIO models for Sweden for GHG emissions from fossil fuels and also calculated water and material footprints looking at the most important countries. Schmidt et al. (2019) looked at emissions of greenhouse gases from Swedish consumption using EXIOBASE identifying the most important countries and regions as well as consumption clusters and the development between 1995 and 2014.

There have been several informative studies published in this field, however, they do not provide the levels of detail to answer the questions of interest in this paper. For example, the study by Ivanova et al. (2016) included greenhouse gases, land, material and water footprints of consumption of households for 43 countries, including Sweden. The results showed the total environmental pressure per country, but with no detail on which sectors or in which countries impacts occurred. Furthermore, since this study was focused on household consumption, the other components of final demand (government consumption and capital investment) were not included. Similarly, in the UNEP study on material footprints (UNEP, 2016) no details were provided about the countries from which the materials were extracted to meet the consumption demands. Steen-Olsen et al. (2016) looked at the carbon footprint of households in Norway and analysed the importance of different product groups. Yet, the study focused on households' footprints and not national footprints and only on carbon emissions. Also, Schmidt et al. (2019) focused on greenhouse gas emissions using the EXIOBASE model. In this study, we therefore aim to fill this gap and provide a detailed analysis for Swedish consumption, at both the product group and country of origin level, for a range of environmental pressures. We will then examine the results in the context of the Swedish Generational Goal and associated sustainable consumption policies. In addition, we compare the production- and consumption-based environmental impacts for Sweden. We consider seven different environmental pressures: emissions of GHG, SO_2, NO_X, and particulates (PM10 and PM2.5) as well as use of land, water and material resources. By examining several environmental pressures simultaneously, we are able to investigate whether pressures occur in similar product groups and countries, and consider whether strategies that may be needed for a reduction in one pressure could occur to the advantage of another. In order to provide insights into the origin of those pressures we use an environmentally extended MRIO model, representing the global economy. Palm et al. (2019) analyse the total results for Sweden and compare trends in environmental pressures over time. In this study, we complement this by providing a detailed analysis into the data for the latest year available (2014). In the study, the total Swedish consumption, i.e. both private and public consumption as well as capital investments, is considered. Indicators for hazardous chemical products using the same MRIO model are presented in a parallel paper (Persson et al., 2018).

2. Methods

For this study, a hybrid model MRIO has been developed. The purpose of using a hybrid rather than a stand-alone MRIO model was to ensure consistency with the Swedish national accounts and at the same time include the international detail provided by an MRIO database (Dawkins et al., 2019). Such efforts have gained traction in recent years, with examples such as Christis et al. (2017), Edens et al. (2015), Hambÿe et al.(2018) and Tukker et al.(2018b). The option of structuring data relationships in creating MRIO tables have been further explored in Rodrigues et al. (2016), from which we depart in this work in using a linked national and international model. We use domestic tables to model domestic flows and exports and MRIO tables to model imports into both production and consumption. This thus relaxes the single region domestic technology assumption (Andrew et al., 2009; Wood and Dey, 2009) by using MRIO data to model the environmental intensity of imports, which are then linked to the magnitude of the imports from the Swedish data (which we term a hybrid model for the purposes of this paper). A note on the magnitude of potential errors due to potential inconsistency between data is provided in Moran et al. (2018) and on the use of multipliers for intermediate flows is explored in Wood (2018). These studies indicate that this hybrid approach may be an acceptable method for modelling imports for Sweden.

A full mathematical description of the hybrid model is included in Palm et al. (2019). In summary, Swedish IO tables from Statistics Sweden are used to represent transactions between industrial sectors within the Swedish economy and the final demand for different product groups by private households, the public sector and capital investments. For products that are imported to Sweden, data from the MRIO model EXIOBASE 3 (Stadler et al., 2018) are used. For the environmental data, Swedish data are used for air emissions from Swedish production. For the environmental pressures of production in all other countries EXIOBASE data are used, (Stadler et al., 2018) and in addition the data on land use, material use and water use for Swedish production was also taken from EXIOBASE 3. Greenhouse gas emissions include combustion and non-combustion emissions from all activities except the IPCC category land use, land use change and forestry, and cover six greenhouse gases (CO_2, CH_4, N_2O, SF6, HFC and PFC) using the global warming potentials of the emissions as specified in Myhre et al.(2013). Land use includes cropland, forest area (except marginal use), permanent pastures, and infrastructure (thus excluding the FAO definition of “other land”) as defined by

FAOSTAT. Water use is limited to blue water, which is “the volume of surface and groundwater consumed as a result of the production of a good or service”(Hoekstra et al., 2011). Material use includes all material extraction including biomass, fossil fuels, mineral and mining ores as further described in Giljum et al. (2016). More details about the environmental data are provided in Palm et al.(2019) and about the original EXIOBASE data in Wood et al. (2014) and Stadler et al. (2018). All data are for the year 2014, the most up-to-date available at the time of this study. The full dataset and (coded) work flow for generating results is available on GitHub[1].

The results for Sweden were derived by applying standard Leontief multipliers approach, reallocating the environmental pressures of production across all industrial sectors, to the product groups consumed (c.f. Palm et al. (2019)). The list of product groups used in this study is presented in Table A1 in appendix A, based on the Eurostat NACE Rev. 2 classification (Eurostat, 2008). EXIOBASE was built on NACE Rev. 1.1 and the latest Swedish data use NACE Rev 2. The revision of the classification to NACE Rev. 2 brought more service categories into the economic accounts. As most of the environmental pressures are concentrated in the basic industrial sectors, the changes do not have a large impact on the combining of Swedish and EXIOBASE data, and any new sectors in the Swedish data were aligned to the previous NACE Rev. 1 classification of EXIOBASE. In addition to the environmental pressures associated with consumption of different product groups, we also included direct environmental pressures from households that occur at the point of use (e.g. emissions from burning fuel in the home or in private vehicles). We used a square product by product input-output table (as any analytical work across supply chains requires symmetric tables), both for Sweden and EXIOBASE in order to track the emissions associated with products (cf. industry by industry tables) (Majeau-Bettez et al., 2014). The results are calculated for Swedish consumption based on the 212 country/region level of the Swedish trade data. For analysis purposes the results are then aggregated into 43 countries and 5 “rest of the world regions”. The list of countries and regions are presented in Table A2 in appendix A.

