THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Region-Specific Consumption-Based Environmental Impact:

Hotspot Identification Using Hybrid MFA-LCA

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Cover:
Edited picture of one of the intersections in Gothenburg; original image by David Mark, Pixabay. Overlay of Consumption, Impact, and Policy is developed in detail in Figure 3.

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ABSTRACT

The environmental impacts caused by rising consumption are pressing problems for society today. Decision makers are tasked with setting and meeting environmental targets to ensure that future generations have access to the same quality of resources (like clean water and air) that we have today. Limiting factors like time and funding exacerbate the challenge of meeting these goals. In this thesis, city- and region-specific consumption data are analyzed to identify consumption-based impact hotspots, i.e. product categories with high environmental impact, and to show how this data is relevant for policy development, prioritization, and assessment. Many studies primarily look at climate change as the sole impact indicator while multiple factors can and do affect the environment. To fill this gap, material flow analysis (MFA), which provides data on the quantities of products consumed in a region, is combined with life cycle assessment (LCA) to quantify the environmental impact of a region's consumption. Five environmental indicators are evaluated: global warming potential (climate change), eutrophication potential, acidification potential, photochemical ozone formation potential, and resource depletion. Consumption-based environmental impact results are used to identify hotspots and prioritize existing environmental measures. The results indicate that cities and regions have distinct consumption profiles and that local consumption data is relevant for identifying which products should be addressed in order to maximize the environmental benefit. Existing environmental measures for the city of Gothenburg, Sweden, are assessed for effectiveness in reaching environmental targets.

Keywords: urban metabolism, industrial ecology, environmental impact, sustainable consumption, Sustainable Development Goals, hotspot analysis

Parts of the material in this thesis have previously been published in the licentiate thesis written by the author: A. Lavers Westin (2018) *Identifying Consumption-Based Environmental Hotspots: Development of a Hybrid MFA-LCA Method to Find High Impact Product Groups in a Region,* Chalmers University of Technology, Gothenburg.

PREFACE

This doctoral thesis is based on the research performed by Alexandra Lavers Westin in the Urban Metabolism group at the Department of Architecture and Civil Engineering at Chalmers University of Technology between March 2015 and November 2020 under the supervision of Professor Yuliya Kalmykova and Associate Professor Leonardo Rosado. This research has been funded by the Swedish Research Council FORMAS and Mistra Urban Futures program (funded by the Swedish Innovation Agency Vinnova).

The following appended manuscripts are referred to in the text as papers I-IV:

I. **Lavers[1], A.;** Kalmykova, Y.; Rosado, L.; Oliveira, F.; Laurenti, R. Selecting representative products for quantifying environmental impacts of consumption in urban areas. *J. Clean. Prod.* 2017, *162*, 34–44, doi:10.1016/j.jclepro.2017.06.030.

II. **Lavers Westin, A**.; Kalmykova, Y.; Rosado, L.; Oliveira, F.; Laurenti, R.; Rydberg, T. Combining material flow analysis with life cycle assessment to identify environmental hotspots of urban consumption. *J. Clean. Prod.* 2019, *226*, 526–539, doi:10.1016/j.jclepro.2019.04.036.

III. **Lavers Westin, A**.; Kalmykova, Y.; Rosado, L. Method for Quantitative Evaluation of Sustainability Measures: A Systems Approach for Policy Prioritization. *Sustainability* 2019, doi:10.3390/su11030734.

IV. **Lavers Westin, A.;** Rosado, L.; Kalmykova, Y.; Patrício, J. Methods for Downscaling National Material Consumption Data to the Regional and Municipal Levels. *Sustainability* 2020, doi:10.3390/su12208336

Author's contribution:

In Paper I, Lavers Westin developed the concept as well as the criteria for representative product selection together with Rosado and Kalmykova. Lavers Westin found and organized the existing MFA data. Oliveira and Laurenti matched and developed LCA profiles with suggested representative products and performed the sensitivity analysis. Lavers Westin wrote the manuscript drafts and finalized the manuscript prior to publication after peer review comments.

In Paper II, Lavers Westin developed the concept with input from Kalmykova and Rosado. Lavers Westin developed the methodology and performed the data analysis and interpretation. Kalmykova, Rosado, Oliveira, Laurenti and Rydberg aided with formal analysis. Lavers Westin wrote the manuscript drafts and finalized the manuscript prior to publication after peer review comments.

[1] Lavers is my maiden name, Lavers Westin was used after 2017 as Westin is my married name.

In Paper III, Lavers Westin developed the concept, designed the method, performed the data analysis, and communicated with stakeholders. Lavers Westin wrote the manuscript drafts and finalized the manuscript prior to publication after input from Kalmykova and Rosado as well as peer review comments.

In Paper IV, Lavers Westin, Kalmykova, Rosado and Patrício conceptualized the model. Lavers Westin designed the methodology, Patrício created the programming scripts while Lavers Westin performed data analysis and presentation. Lavers Westin wrote the manuscript drafts and finalized the manuscript prior to publication after peer review comments.

Conference Posters

Poster 1: *Identifying urban consumption hotspots: Hybrid MFA-LCA to find key product types to prioritize policy focus*. Presented at the ISIE/ISST Joint Conference in Chicago, IL, USA (2017) and at the National Workshop for Sustainable Lifestyles in Umeå, Sweden (2017)

Poster 2: *Whodunit? Identifying the consumer of high impact goods*. Presented at the Gordon Conference for Industrial Ecology in Les Diablerets, Switzerland (2018)

Other papers that were co-authored during the realization of this Ph.D. are listed below, but are not appended to the Thesis:

Whetstone, A.; Kalmykova, Y.; Rosado, L.; Lavers Westin, A. Informing Sustainable Consumption in Urban Districts: A Method for Transforming Household Expenditures into Physical Quantities. *Sustainability* 2020, *12*, 802

Patrício, J., Kalmykova, Y., Rosado, L., Cohen, J., Lavers Westin, A. and Gil, J. 2021. Top-down method to support the identification of potential opportunities for industrial symbiosis partnerships. *Under Review*

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To my colleagues at WET, past and present, thank you for stimulating conversations and for expanding my knowledge on all things water. I am lucky to have started the PhD program with such a thoughtful and diverse group of individuals and I thank you for your friendship and support during the roller coaster that is the PhD experience.

Mamma, tack för att du är en fantastisk förebild som har hjälpt mig våga drömma och satsa stort. Jag är där jag är tack vare dig och ditt villkorslösa stöd och kärlek. Dad, thank you for always being willing to discuss, read, and edit my research. This thesis and the work within – much like my life in general – has been greatly influenced by you, and I couldn't ask for a better inspiration. Catharina and Erik, I love you. Thank you for putting up with me and being the best cheer squad a little sister could ask for. Jason, thank you for your Excel-wizardry and ability to translate what idea I have into a functioning formula.

Last, but certainly not least, tack till John för all uppmuntran, stöd, och kärlek. Tack för att du var villig att upptäcka en ny stad så att jag kunde få följa mina drömmar. Oliver and Elliot, thank you for giving me perspective and a reason to keep trying to make this planet a better place. I love you.

ABBREVIATIONS

CN	combined nomenclature
CF	carbon footprint
CO_2-eq	carbon dioxide equivalents
COICOP	Classification of individual consumption by purpose
DE	domestic extraction
EEIO	environmentally extended input-output
EPD	Environmental Product Declaration
EF	ecological footprint
GHG	greenhouse gas
GWP	global warming potential
H+-eq	hydrogen ion equivalents
HBS	Household budget survey
HS	harmonized system
kg	kilogram
LCA	life cycle assessment
LCI	life cycle impact
MCDA	multi-criteria decision analysis
MF	material footprint
MFA	material flow analysis
mol	mole
MRIO	multi-regional input-output
NACE	statistical classification of economic activities in the European Community
N-eq	nitrogen equivalents
NMVOC	non-methane volatile organic compounds
P-eq	phosphorous equivalents
RQ	research question
Sb-eq	antimony equivalents
SDG	Sustainable Development Goal
UMAn	Urban Metabolism Analyst
UN	United Nations

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Science alone does not hold the power to achieve the goal of greater sustainability, but scientific knowledge and wisdom are needed to help inform decisions that will enable society to move forward to that end.

Jane Lubchenco (1998)

1 INTRODUCTION

Global populations are rising, particularly in cities, as are incomes and consumption rates (Schandl *et al.*, 2017; OECD, 2019). Krausmann et al found that per capita consumption has almost doubled since 1900 (Krausmann *et al.*, 2009; Ferrão and Fernández, 2013). Moreover, the globalized economy results in externalized impacts where consumption that takes place in one country may have impacts elsewhere (Peters, 2008; Peters and Hertwich, 2008). These changes have given rise to greater resource use and continuation of this pattern will likely lead to significant environmental impacts that can alter our earth's ecosystems and change the way our planet functions (Steffen *et al.*, 2015).

Today, we are beginning to see the dramatic effects that environmental impacts like climate change and eutrophication can have. In the past ten years, we have experienced the highest global temperatures ever recorded, with 2019 among the warmest years on record (Lindsey and Dahlman, 2020). The dramatic forest fires in Europe and the United States in recent years can likely be linked to climate change (Flannigan and Van Wagner, 1991; Goss *et al.*, 2020; Venäläinen *et al.*, 2020). Locally, the Baltic Sea suffers extreme algae blooms and dead zones which are connected to overuse of fertilizers, fossil fuel emissions, and subsequent eutrophication (Conley *et al.*, 2009). In fact, dead zones on ocean coasts have spread exponentially since the 1960s (Diaz and Rosenberg, 2008). These global impacts cannot be linked to one singular cause, but are a result of numerous intersecting factors.

Historically, environmental management has considered end-of-pipe solutions where environmental policies were mostly reactive and focused on site-specific solutions for direct impacts (i.e., impacts that directly impact the environment like exhaust emissions or effluent). Although these are still necessary, a systems perspective is needed today to meet the growing challenges to multiple media (i.e., air, water, and land) by a greater variety of pollutants as well as increasingly complex supply chains. Building upon the concept of "cleaner production" developed in the 1980s, the concept of "sustainable consumption" has risen (UNEP, 2012). Sustainable consumption has a multitude of interpretations, but a common element is that it can be achieved by consuming more efficiently or more responsibly, or by consuming less (Dawkins, 2019). These approaches require more holistic thinking than only reducing direct emissions.

In recent years, there has been a greater push to reduce indirect impacts that occur throughout a product's value chain or life cycle. Indirect impacts are not visible to the consumer, but take place either "upstream" (i.e., during resource extraction or production) or "downstream" (i.e., as a result of waste management) from actual consumption.[2] Indirect impacts can also include changes in land use or resource use due to increasing demand for specific materials. An example of this increased attention is the Swedish government's announcement in October 2020 that the Environmental Objectives Committee (*Miljömålsberedningen*) has been tasked with proposing an overall strategy to reduce consumption-based climate impact in Sweden, which includes indirect impacts that take place in the product-producing countries outside of Sweden (Government Offices of Sweden, 2020). Other examples include the United Nations (UN) Sustainable Development Goals (SDGs) (United Nations, 2017; Bengtsson *et al.*, 2018), part of Agenda 2030, as well as local initiatives like the city of Gothenburg, Sweden's target of reducing consumption-based emissions from current estimates of approximately 8 to 9 tons to 3.5 tons carbon dioxide equivalents (CO_2-eq) per inhabitant by 2035 (Gothenburg, 2014). Umeå municipality (Sweden) has set a target of 2 tons consumption-based CO_2-eq per person by 2040, and 1 ton by 2050 (Umeå Kommun, 2020). The city of Vancouver, Canada, has set a target to reduce their ecological footprint by 33% (see Chapter 2 for a description of this indicator) compared to 2006 levels by 2020 (City of Vancouver, 2020). Västra Götaland, a region comprising 49 municipalities in western Sweden, has also set an ambitious regional target to reduce consumption-based CO2-eq by 30% compared with 2010 values by 2030 (*Klimat 2030*, no date).

These broad targets and ambitious goals require aggressive action in order to meet them. However, it may be difficult for decision makers to know what policies or measures should be prioritized or what level of effort is required to reach environmental goals. Moreover, they may lack time and financial resources to perform intricate analyses. To add to the complexity of these issues, it has been shown that different cities and regions can have different consumption-related impacts (Jones and Kammen, 2013; Minx *et al.*, 2013; Miehe *et al.*, 2016). Regional or city-scale consumption patterns may be dependent on local factors like public transportation availability, population density, climate, and more (Kalmykova, Rosado and Patrício, 2015a). Reaching environmental goals would therefore require different road maps for different cities. Using urban metabolism tools, in which inputs (such as materials) and outputs (such as waste) in cities and regions are quantified, we can expand the toolbox that decisions makers have to help

[2] Some readers may be more familiar with the terminology from the Greenhouse Gas Protocol in which direct emissions that take place within a city/organization are called "Scope 1" emissions. "Scope 2" emissions that take place as a result of grid-supplied electricity, heating, or cooling are considered indirect, as are "Scope 3" emissions, which take place elsewhere in the value chain (World Resources Institute, C40 Cities Climate Leadership Group and ICLEI - Local Governments for Sustainability, 2014).

prioritize environmental measures (Kennedy, Cuddihy and Engel-Yan, 2007; Kennedy, Pincetl and Bunje, 2011).

Moreover, urban metabolism methods can describe consumption in terms of material flows at the product level. Products are concrete, tangible goods whose consumption can be measured and clearly targeted. Policies or measures intended to achieve sustainable consumption can be product-specific (e.g., focused on modal shift of transportation from vehicles to bicycles or public transportation, or reduction of meat consumption by providing vegetarian meals in school lunches). Products studied in this thesis are *final goods,* which are described in more depth in Chapter 5. Municipalities have agency over products, in particular the ones that are purchased for government use (public procurement). I propose that by using locally relevant consumption data, it may be possible to pinpoint product types whose reduction would have the greatest impact in reaching environmental targets effectively. I will refer to these priority product categories as "hotspots" and describe them in further detail in Chapter 5[3]. Furthermore, I suggest that by using both urban and national consumption trends evaluated over multiple impact types, it is possible to better identify whether consumption should be targeted by national policies or should be addressed locally instead.

Sustainability indicators and consumption impact data have previously been used for policy prioritization (e.g., Fitzgerald *et al.*, 2012, 2015; Jones, Wheeler and Kammen, 2018). These prioritization methods generally use generic policies that are not city- or region-specific, however. There are several integrated sustainability assessment tools like multi-criteria decision analysis (MCDA) that can use both quantitative and qualitative data to identify optimal policies (Ness *et al.*, 2007). Some MCDA methods are sector specific (e.g., energy) (Browne, O'Regan and Moles, 2010; Nikas, Doukas and Martínez López, 2018). These methods are intended to help generate dialogue among stakeholders and reach consensus and are used for strategic planning purposes rather than detailed local measure prioritization. Kennedy et al (2007) envisioned using urban metabolism to form policy, and I suggest that we can even use it to prioritize existing measures.

Moreover, decision makers will likely require useable tools to help implement evidence-based policies and measures to achieve sustainable consumption and meet environmental targets (Dawkins *et al.*, 2019). Including stakeholder engagement in the development and assessment of consumption-based

[3] Hotspots can also be specific parts of a product's life cycle that create the highest impact, but that is not the usage intended in this thesis.

environmental impact research will increase the likelihood that resulting tools will be effective and more readily adopted. Some argue that transitions to sustainable societies will not be possible without transdisciplinary research, where non-academic practitioners work together with academics to perform research and find solutions to challenging problems (Lang *et al.*, 2012).

1.1 Objectives and research questions

Sustainable consumption can be a difficult target to achieve. The purpose of this work is to investigate how an urban metabolism approach using consumption-based environmental impact data can be applied to reach sustainability targets and goals. This thesis aims to investigate the following research questions (RQ):

(RQ1) How does region-specific consumption affect hotspots?

(RQ2) How can region-specific consumption and impact data be used for policy prioritization and assessment?

To answer these questions, the objectives of this thesis are to:

- Present a method for combining material flow analysis (MFA) and life cycle assessment (LCA) (Paper I, II);
- Illustrate a hotspot identification method for urban areas (Paper II, Poster 1);
- Identify sectors driving hotspots (Poster 2); and
- Test how data can be used by decision makers (Paper III, IV).

1.2 Thesis structure

First, I present a background on sustainable consumption and consumption-based environmental impact in Chapter 2. In Chapter 3, I provide an overview of the state of research within urban metabolism. I describe the research design in Chapter 4. Methods are described in Chapter 5. Results are presented in Chapter 6, discussion and conclusions are presented in Chapter 7, and Chapter 8 provides insight into future work. Finally, Papers I, II, III, and IV are appended to this thesis.

2 SUSTAINABLE CONSUMPTION

The term *sustainable development* has been cited in the literature since the 1987 Brundtland report (Brundtland, 1987), expanded upon in Agenda 21 (Tanguay *et al.*, 2010), and is now commonly used. Simply put, we must meet the needs of the present without compromising the ability of future generations to meet their own needs. These needs can include materials, access to clean water, food, and more.

In 2016, the UN's Agenda 2030, which includes 17 goals working towards sustainable development (the SDGs), came into effect. Of these SDGs, *Goal 11: Sustainable cities and communities* and *Goal 12: Ensure sustainable consumption and production patterns* are particularly relevant to this body of research. Each goal has targets to reach by 2030, as well as indicators to measure progress towards the target. For example, Goal 12 has eleven targets, and each target has at least one indicator. Target 12.2 is "By 2030, achieve the sustainable management and efficient use of natural resources" and the two indicators are 12.2.1 "Material footprint, material footprint per capita and material footprint per GDP" and 12.2.2 "Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP" (United Nations, 2017). The SDGs are expected to be implemented at all administrative and geographical scales, including municipalities (Graute, 2016). This is a challenge for many municipalities that may lack data to identify where they can most effectively work to reduce their consumption-based environmental impact. For example, Gothenburg's 2013 Environmental Program included 212 measures and the revised version (2018) included 189 measures (Göteborgs Stad, 2013, 2018); knowing where to prioritize efforts can increase effectiveness of the measures. See the following chapter on urban metabolism for a description of consumption quantification methods at the urban scale.

The concept of sustainable consumption falls under the umbrella of sustainable development. In 1995 a formal definition of sustainable consumption was adopted by the UN Commission on Sustainable Development as:

> *"The use of services and related products which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life-cycle so as not to jeopardize the needs of future generations."* (UNEP, 2001)

Reducing the adverse environmental impact of consumption can take three forms: improving (or "greening") production and products, consuming less material or goods overall, or changing the demand so that low-impact goods are substituted for high-impact goods (Tukker *et al.*, 2008). This requires data as to which goods have a high impact, what are possible replacement options, and which approaches will achieve targets. In this thesis, I aim to investigate all three options with a focus on first identifying which goods have a high impact and should be prioritized.

Identifying which approach will reduce targets can be deceivingly difficult. Care is required in selecting what measures to take, as some initially attractive approaches may ultimately prove to be unsatisfactory. For example, in some cases improving production or energy efficiency has led to increased production that has either reduced the apparent emissions reduction or even resulted in increased consumption in what is termed a rebound effect (Greening, Greene and Difiglio, 2000). We also need to consider more impact categories than just global warming potential (GWP), as replacements may result in higher risks for eutrophication or other impacts, as can be seen in the replacement of internal combustion engine vehicles with electric vehicles in Italy (Girardi, Gargiulo and Brambilla, 2015).

2.1 Consumption-based impact quantification

There are a variety of methods to quantify the environmental impact of consumption. These evaluations vary in terms of units and indicators used, resolution, and applicable geographical scale. Selection of impact quantification method is dependent on how the results will be used as well as data availability. In this section, I will give a brief overview of the predominant methods presented in today's literature used in industrial ecology as well as some of the possible advantages or disadvantages of each. See Table 1 for a summary of the described methods.

Regardless of method, consumption data is needed to quantify the impact of consumption. There are a number of available sources for national consumption data, usually presented using mass (tons) or currency as a unit of measure. These include national statistics used for input-output tables or trade data. To understand the consumption of goods and materials in a specific region, including cities, municipalities, or counties, we need to either extrapolate national level to the regional level (a *top-down* assessment), or collect consumption data at the regional level (a *bottom-up* assessment). Household budget or consumption surveys are examples of bottom-up data collection. A top-down method can be used to create a flexible model that can easily be applied to any region whereas a bottom-up assessment can be more accurate, albeit depending on the sources of and gaps in available data.

Table 1: Summary of consumption based environmental impact quantification methods

Category	Method name	Input data	Output data	Geographic scale	References	Advantages	Disadvantages
IPAT		Population, GDP per capita, technology factor	Environmental impact (unit depends on technology factor used)	National	(Ehrlich & Holdren, 1971; Holdren & Ehrlich, 1974)	Simple, low data requirements	Oversimplification for specific policy use
Footprints	Ecological footprint	Consumption, land and water required to support that consumption	Land use in global hectares	National, city	(Wackernagel & Rees, 1996)	Easily comparable, pedagogical/easy to understand and communicate; widely applicable	Aggregated values, assumptions and oversimplification, data availability
	Carbon footprint	Various input-output models (see below) or product-specific bottom-up data	Tons CO_2-equivalents	National to product level	(European Commission, 2010; Wiedmann et al., 2010)		
	Material Footprint	Material input per unit of product or service	Sum of biotic and abiotic resources required to meet consumption	National to product level	(Bringezu et al., 2017; Laakso & Lettenmeier, 2016; Lettenmeier et al., 2009)		
Input-output & Consumption-Based Accounting	Environmental extended input-output tables (EEIO)	Economic or physical values data	Total energy use or emissions; energy use or emissions per sector	Global, national, regional an extent	(Hoekstra, 2010; Kitzes, 2013)	Data availability (IO tables are compiled by national governments)	Aggregated sectors, predominantly available at national level, lack of transparency
	Multi-regional input-output tables (MRIO)	Financial and resource values exchanged between economies	N/A	Global, national	(Aguiar et al., 2019; Tukker & Dietzenbacher, 2013)	Data availability (large databases are consistently compiled)	
Life cycle assessment		Emissions associated with each phase a product's life cycle	Environmental impact per functional unit	Product level	(Baumann & Tillman, 2004)	Comprehensive understanding of environmental impact of product	Data availability, time, expense
Urban metabolism	Material flow analysis or accounting (MFA)	Physical flows of goods, water, energy, materials	Mass (kg) of materials or products consumed	National, regional, municipal, city	(Brunner & Rechberger, 2003; Daniels & Moore, 2001; Rosado et al., 2014)	Comprehensive view of materials or products in a system, transparency	Data availability

2.1.1 IPAT

Among the first calculations to quantify the relationship between consumption and environmental impact is the so-called *IPAT* equation, developed by Paul Ehrlich and John Holdren (Holdren and Ehrlich, 1974). Simply, environmental impact (I) is the product of population (P), affluence (A), and technology (T). The authors extend this equation to:

Environmental disruption (or impact) = population x consumption per person x damage per unit of consumption

As Chertow notes, this equation has had many variants since its inception and is one of the original quantification methods used (Chertow, 2000), even called the "master equation" of industrial ecology (Graedel, 2000). It has been primarily used at the national level, with limited use at the local level (Kissinger and Karplus, 2014).

2.1.2 Footprints

Rees and Wackernagel pioneered the use of "footprints" as sustainability indicators, developing the concept of *ecological footprint* (EF) (Wackernagel and Rees, 1996). The ecological footprint connects economic terms like consumption to biophysical ones like land-use demand (Rees, 2003). The EF is calculated based on how much biologically productive land and sea area is necessary to maintain consumption demands; consumption is quantified based on national statistics using:

production + imports – exports = consumption

The land and water required to support that consumption is calculated using annually updated yield data from crops, forests, grazing land and fisheries. The land use value, expressed in global average hectares, can be compared to the global productive land and sea available (in 1999, biologically available land and sea was estimated to be 2.3 ha per capita globally (Holmberg *et al.*, 1999). This value can be compared to same year's estimate of the average consumer's ecological footprint as an indicator of sustainability. For example, Sweden's 1999 ecological footprint was estimated to be 7.2 ha per capita (Wackernagel, Lewan and Hansson, 1999), thus exceeding average available resources by a factor of almost three. This illustrative indicator has led to concepts like "Earth Overshoot Day" which is intended to improve consumer awareness on how their consumption choices can impact resource use (Collins *et al.*, 2020). In more recent years, this indicator has been connected to other methods like input-output analysis to evaluate smaller geographic scales like cities (Kissinger *et al.*, 2013), and system dynamics (Jin, Xu and Yang, 2009). Ecological footprint has some disadvantages, however, including the uncertainties associated with aggregation.

The *carbon footprint* is calculated by quantifying the total amount of GHG emissions, both direct and indirect, associated with a product, calculated using input-output analysis or life cycle assessment (LCA) (both are described below) (Hertwich and Peters, 2009). Like the ecological and material footprints, it can be applied at multiple scales. It is limited to one indicator, however, which may miss tradeoffs.

The *material footprint* (MF) is the amount of primary materials needed to meet basic needs for food, clothing, infrastructure, and more (Wiedmann *et al.*, 2013; Schandl *et al.*, 2017). The global MF grew from 73.2 billion metric tons in 2010 to 85.9 metric tons in 2017 (United Nations, 2020) – mostly in the built environment (i.e., the "physical structures and elements of the human-made environments in which we live, work, travel, and play" (Frank, Chair and Engelke, 2005), mostly construction materials). Material footprint per capita is 10 times higher in high income countries than in low-income countries. This indicator is built upon the Material Input Per unit of Service (MIPS) concept, where material inputs required throughout the lifecycle of a product or service are estimated (Liedtke *et al.*, 2014; Laakso and Lettenmeier, 2016). The MF is the sum of abiotic and biotic resources plus, in the case of agriculture, topsoil erosion, caused by consumption.

2.1.3 Input-output analysis

Input-output (IO) tables present the transactions between economic sectors of a considered region, including the final demand and value added (Leontief, 1970). Economic sectors are defined here as private, public (i.e., governmental), and industrial consumption. The sectors can be linked to environmental impacts like emissions, resource use, or land use in the form of environmentally-extended input-output (EEIO) tables (Tukker *et al.*, 2006). Multi-regional input-output tables (MRIO) link input-output tables among countries or regions within a country, and can be further linked to emissions or energy use as in EEIO (Lenzen, Pade and Munksgaard, 2004; Peters, 2007; Druckman and Jackson, 2009; Hertwich and Peters, 2009). Research projects like the PRINCE project have used the EXIOBASE database to quantify consumption-based impact at the national level (Wood and Palm, 2016; Wiebe *et al.*, 2019). Some studies link ecological footprints to input-output analysis (Wiedmann *et al.*, 2006). Input-output based tools have the benefit of using nationally collected statistical tables that increase accessibility of the method. However, with some exceptions, these are mostly based on economic sectors and lack resolution at the product level (Jungbluth *et al.*, 2011). Some studies link IO to LCA, which is described in the next subchapter.

2.1.4 Life cycle assessment

Life cycle assessment is a method used to estimate the potential environmental impacts throughout a product's life cycle. It is a systems tool, where it is possible to analyze a sequence of connected events within the lifespan of a product. The assessment includes raw material extraction, production, manufacture, use, and end-of-life treatment (recycling and/or final disposal) (Baumann and Tillman, 2004).

First, a life cycle inventory is performed by estimating the inputs and outputs for each stage of the life cycle, including materials, energy, water, emissions, and waste. The life cycle impact assessment is then performed to identify the potential environmental impacts of the life cycle inventory results based on characterization factors (Baumann and Tillman, 2004). It is possible to either sum the total environmental impact of all stages of the life cycle or look at them individually.

Potential environmental impacts evaluated include, but are not limited to climate change, eutrophication, acidification, photochemical ozone formation, and resource use. The assessment can be made from "cradle-to-grave", i.e., from resource extraction through the end-of-life (waste treatment), or from "cradle-to-gate", i.e., from resource extraction through manufacturing, but not including the use or end-of-life phase. The LCA results in a life cycle impact (LCI) profile for the product of interest. Life cycle assessments are performed at the product level, and are dependent on the quality of available data.

Life cycle assessment results are dependent on choices made throughout the analysis. The choice of system boundaries, for example, can affect the outcome significantly (Tillman *et al.*, 1994).

2.1.5 Tool availability

Several of these methods are linked to online tools and calculators enabling a private consumer to identify his or her environmental impact in terms of ecological or carbon footprint, e.g. the WWF footprint calculator or the CarbonFootprint calculator (Collins *et al.*, 2020). There are fewer tools available for larger scale actors like companies or municipalities. Companies can use Environmental Product Declarations (EPDs) to quantify the LCA-based environmental impact of their products for marketing use (Zbicinski *et al.*, 2006; Del Borghi, 2013). More recent work is focused on making IO analysis possible at smaller geographic scales than the national level and developed into a tool for municipalities, but this work is not yet published (Stockholm Environment Institute, 2020). At the national level, MRIO- and carbon footprint-based tools like EXIOBASE are readily available (e.g., Tukker *et al.*, 2014; Wood *et al.*, 2014).

2.1.6 Gap identification

As described above and shown in Table 1, there is a wealth of models and methods to quantify consumption and its impacts. However, the majority of them are applicable at the national level and include aggregated indicators that can be interpreted in many ways. Such data may be difficult for municipal or regional decision makers to use for prioritization purposes. Several of the methods described use monetary values that are perhaps easily collected but provide impact data per aggregated sector rather than specific product categories. This may limit decision-makers' ability to act, as it may be more difficult to develop and monitor the effectiveness of measures targeting sector-based emissions.

The missing piece is region-specific (e.g., municipality, metropolitan area) consumption impact data at the product level for all product groups. Product category specificity can enable decision makers to prioritize measures more precisely. Moreover, it is important to look at several indicators rather than just one, like CO_2 emissions or energy, which most methods focus on. Material flow assessment and LCA can help achieve these objectives by providing product-level specificity in addition to several environmental indicators.

2.2 Consumption-based impact related policies

As noted earlier, decision makers at local, regional, and national levels are responsible for meeting and reporting progress towards sustainability targets for the UN Agenda 2030 as well as on their own initiatives. To the reach the SDGs, collaboration among actors and action at the municipal and regional level is key (Gustafsson and Ivner, 2018).

Sustainability issues are often connected to global problems that can best be addressed by multilevel governance (Mazmanian and Kraft, 2009; Bulkeley, 2010). For example, Sweden has implemented the so-called "generational goal" at the national level which directs environmental policy to strive towards consumption of goods and services with the lowest possible impact on both the environment and human health (Swedish Environmental Protection Agency, 2018). Subnational actors like regions, municipalities, and consortia act to achieve these goals. Like the example noted earlier, the municipality of Gothenburg set an ambitious target that by 2035, consumption-based, indirect greenhouse gas emissions will be no higher than 3.5 tons per capita – a significant reduction from their estimate of 8 tons of carbon dioxide (CO_2)-equivalents per capita today (Gothenburg, 2014). Sweden would be unlikely to reach the generational goal without local-level action.

A survey study by Axelsson and Dawkins (2019) found that approximately 60% of responding Swedish municipalities have integrated sustainable consumption into their strategies, action plans, or environmental programs. Most actions are primarily geared towards the municipality's own consumption (public procurement), while 30% of respondents also have actions geared towards households (Axelsson and Dawkins, 2019). Nearly one fourth of respondents had some kind of goal or target for the municipality's own consumption-based climate impact, but the majority did not have any specific target.

Axelsson and Dawkins (2019) also found that 75% of Swedish municipalities need a tool to collect and process consumption-related data to assist them in meeting consumption-based targets. This is echoed by the Swedish Consumer Agency (*Konsumentverket*), who also note that a tool is needed so that municipalities can compare one another as well as understand the current situation against their targets (Konsumentverket, 2017). When developing methods and tools for practitioners, national backing is often needed for permanence (Fred, 2018).

It may be beneficial in deciding what environmental measures to adopt for decision makers to know to what extent the different sectors in society (i.e., households, industry, and government (public procurement)) are responsible for consumption. Municipal policymakers, for example, can control public procurement but have limited control over household or industrial consumption. Specific data may be needed in order to quantify the contribution of different sectors to overall consumption and to design more effective policies.

3 URBAN METABOLISM

Urban metabolism (UM) is the idea that inputs (e.g., materials), transformations (e.g., industrial production), and outputs (e.g., waste, emissions) of the sociotechnical systems in cities can be likened to biological metabolism. The term is attributed to Abel Wolman, who defined the metabolic requirements of a city as "all of the materials and commodities needed to sustain the city's inhabitants at home, at work, and at play," also including the materials needed to build and maintain the city (Wolman, 1965; Bettencourt *et al.*, 2007; Kennedy, Cuddihy and Engel-Yan, 2007; Zhang, Yang and Yu, 2015). We can track the flows of materials, water, or energy in and out of the city (or system) in order to identify possible problems, like water depletion, and solutions, like recycling water, as well as identify relevant stakeholders. Urban metabolism studies can include other spatial scales, like households, neighborhoods or metropolitan areas (Kennedy, Cuddihy and Engel-Yan, 2007; Codoban and Kennedy, 2008; Lenzen and Peters, 2010)

Ferrão and Fernández note that "our cities are the products of global transfers… [and are] the primary engines of consumption in our societies" (Ferrão and Fernández, 2013). This means that to achieve sustainable societies, we must understand cities and their metabolism. The most sustainable urban metabolic system would be closed, as it is in the biological sphere. However, in today's society, new materials are introduced into cities at increasing rates and waste products are not fully recycled or reused (Baynes and Musango, 2018). By analyzing a city's metabolism, it is possible to find key points where resource use can be minimized and loops can be closed (Lavers Westin, 2018).

Initially, UM studies focused on quantifying physical flows within cities like materials, water, or energy (Wolman, 1965; Barles, 2009). These studies have identified the massive additions to "stock" in the built environment of cities as they grow. For example, there are large stocks of construction materials built into buildings and roads. Knowing this, decision makers can utilize the resources available in the city for future construction and renovations (Ferrão and Fernández, 2013; Ferreira and Conke, 2015). Recent studies have linked stocks to their environmental impact and potential impact of replacing these materials (Müller, Liu and Bangs, 2013; Lanau, Herbert and Liu, 2021). UM studies also have drawn attention to the dependence cities have on their surrounding areas, referred to in the literature as the hinterland, and the parasitic nature of cities (e.g., cities do not produce their own goods and instead import goods from and dispose of waste to the hinterland) (Ferrão and Fernández, 2013; Rees, 2018; Bahers, Tanguy and Pincetl, 2020).

In recent years, UM studies have evolved to include analyses of factors such as environmental impact, policy alternatives, and circular economy, to name a few (Kalmykova and Rosado, 2015). The concept of urban metabolism can help researchers and decision makers gain a new perspective on cities, their resource use, and the environmental impacts of consumption. Recent studies have linked UM to sustainability and environmental impact indicators (Goldstein *et al.*, 2013; González-García and Dias, 2019; Maranghi *et al.*, 2020; González-García *et al.*, 2021).

What we see from these studies is that consumption patterns vary among cities; materials and product types consumed in the area will depend on the city's typology. Moreover, cities that by appearance are similar (e.g. Stockholm and Gothenburg which both have similar climates, public transportation accessibility, and more) can have vastly different metabolisms. In fact, these cities show opposite trends in material consumption, where Stockholm appears to be in a state of relative dematerialization while Gothenburg has shown increasing material intensity over the same timespan (Kalmykova, Rosado and Patrício, 2015b). Kalmykova, Rosado, and Patrício also found that the three major metropolitan areas in Sweden, Stockholm, Gothenburg, and Malmö, had different consumption drivers and therefore varying consumption profiles based on their economies (service, manufacturing, or in transition between these two) (2016). Region- or city-specific metabolism data may therefore be crucial to understanding what measures may effectively enable meeting sustainability targets (Bianchi, Tapia and Valle, 2020).

Urban metabolism models are expected to serve decision-makers with data to support evidence-based policy (Kennedy, Cuddihy and Engel-Yan, 2007; Davoudi and Sturzaker, 2017; Villarroel Walker *et al.*, 2017; Longato *et al.*, 2019) and can also be used to assess or predict the success of policies (e.g., (Gunawan and Pusaka, 2016; Kissinger and Stossel, 2021). To understand the metabolism of a city or region, however, vast data quantities are often needed. Material flow analysis (MFA), for example, if performed using bottom-up methodology, may require extensive data collection at the local level, depending on the flow being modeled (Brunner and Rechberger, 2003). A top-down, extrapolation-based MFA, however, may also be data intensive, often relying on national and international statistical databases using assumptions to allocate data to the appropriate region (e.g., Rosado, Niza and Ferrao, 2014). See the subsequent section for a detailed description of MFA.

Urban metabolism studies can be linked to sustainability indicators. However, many sustainability studies (including UM-based ones) focus solely on climate change indicators like GWP. This narrow focus neglects other environmental impacts like acidification, eutrophication, photochemical ozone formation, and resource use (Hertwich and Peters, 2009; Department for Environment Food and Rural Affairs, 2011; Minx *et al.*, 2013; Yetano Roche *et al.*, 2013). One exception to this is Huppes (2006), who also considered multiple environmental impacts like acidification, ozone layer depletion, human- and eco-toxicity. A sole focus on GWP may limit the types of products identified or encourage substitution that may lead to an increase in other impact types.

The challenges to quantifying the environmental impact of consumption are therefore twofold: data availability, and the limited scope of indicators evaluated in traditional UM studies. In this thesis, I aim to expand the environmental indicators addressed and investigate potential simplifications of UM models.