In the results section, an initial distinction is made between environmental pressures from Swedish production and consumption (emissions and resource use). The consumption-based environmental accounting of this study provides a complementary perspective to the more traditional production-based or territorial environmental pressure accounting. By focusing on consumption, it is possible to analyse environmental pressures linked to the production and delivery of all goods and services in a country, regardless of where those environmental pressures originate (Peters, 2008). The environmental pressure from production covers all goods and services produced in Sweden, including any goods or services that are exported (Usubiaga and Acosta-Fernández, 2015). The environmental pressure from consumption is here defined as the pressure related to all Swedish private and public consumption, plus capital investments, including goods and services imported and excluding those that are exported for consumption elsewhere.

3. **Results**

[1] https://github.com/rich-wood/hySNAC

As shown in Fig.1 and Table 1, the environmental pressure from Swedish consumption is for most indicators larger than the environmental pressure from Swedish production. Land use and material use are the only two indicators for which production-based environmental pressure in Sweden is higher than the consumption-based. The largest difference in magnitude is found for the blue water consumption where the impact using a consumption perspective is about 3.5 times higher than for a production perspective, followed by sulphur dioxide (SO_2) emissions (2.8 times higher).

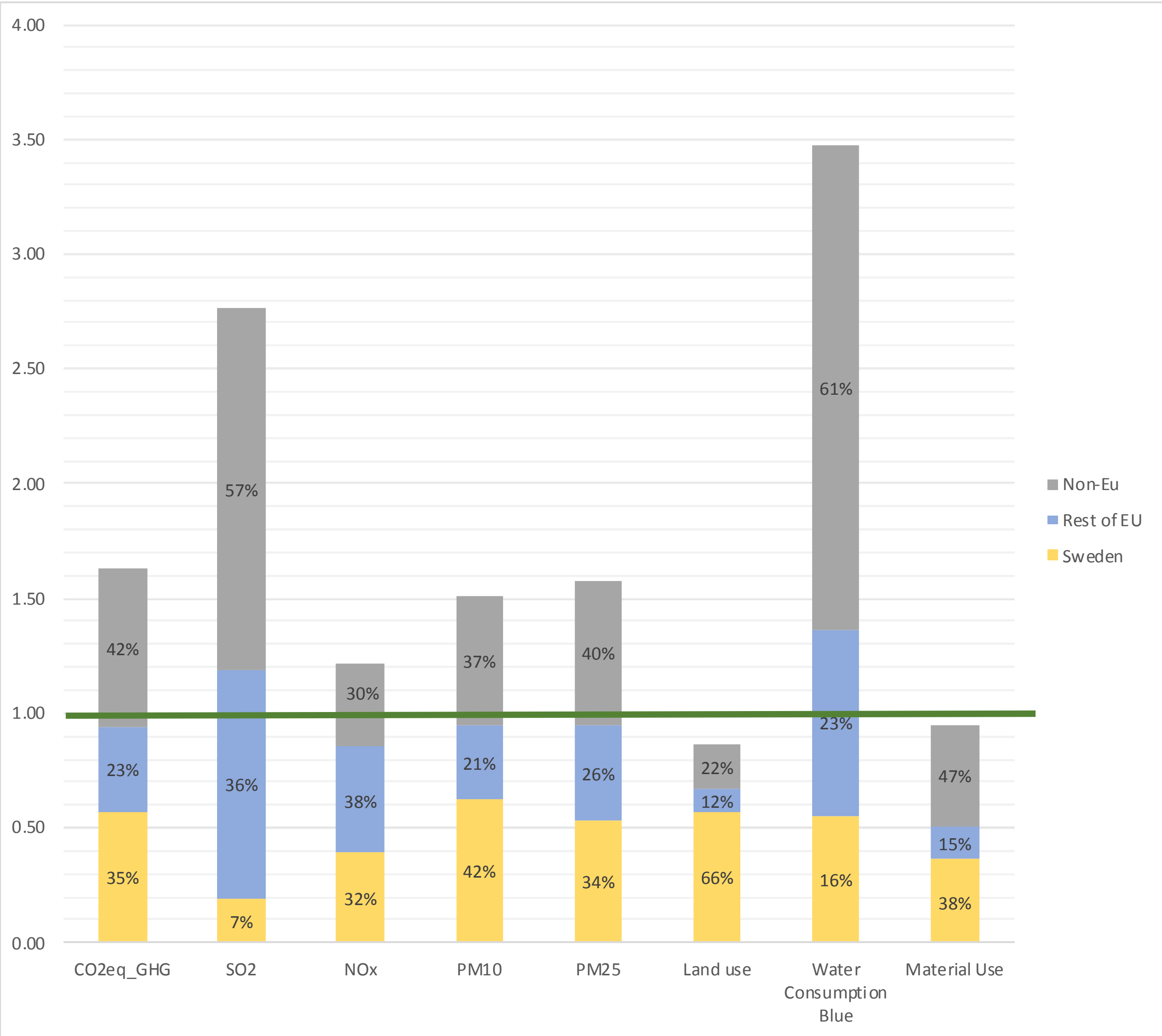

Figure 1: Emissions from Swedish consumption normalised in relation to emissions from production (green line) in 2014 and proportion of consumption-based emissions occurring in Sweden, EU and Rest of EU.

Table 1: Total pressure from Swedish consumption and from production respectively for all impact categories.