3.1 Material flow analysis

Material flow analysis (MFA) is a method commonly used in the field of UM to quantify the flows (e.g., the flow of goods from producer to consumer to waste facility) within a set boundary based on the law of conservation of mass (Brunner and Rechberger, 2003). This boundary usually is geographical and/or temporal; for example, one can quantify all the material flows within a specific city over one year (economy-wide MFA) (Weidema *et al.*, 2005; Eurostat, 2013). Some have used MFA to map specific materials like critical metals or contaminants within a system e.g. (Arp *et al.*, 2017; Restrepo *et al.*, 2017). MFA can be used to estimate the materials, or products, flowing in and out of a city to understand the metabolism of the area of interest. One measures the input of materials or resources, i.e., imports and domestic production (the transformations of raw and intermediate materials to final goods), and the output (exports and wastes/emissions). Some products have long lifespans and may remain within the boundaries for an extended time, e.g., asphalt, and are considered additions to stock. Others have a short lifespan and are consumed and transformed into waste within the year. These factors are taken into account in an MFA. In this study, we have used data from an existing MFA model that is described in the next paragraph, as well as evaluated the efficacy of a simpler extrapolation technique (see Chapter 5.1 and 5.5).

The Urban Metabolism Analyst (UMAn) model is an MFA model that uses trade, transport, production, and employment data to estimate the total consumption within a metropolitan area. The model quantifies the urban or metropolitan Domestic Material Consumption (DMC) by summing domestic extraction (DE) and imports, and subtracting exports, using transport and trade data. Raw goods or intermediate products are transformed into final goods based on the economic activities found in the area of study. Consumption data therefore include final goods produced locally as well as imported materials in the form of final goods. Figure 1 presents an overview of the UMAn model, and depicts how an urban economy can be viewed as a system and how MFA can quantify it. More information about the UMAn model can be found in Kalmykova, Rosado and Patrício (2015), Rosado, Niza and Ferrao (2014) and Patrício *et al.* (2015).

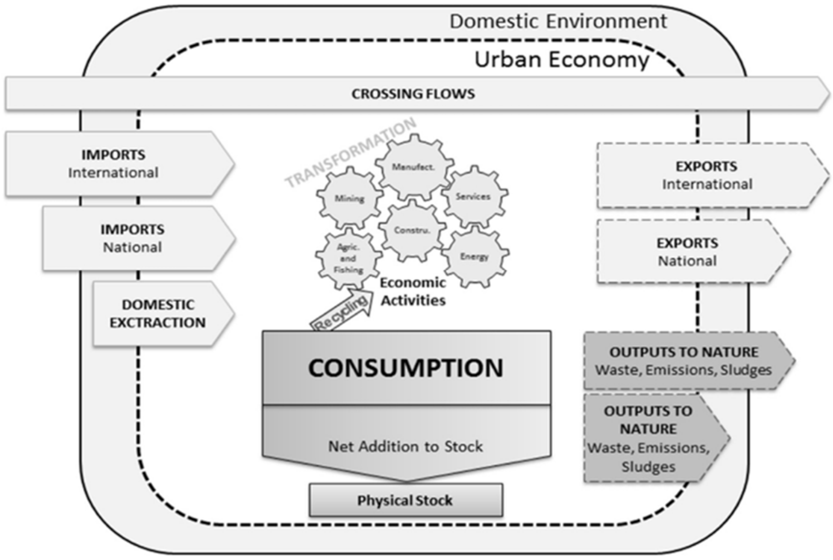

Figure 1. UMAn method, from Kalmykova et al 2015

The UMAn model results for Stockholm, Gothenburg, and Malmö metropolitan areas for 1996-2011 were used for the steps presented in Chapter 5.2.

4 RESEARCH DESIGN

In this section, I present the research design that was implemented to ensure that the data used and interpreted to answer the research questions followed the rules of the scientific method (Byrne, 2017). An overview is presented in Figure 2. Systems analysis, quantitative assessment, and case study research methods were used to achieve the objectives stated in Chapter 1.1. As is common in sustainability research, multiple methods and research tools were necessary (Evans, 2011).

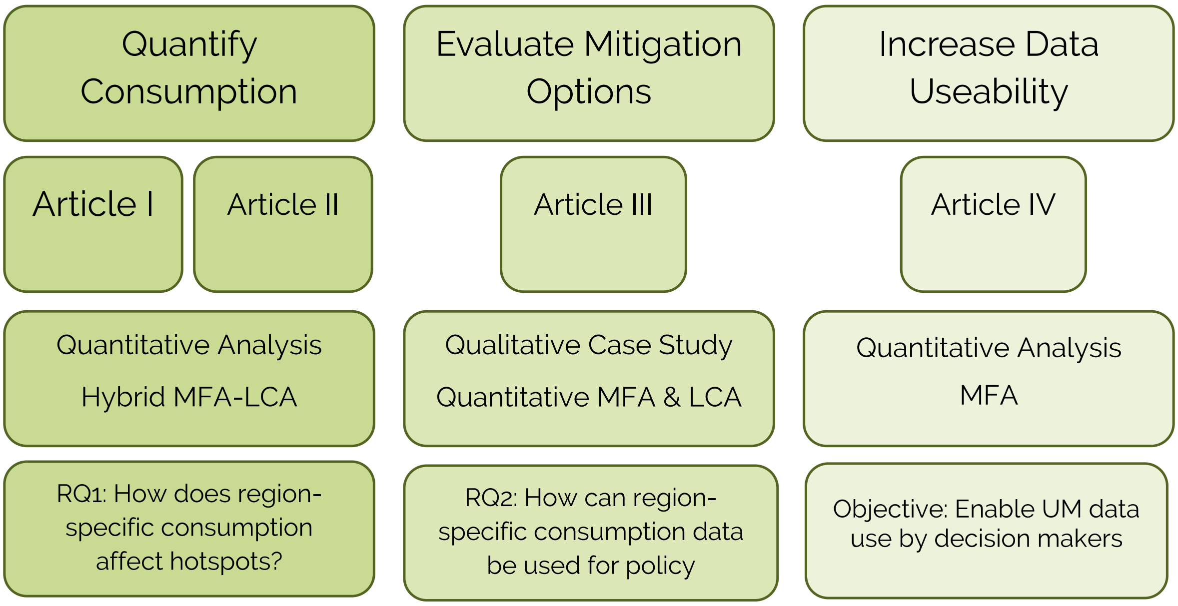

Figure 2. Research design

The research questions were investigated by using systems analysis and quantitative assessment, with a case study aspect which included continuous communication with the stakeholders to evaluate applicability of the method (see Table 2). The first objective was to quantify consumption impacts and identify hotspots; this was done by combining MFA and LCA. These results were used to achieve the second objective, to develop a method to prioritize policies and evaluate potential reductions in consumption and impacts. The work presented in this thesis was carried out in collaboration with the city of Gothenburg, Sweden, as well as with input from other municipal stakeholders in Sweden.

Table 2: Research questions and methods used to approach them

	Literature Review	MFA	LCA	Case study
How does region-specific consumption affect hotspots?	x	x	x	x
How can region-specific consumption data be used for policy prioritization and assessment?	x		x	x

When looking to solve complex problems like sustainability issues, it can be useful to apply "systems thinking" (Van Bueren and De Jong, 2007). Systems thinking is a holistic approach, where relationships within the system are just as important as the components of the system themselves (Hjorth and Bagheri, 2006), i.e., the system is more than the sum of its parts (Skyttner, 2005). Systems thinking and systems analysis have been applied to sustainability and environmental work for several decades; for example, in the influential 1972 report *The Limits to Growth,* in which Meadows and colleagues modeled global resource consumption and production using system dynamics (Meadows *et al.*, 1972). Systems thinking is not limited to environmental questions; it is used in several disciplines including business management and information technology.

Using systems thinking, consumption can be viewed as more than just the act of selecting and purchasing goods. The product consumed is part of a larger picture including raw material extraction, transport, production, and more. Moreover, the reason one product is selected over another is connected to the economic, social and cultural aspects of the surrounding system (Seiffert and Loch, 2005). Systems thinking is a useful tool in mitigating the impacts connected to consumption. Urban metabolism is an example of applied systems thinking.

Studies that intend to aid in the transformation to sustainable societies require stakeholder engagement (Wiek *et al.*, 2012). Moreover, creation of reality-based models and tools that will actually be used by decision makers will be enhanced by inclusion of those decision-makers in the development process. Research that includes practitioners is termed “transdisciplinary research”, which aims to bridge the gap between academia and practice. In transdisciplinary research, practitioners are not only invited to provide feedback, but to participate in the research process itself (Pohl, Krütli and Stauffacher, 2017). Case studies are among the tools used for transdisciplinary research and in social science research to provide descriptive information as well as suggest theoretical relevance (Mills, Durepos and Wiebe, 2013).

This research was conducted to test the concept of using consumption-based environmental impact data to prioritize existing environmental measures, with the intention that the knowledge learned in the case study would be applicable to other regions in the European context. In this thesis, we have used the City of Gothenburg's Environmental Program from 2013 (Göteborgs Stad, 2013) as well as the municipality's Climate Strategy Plan from 2014 (Göteborgs Stad, 2014). There are risks associated with case study research, e.g., results may not be translatable to other geographical areas with different circumstances. To reduce these risks, we also included a workshop to expand the frame of reference to other Swedish municipalities and regions in addition to reference group meetings throughout the project with other actors.

5 METHODS

In this section, I present in detail the methods used to quantify the environmental impact of urban consumption and assess mitigation measures to answer the research questions and meet the stated objectives. First, I describe the MFA consumption data used and how hotspots were defined and identified by combining this consumption data and LCA. Then, I describe how hotspots were used to evaluate mitigation measures using the case study of Gothenburg. Finally, I present some alternatives for identifying which sectors are responsible for consumption and potential methods to extrapolate regional consumption values from the national level to provide decision makers with a simpler calculation method.

An overview of the method is presented in Figure 3. As seen here, the method is built upon consumption data at the product level and the main objectives have been to identify consumption-based environmental impact hotspots (Research Question 1) and use these to evaluate and prioritize mitigation measures (Research Question 2). I have also looked at an alternative approach to assessing the consumption hotspots using a sector contribution analysis. The aim throughout the work has been to work towards useable results for municipal and regional practitioners and decision makers.

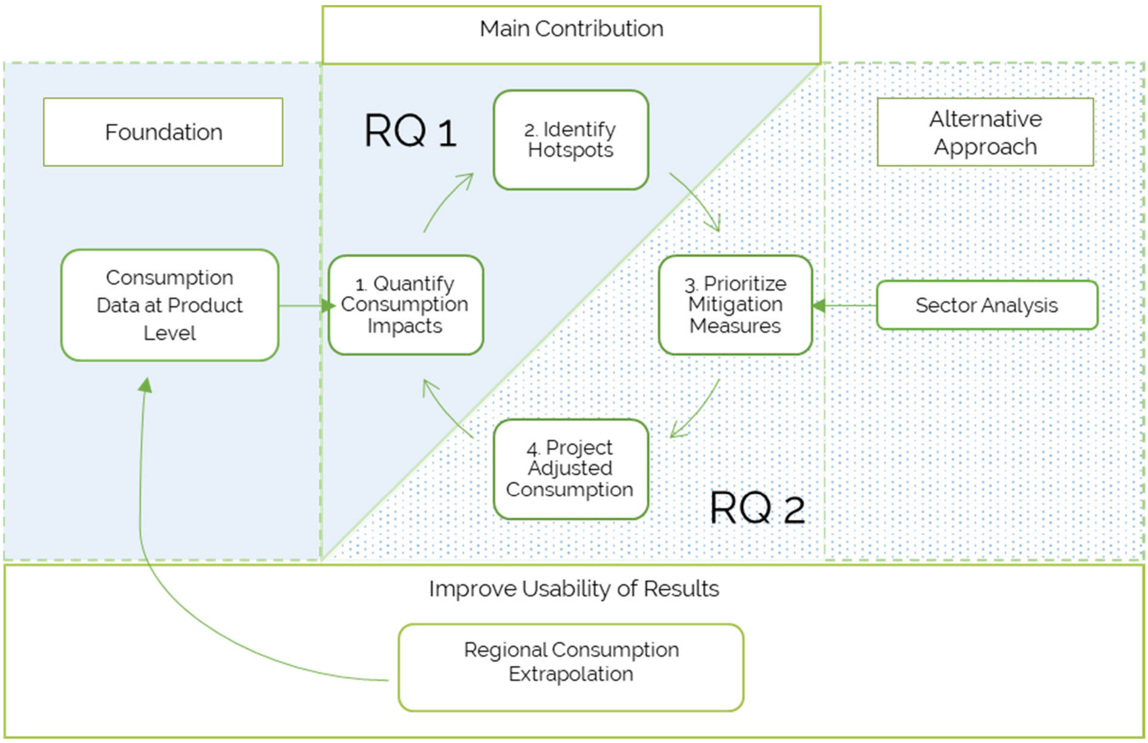

Figure 3: Overview of method steps. Steps 1 & 2 and the areas solid shaded in blue are related to Research Question 1 while steps 3 & 4 and the areas shaded with dots are related to Research Question 2.

A summary of data sources is presented in Table 3 and specific details on the datasets used are described in the following subchapters. Existing MFA results from the UMAn model, as described in Chapter 3, were used for consumption data at the national, county, metropolitan, and municipal level. Life cycle assessment, as described in Chapter 2.1, was used to quantify the environmental impact of consumption. Data sources for the life cycle impact (LCI) profiles came from Sphera's (previously Thinkstep) Ecoinvent database as well as IVL Swedish Environmental Research Institute's proprietary database.

Table 3: Data sources used

Category	Data	Unit	Model or Software	Year	Ownership
MFA	Consumption data at the product level	Kg or tons	UMAn	1996-2011 for Gothenburg, Stockholm Malmö 2000-2011 for Sweden	(Rosado, Kalmykova and Patrício, 2016)
LCA	IVL proprietary LCA Profiles	Impact per kg	GaBi	Varying	IVL Swedish Environmental Research Institute
	Ecoinvent v 3.1 LCA profiles	Impact per kg	GaBi	Varying	Sphera
	Literature including public Environmental Product Declarations or peer-reviewed publications	Impact per kg	Varying	Varying	Varying
Case study	City of Gothenburg environmental plans and programs	--	--	2013, 2018	City of Gothenburg
	Feedback from reference group	- -	--	Throughout	--
	Comments and feedback from workshop with municipal environmental strategists	--	--	2020	--

5.1 Consumption data at the product level

Consumption impact is measured by multiplying the mass of a product or class of products consumed by its impact per unit of mass. Therefore, the first steps are to quantify consumption mass of these products.

Throughout this thesis, I refer to consumption as the consumption of *final goods* in a region. Final goods are products that are either sold or provided in the form of services to the consumer. A consumer can be a private individual (e.g., household), a government entity (e.g., public procurement), or an industry (e.g., a factory purchasing infrastructure for its facilities, *not* the materials it transforms into a final good). Raw materials and intermediate goods are used to produce final goods. However, as some goods are exported beyond the region of interest, these are out of scope. Some raw materials or intermediate goods can also be considered final goods, like flour or plywood, as these are purchased by consumers for their own use. Raw materials can either come from domestic extraction or imports. See Figure 4.

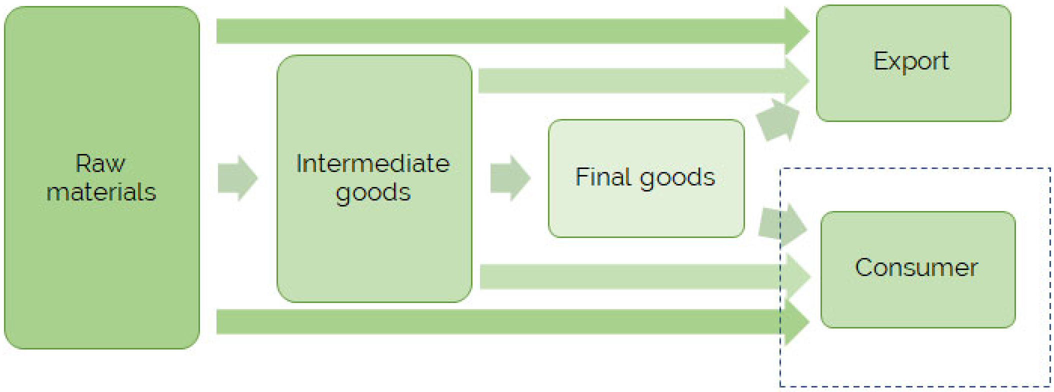

Figure 4. Schematic diagram of the different types of goods. The dashed box indicates which goods are evaluated in this thesis. A consumer can be a private individual, a government entity, or an industry.

The work performed in this thesis relies on data quantified by the economy-wide MFA based UMAn model (described in Chapter 3) and is available for years 1996 to 2011 at the metropolitan level and for years 2000 to 2011 at the national level (Kalmykova, Rosado and Patrício, 2016; Rosado, Kalmykova and Patrício, 2016). The data is organized in accordance with the combined nomenclature (CN), which is a system used widely in the European Union and is almost identical to the harmonized system (HS) used elsewhere. Each product that is handled in trade is given an eight-digit classification number, with each pair of digits adding a level of specificity where the CN-8 (eight digits) is the most detailed level. The first two digits (CN-2) indicate the product category (e.g., 04 is dairy) and the first four digits (CN-4) specify the product type (e.g., 0406 is cheese and curd). The final four digits add specificity (04064050 is Gorgonzola).

There are 95 to 99 CN-2 product categories, depending on the year, an average of thirteen CN-4 product types within each CN-2 product category, and an average of 129 CN-8 products per CN-4 product type. Due to the extrapolation techniques used in the UMAn model and the assumptions made, the CN-8 detailed list of products can have a higher degree of uncertainty. The four-digit CN-4 level (product type) and two-digit CN-2 level (product category) were therefore used in this thesis.

5.2 Quantification of consumption impacts

Once the consumption of different materials and product types has been quantified for the region in question, the impact is estimated using LCA. Figure 5 presents an overview of the steps to quantify impacts and thereby identify hotspots, i.e., product groups with high environmental impacts.