Indicators	**GHG**	**SO_2**	**NO_X**	**PM 10**	**PM2.5**	**Land use**	**Blue water**	**Materials**
Unit	Mt.CO2 eq.	Kt.	Kt.	Kt.	Kt.	Km^2	Mm^3	Mt
Consumption	101	172	315	68	42	223 000	1200	233

Production	62	62	258	45	26	259 000	345	245

Fig.1 also shows to what extent the environmental pressures from Sweden occurs in Sweden, in the rest of EU and the rest of the world. Rest of EU is defined here as EU 29, i.e. the 28 EU countries excluding Sweden but including Norway and Switzerland since these countries have similar environmental legislation as the EU. For all indicators except for land use, the pressure from Swedish consumption occurs to a larger extent abroad than in Sweden. This has been the case since 2008 as shown in Palm et al. (2019). For sulphur dioxide emissions, the share of emissions occurring abroad as a result of Swedish consumption is more than thirteen times higher than that occurring in Sweden and a large part occurs outside the EU. Blue water consumption is another pressure that stands out. The blue water used abroad as a result of Swedish consumption is about five times larger than the use of domestic blue water, with a large share outside the EU. For other indicators, most of the environmental pressures occur within EU (Sweden plus rest of the EU).

Of note, is the relative amount of pressure that is exported. Whilst the consumption-based pressure for SO_2 is in total nearly 2.5 times the production-based one (Fig. 1), there is a large in and out flow of embodied SO_2 with only about 20% of the production account staying in Sweden (i.e. used for domestic consumption). Thus about 80% of the production account (difference between the production account and the consumption account with Swedish source) is embodied in exports from Sweden. Also for other pressures, a significant proportion of the production account is related to Swedish exports.

In Table 2, the environmental pressure from Swedish consumption is divided into different product groups. The order of the product groups is from high to low pressure, based on the average ranking across indicators. The results show that construction and food products are consistently high across all environmental pressures as well as wholesale and retail, architecture and engineering, machinery and equipment, motor vehicles and dwellings for emissions to air. Household direct pressures rank high for emissions of GHG, NOx and particulate matters as well as water use, but low for the remaining indicators. Coke and refined petroleum ranks high for GHG emissions and material use whereas forestry product rank high for land use and material use. Electricity is comparatively low, which partly is because electricity is used for production of other products, and emissions from electricity production will therefore be allocated to those product groups. In addition, the Swedish electricity is also mainly produced from hydro, nuclear and wind power with low GHG emissions, and Swedish district heating systems are largely based on biofuels. For air transportation it is important to note that high-altitude impacts are not included, which means that the impact of GHG emissions in this product group is an underestimation.

Table 2. Overview of product groups with highest pressures or resource use across indicators. The length of the bars in the Table indicate the magnitude for each number compared to the highest number for each indicator.

Product groups	GHG Mt CO2-eq	SO2 kt	NOx kt	PM10 kt	PM25 kt	Land use 1000 km2	Water Consumption Blue Mm3	Material Use Mt
Constructions	10	17	30	6	4	33	53	48
Food products	9	12	35	4	3	24	272	22
Wholesale and retail	5	10	19	3	2	7	32	10
Architecture and engineering	4	11	13	3	2	7	64	10
Machinery and equipment	3	13	11	4	3	2	31	6
Motor vehicles	3	11	11	4	2	2	27	6
Real estate	4	6	11	2	1	12	21	15
Furniture	3	8	7	2	1	4	27	5
Agricultural products	3	1	10	1	1	11	173	10
Household direct emissions	10	1	19	14	8	10	95	0
Health care	3	5	8	2	1	4	41	5
Electricity	5	3	10	1	1	4	16	6
Textiles	2	5	5	1	1	3	77	5
Warehousing and postal services	3	7	18	2	1	1	6	5
Electronic products	2	7	7	2	1	1	25	4
Public administration and defence	2	4	9	1	1	3	16	5
Fabricated metals	1	6	5	2	1	1	17	3
Coke and refined petroleum	6	5	9	1	1	1	5	16
Land transport	3	3	10	1	1	1	6	6
Accommodation	2	3	7	1	1	4	39	4
Electrical equipment	1	5	4	1	1	1	14	3
Education	2	3	6	1	1	3	16	4
Chemicals and pharmaceuticals	2	3	4	1	1	1	48	2
Social work	1	2	4	1	0	2	14	3
Computer programming	1	2	4	1	0	1	7	2
Other transport equipment	1	2	2	1	0	1	5	1
Forestry products	0	0	2	0	0	66	1	13
Sporting	1	1	2	0	0	1	8	1
Telecommunications	1	1	2	0	0	1	5	1
Air transport	2	2	9	0	0	0	3	1
Creative services	1	1	2	0	0	1	4	1
Rental and leasing	0	1	1	0	0	1	3	1
Rubber and plastics	0	1	1	0	0	0	7	1
Water transport	0	3	8	1	0	0	0	0
Remaining Product groups	3	6	12	2	1	10	0	8

As shown in Fig. 1, environmental pressures from Swedish consumption occur globally and, by using the hybrid MRIO approach in this study, it is possible to identify in which countries or regions these environmental pressures occur. Overall, across all indicators, the country (or regional grouping) contributing most to the environmental pressures individually is Sweden, followed by China, Rest of Asia and Pacific (i.e. Asia and Pacific except Indonesia, Taiwan, Australia, India, South Korea, China and Japan), Russia and Germany. In Fig. 2-7 the most important product groups for different environmental pressures are shown aggregated into the five most important countries and/or regional groupings for each indicator, with all the remaining countries aggregated into Other EU (remaining countries from the EU 29 grouping as defined above) or Rest of the world, accordingly. Land use was excluded here as most pressure occurs domestically and PM10 was also excluded as the results were very similar to those for PM2.5. The five most important countries vary for the different environmental pressures. It always includes Sweden and China, but the other countries and regions vary. This also means that the countries included in Other EU and Rest of the world are different for each environmental pressure. The figures show the product groups that make up 80 % of the total pressure, and therefore the number of product groups displayed also varies between each environmental pressure. The product groups are listed in the order according to their rank across all the country groupings, this means that if pressures from a particular product group are high, but only from one country (e.g. coke and refined petroleum in the case of GHGs it is Russia, Fig. 2), then it appears further down in the list than product groups that are ranked highly across many countries, like construction for GHGs Fig. 2).