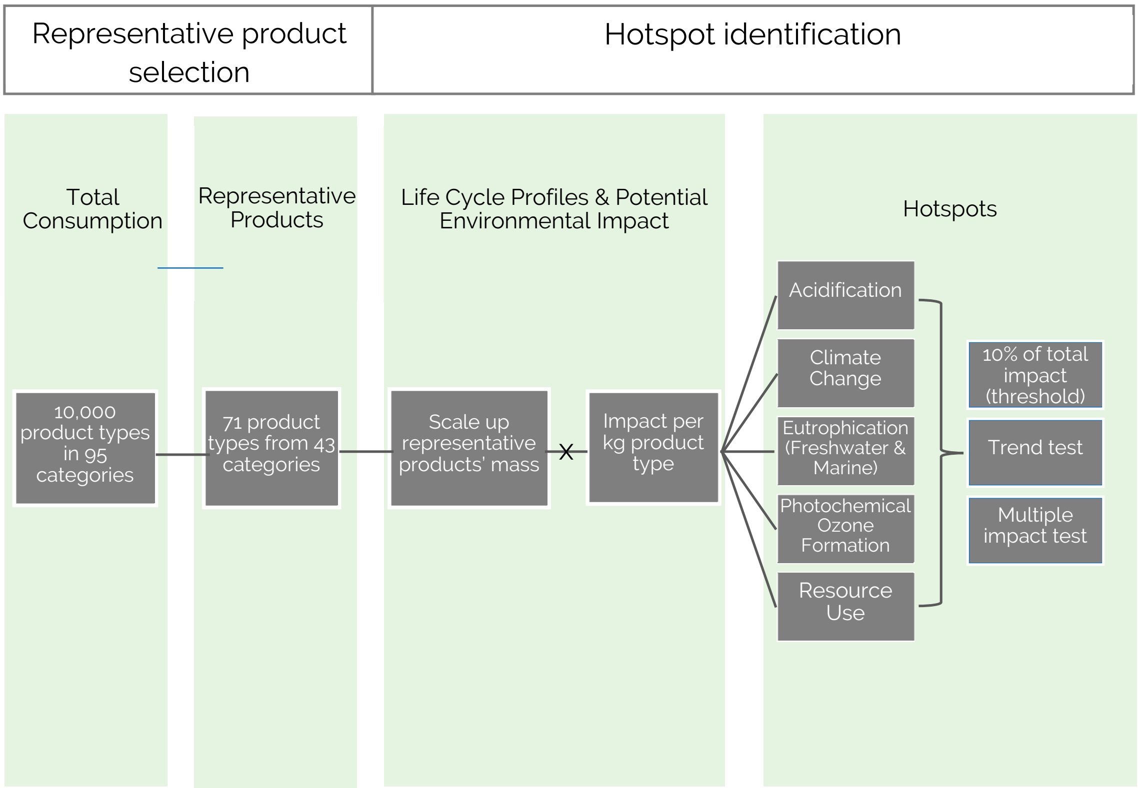

Figure 5. Flow chart of method to find target product groups with high environmental impact ("hotspots") from Lavers Westin et al., 2019.

The steps taken to identify representative products are presented in Section 5.2.1. Section 5.2.2 describes how the representative products were used to quantify the environmental impact of each region.

5.2.1 Identification of representative products

There are thousands of products consumed in a city; however, there are only a limited number of available LCI profiles as they are data intensive and can be expensive to prepare. Representative product types for each product category were therefore identified as proxies for the entire category based on the MFA data and available LCA profiles.

Representative products were selected by the steps presented in Figure 6. See Paper I for more detail. This type of approach has been referred to in the literature as a "basket of products" method, but selection criteria and final product choices have varied (European Commission, 2012; Rydberg *et al.*, 2014; Notarnicola *et al.*, 2017). This study's specific criteria are explained below.

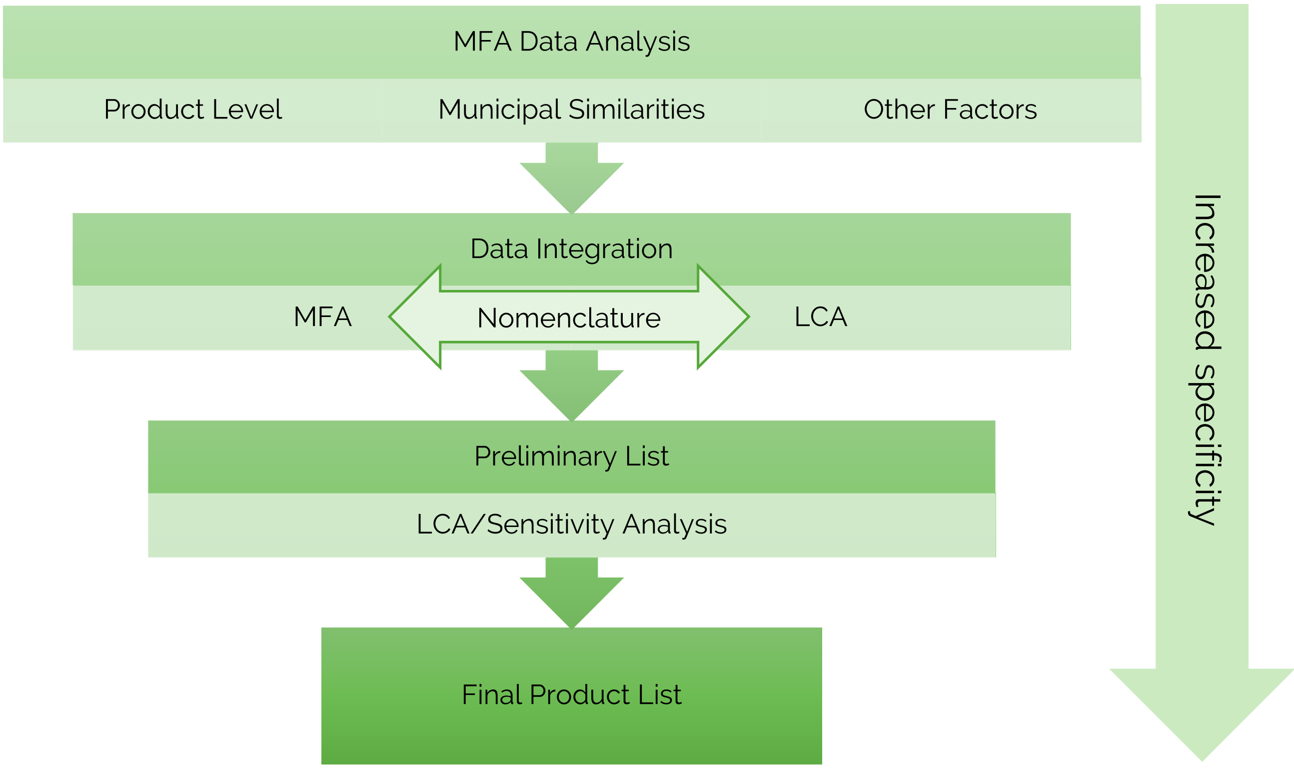

Figure 6. Representative product selection method (from Lavers et al (2019))

First, consumption data were analyzed to identify preliminary representative products. These were defined as product types (CN-4 level) that in the aggregate represented more than 50% of the total mass of products within the corresponding product category (CN-2 level). The preliminary representative products were initially selected according to the following criteria:

- they were consumed in high quantities by mass (at least one of the top five product types annually),
- they were consumed frequently (appeared in the consumption data more than three times over the sixteen-year time span), and
- they were increasing in consumption over time (i.e., not becoming obsolete).
- Products whose product mass was less than 1% of the total consumption were not included in the preliminary list of products.

However, mass is not the only indicator of environmental impact. Products that are lower in mass may still have a high environmental impact. Therefore, products that have been confirmed in the literature as high impact products were added to the list if they were not already present.

The preliminary list of representative products was then matched to a suitable LCI-profile from commercial and proprietary LCA databases based on a top CN-8 product within the CN-4 product type. For example, if the CN-4 code 0804 "Bananas, incl. plantains, fresh or dried" was on the preliminary list based on the criteria above, the top CN-8 product, "Bananas, fresh (excl. plantains)", was matched with the appropriate LCI-profile "Ecoinvent 3.1: GLO - banana production." If a suitable impact profile was not available, a "proxy product" was developed using similar materials or substituted with a different product from the same product category.

To determine if the number of representative products was sufficient for the product category, a sensitivity analysis was performed. The impact results of preliminary representative products selected were compared within each product category. Similar impacts within a product category would indicate that one or two representative products was sufficient but a large difference would indicate the potential need for more representative products.

The consumption results for the three cities were compared to see if the same representative products could be used for all three regions. First, the ratio of the sum of selected CN-4 product types to the sum of the entire CN-2 product category was taken for each city. The products were then ranked, and the rankings were compared. For any product type that differed significantly among the regions (i.e. where the standard deviation in the CN-4:CN-2 product ratios was greater than 0.2) or only occurred in one of the three urban areas, the ratio was taken of mass of the product type to the mass of the respective CN-2 category, to see if the product type contributed a significant amount of mass to the category. If the mass was not significant, the product types that were consistent among the regions were selected. If it was significant, additional representative products may need to be added. For example, the sum of CN-4 product 0401, milk and cream, was 54% of CN-2 product category 4 (dairy) in Stockholm, 50% in Gothenburg, and 58% in Malmö. The standard deviation between these numbers is 0.04, far below the threshold of 0.2. All the product types within product category 4 had standard deviations well below 0.2 so the same representative products were used.

5.2.2 Quantification of environmental impacts

The mass of the representative products was proportionally scaled up to represent the mass of the entire respective category, establishing the mass used for the LCA calculations. In order to scale up, the mass of the representative product was first divided by the total mass of all representative products in the same CN-2 product category. Then, the total mass of all products within a product category was distributed among the representative products according to the ratio of their masses. For example, product category CN27 is fuels. The two representative products used were CN2710 petroleum oils (specifically, diesel) and CN2711 petroleum gas and other gaseous hydrocarbons (specifically, natural gas). In 2011 the annual consumption of fuel in Gothenburg was approximately 2,182,064 tons. Diesel/gasoline represented approximately 83%, and natural gas, approximately 6%, resulting in a total coverage of 89% of fuel consumption in Gothenburg. These percentages were then scaled up proportionally so that the ratio summed to 100%, and the total consumption of fuel was distributed accordingly. The total impact in 2011 was based on the relative ratio of the two representative products (i.e., 2,040,217 tons or 93% diesel/gasoline, and 141,847 tons or 7% natural gas). This process was performed for each product category (43 in total) and geographical region (4 in total). For the product categories with only one representative product, the consumption of the total product category was used.

The software GaBi v7 was used to calculate the potential environmental impacts of consumption based on the representative products' LCI profiles. The cradle-to-gate impact assessment methods recommended by the European Commission Joint Research Centre International Reference Life Cycle Data System (JRC/ILCD) Handbook for climate change, acidification, eutrophication (freshwater and marine), photochemical ozone formation, and resource depletion were used (JRC European commission, 2011). Cradle-to-gate analyses include all impacts from resource extraction through production, but do not include transport to the user, the use phase, nor the waste phase of the product's life cycle. This was to reduce the risk of double counting. For example, gasoline is considered a source of impact in the use phase of a vehicle, but fuel consumption is already accounted for in the consumption data. If the use phase were counted for both vehicles and fuel, the results would be inaccurately high.

The scaled-up annual consumption of each representative product (CN-4 level) was multiplied by its life cycle impact and the results were summed to quantify the environmental impact of consumption of each CN-2 product category. The annual impact as well as the average for all years analyzed were quantified.

5.3 Identification of hotspots

Hotspots are the product groups that drive consumption-based environmental impact. Criteria were set up to identify hotspots based on both MFA (what is the consumption trend?) and LCA (what are the impacts?). Product types with high environmental impact were identified for each region using the three following criteria.

First, ten percent of the average total impact of all product categories (for each impact type) was used as a hotspot threshold, a value that was compared to the average impact value for each product category for all sixteen years studied. Any product category which had impact values above the threshold was selected as a preliminary hotspot. The purpose of the threshold is to enable simple and systematic prioritization of product groups and to ensure that several impact categories can be addressed simultaneously. As noted in Section 3.2 in Paper II, however, the use of a certain percentage threshold to identify hotspots may affect results. A higher percentage will reduce the number of hotspots found, and a lower threshold may identify too many to allow for effective prioritization.

These preliminary hotspots were then compared to the consumption trend of that specific product category, in order to see if a hotspot was forming or fading. For example, if the average impact of articles of iron/steel exceed the 10% threshold for acidification, the consumption over the time span studied was analyzed via a so-called "trend test". If the consumption mass was constant or increasing, the preliminary hotspot remained as such. If the consumption was decreasing, however, the environmental impact for the last year (2011) was analyzed; if the impact exceeded the 10% threshold, it remained a preliminary hotspot, but if it did not, it was removed from the list. Final hotspots are intended to aid decision makers in prioritizing product groups for mitigation. If consumption is already decreasing, measures could be better focused on goods with increasing consumption trends. Finally, if product categories exceeded the threshold and passed the trend test in two or more impact categories, they were considered "final hotspots".

If product categories had maximum values over the time span that exceeded the threshold, but the average value was less than the threshold, they were evaluated to see if they did so in multiple impact categories. The consumption trend was evaluated as well. If consumption trends were increasing and the product category had a maximum value exceeding the threshold in two or more product categories, it was considered to be a "potential future hotspot".

5.4 Prioritization of mitigation measures and projection of changes in consumption

After hotspots were identified, the mitigation measures in Gothenburg's Environmental Action Plan were linked to product categories by going through each measure individually and considering if (1) the measure could be linked to a material flow (product category) and (2) if so, to a hotspot. The measures that were connected to hotspots in Gothenburg as found in Chapter 5.3 were compiled and evaluated as described in this section. See Figure 7 for an overview of the mitigation measure evaluation process and Paper III for a detailed method description.

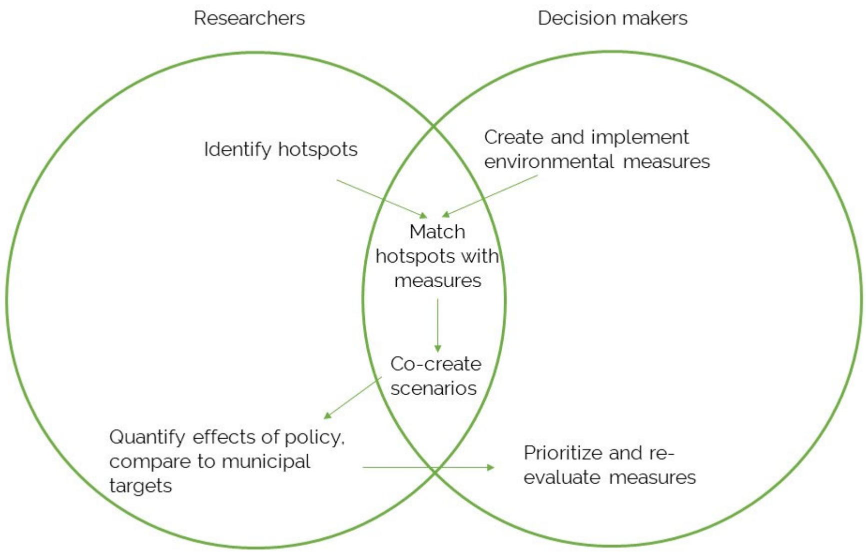

Figure 7: Overview of municipal measure evaluation (revised from Lavers Westin, Kalmykova and Rosado, 2019)

Together with the practitioners from the City of Gothenburg who had planned and designed the measures, scenarios presenting possible results of measures that were related to the hotspots "fuel and personal vehicles" and "electronics" were developed. The scenarios were intended to show different effects that the measures could have on the consumption of hotspot product categories. For example, the scenarios could indicate how many citizens in the municipality would be expected to reduce their consumption of the product as a result of measure implementation.

The Gothenburg Environmental Action Plan included both internal and external measures, where internal measures affected the governing body's own offices (e.g., public procurement) and external measures were intended to enable residents to make more sustainable choices (e.g., providing charging stations for electric vehicles to encourage electric vehicle use). This meant that the scenarios needed to reflect the varying adoption rates of the measures, which depended on their target consumers.

The scenarios' results were intended to show a range of possible outcomes of the measures in terms of reductions in both material flows and impacts over the time span studied (2017-2035). The environmental impacts were then quantified for each product affected by the scenarios by multiplying the expected consumption values (mass) by the appropriate LCI profile. Finally, the results were compared to Gothenburg's consumption-based climate target of 2.0 tons consumption-based CO_2-eq per capita by 2035.

5.5 Regional consumption extrapolation

One aim of this doctoral project was to increase the availability of consumption data to municipal and regional decision makers. The UMAn model is data intensive, so in order to reduce the amount of data required, the possibility to extrapolate regional consumption from national consumption using employee data for the relevant economic activity was evaluated. See Paper IV for a more detailed description.

The UMAn model extrapolates DMC from the county level to the municipal level based on the number of employees working in each economic activity within the region, assuming that these values have a linear relationship. The number of employees was also used to estimate production and domestic extraction (Rosado, 2012; Rosado, Niza and Ferrao, 2014). The number of employees can be linked to waste production as well (Patricio, Kalmykova and Rosado, 2020). Building upon this, the number of employees was evaluated as a potential proxy for consumption. A higher number of employees in a retail store, for example, could indicate higher consumption (sales).

Employee data is collected by national statistics offices and is easily available. To make use of employee data, a link must be established between the number of employees and consumption data. Although there is no readily available direct connection between these values, a potential indirect link is available in some cases using economic activity as an intermediary. In Sweden, employee data is provided using a standard classification system of economic activities; this statistical classification of economic activities in the European Community (NACE) consists of a four-digit code, where the first two digits describe the economic activity category and the second two digits provide more specificity (e.g., NACE category 52 is retail trade, NACE code 5242 is retail sale of clothing). The link between employee data and product consumption is presented in Figure 8 and described in the text below.

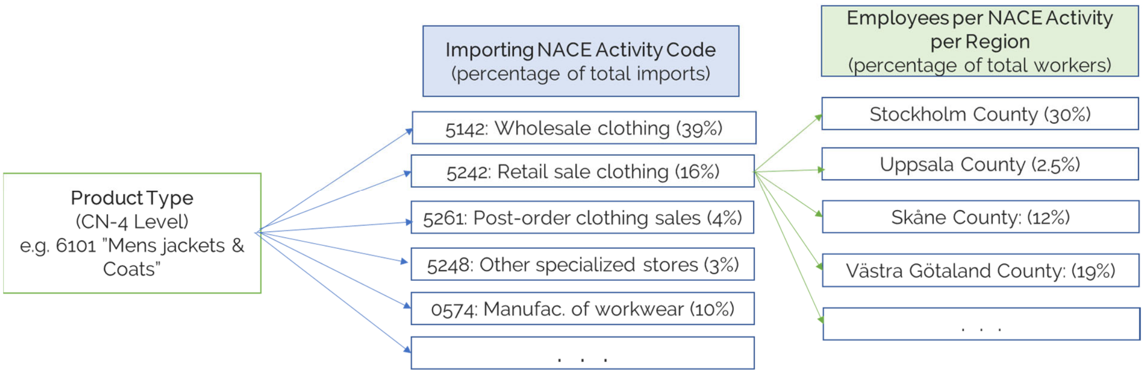

Figure 8: Example linkage between employee data and product types using NACE codes using 2010 data.

National statistics offices like Statistics Sweden collect data on the number of employees working in each NACE category at the municipal, county, and national scale. Using these data, it was possible to calculate an Employee Ratio, defined as the number of employees in each NACE code in each region divided by the total number of employees nationally in that NACE code, see the number in parentheses under "Employees per NACE activity per Region" in Figure 8. The Employee Ratio could then be used to extrapolate the national consumption for all product types to the appropriate region as follows.

Product types at the CN-4 level were linked to NACE economic sectors using international trade data. Since trade data includes information on which NACE codes import which CN products, this information can be used to connect the two in some cases. As in the example in Figure 8, CN product category 6101, "men's coats and jackets" was imported by several NACE categories in 2010. Not all importing sectors were considered, however. For example, wholesale companies are often centralized and not located in all regions, but they are often responsible for importing goods. Moreover, wholesale companies are unlikely to be the final destination of final goods. Results would likely be misleading if national consumption was extrapolated to the regional level using values based on wholesale imports. Wholesale employees were therefore excluded from this analysis. Most CN codes were imported by several NACE codes. In these cases, the mass of the CN-4 was allocated to each NACE code using the import ratios. We assume that domestically produced goods mirror the import ratios for imported goods of the same type.