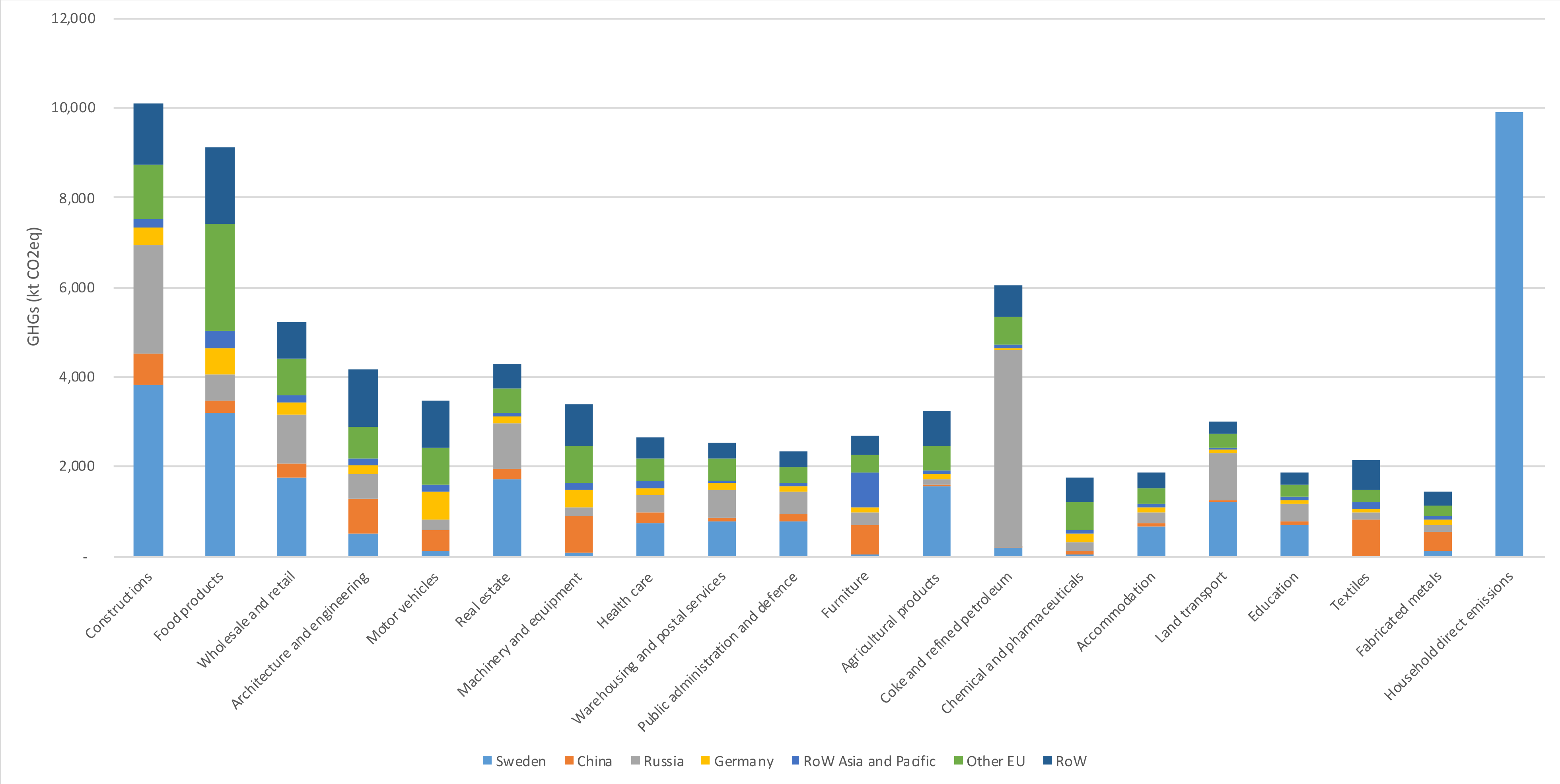

Figure 2: : GHG emissions of Swedish consumption by product group and country of origin. Top 5 countries and regions of environmental pressures and Other EU and RoW aggregated. Top products, ranked across all countries, regions and aggregated countries and regions were selected, and those accounting for 80% of the GHG emissions from Swedish consumption in total are displayed.