To investigate this extrapolation method, approaches were tested as shown in in Figure 9.

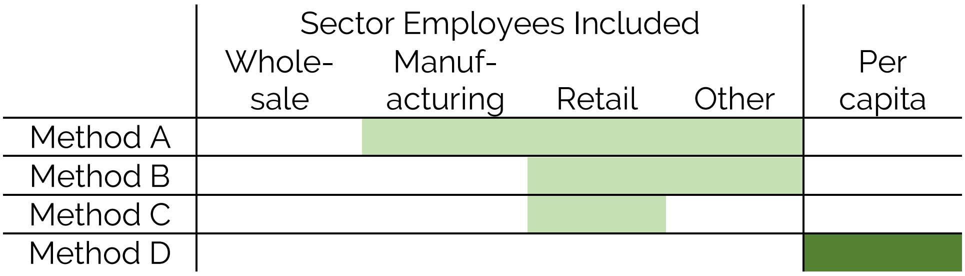

Figure 9: Overview of extrapolation methods

Three approaches were investigated and compared to per capita extrapolations as well as to reported values:

- Method A: Use all economic sectors except wholesale (i.e., use all NACE codes except for those in category "51")
- Method B: Use all economic sectors except wholesale and manufacturing (i.e., use all NACE codes except for those in categories "01" through "36" and "51").
- Method C: Use only retail economic sectors (i.e., any NACE codes in categories "50" or "52")

Estimations using per capita values were called "Method D."

To quantify the consumption in a region using the Employee Ratio, the country DMC in tons of each CN-4 product type was first multiplied by the mass fractions going to each economic sector (NACE code) to quantify the product's consumption per NACE code. Then, the DMC for each NACE code was multiplied by the Employee Ratio for each NACE code in each region. Finally, consumption in each region was summed for each CN-4 product type (one CN-4 may have gone to multiple NACE codes).

This analysis was performed first at the county level, and then at the municipal level. All 22 Swedish counties and 27 of Sweden's 295 municipalities were analyzed. Municipalities in Sweden are categorized by the Swedish Association of Local Authorities and Regions (SALAR) into nine groups based on structural parameters like population and commuting patterns; three municipalities were chosen from each category, including at least one municipality from each county.

The extrapolation results were compared to reported values of specific goods to evaluate the accuracy of the different methods. Reported values were available for wine, personal vehicles, and fuel and these categories were therefore selected for analysis.

5.6 Sector contribution analysis

To estimate the contribution of each sector to total consumption, four approaches were considered. Each approach targeted one of the different sectors to try to find the fraction of total consumption that the sector was responsible for. All approaches would require a conversion from either currency to mass using, e.g., assumed masses for different product types and average cost per kg of product to be compatible with LCI profiles.

The first approach used public spending data to quantify how much of consumption is governmental (i.e., public procurement). For example, Gothenburg categorizes monthly spending by administrative office and standardized cost center (e.g., “food”, “IT-service”, “transport”). These databases are available to the public due to the Swedish “principle of public access,” but are currently limited to years 2016-2018. The databases are Excel spreadsheets that list the date and SEK value of the financial transaction for each vendor.

The second approach quantified public functions to find the public sector’s consumption. The city and region are divided into administrative departments, which aim to meet the city’s legal requirements (e.g., provide education, public transportation, healthcare, etc.). We considered using workshops or surveys to identify product types and categories associated with each office and/or function as well as the estimated quantities of annual consumption. This would then be compared to the total consumption in the municipality to understand how much of the total consumption was associated with public procurement.

The third approach assessed household consumption. The household budget survey (HBS) that is collected approximately every 5 years could provide insight on the contribution of household consumption to total consumption. The HBS is a survey in which survey participants answer how much they have spent on different categories (using the classification of individual consumption by purpose, or COICOP) over a certain amount time. This data requires harmonization between the COICOP and CN nomenclatures in addition to currency to mass conversion.

Assuming that the fraction of household and government consumption could be identified, industrial consumption could be found simply via mass balance, given that total consumption is the sum of household, government, and industrial consumption.

5.7 Data usability

Practitioners from several organizations provided regular feedback during the work performed in this thesis as described in Chapter 5.4. Additional practitioners were consulted via a workshop held on November 12, 2020 with 18 practitioners from 8 different municipal environmental offices and three environmental organizations in Sweden. The workshop had two goals: (1) demonstrate to practitioners the capabilities of the developed methods and data and (2) get feedback on the method and suggestions for improving its usability.

First, participants were invited to answer a questionnaire (see Appendix C for the list of questions) one week prior to the workshop. In the workshop, participants were presented with an overview of the method and the consumption-based environmental impact hotspots for Stockholm, Gothenburg and Malmö. The attendees provided input on:

- If and how they work with consumption-based impacts today
- If there is a need for a consumption-based impact calculator or tool
- If region-specific data is important to practitioners or if per capita data would suffice
- If a tool would be more useful in the planning/targeting of measures or to follow-up on the impact that measures had
- If hotspots are relevant for policy work, and if so, how?
- If sector-specific consumption is more relevant than total consumption (i.e., government, household, or enterprise/industry)

5.8 Assumptions and limitations

As mentioned in Chapter 4 there are risks and limitations to viewing cities as systems. Any assumption can have diverse impacts on the results, and it is important to have these limitations in mind when interpreting the results. The main assumptions and limitations are:

Consumption data

- The consumption data used is based on the UMAn model results, which uses national level and regional level data. The assumptions and limitations of the UMAn model are applicable to this study as well. For this reason, all hotspots are stated at the CN-2 level, where data is not as sensitive (see Chapter 5.1), and not at the more specific sublevels.

- Consumption data for Stockholm, Gothenburg, and Malmö is based on metropolitan data; it is assumed that metropolitan area consumption is the same as the municipality in question as the economies are connected.
- Increasing consumption may not be reflected in increasing mass if goods become lighter (e.g., plastic replaces metal in manufactured products).

Impact assessment

- Representative products are assumed to have environmental characteristics that are similar or within the same range as the other products within the product category and can therefore serve as proxies. The accuracy of this assumption is dependent on the heterogeneity of the product group and the share (by mass) of the representative product. Multiple representative products were used in certain categories to reduce the effect of such variation.
- Representative products that were used for the cities were assumed to be appropriate at the national level.
- The consumption impact is based on cradle-to-gate, rather than cradle-to-grave, LCA-data and thus only the upstream impact of the consumption (and not the use or end-of-life phases) are considered.
- The LCA datasets used were generic and static, and did not provide region-specific data. This means that the specific environmental performance that may vary between regions of production will not be seen in the results. The variability is unlikely to be so extreme as to render the data unsuitable for hotspot identification.
- Some of these assumptions and limitations may lead to over- or underestimation of environmental impacts of the respective product category, and therefore should be kept in mind during the interpretation phase.
- There is a risk of error propagation; if there are errors in the UMAn model or in the LCA profiles, the errors are multiplied as single product types represent parts of, or in certain cases, an entire product category.

Hotspot identification

- The 10% threshold can be seen as arbitrary, but enables filtering of results. Future users may select their own threshold.
- The impacts analyzed are specifically relevant to ecological sustainability as social sustainability is not addressed.

Modeling

- While viewing cities as systems and sustainability as a systems issue, we must be aware of the limitations of this approach and the risks of oversimplification. Sustainability and sustainable development have been referred to as "wicked problems" (Kovacic and Sousa-Poza, 2013; Yearworth, 2016), in which, among other aspects, there is no "right" solution and the problem definition is perspective-dependent.
- The accuracy of the scenario modeling is dependent on the assumptions made.
- The assessment of the various consumption extrapolation methods is limited by the availability of reported values for consumed goods.

5.9 Study area

In this thesis, the results for Sweden as a whole, and the metropolitan areas of Stockholm, Gothenburg and Malmö individually are presented. The metropolitan regions are comprised of several municipalities: 26 in Stockholm, 13 in Gothenburg, and 12 in Malmö, with populations of 2.370.000, 1.040.000, and 740.000, respectively. Sweden has a population of approximately 10.300.000. All three metropolitan areas have shown growing trends in both population and GDP over the past three decades. As mentioned above, the municipalities within each metropolitan area are assumed to share the same consumption patterns as the region of which they are a part.

A municipality can be comprised of a single city or multiple cities. The benefit of using a municipality is that there is a suitable scale for action given that it has an administrative boundary and its own governance and agenda, and is required to report to the national level. The municipality of Gothenburg was used for the majority of the case study work. A larger selection of Swedish municipalities was used for the consumption extrapolation methods. The country and municipalities described in this thesis are meant to showcase the methods and present the potential output of hybrid MFA-LCA. The methods, however, are intended to be useful for any region at any scale (national, regional, urban) with appropriate data.

Several stakeholders were involved in the realization of this thesis; these include practitioners from the City of Gothenburg administrative offices (including the environmental, traffic, education, procurement, properties, waste and water administrations) in addition to the Swedish Environmental Protection Agency (*Naturvårdsverket*).

6 RESULTS

In this section, a summary of the main results for each research question are presented first, followed by an in-depth description.

6.1 Quantification of consumption impacts

RQ1: How does region-specific consumption affect hotspots?

6.1.1 Main results

- Region-specific consumption-based hotspots were identified for Stockholm, Gothenburg, and Malmö metropolitan areas and Sweden as a whole using seventy-one representative products from forty-three product categories.
- Hotspots varied among the metropolitan areas, which also differed slightly from the national-level results. Fuel and electronics were hotspots in all areas.
- Environmental impact per capita varied among the geographical areas investigated.
- Inclusion of more than one environmental indicator affected hotspot identification; i.e., looking at more than just climate change was significant.

6.1.2 Representative Products

Of the possible total 99 product categories in the combined nomenclature, 43 gave rise to 99% of the total mass of consumption or were known to include high-impact goods and were used to identify representative products. In a majority of cases, one or two product types represented 50% or more by mass of the entire product category. The remaining 56 categories had low consumption by mass and did not include known high-impact product types (e.g. CN97 "works of art, collectors' pieces and antiques" or CN45 "cork and articles of cork", which comprised less than 0.01% of the total consumption by mass. Preliminary representative products were compared for the three urban areas evaluated. The results show that 64% of the product categories shared identical top five products, although some had different rankings. Those that were not completely identical shared 80% similarity, i.e. four of the top five products were shared across the urban areas.

A comparison of the ratios of the mass of the CN-2 categories to the mass of the CN-4 product types within each category showed very similar results for all three urban areas across all categories. The preponderance of product types (99%)

have similar relative ratios, which indicates that that consumption patterns are similar enough to share representative products. For example, product type 0403 (buttermilk, curdled milk and cream, yogurt, kephir and other fermented or acidified milk and cream), comprises 20% of category 04, dairy, in Stockholm, 21% in Malmö, and 23% in Gothenburg. The total mass of the 12 product types where the standard deviation was greater than 0.2 was approximately 0.5% of total consumption, indicating that these are not significant product types.

The same representative products were therefore selected for all areas analyzed; see Appendix A for the complete list of representative products. In total, 71 representative products were used to represent the consumption in Stockholm, Gothenburg, Malmö and Sweden as a whole.

The ten product categories with the highest impact per kilogram for each impact category (based on the representative products selected) are presented in Table 4. The top-ranking products show some variation among the impact types, although electronics appears to have the highest impact per kg in all but one category (it is ranked second in marine eutrophication).

Table 4: Top ten product categories with respect to impact per kilogram for each impact category

Climate Change (kg CO_2-eq)	**Acidification (mol H+-eq)**	**Eutrophication – Freshwater (kg P-eq)**	**Eutrophication – Marine (kg N-eq)**	**Photochemical Ozone Formation (kg NMVOC-eq)**	**Resource Use kg Sb-eq)**
Electronics	Electronics	Electronics	Meat	Electronics	Electronics
Machinery/ appliances	Meat	Machinery/ appliances	Electronics	Machinery/ appliances	Machinery/ appliances
Meat	Machinery / appliances	Technical instruments	Machinery/ appliances	Meat	Technical instruments
Textiles	Textiles	Meat and edible meat offal	Dairy	Textiles	Vehicles
Aluminum and articles thereof	Aluminum and articles thereof	Textiles	Furniture	Aluminum and articles thereof	Aluminum and articles thereof
Toys/ sports equipment	Dairy	Toys/sports equipment	Fish	Toys/sports equipment	Furniture
Pharmaceutical products	Toys/sports equipment	Aluminum and articles thereof	Processed meat or fish	Vehicles	Ceramic products
Dairy	Fish	Fish	Textiles	Printed books/ newspapers	Meat and edible meat offal
Technical instruments	Technical instruments	Vehicles	Animal/ Vegetable Oil	Technical instruments	Toys/sports equipment
Printed books/ newspapers	Vehicles	Printed books/ newspapers	Cereals	Dairy	Textiles

As seen in Table 4, many products have varying placement in the top ten product categories (depending on impact type). It is also apparent that looking at multiple indicators is key to avoid burden shifting. For example, fish may be recommended as a “carbon-friendly” replacement for meat, but that could lead to increased acidification or eutrophication.

6.1.3 Quantification of region-specific environmental impacts

The scaled-up annual consumption (in kg) of each representative product was multiplied by the life cycle impact per kilogram to quantify the environmental impact of consumption in each metropolitan area as well as at the national level. Average total annual impact for each impact type for years 1996 to 2011 per metropolitan region and for years 2000 to 2011 for Sweden is presented in Table 5; average annual per capita impact values are presented in Figure 10.

Table 5: Average total annual impact per geographic region and impact type

Region	Climate Change (kg CO_2-eq)	Acidification (mol H+-eq)	Eutrophication – Freshwater (kg P-eq)	Eutrophication – Marine (kg N-eq)	Photochemical Ozone Formation (kg NMVOC-eq)	Resource Use kg Sb-eq)
Stockholm	$1.3X10^{10}$	$1.4X10^{8}$	$1.4X10^{7}$	$2.3X10^{7}$	$6.0X10^{7}$	$4.4X10^{6}$
Gothenburg	$7.9X10^{9}$	$9.3X10^{7}$	$1.2X10^{7}$	$1.2X10^{7}$	$3.8X10^{7}$	$3.2X10^{6}$
Malmö	$7.8X10^{9}$	$8.1X10^{7}$	$7.1X10^{6}$	$1.5X10^{7}$	$3.0X10^{7}$	$2.0X10^{6}$
Sweden	$9.1X10^{10}$	$1.0X10^{9}$	$1.0X10^{8}$	$1.6X10^{8}$	$4.0X10^{8}$	$3.2X10^{7}$

As seen in Table 5 and Figure 10, per capita values vary to some extent among the geographical areas investigated. Malmö, for example, has the highest per capita values for climate change, acidification, and marine eutrophication, but Gothenburg has the highest per capita values for freshwater eutrophication and resource use.

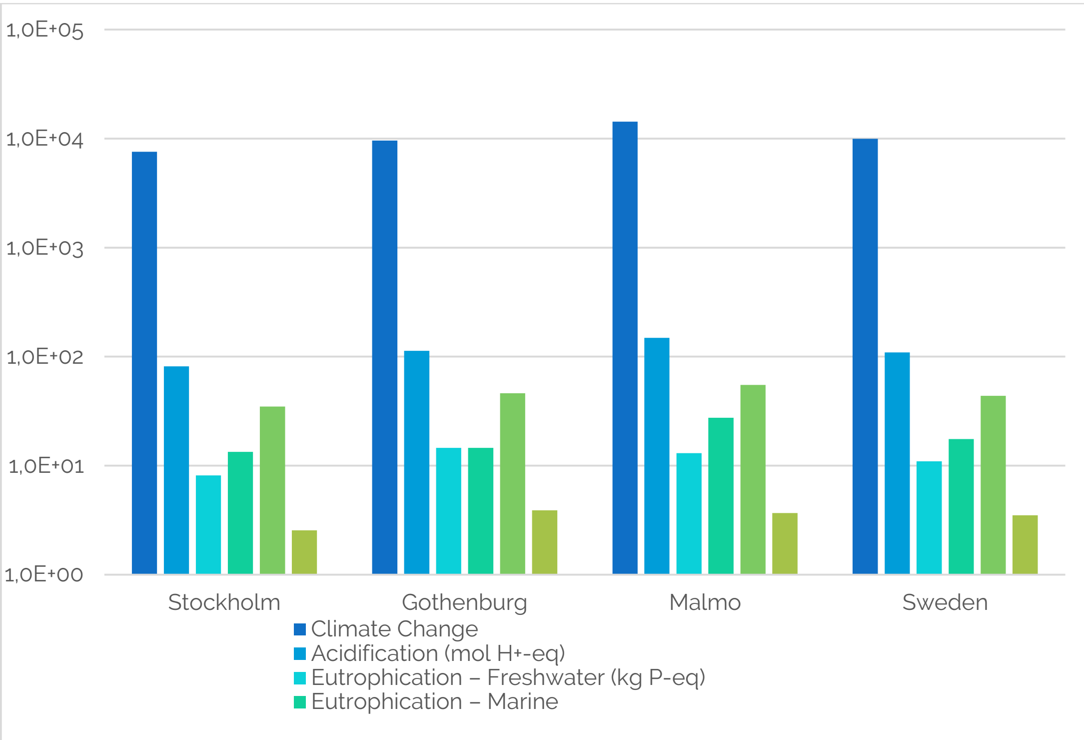

Figure 10: Average per capita annual impact per geographic region and impact type

6.1.4 Hotspot identification

Using the three criteria described in Chapter 5-3, hotspots were found for Stockholm, Gothenburg, Malmö, and Sweden. Table 6 presents the product categories exceeding the 10% threshold per environmental impact type in each geographical region, and Table 7 shows the potential hotspots based on the maximum impact values and the hotspot criteria. The final and potential future hotspots (those with increasing consumption trends) are presented in Table 8.

Table 6: Product categories exceeding the 10% threshold per region and impact type, ranked by the percentage of each total impact type, based on average impact over the time span studied

Environmental Impact Category	Stockholm	Gothenburg	Malmö	Sweden
Climate change	Fuel (17%) Electronics (11%) Machinery (11%)	Electronics (19%) Machinery (17%) Fuel (15%) Vehicles (14%)	No product category exceeded the 10% threshold.	Electronics (22%) Fuel (12%) Machinery (12%)
Acidification	Fuel (21%) Electronics (21%)	Electronics (35%) Fuel (16%) Machinery (12%)	Electronics (19%) Meat (14%) Dairy (12%) Fuel (10%)	Electronics (32%) Fuel (14%) Meat (12%)
Eutrophication – Freshwater	Electronics (52%) Machinery (20%)	Electronics (64%) Machinery (20%)	Electronics (54%) Machinery (15%)	Electronics (58%) Machinery (20%)
Eutrophication – Marine	Meat (19%) Electronics (14%) Processed meat (12%) Furniture (10%) Fuel (10%)	Electronics (26%) Meat (18%)	Meat (26%) Dairy (17%) Processed meat (11%)	Meat (26%) Electronics (14%) Furniture (13%)
Photochemical Ozone Formation	Fuel (29%) Electronics (14%) Machinery (10%)	Fuel (24%) Electronics (24% Machinery (15%) Vehicles (13%)	Fuel (17%) Electronics (13%)	Electronics (25%) Fuel (21%) Machinery (11%)
Resource Use	Electronics (29%) Technical instruments (24%) Vehicles (23%) Machinery (12%)	Electronics (40%) Vehicles (30%) Machinery (15%)	Vehicles (27%) Electronics (26%) Technical instruments (18%)	Electronics (46%) Vehicles (15%) Machinery (14%) Technical instruments (13%)

Although fuel did not appear as a top contributor per kg in Table 4, it is a significant contributor when looking at total consumption, as seen in the results for climate change, acidification, and photochemical ozone formation.