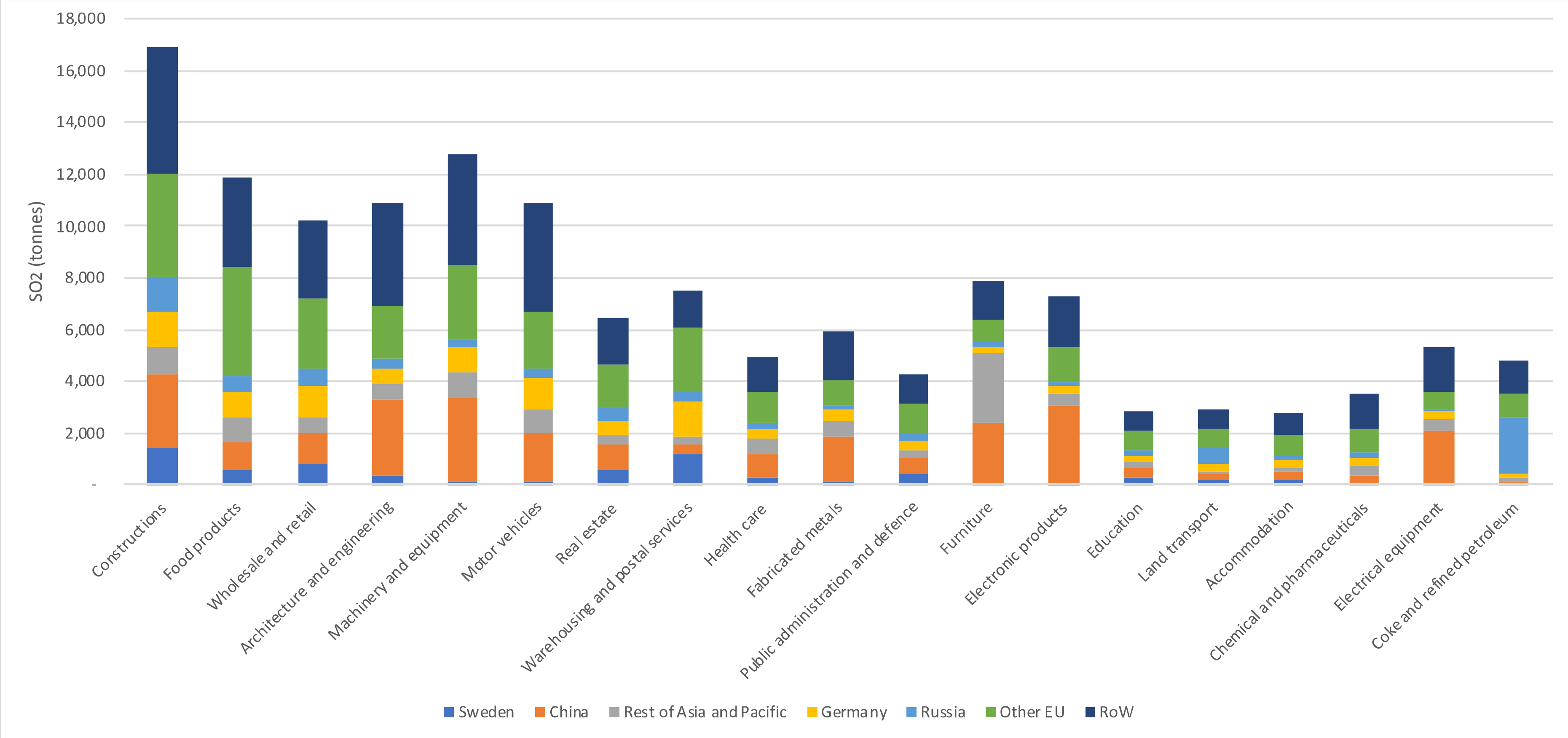

Figure 3: SO_2 emissions of Swedish consumption by product group and country of origin. Top 5 countries and regions of environmental pressures identified and Other EU and RoW aggregated. Top products, ranked across all countries, regions and aggregated countries and regions were selected and those accounting for 80% of the SO_2 emissions from Swedish consumption in total are displayed.

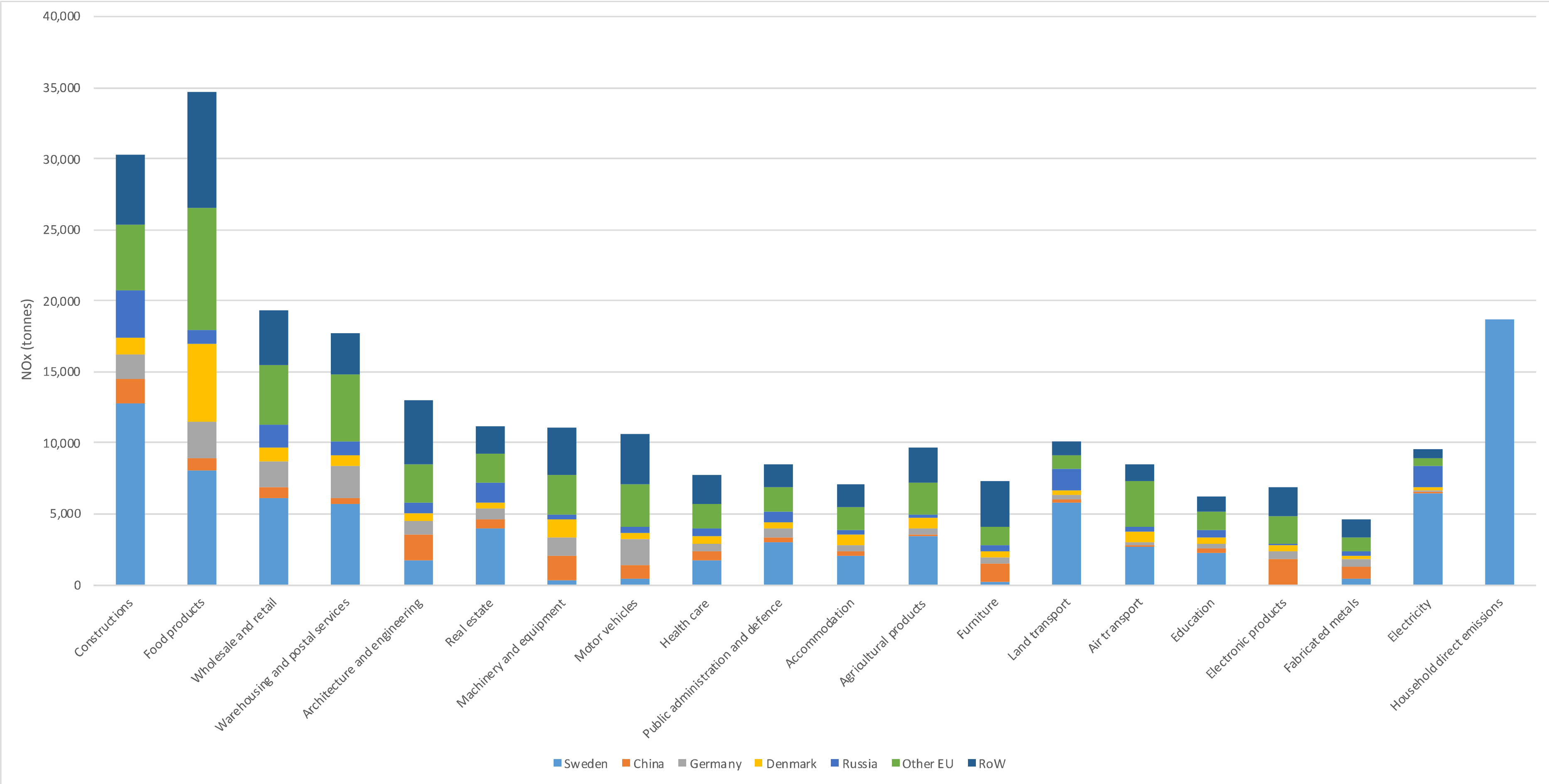

Figure 4: NOx emissions of Swedish consumption by product group and country of origin. Top 5 countries and regions of environmental pressures identified and Other EU and RoW aggregated. Top products, ranked across all countries, regions and aggregated countries and regions were selected and those accounting for 80% of the NOx emissions from Swedish consumption in total are displayed.

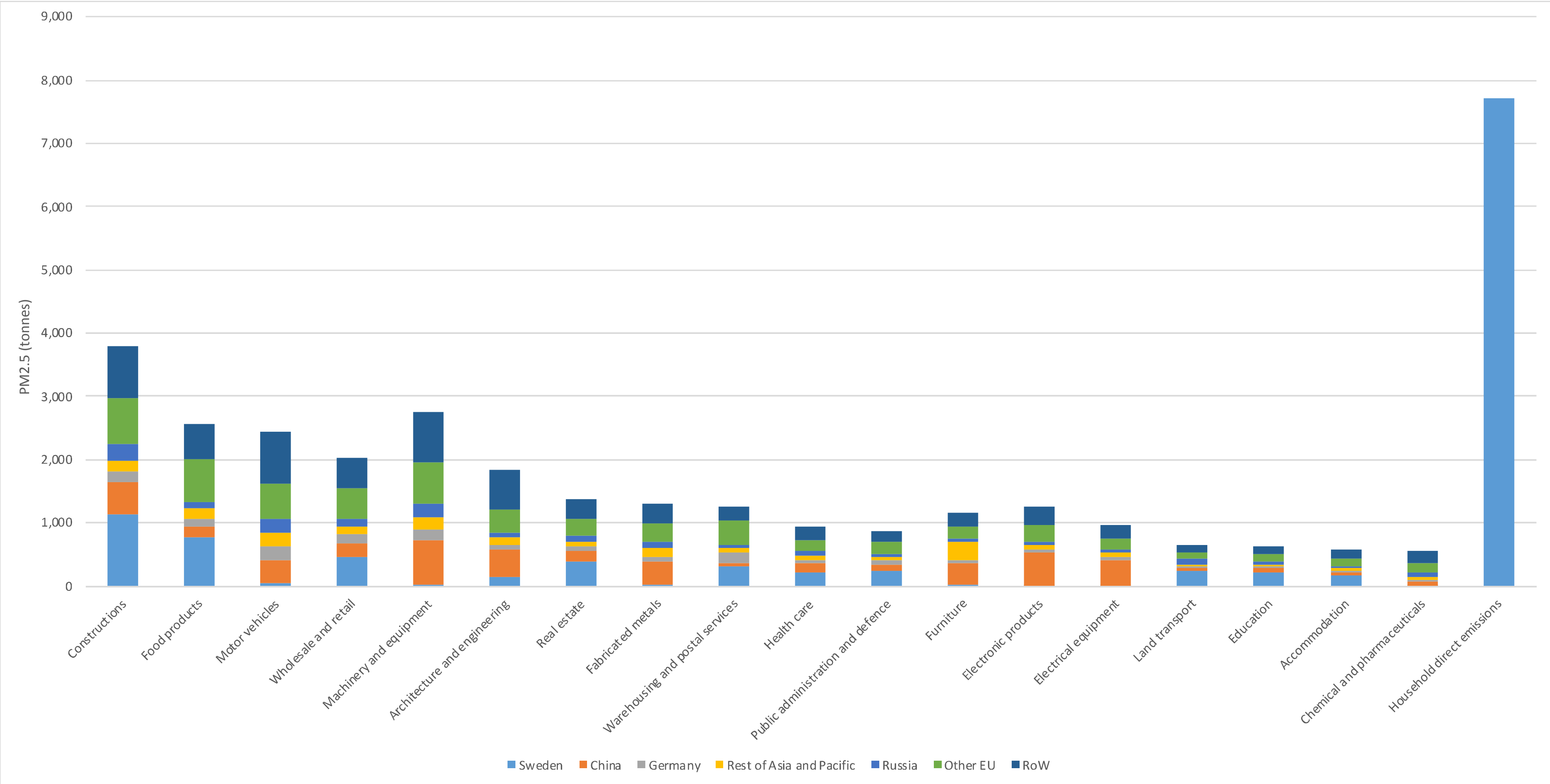

Figure 5: PM2.5 emissions of Swedish consumption by product group and country of origin. Top 5 countries and regions of environmental pressures identified and Other EU and RoW aggregated. Top products, ranked across all countries, regions and aggregated countries and regions were selected and those accounting for 80% of the PM2.5 emissions from Swedish consumption in total are displayed.