Table 7: Preliminary hotspots based on average impact values for Stockholm, Gothenburg, Malmö and Sweden

Region	Preliminary hotspots CN-2 code and name		Impact category exceeded	Consump-tion trend	Trend test*	Multiple impact categories	Final hotspot
Stockholm	02	Meat	Eutrophication marine	Constant	N/A	✗	✗
	16	Processed meat	Eutrophication marine	Constant	N/A	✗	✗
	27	Fuel	All	Increasing	N/A	✓	✓
	84	Machinery	All but acidification	Constant	N/A	✓	✓

Region	Preliminary hotspots CN-2 code and name		Impact category exceeded	Consump-tion trend	Trend test*	Multiple impact categories	Final hotspot
	85	Electronics	All	Decreasing	✓	✓	✓
	87	Vehicles	Resource use	Increasing	N/A	✗	✗
	90	Technical instruments	Resource use	Constant	N/A	✗	✗
	94	Furniture	Eutrophication marine	Slightly increasing	✓	✗	✗
Gothenburg	02	Meat	Eutrophication marine	Constant	N/A	✗	✗
	27	Fuel	Climate change, acidification, photochemical ozone formation	Increasing	N/A	✓	✓
	84	Machinery	All	Slightly decreasing	✓	✓	✓
	85	Electronics	All	Slightly decreasing	✓	✓	✓
	87	Vehicles	Climate change, photochemical ozone formation, resource use	Increasing	N/A	✓	✓
Malmö	02	Meat	Acidification, eutrophication marine	Decreasing	✗	✓	✗
	04	Dairy	Acidification, eutrophication marine	Decreasing	✗	✓	✗
	16	Processed meat	Eutrophication marine	Decreasing	✗	✗	✗
	27	Fuel	Acidification, photochemical ozone formation	Increasing	N/A	✓	✓
	84	Machinery	Eutrophication freshwater	Constant	N/A	✗	✗
	85	Electronics	Acidification, eutrophication freshwater, photochemical ozone formation, resource use	Slightly decreasing	✓	✓	✓
	87	Vehicles	Resource use	Increasing	N/A	✗	✗
	90	Technical instruments	Resource use	Slightly decreasing	✓	✗	✗
Sweden	02	Meat	Acidification, eutrophication marine	Constant	N/A	✓	✓
	27	Fuel	Climate change, acidification, photochemical ozone formation	Constant	N/A	✓	✓
	84	Machinery	Climate change, eutrophication freshwater	Constant	N/A	✓	✓
	85	Electronics	All	Slightly decreasing	✓	✓	✓

Region	Preliminary hotspots CN-2 code and name		Impact category exceeded	Consump-tion trend	Trend test*	Multiple impact categories	Final hotspot
	87	Vehicles	Resource use	Slightly increasing	N/A	✗	✗
	90	Technical instruments	Resource use	Slightly decreasing	✓	✗	✗
	94	Furniture	Eutrophication marine	Constant	N/A	✗	✗

*The trend test was only performed for product types with a decreasing trend N/A = not applicable

Using the criteria presented in Table 7, Stockholm's eight preliminary hotspots were reduced to three, Gothenburg's five preliminary hotspots were reduced to four, Malmö's eight preliminary hotspots were reduced to two, and Sweden's seven hotspots were reduced to four. The final hotspots and potential future hotspots are presented in Table 8.

Table 8: Final list of hotspots and potential future hotspots for all regions

	Final hotspot	Potential future hotspot
Stockholm	CN27 fuel CN84 machinery CN85 electronics	CN76 aluminum CN87 vehicles
Gothenburg	CN27 fuel CN84 machinery CN85 electronics CN87 vehicles	CN49 printed books/newspapers CN76 aluminum
Malmö	CN27 fuel CN85 electronics	CN87 vehicles
Sweden	CN02 meat CN27 fuel CN84 machinery CN85 electronics	None

Fuel and electronics are shared hotspots in all regions. Vehicles are a hotspot in Gothenburg, and a potential future hotspot in Stockholm and Malmö. Potential future hotspots are based on increasing consumption trends over the time span analyzed.

6.2 Mitigation option evaluation

RQ2: How can region-specific consumption data/hotspots be relevant/used for policy prioritization and assessment?

6.2.1 Main results

- Mitigation measures were successfully coupled to material flows and their environmental benefit, i.e., potential impact reduction, quantified.
- The mitigation measures evaluated for the Gothenburg municipality's hotspots would not be enough to meet the city's own climate targets.
- Including several environmental impact types affected measure prioritization.

6.2.2 Measure evaluation

The measures in the 2013 Gothenburg Environmental Action Plan were matched with product types and evaluated in various scenarios projecting potential outcomes of measure implementation; the projected reductions in environmental impacts coupled to the scenarios were compared to the city of Gothenburg's target of 3.5 tons CO_2-eq by 2035 (a significant reduction from the city's own evaluation of 8 tons per capita or this study's estimation of 9.6). Most of the measures were not written in a way to be quantified. It was possible, however, to link 31% of measures to quantifiable product categories, and of these, 44% were related to hotspots. See Appendix B for a complete list of measures and corresponding product categories. For example, Measure 45 "Facilitate electric vehicle charging for housing in multi-family houses" was linked to both product categories CN87 vehicles and CN27 fuel. The mitigation measures that were connected to hotspots fuel, personal vehicles, and electronics were assessed.

Two sets of scenarios were evaluated. The first set of scenarios assessed measures related to fuel reductions; the results are presented in Table 9. As shown here, Scenario 3 had the greatest success in reducing all three impact types evaluated. This was, however, the most restrictive and least likely scenario to be achievable according to the stakeholders consulted.

Table 9: Impact reductions for fuel scenarios

Scenario	Brief Description	Kg CO2-e per capita		Relative Reduction		
		In 2017	In 2035	Climate Change	Acidification	Eutrophication
Scenario 0	Business as usual	780	529	−33%	−1%	−0.1%
Scenario 1a	Low increase in electric vehicles	780	522	−34%	−2%	−1%
Scenario 1b	High increase in electric vehicles	780	316	−60%	−7%	−9%
Scenario 2a	20% reduction in km traveled	780	423	−46%	−21%	−20%
Scenario 2b	50% reduction in km traveled	780	280	−65%	−48%	−47%
Scenario 3	50% reduction in km traveled, no increase in vehicle fleet	780	213	−73%	−86%	−86%
Scenario 4	(1a) combined with (2a)	780	305	-61%	-25%	-27%

The results also showed the importance of considering multiple impact types. For example, several scenarios showed similar reductions of climate change impact but there were significant differences in acidification and eutrophication reduction among the scenarios. Had only climate change (GWP) been considered, Scenarios 1b, 2b, and 4 would have been seen as similarly effective. By considering acidification and eutrophication, however, Scenario 2b would be far more effective than scenarios 1b or 4. Scenarios that solely focused on an increase in electric vehicles had negligible reductions in acidification and eutrophication impact categories whereas scenarios that encouraged a modal shift and reduction in km traveled resulted in significantly higher reductions in these two impact types.

The second set of scenarios evaluated the potential for extended lifespans of electronics (specifically, laptops, mobile phones, tablets, and monitors were evaluated) to reduce the environmental impact. In Table 10 it can be seen that there would be similar relative reductions in climate change and eutrophication for municipality owned and privately owned electronics, but acidification reductions would be significantly higher if privately owned devices had extended lifespans. The overall reduction in all three impact categories is approximately ten times higher if households extend lifespans of electronics than if only municipality owned electronic devices are targeted.

Table 10: Lifespan extension impact results.

Scenario	1: Only Municipality-Owned Electronic Devices	2: Only Privately-Owned Electronic Devices in the City
	Climate impact, kg CO_2-eq /capita per year	
Short lifespan (business as usual)	3.3	33
Long lifespan	2.5	24
Relative reduction in annual impact, %	**−25%**	**−29%**
	Acidification, mol H^+-eq/capita per year	
Short lifespan (business as usual)	0.17	0.28
Long lifespan	0.13	0.19
Relative reduction in annual impact, %	**−19%**	**−31%**
	Eutrophication, g P-eq/capita per year	
Short lifespan (business as usual)	2.3	21
Long lifespan	1.8	15
Relative reduction in annual impact, %	**−24%**	**−25%**

6.3 Regional consumption quantification

Objective: Enable use of data by decision makers

6.3.1 Main results

- Per capita extrapolations were more accurate than extrapolations using sector employees to estimate product consumption at the county level.
- Extrapolations of total consumption at the municipal level using sector employees had varying accuracy. Further research is necessary.

6.3.2 Extrapolation results

Product types were linked to NACE economic sectors using international trade data. Methods A, B, and C each examined a specific set of sectors for which the Employee Ratio was used to extrapolate total consumption to regional consumption. Method D used per capita values for the same purpose. The consumption estimations at the county and municipal level using each method were compared to reported values of consumption of personal vehicles (CN code 8703) and fuel (CN code 2710). Reported values for wine (CN code 2204) were available at the county level only. A summary of the results is presented in Table 11.

Methods using the Employee Ratio varied in similarity to per capita estimates when comparing to reported values for fuel, personal vehicles, and wine. The accuracy of the methods varied among municipalities, but there was no correlation between municipality or county population size and accuracy. On average, per capita estimations best matched reported values at the county level. At the municipal level, Method B (excluding wholesale and manufacturing) and Method C (retail only) were closest to reported values. If more product types with reported values were available, and with the addition of more years of data, it may be possible to identify patterns in the relationship between consumption and employee data.

Table 11: Comparison of average results for calculated values against reported values. Values are presented as +/− compared to 100% of the reported value.

Consumption	A: Excluding Wholesale	B: Excluding Wholesale and Manufacturing	C: Retail Only	D: Per Capita
		Fuel		
County	−28	+6	+15	+5
Municipality	−24	0	+26	+21
		Personal Vehicles		
County	+7	+14	+14	+14
Municipality	−20	−15	−15	+50
		Wine		
County	−49	−40	−15	−10

6.4 Sector contribution analysis

Objective: Identify sectors driving hotspots in order to hone mitigation efforts

- Main result: Sector contribution analysis could not be finalized due to a variety of factors including lack of data and feasibility issues.

The main aim of the contribution evaluation was to quantify how much of total consumption could be attributed to public procurement or government spending as the municipality has the greatest ability to affect this type of consumption. Several meetings and conversations were held with practitioners from different administrative offices in Gothenburg to investigate various options, including the public procurement office, the environmental office, the properties office, and the traffic office.

First, public expenditure data for the city of Gothenburg was reviewed. The years for which public spending data was available did not match the years for which we had the city's total consumption data, so these were not comparable. Moreover, several of the functions that the city provides that consume goods (e.g., education requires electronics, textbooks, writing materials, construction materials for facilities, etc.) are outsourced as *totalentreprenad* or "turnkey contracts" where external actors are given a lump sum to meet requirements and fulfill the function. This meant that finding exact product use within the public spending data was not possible and that it was not feasible to couple specific products to municipal functions and thereby estimate the government contribution.

As noted in Chapter 5, municipalities and administrative regions in Sweden are legally required to provide services and functions like education, health care and public transportation. These functions use resources (e.g., fuel, construction materials, furniture, electronics, and food). A bottom-up analysis of the materials and products required was stymied by turnkey contracts and data scarcity.

Meanwhile, the Swedish National Agency for Public Procurement (*Upphandlingsmyndigheten*) started an initiative in 2017 to quantify the CO_2-eq associated with public spending at the municipal level. We explored using their data and comparing it to our dataset to evaluate to what extent government spending is responsible for emissions. Here, legal issues including confidentiality constraints prevented a collaboration from coming to fruition.

Household consumption can be quantified in terms of spending based on the household budget survey that is available for years 2006-2009. These data are however also bound by confidentiality and were not accessible during this thesis' work. Given that the household and government consumption were not identified, industrial consumption was also not found.

6.5 Data usability workshop

Objective: Increase visibility of urban metabolism methods to practitioners while strengthening usability of the method

6.5.1 Main results:

- Workshop attendees agreed on the need for an accessible tool to help prioritize efforts to reduce consumption-based impacts; however, there were conflicting statements regarding the specificity required.
- Workshop attendees stressed the need for municipality or region-specific data to be able to follow-up reduction efforts.
- Hotspot identification was seen as useful for both measure prioritization work and as a communication tool for encouraging citizens to consume sustainably.

6.5.2 Workshop findings

A workshop was held on November 12, 2020 with 18 attendees including practitioners from eight different municipal environmental offices and several environmental organizations in Sweden. Several practitioners worked with consumption-based impact indicators related to public procurement, mostly food-related, using procurement specific tools like the Environmental Expenditure Analysis (*Miljöspendanalys)* from the Swedish National Agency for Public Procurement, or Mashie/Compare, a digital tool for commercial kitchens that quantifies food cost along with CO_2-eq and food waste (Upphandlingsmyndigheten, 2019). A popular science summary of the workshop is presented in Appendix D.

The practitioners agreed that a tool would be useful in prioritizing mitigation efforts, but that to be truly useable it must be possible to follow up mitigation measures and feed in updated consumption data. Consumption data must therefore be accessible and easily quantifiable. Moreover, the risk of overlap within the tools available to municipalities, and the need for integration with existing databases and reporting software (e.g., Kolada) are hurdles that need to be overcome. Other examples of tools marketed to municipalities include Climate Views, Transition Targets and Future Proofed Cities. The tool itself should be simple to use as time and resources for complicated software or calculations that they have to perform themselves are chronically limited.

Total city's consumption was relevant for practitioners, but there was a need to be able to calculate the public procurement impact specifically as this is the area over which they have some measure of control. Household consumption is interesting because several measures are aimed at households and they want to be able to measure results. Industry consumption was also important as municipality and regions have joint environmental programs with industry. The tool would thus be most helpful if it could provide an overall assessment of the impact of total consumption that can be divided into the three sectors (public, household, and industry/business).

There were some differing opinions as to the level of detail needed. For example, some practitioners thought a “rough” tool would be adequate to provide guidance as to which product groups to prioritize and to assist in development of evidence-based policy. Hotspot identification was seen as useful but more information about which consumers or activities drive consumption is required to select measures that will effectively achieve targeted results. It was not clear if it was necessary to quantify the extent to which different activities were responsible for the environmental impact. Hotspots can also have a high communicative value if used to highlight the consumer's own responsibility for reducing consumption.

There were divided opinions as to whether it would be helpful to calculate the effect of mitigation efforts produced by the measures by using so-called "scenarios". Information in an area that the municipalities do not have control over was not regarded as very helpful, however, it can be interesting to know if planned measures have the potential to take the municipality all the way to the goal.

7 DISCUSSION

The aim of this thesis was to investigate if and how region-specific consumption affects environmental impact hotspots. Using urban metabolism-based concepts and methods, I also analyzed how identification of hotspots could be used to prioritize consumption-related measures to meet environmental targets. In this chapter, I analyze and discuss the results while connecting them to other studies' findings.

7.1 Quantification of consumption impacts and hotspot identification

To answer Research Question 1, ***How does region-specific consumption affect hotspots?,*** representative products were first identified and used to quantify region-specific environmental impacts for Stockholm, Gothenburg, and Malmö. Hotspots were then identified for each region using several criteria. The results show that region-specific variation in consumption affects which product groups are hotspots. Although the same representative products were used for each region, as the types of consumed goods were similar among them, the variation in regional consumption profiles affected priority product groups and resulted in hotspots that were similar but not identical (see Table 8).

7.1.1 Representative product selection

Representative products were selected based on several criteria (high consumption by mass, frequent and increasing consumption over time, and known high-impact product types). The estimated weighted average environmental impact per kg based on LCA profiles of these products was multiplied by the total mass of the respective product categories and used to quantify the product category's environmental impact. As noted in Chapter 5.8, there is uncertainty associated with this approach; representative products are assumed to have environmental impacts that are similar or within the same range as the other products within the product category. The accuracy of this assumption is dependent on the heterogeneity of the product group and the share (by mass) of the representative products. The sensitivity analysis described in Chapter 5.2 compared the impact results among the preliminary list of representative products and indicated if more representative products were needed per product category. More heterogeneous categories required more representative products, as seen in product category 85, electronics. It is possible that additional representative products in more product categories would give a more robust assessment. Although only 41 product categories out of 98 were given representative products, the remaining 57 product categories altogether contributed less than 1% of the total consumption by mass. The representative products covered 79 to 86% by mass of total consumption of their respective categories.

The basket-of-products method presented in this thesis has been further developed by Corrado *et al.*, (2019), who expand upon the representative product selection sequence. They suggest complementing the selection of product groups based on mass and economic values with the product groups with high impacts according to EEIO tables. Increasing the number of representative products and including EEIO aspects broadens the analysis to include a top-down impact approach in addition to the bottom-up approach from LCA.

Were the similarities in hotspots in the metropolitan areas a result of using the same representative products for all regions? As described in Chapter 5.2.1, in order to see if the same representative products could be used, the mass fraction of the most consumed products in each product category was compared among the regions using the standard deviation. If the standard deviation was greater than 0.2, additional representative products were considered. Only twelve product types from eight product categories products had a standard deviation greater than 0.2, and these only contributed 0.02% of the total consumption by mass and were considered insignificant. The same representative products where therefore used for all areas studied.

This brings us to the next question: would the use of a lower standard deviation as a threshold have indicated a need for different representative products among the regions? Had 0.1 been used, for example, 17 additional product categories and 22-25% of the total consumption by mass would have been included for additional assessment (rather than the 0.02% of total consumption by mass covered in product categories considered using a standard deviation of 0.2). Upon a closer look, however, the lower standard deviation would make little change in the product selection. The reason for the large increase from 0.02% to 23% of the total consumption by mass is due to product types 2710 (petroleum oils, fuel) and 2711 (petroleum gas) as well as 4401 (fuel wood) and 4410 (particle board). The mass fraction of the two product types within each product category vary among the cities. For example, product type 2710 (petroleum oils (fuel)), which was approximately 84% of the mass of CN-2 category 27 in both Stockholm and Gothenburg, is only 54% in Malmö. In Malmö, 2711, petroleum gas is more dominant (32% by mass) than in Gothenburg and Stockholm (5-10% by mass). In the cases of both fuel and wood, the affected product types were representative products and, as consumption is redistributed among the representative products using their relative mass ratio, the differences would not affect results. As long as the product categories for which there are large differences among the highest consumed products by mass have additional representative products that cover the differences in consumption by mass (i.e., the product types that create the larger variation), the results should not be affected. This indicates that using the same representative products did not cause the similarity of hotspots among the regions.