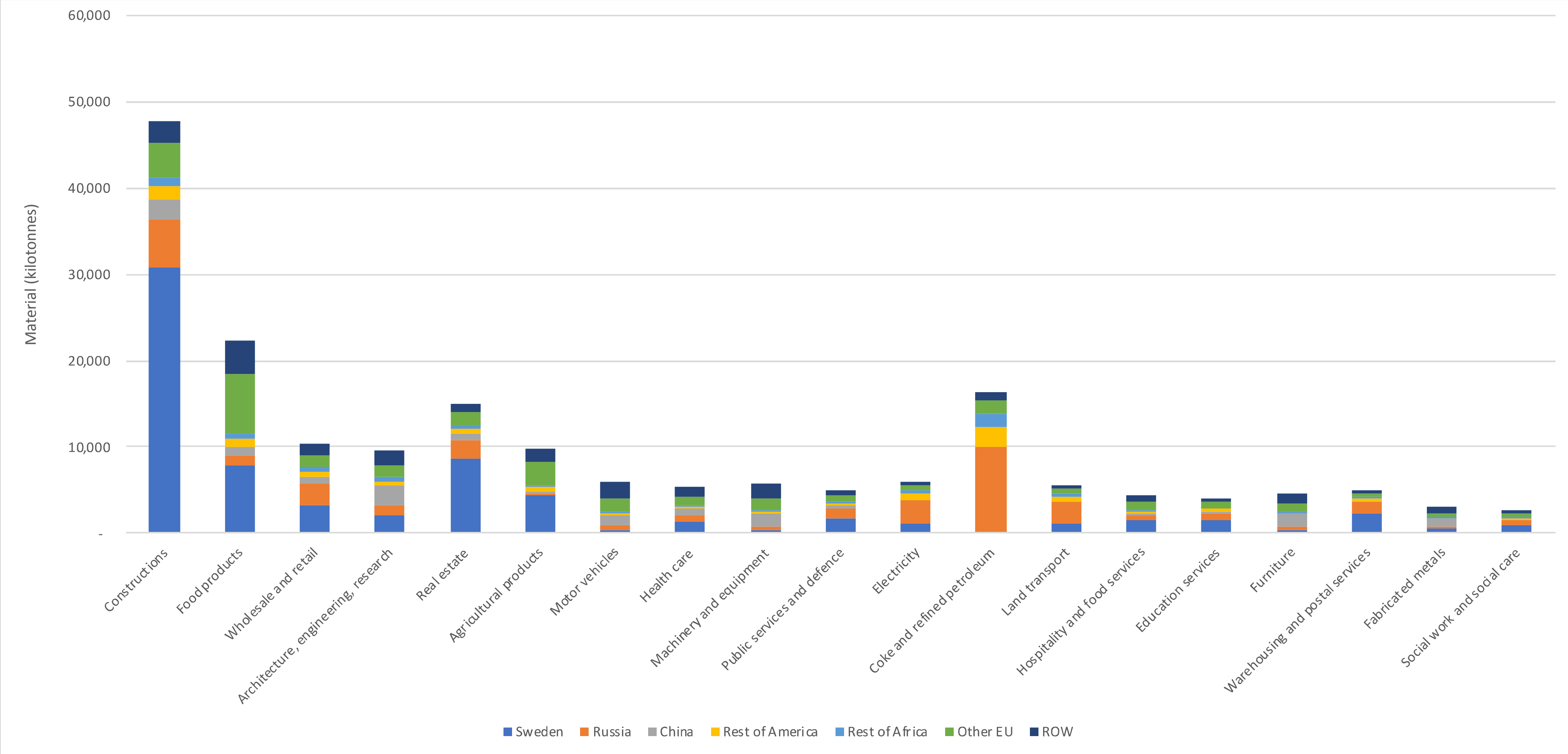

Figure 6: Material use of Swedish consumption by product group and country of origin. Top 5 countries and regions of environmental pressures identified and Other EU and RoW aggregated. Top products, ranked across all countries, regions and aggregated countries and regions were selected and those accounting for 80% of material use from Swedish consumption in total are displayed