7.1.2 Hotspot evaluation

Hotspots were identified for Stockholm, Gothenburg and Malmö, where several categories were shared hotspots. Electronics and fuel, for example, were hotspots for all regions, and machinery was a hotspot for Stockholm, Gothenburg, and Sweden as a whole. The impact results, however, show differences among the regions. As we see in Table 7, the results for the climate change indicator GWP varied among the metropolitan regions. In Stockholm, fuel dominated the GWP impact at 17% of the total impact, with electronics and machinery just over the 10% threshold. In Gothenburg, GWP was more evenly spread among four product categories (electronics, machinery, fuel and vehicles), while in Malmö no category exceeded the 10% threshold and seven product categories had levels just below the threshold. Eutrophication in freshwater, however, had similar results for all regions (the same two product categories and percent of total impact). The results for eutrophication in freshwater suggest that electronics and machinery are the main drivers of this impact type in all of the cities studied. Fuel and electronics had high impacts in impact categories climate change, acidification, eutrophication in marine environments and photochemical ozone formation which suggests that these product types should be prioritized for reduction in all regions.

The similarities in hotspots suggest that although consumption profiles may differ, product categories like fuel, vehicles, and electronics will likely dominate hotspots in most areas as long as these product types are consumed at such high quantities. Fuel, for example, does not appear in the top ten product categories with respect to impact per kilogram (see Table 4) yet is consumed at such high levels that it is a hotspot in all areas studied. Electronics has the highest impact per kilogram in five of six impact categories, but this can change if technology improves and impacts are reduced. Changing consumption patterns, whether due to new technologies, incentives, or changing behaviors, will affect which product types are hotspots. As fuel and electronics were hotspots in all regions, these are likely product categories that should be prioritized for impact mitigation at the national level. Fuel is already targeted at the national level (e.g. Infrastrukturdepartementet, 2017) but electronics should also be.

Hybrid MFA-LCA hotspot identification can also find goods that are perhaps not the most dominant but those that differ among cities. In order to find these "second tier" product categories, perhaps a lower threshold than 10% of the total impact could be used to identify hotspots. In Gothenburg, a 5% threshold would not lead to any hotspots other than those found using 10%, but 2% would result in the addition of meat, dairy, articles of iron or steel, technical instruments, aluminum, and furniture. In Stockholm, a 2% threshold would include the same additional hotspots as Gothenburg but also processed meat and fish, vehicles, printed books and newspapers, inorganic chemicals, and machinery. Malmö shared most of Stockholm's second tier hotspots, but instead of inorganic chemicals, paints and varnishes appeared as a hotspot. Although these product categories may not contribute as much as fuel to the total impact, their reduction could still increase the likelihood of reaching environmental targets.

The hotspots found in this thesis using the representative products for Sweden are in agreement with previous studies. There are several studies that evaluate the environmental impact of consumption that are based either on LCA or EEIO. For example, Tukker et al (2008) consider cars and transport to be among the top contributors to life cycle based environmental impact. Moreover, transport is often reported to be one of the major contributors to environmental impact and a priority sector to achieve the SDGs (United Nations, 2016). Interestingly, fuel and vehicles are a hotspot even when only including cradle-to-gate impacts. Transport's impacts are generally thought of as primarily direct, but these results indicate that upstream impacts (i.e., impacts that take place prior to consumption) are significant as well. A recent United Nations report finds electronics to be a priority product group that drives environmental impact, and a 2009 study found that upstream impacts for electronics are significant (Huang, Weber and Matthews, 2009; United Nations, 2020).

Construction materials is a product group that has been often cited as a significant contributor to climate change but that was conspicuously absent from the hotspots found in this research (e.g., Dias *et al.*, 2017; González-García and Dias, 2019). This may be due to the slower rate of construction in the built environment of existing metropolitan areas than in "new" or quickly developing cities or metropolitan areas. Reducing the hotspot threshold from 10% of the total impact to 2% of the total impact resulted in CN-2 category 25 (earth and stone) becoming a hotspot for Sweden as a whole. Category 25 is one of several categories related to construction materials. The category did not, however, become a second-tier hotspot in the metropolitan areas, which is surprising as one Swedish report found that construction processes in Sweden including roads, houses, non-residential buildings and multifamily dwellings cause nearly as much emissions as the emissions from all cars in Sweden (Royal Swedish Academy of Engineering Sciences, 2014). The fact that construction materials do not appear as hotspots may also be due to the fact that they are split among several product categories (CN-2 categories 25, 68, 69, and 70 can all be related to construction) and the impact is dispersed among these. This may indicate a need to examine construction material profiles used, or that product groups related to construction materials may need to be aggregated to get a true indication of their importance in reaching environmental targets.

7.1.3 Limitations and uncertainties

Some of the limitations described in Chapter 5.8 are relevant to discuss here. The environmental impact results described and used to identify hotspots are dependent of the life cycle profiles selected. The profiles used were not always based on Swedish-specific producers. This may lead to an over- or underestimation of environmental impact with regards to specific production methods or electrical grids used. To avoid the risk of double counting, only cradle-to-gate profiles were used, which means the results do not present the impacts associated with the use or waste phases. This could also lead to underestimation of impact in certain categories. The profiles that were used may not necessarily reflect the most up-to-date processes used today to produce goods.

Using a selection of products to represent a larger product category has inherent uncertainty. This uncertainty, however, can be compared to using emission factors per unit of currency per sector as is used in other environmental analyses, for example (Weber, 2008). Extrapolations of national-level MFA to the regional scale are uncertain as well (Patrício *et al.*, 2015). The results should therefore be seen as recommendations for prioritization areas (product categories), but not a way to pinpoint a specific product type.

7.2 Mitigation option/measure evaluation

To answer Research Question 2, ***How can region-specific consumption data be used for policy prioritization and assessment?***, hotspots were first linked to existing measures in Gothenburg. The measures were then translated into scenarios to project potential consumption changes over time. The resulting impact reductions based on the projected changes in consumption were calculated using LCA and the results were compared to existing environmental targets to identify the most effective options. The results indicate that the measures evaluated will not by themselves reach targets.

As seen in Table 9, considering several environmental impact types affected measure prioritization. The results for personal vehicles and fuel with regards to acidification and eutrophication suggest that measures associated with Scenarios

2 or 3 should be prioritized over Scenario 1, despite similar values for potential reduction in climate change.

The study also evaluated measures associated with extending the lifespan of electronics, comparing their application to municipality-owned devices and to privately-owned devices. The study indicated that the lifespan extension scenarios evaluated for electronics would at most only contribute to 0.2% of the 4.5-ton reduction needed to meet Gothenburg's climate target. This suggests that the information campaigns on extending electronics lifespans should not be the municipality's primary focus area for investment of significant funding.

Given that the measures associated with lifespan extension of electronics did not lead to high impact reductions, more product types found in the electronics category could be evaluated. For example, previous studies have identified televisions, household appliances like refrigerators and laundry machines, and domestic heating equipment to be impact drivers (Tukker and Jansen, 2006; Huysman *et al.*, 2016). These product types could be linked to additional environmental measures and evaluated further to see if reduction of these specific product types increased progress towards targets.

Assessment of the studied scenarios shows that Gothenburg may need to adopt significantly broader or more stringent measures than those evaluated here to reach their desired target of 3.5 tons consumption-based CO2 eq per capita. Even if the results of the fuel and electronics scenarios are combined, at most 14% of the 4.5- ton CO_2-eq reduction needed to meet the goal is achieved. As other studies have found, there must be additional and simultaneous efforts to reduce consumption and subsequent environmental impact if the target is to be reached by 2035 (Fitzgerald *et al.*, 2015).

These findings are in line with some transition studies, i.e., studies that, among other aspects, evaluate the features of societal change (e.g., how to achieve sustainable societies) (Zolfagharian *et al.*, 2019), that have found that fundamental changes in the way society operates would be needed to reach the SDGs (Akenji and Bengtsson, 2014). Welch and Southerton (2019) argue that a comprehensive and radical shift in consumption going beyond individual behavior needs to take place in order to reach climate targets. This requires more interaction and coordination among policy makers, businesses, and other stakeholders within production-consumption systems to affect the dynamic consumption patterns that change along with society, culture, economy, and technology (Welch and Southerton, 2019). Some scholars argue that sustainability will not be achieved by technological solutions (e.g., consuming more effectively), but will require “degrowth” or a steady-state economy (Hobson, 2013; Sekulova *et al.*, 2013).

7.2.1 Limitations and uncertainties

The LCA limitations discussed in Chapter 7.1.3 are relevant here as well. Moreover, pinpointing the exact outcome of a proposed measure is not feasible due to a multitude of uncertainties. The results are therefore intended to guide practitioners as to the order of magnitude of impact reduction they can expect a set of measures to achieve.

It is also important to reflect on the relative scale at which the measures are proposed and projected. Initiatives to increase electrification of the personal vehicle fleet, for example, take place at the national and local level. Identifying to which extent local measures are responsible for uptake compared to national measures may not be possible – but would that be necessary? Moreover, Kissinger and Stossel (2021) found that interaction between measures can reduce or increase consumption or impact reduction, depending on how material flows are related to one another. The potential cross-connections between measures were not evaluated in this study but would be an interesting point for further analysis.

7.3 Regional consumption quantification

Municipalities need easily accessible local or regional data to enable them to prioritize measures and track their progress towards meeting environmental targets. This sentiment was echoed during the workshop held with practitioners in November 2020 (see Chapter 6.5.2). As described in Chapter 5.5, several methods for extrapolating national statistics to regional levels were evaluated based on the number of employees working in economic sectors (NACE) to assess whether the number of employees is a more reliable proxy for consumption than per capita values.

The extrapolation methods evaluated in this thesis and Paper IV indicate that per capita results may be sufficient for consumption estimations for counties. At the municipal level, Method B, which uses employees from economic sectors excluding wholesale and manufacturing, had the best results on average, but Method D, per capita, was more accurate when looking at individual municipalities. The few available product types with reported values limit the ability to provide more specific recommendations for method choice based on type of municipality. Per capita estimations would be significantly easier than other data sets for practitioners to obtain and thus increase accessibility of the method. In the future, per capita estimations could be differentiated using regional characteristics, like the municipal classifications (rural, commuter, etc.)

and by making assumptions on how consumption could be affected by these characteristics.

As discussed in the workshop, however, region-specific consumption data is needed to follow up the results of a particular measure or set of measures. Per capita estimations would not be useful for assessing the outcome of a measure and its success in reducing consumption of certain goods, as per capita values are based on national level consumption and would not capture local consumption changes.

7.4 Sector contribution analysis

The sector contribution analysis was not finalized in this thesis due to data inadequacy. There are other studies, however, that have tried to evaluate the contribution of household, government, or industry to total consumption. For example, there are multiple studies that estimate the contribution of government spending on consumption-based impacts, ranging from 5 to 14%. A report by the Swedish EPA confirms that public procurement is a significant part of Swedish consumption (Brolinson *et al.*, 2010); one study found that it drives 1.2 tons CO_2-eq per capita (approximately 12% of total consumption-based CO_2-eq emissions) and another found that 14% of Sweden's carbon footprint is driven by public procurement (Minx *et al.*, 2008; Palm *et al.*, 2019). Yet another report by Statistics Sweden found that only about 5% to 7% of Sweden's total consumption-based CO_2-eq emissions are from public procurement (SCB Statistics Sweden, 2016). Hertwich and Peters (2009) attribute 10% of greenhouse gas emissions to government consumption. It is not possible to see, however, if these percentages are applicable across all product categories or for specific ones.

Previous studies have found households to be significant drivers of consumption-based emissions, estimating that 60 to 76% of global greenhouse gas (GHG) emissions may be attributed to them (Minx *et al.*, 2008; Hertwich and Peters, 2009; Ivanova *et al.*, 2014; Dubois *et al.*, 2019).

If government consumption gives rise to 5 to 14% of GHG emissions and households are approximately responsible for 60-72%, this would suggest that industries are responsible for 14 to 35% of consumption based GHG emissions. Using these assumptions, household-related measures should be prioritized. However, reduction efforts focused on public procurement are decidedly easier to implement and ensure adoption.

7.5 Data usability

One of the aims of this project was to increase usability by decision makers of consumption and consumption-based impact data. Communication with practitioners has taken place throughout the project, given that tools meant to be used by practitioners should be developed in concert with them. As noted in Chapter 2, decision makers need quantitative tools in order to meet their environmental targets and evaluate the effectiveness of measures taken. Practitioners from the City of Gothenburg, IVL Swedish Environmental Research Institute, the Swedish Environmental Protection Agency, and the Swedish National Agency for Public Procurement have taken part in and influenced the work in this thesis.

As described in Chapters 5.7 and 6.5, the workshop held in November 2020 underscored the importance of understanding the needs of the intended users. This workshop was attended by practitioners from several municipalities not involved in the project. A summary of the workshop results is presented in Appendix D. The primary finding was that consumption data and subsequent impact assessment must be municipality- or region-specific and not based on generalized per capita calculations. Consumption data must therefore be made available or easily quantifiable. Practitioners also said that, although prioritization of measures was helpful, the tool would be more helpful if it could quantify the outcome of consumption reduction measures, i.e., confirm that the measures had the desired outcome. Many practitioners expressed a need for public-procurement specific impact information in addition to total impact. Perhaps existing tools that measure public procurement-based impact could “plug-in” to the hybrid MFA-LCA method to meet both needs. The practitioners expressed a need for integration with existing databases and monitoring systems, which is a sentiment echoed by practitioners interviewed by Gustafsson et al. (Gustafsson, Hedström and Vasilev, 2018).

This transdisciplinary project was designed and carried out with input and guidance from local practitioners who helped form the research questions and provided continuous guidance throughout the project. There are several challenges to transdisciplinary studies, like differences in perspectives and time scales (Pohl and Hadorn, 2008; Polk, 2015). Successful transdisciplinary studies require reciprocal relationships between practitioners and researchers in order to overcome the associated challenges of combining their different views, aims, and timelines (Norris *et al.*, 2016; Hansson and Polk, 2018). In this project, there were challenges with aligning timelines between researchers and practitioners, but we were able to communicate well throughout.

8 CONCLUSIONS AND FUTURE RESEARCH

In this final chapter, I summarize the main conclusions of this thesis and present possible further development of the methods.

8.1 Conclusions

This thesis investigated if and how region-specific consumption affects product-specific environmental impact hotspots (i.e., product categories with significant environmental impact that should be prioritized for reduction) and how region-specific consumption and impact data could be used for policy assessment and prioritization. Using the methods outlined in this thesis and the appended papers, MFA and LCA were combined and used to identify consumption-based environmental impact hotspots.

Fuel and electronics were hotspots in all regions studied. Machinery was found to be a hotspot in Stockholm, Gothenburg, and Sweden, and vehicles were a hotspot in Gothenburg. Potential future hotspots included aluminum and vehicles in Stockholm, printed materials and aluminum in Gothenburg, and vehicles in Malmö. Hotspots were first identified and then used to assess environmental measures in the city of Gothenburg, Sweden and estimate the measures' ability to reach environmental targets.

Hotspots are expected to change if consumption patterns change or if the life cycle impact of representative products improves. A hotspot identification method may be useful in distinguishing both major contributors (like fuel and electronics found in this case) as well as second tier environmental impact drivers. Understanding the extent to which different product groups drive impact can aid decision makers to understand the potential benefit of mitigating impacts resulting from consumption of certain goods while also enabling prioritization of policies or measures.

The case study of Gothenburg's environmental measures shows that the measures could result in a range of impact reductions, but even under the most optimistic of scenarios the measures evaluated would not be enough to reach targets. This suggests that solely focusing on hotspots would be insufficient and that in order to reach challenging environmental goals, a broad-scale approach is necessary. Scenarios may help gauge the potential success of measures as well as give decision makers a better indication of how much effort is needed to reach targets.

Practitioners describe a need for accessible, usable data and tools that both prioritize and follow up consumption-based environmental impact mitigation measures. Urban metabolism approaches can be useful for evidence-based policy as long as data is made available. Some suggestions for improving data availability are presented in Chapter 8.2.

8.2 Future research and development

The methods developed as part of this work can be used to plan more efficient measures, but I see room for further development as follows:

Consumption Quantification

- Develop simpler ways of transforming DMC into final goods. The UMAn model is data intensive and data requirements may be a barrier to entry. In the UMAn model, goods are classified by their life cycle phase to identify final goods. This information is then connected to local production data to simulate the transformation from raw or intermediate materials to final goods. Perhaps this vector for material consumption of final goods could be performed at the national level and assumed to be valid at the local level to reduce data needs. This would reduce the region-specific nature of the data, however.
- In order to make product-level consumption data by region and associated impact assessments accessible, urban metabolism models could be adopted by national statistics offices like Statistics Sweden. Today, input-output tables are provided by national governments. As the statistics used in the UMAn model are provided by them as well, they could also do the modeling. Another actor who could facilitate provision of regional consumption data is SALAR (the Swedish Association of Local Authorities and Regions).
- Perform similar analysis using non-European data to compare hotspots. Investigate how region-specific consumption impacts differ globally. For example, do personal vehicles dominate in the same manner in China?

Sector Contribution

- Develop the capability to measure up-to-date consumption data to evaluate if the measures employed are leading to the consumption changes expected. This may not be fully feasible for total consumption including households and businesses but is possible at the governmental level. Public procurement tenders could require vendors to submit mass quantities of consumption instead of solely providing monetary units in order to measure government consumption-based impact.

- Explore additional ways to measure the contribution of different sectors to consumption and the subsequent impacts.
- Link household expenditure/budget survey data to mass and compare to total consumption values.
- Investigate industrial contributions using survey data. Non-sensitive data on consumption could be collected from a statistically significant number of establishments from each NACE economic sector to estimate non-production-based consumption from the industrial sector.

Tool Development

- Practitioners took part in the research proposal, but moving forward, they should be included at earlier stages in the planning of tool development to ensure more buy-in and applicability. Interweave the tool or method with indicators used in existing databases and reporting software used by practitioners. For example, Gothenburg now plans to focus efforts on reducing consumption-based impact of public procurement. Tool development could take this prioritization into account.
- Investigate the possibility of connecting consumption to more indicators used in the SDGs like material footprint, or expand the list of representative products to include more product types and indicators. This would enable easier integration with existing databases measuring progress towards reaching the SDGs.

9 REFERENCES

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10 APPENDICES

Appendix A: Final list of representative products used for Stockholm, Gothenburg, Malmö and Sweden

The final list of representative products for Stockholm, Gothenburg, Malmö and Sweden is presented in Table A1. Columns one and two show the CN-2 product category and the most consumed CN-4 product type. The third column presents the CN-4 product type description from the CN system, and the fourth column presents the selected representative product. Columns five through eight show how large share the CN-4 product type has of the CN-2 category (in percent) for each city and Sweden, respectively.