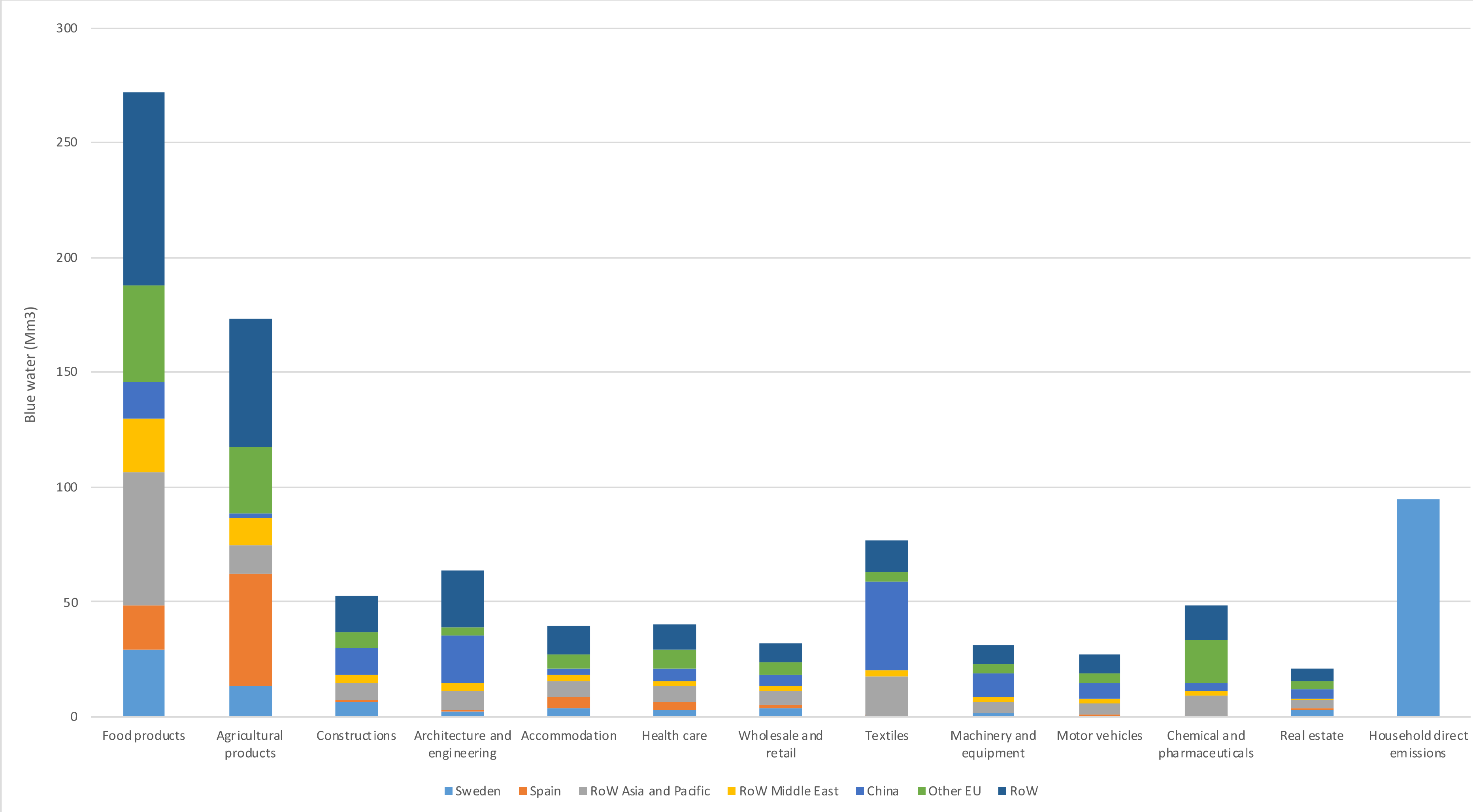

Figure 7: Blue water use of Swedish consumption by product group and country of origin. Top 5 countries and regions of environmental pressures identified and Other EU and RoW aggregated. Top products, ranked across all countries, regions and aggregated countries and regions were selected and those accounting for 80% of the blue water use from Swedish consumption in total are displayed

The impacts in terms of pressures and resource use are spread across many countries for emissions of GHG (Fig.2), SO_2 (Fig. 3), NOx (Fig. 4), PM2.5 (Fig. 5) as well as for Materials (Fig.6) whereas it is more concentrated for Water use (Fig. 7).

Water use (Fig. 7) has a different profile compared to the other indicators, where food and agricultural products, as well as textiles and chemical products, are among the most important product categories. The country profile is also different. For food and agricultural products, Rest of Asia and pacific and Spain are important countries and regions. For textiles, China and Rest of Asia and Pacific are important and for chemical products, other EU countries (except Spain and Sweden) are important.

Household direct emissions and resource uses are significant for some indicators: GHG (Fig.2), PM2.5 (Fig. 5), NOx (Fig. 4) and Water use (Fig. 7) and are caused by households when burning fuel in cars or homes for example and consequently the pressure always occurs in Sweden. Also, for some other product groups, e.g. construction, food products as well as wholesale and retail, a large proportion of pressure in terms of emissions of GHG (Fig. 2), NOx (Fig. 4) and PM2.5 (Fig. 5) occurs domestically. This is also the case for material use for several product groups (Fig. 6).

Some countries rank high for several environmental pressures and resource use. This is the case for Russia. It is a dominating country for emissions of GHG and material use for coke and refined petroleum products (Fig.2 and Fig.6). Also, a significant proportion of emissions and resource use occur in Russia as a result of the Swedish consumption of construction, wholesale and retail products (for GHGs (Fig.2), NOx (Fig. 4), material use (Fig. 6)), and land transport (for GHG (Fig.2)) and NOx (Fig 4)). China ranks high across almost all of the most important product groups when it comes to SO_2 emissions and for the product groups constructions, architecture, other machinery and furniture for GHG (Fig. 2), NOx (Fig. 4), PM2.5 (Fig. 5) as well as electronic products for NOx (Fig. 4), PM2.5 (Fig. 5), food products and textiles (for blue water (Fig. 7)).

Some other countries rank high for specific indicators and product groups. One example is Germany for motor vehicles, food products, construction, other machinery, wholesale and retail across the indicators GHG (Fig. 2), SO_2 (Fig. 3) and NOx (Fig. 4) as well as PM2.5 (Fig. 5) for construction, motor vehicles and wholesale and retail. The rest of the Asia and Pacific region ranks high for the product groups furniture (GHG (Fig. 2), PM2.5 (Fig. 5) and SO_2 (Fig. 3)), food products (GHG (Fig.2) and SO_2 (Fig.3) and blue water (Fig. 7)) agricultural products and textiles (blue water (Fig.7)) as well as motor vehicles and other machinery for SO_2 (Fig.3) and PM2.5 (Fig. 5).

For material use, the largest products groups are related to construction and food products (Fig. 6). Sweden is the dominating country of origin together with other EU-countries for the material use associated with Swedish consumption of food products. The material use indicator comprises four different categories: Bio-based materials (including food and forestry products), fossil fuels, metals and non-metallic minerals (including sand and gravel). Figure 8 presents the material use divided into these categories for the total material use and in table 4, the same categories are used for the most important product groups and the most important countries and regions.

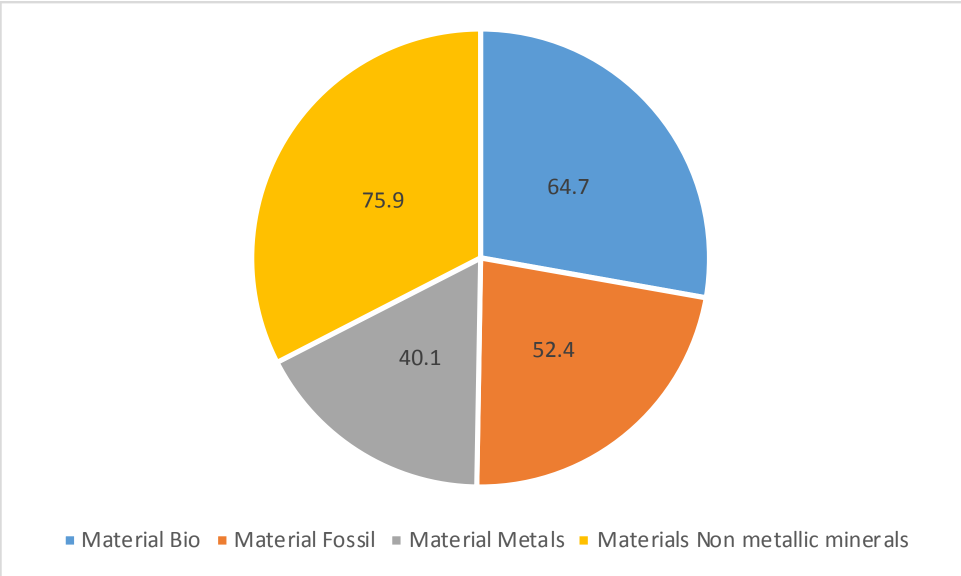

Figure 8: Total material use from Swedish consumption per material type in Mt. (2014)