Table A1: List of Representative Products for Stockholm, Gothenburg, Malmö and Sweden

CN-2	TOP CN-4	CN-4 Product Type Description	Representative Product*	Sto	Got	Mal	Swe
01	Product category/ies with insignificant consumption, no representative products identified						
02	0201	Meat of bovine animals, fresh or chilled	Beef	20%	24%	23%	25%
02	0203	Meat of swine, fresh, chilled or frozen	Pork	36%	40%	46%	43%
02	0207	Meat and edible offal of fowls of the species Gallus domesticus, ducks, geese, turkeys and guinea fowls, fresh, chilled or frozen	Chicken	20%	22%	11%	19%
03	0302	Fish, fresh or chilled (excl. fish fillets and other fish meat of heading 0304)	Salmon	65%	66%	65%	58%
04	0401	Milk and cream, not concentrated nor containing added sugar or other sweetening matter	Milk	54%	50%	58%	56%
04	0403	Buttermilk, curdled milk and cream, yogurt, kephir and other fermented or acidified milk and cream, whether or not concentrated or flavored or containing added sugar or other sweetening matter, fruits, nuts or cocoa	Yogurt	20%	23%	21%	23%
04	0406	Cheese and curd	Cheese	8%	10%	6%	9%
05-06	Product category/ies with insignificant consumption, no representative products identified						
07	0701	Potatoes, fresh or chilled	Potatoes	22%	21%	23%	36%
07	0702	Tomatoes, fresh or chilled	Tomatoes	14%	14%	5%	9%
07	0707	Cucumbers and gherkins, fresh or chilled	Cucumbers	10%	6%	4%	6%
08	0803	Bananas, incl. plantains, fresh or dried	Bananas	27%	26%	25%	25%
08	0808	Apples, pears and quinces, fresh	Apples	24%	23%	24%	25%
09	0901	Coffee, whether or not roasted or decaffeinated; coffee husks and skins; coffee substitutes containing coffee in any proportion	Coffee	93%	90%	94%	91%
10	1006	Rice	Rice	57%	63%	55%	37%
11	Product category/ies with insignificant consumption, no representative products identified						
12	1213	Cereal straw and husks, unprepared, whether or not chopped, ground, pressed or in the form of pellets	Straw	6%	11%	23%	23%
12	1214	Rutabaga, mangolds, fodder roots, hay, alfalfa, clover, sainfoin, forage kale, lupines, vetches and similar forage products, whether or not in the form of pellets	Beets	94%	88%	77%	77%
13-14	Product category/ies with insignificant consumption, no representative products identified						
15	1514	Rape, colza or mustard oil and fractions thereof, whether or not refined, but not chemically modified	Rapeseed oil	29%	35%	17%	42%

CN-2	TOP CN-4	CN-4 Product Type Description	Representative Product*	Sto	Got	Mal	Swe
16	1601	Sausages and similar products, of meat, offal or blood; food preparations based on these products	Sausage	33%	27%	35%	28%
17	1701	Cane or beet sugar and chemically pure sucrose, in solid form	Sugar	8%	11%	63%	11%
18	Product category/ies with insignificant consumption, no representative products identified						
19	1905	Bread, pastry, cakes, biscuits and other bakers'' wares, whether or not containing cocoa; communion wafers, empty cachets of a kind suitable for pharmaceutical use, sealing wafers, rice paper and similar products	Bread	72%	59%	77%	77%
20	2004	Vegetables prepared or preserved otherwise than by vinegar or acetic acid, frozen (excl. preserved by sugar, and tomatoes, mushrooms and truffles)	Cooked potatoes	17%	22%	20%	14%
20	2005	Other vegetables prepared or preserved otherwise than by vinegar or acetic acid, not frozen (excl. preserved by sugar, and tomatoes, mushrooms and truffles)	Table olives	16%	24%	33%	16%
20	2009	Fruit juices, incl. grape must, and vegetable juices, unfermented, not containing added spirit, whether or not containing added sugar or other sweetening matter	Orange juice	27%	20%	21%	40%
21	Product category/ies with insignificant consumption, no representative products identified						
22	2201	Waters, incl. natural or artificial mineral waters and aerated waters, not containing added sugar, other sweetening matter or flavored; ice and snow	Bottled water	32%	47%	34%	34%
22	2202	Waters, incl. mineral waters and aerated waters, containing added sugar or other sweetening matter or flavored, and other non-alcoholic beverages (excl. fruit or vegetable juices and milk)	Soft drink	5%	14%	27%	29%
22	2207	Undenatured ethyl alcohol of an alcoholic strength of >= 80%; ethyl alcohol and other spirits, denatured, of any strength	Alcoholic beverage	14%	14%	4%	9%
23	2309	Preparations of a kind used in animal feeding	Animal feed	60%	81%	70%	81%
24	Product category/ies with insignificant consumption, no representative products identified						
25	2517	Pebbles, gravel, broken or crushed stone, for concrete aggregates, for road metaling or for railway ballast, shingle and flint, whether or not heat-treated; macadam of slag, dross or similar industrial waste, whether or not incorporating the materials cited in the first part of the heading; tarred macadam; granules, chippings and powder, of stones of heading 2515 and 2516, whether or not heat-treated	Crushed stone	97%	97%	96%	97%
26	Product category/ies with insignificant consumption, no representative products identified						
27	2710	Petroleum oils and oils obtained from bituminous minerals (excl. crude); preparations containing >= 70% by weight of petroleum oils or of oils obtained from bituminous minerals, these oils being the basic constituents of the preparations, n.e.s.; waste oils containing mainly petroleum or bituminous minerals	Diesel	86%	83%	54%	76%
27	2711	Petroleum gas and other gaseous hydrocarbons	Natural gas	5%	9%	32%	9%
28	2804	Hydrogen, rare gases and other non-metals	Hydrogen	90%	57%	85%	7%
28	2833	Sulfates; alums; peroxosulphates "persulphates"	Iron sulfate	2%	17%	2%	33%
28	2836	Carbonates; peroxocarbonates "percarbonates"; commercial ammonium carbonate containing ammonium carbamate	Ammonia	4%	19%	8%	29%
29	Product category/ies with insignificant consumption, no representative products identified						
30	3004	Medicaments consisting of mixed or unmixed products for therapeutic or prophylactic uses, put up in measured doses "incl. those in the form of transdermal administration" or in forms or packings for retail sale (excl. goods of heading 3002, 3005 or 3006)	Pharmaceutical products	82%	77%	81%	83%
31	3101	Animal or vegetable fertilizers, whether or not mixed together or chemically treated; fertilizers produced by the mixing or chemical treatment of animal or vegetable products (excl. those in pellet or similar forms, or in packages with a gross weight of <	Poultry manure	5%	5%	2%	3%
31	3105	Mineral or chemical fertilizers containing two or three of the fertilizing elements nitrogen, phosphorus and potassium; other fertilizers (excl. pure animal or vegetable fertilizers or mineral or chemical nitrogenous, phosphatic or potassic fertilizers); animal,	NPK Fertilizer	94%	94%	97%	96%

CN-2	TOP CN-4	CN-4 Product Type Description	Representative Product*	Sto	Got	Mal	Swe
		vegetable, mineral or chemical fertilizers in tablets or similar forms or in packages of a gross weight of <= 10 kg					
32	3209	Paints and varnishes, incl. enamels and lacquers, based on synthetic polymers or chemically modified natural polymers, dispersed or dissolved in an aqueous medium	Varnish	22%	21%	22%	26%
32	3214	Glaziers'' putty, grafting putty, resin cements, caulking compounds and other mastics; painters'' fillings; non-refractory surfacing preparations for façades, indoor walls, floors, ceilings or the like	Cement mortar	51%	55%	50%	48%
33	Product category/ies with insignificant consumption, no representative products identified						
34	3402	Organic surface-active agents (excl. soap); surface-active preparations, washing preparations, incl. auxiliary washing preparations, and cleaning preparations, whether or not containing soap (excl. those of heading 3401)	Washing detergent	73%	77%	70%	70%
35-37	Product category/ies with insignificant consumption, no representative products identified						
38	3824	Prepared binders for foundry molds or cores; chemical products and preparations for the chemical or allied industries, incl. mixtures of natural products, n.e.s.	Concrete	98%	91%	97%	96%
39	3923	Articles for the conveyance or packaging of goods, of plastics; stoppers, lids, caps and other closures, of plastics	Plastic bag	30%	29%	19%	36%
40	4011	New pneumatic tires, of rubber	Tires	56%	64%	40%	40%
41-43	Product category/ies with insignificant consumption, no representative products identified						
44	4401	Fuel wood, in logs, billets, twigs, faggots or similar forms; wood in chips or particles; sawdust and wood waste and scrap, whether or not agglomerated in logs, briquettes, pellets or similar forms	Wood pellet production	77%	81%	49%	6%
44	4410	Particle board and similar board "e.g. oriented strand board and waferboard" of wood or other ligneous materials, whether or not agglomerated with resins or other organic binding substances (excl. fiberboard, veneered particle board, hollow-core composite panels and board of ligneous materials agglomerated with cement, plaster or other mineral bonding agents)	Particle board	6%	3%	30%	1%
45-47	Product category/ies with insignificant consumption, no representative products identified						
48	4818	Toilet paper and similar paper, cellulose wadding or webs of cellulose fibers, of a kind used for household or sanitary purposes, in rolls of a width <= 36 cm, or cut to size or shape; handkerchiefs, cleansing tissues, towels, tablecloths, serviettes, napkins for babies, tampons, bedsheets and similar household, sanitary or hospital articles, articles of apparel and clothing accessories, of paper pulp, paper, cellulose wadding or webs of cellulose fibers	Recycled Paper	5%	29%	4%	54%
48	4901	Cartons, boxes, cases, bags and other packing containers, of paper, paperboard, cellulose wadding or webs of cellulose fibers, n.e.s.; box files, letter trays, and similar articles, of paperboard of a kind used in offices, shops or the like	Corrugated board boxes	19%	22%	21%	16%
49	4902	Printed books, brochures and similar printed matter, whether or not in single sheets (excl. periodicals and publications which are essentially devoted to advertising)	Graphic paper	75%	70%	73%	81%
49	6109	Newspapers, journals and periodicals, whether or not illustrated or containing advertising material	Newspaper	26%	27%	26%	24%
50-60	Product category/ies with insignificant consumption, no representative products identified						
61-63	6810	T-shirts, singlets and other vests, knitted or crocheted	Textiles	77%	70%	74%	65%
64-67	Product category/ies with insignificant consumption, no representative products identified						
68	6904	Articles of cement, concrete or artificial stone, whether or not reinforced	Concrete blocks	10%	10%	11%	13%
69	6908	Ceramic building bricks, flooring blocks, support or filler tiles and the like (excl. those of siliceous fossil meals or similar siliceous earths, refractory bricks of heading 6902, and flags and pavings, hearth and wall tiles of heading 6907 and 6908)	Ceramic tiles	27%	25%	28%	31%
70	7010	Carboys, bottles, flasks, jars, pots, phials, ampoules and other containers, of glass, of a kind used for the conveyance or packing of goods, preserving jars, stoppers, lids and other closures, of glass	Green glass (packaging)	46%	45%	73%	56%

CN-2	TOP CN-4	CN-4 Product Type Description	Representative Product*	Sto	Got	Mal	Swe
		(excl. glass envelopes and containers, with vacuum insulation, perfume atomizers, flasks, bottles etc. for atomizers)					
71	Product category/ies with insignificant consumption, no representative products identified						
72	7214	Bars and rods, of iron or non-alloy steel, not further worked than forged, hot-rolled, hot-drawn or hot-extruded, but incl. those twisted after rolling (excl. in irregularly wound coils)	Reinforcing steel	18%	35%	17%	20%
73	7326	Articles of iron or steel, n.e.s. (excl. cast articles)	Steel products	46%	32%	22%	45%
74-75	Product category/ies with insignificant consumption, no representative products identified						
76	7612	Casks, drums, cans, boxes and similar containers, incl. rigid or collapsible tubular containers, of aluminum, for any material (other than compressed or liquefied gas), of a capacity of <= 300 l, not fitted with mechanical or thermal equipment, whether or not lined or heat-insulated, n.e.s.	Aluminum products	66%	74%	69%	62%
77-83	Product category/ies with insignificant consumption, no representative products identified						
84	8414	Air or vacuum pumps (excl. gas compound elevators and pneumatic elevators and conveyors); air or other gas compressors and fans; ventilating or recycling hoods incorporating a fan, whether or not fitted with filters; parts thereof	Air compressor	2%	3%	2%	2%
84	8418	Refrigerators, freezers and other refrigerating or freezing equipment, electric or other; heat pumps; parts thereof (excl. air conditioning machines of heading 8415)	Refrigerator	5%	7%	6%	5%
84	8422	Dishwashing machines; machinery for cleaning or drying bottles or other containers; machinery for filling, closing, sealing or labelling bottles, cans, boxes, bags or other containers; machinery for capsuling bottles, jars, tubes and similar containers; other packing or wrapping machinery, incl. heat-shrink wrapping machinery; machinery for aerating beverages; parts thereof	Dishwashing machine	2%	3%	4%	2%
84	8429	Self-propelled bulldozers, angledozers, graders, levellers, scrapers, mechanical shovels, excavators, shovel loaders, tamping machines and roadrollers	Hydraulic digger	12%	13%	17%	8%
84	8433	Harvesting or threshing machinery, incl. straw or fodder balers; grass or hay mowers; machines for cleaning, sorting or grading eggs, fruit or other agricultural produce; parts thereof (other than machines for cleaning, sorting or grading seed, grain or dried leguminous vegetables of heading 8437)	Tractor	2%	3%	2%	4%
84	8443	Tools for working in the hand, pneumatic, hydraulic or with self-contained electric or non-electric motor; parts thereof	Electric drill	2%	2%	1%	2%
84	8471	Automatic data-processing machines and units thereof; magnetic or optical readers, machines for transcribing data onto data media in coded form and machines for processing such data, n.e.s.	Computer	3%	3%	3%	4%
85	8501	Electric motors and generators (excl. generating sets)	Electric motor	30%	32%	4%	62%
85	8508	Electromechanical domestic appliances, with self-contained electric motor; parts thereof	Vacuum cleaner	1%	1%	1%	0%
85	8528	Radar apparatus, radio navigational aid apparatus and radio remote control apparatus	Mobile GPS	4%	3%	3%	1%
85	8536	Monitors and projectors, not incorporating television reception apparatus; reception apparatus for television, whether or not incorporating radio-broadcast receivers or sound or video recording or reproducing apparatus	Television	3%	2%	3%	1%
85	8544	Insulated “incl. enameled or anodized” wire, cable “incl. coaxial cable” and other insulated electric conductors, whether or not fitted with connectors; optical fiber cables, made up of individually sheathed fibers, whether or not assembled with electric conductors or fitted with connectors	Cables	25%	23%	47%	7%
86	Product category/ies with insignificant consumption, no representative products identified						
87	8703	Motor cars and other motor vehicles principally designed for the transport of persons, incl. station wagons and racing cars (excl. motor vehicles of heading 8702)	Passenger car	46%	45%	58%	43%
88-89	Product category/ies with insignificant consumption, no representative products identified						

CN-2	TOP CN-4	CN-4 Product Type Description	Representative Product*	Sto	Got	Mal	Swe
90	9018	Instruments and appliances used in medical, surgical, dental or veterinary sciences, incl. scintigraphic apparatus, other electro-medical apparatus and sight-testing instruments, n.e.s.	Medical instrument	5%	9%	10%	4%
91-93	Product category/ies with insignificant consumption, no representative products identified						
94	9403	Furniture and parts thereof, n.e.s. (excl. seats and medical, surgical, dental or veterinary furniture)	Door production	47%	49%	52%	49%
94	9406	Prefabricated buildings, whether or not complete or already assembled	Prefabricated building	33%	23%	28%	36%
95	9503	Tricycles, scooters, pedal cars and similar wheeled toys; dolls'' carriages; dolls; other toys; reduced-size "scale" recreational models, working or not; puzzles of all kinds	Bicycle	34%	35%	34%	30%
95	9506	Articles and equipment for general physical exercise, gymnastics, athletics, other sports, incl. table-tennis, or outdoor games, not specified or included in this chapter or elsewhere; swimming pools and paddling pools.	Steel – gym equipment	45%	44%	47%	53%
96-99	Product category/ies with insignificant consumption, no representative products identified						

* Products marked with an asterisk (*) have been modelled using a proxy.
Sto = Stockholm, Got = Gothenburg, Mal = Malmö, Swe = Sweden, n.e.s. = not elsewhere specified

No.	Swedish	English	Category	Category (English)	Relevant to material or rf?	Related to hotspots?	Material flow
1	Vidareutveckla grön upplåning	Further develop green borrowing	Minskad klimatpåverkan	Reduced climate impact	no	no	
2	Utveckla stödstrukturer för en hållbarare livsmedelsbransch	Develop support structures for a sustainable food industry	Minskad klimatpåverkan	Reduced climate impact	maybe	no	
3	Utred möjligheten att skapa ett nätverk för aktörer inom stadsnära odling	Investigate the possibility of creating a network for actors in urban farming	Minskad klimatpåverkan	Reduced climate impact	maybe	no	
4	Verka för integrerad energidesign	Work for integrated energy design	Minskad klimatpåverkan	Reduced climate impact	no	no	
5	Ta fram en klimatfärdplan för Älvstadens utbyggnad	Develop a climate roadmap for Älvstadens expansion	Minskad klimatpåverkan	Reduced climate impact	no	no	
6	Etablera cirkulära Älvstaden	Establish circular Älvstaden	Minskad klimatpåverkan	Reduced climate impact	yes	maybe	several
7	Planera för miljöanpassade transporter i Älvstaden	Plan for environmentally adapted transport in Älvstaden	Minskad klimatpåverkan	Reduced climate impact	yes	yes	fuel
8	Samordna Göteborg Stads energitjänster till företag	Coordinate Göteborg City energy services to companies	Minskad klimatpåverkan	Reduced climate impact	no	no	
9	Informera företag om energieffektiviseringsstöd	Inform companies about energy efficiency support	Minskad klimatpåverkan	Reduced climate impact	no	no	
10	Satsa på energi- och klimatrådgivning till företag och organisationer	Focus on energy and climate advice for companies and organizations	Minskad klimatpåverkan	Reduced climate impact	no	no	
11	Visualisera energianvändning för företag, hushåll och organisationer	Visualize energy use for companies, households and organizations	Minskad klimatpåverkan	Reduced climate impact	no	no	
12	Informera om egenproducerad el	Inform about self-produced electricity	Minskad klimatpåverkan	Reduced climate impact	no	no	
13	Ta fram plan för produktion av förnybar el	Develop plans for the production of renewable electricity	Minskad klimatpåverkan	Reduced climate impact	maybe	no	
14	Ökad användning och utveckling av fjärrkyla i staden	Increased use and development of district cooling in the city	Minskad klimatpåverkan	Reduced climate impact	yes	no	
15	Planera för fossilfri fjärrvärme	Plan for fossil-free district heating	Minskad klimatpåverkan	Reduced climate impact	yes	yes	fuel
16	Verka för klimatanpassade reseavdrag	Work for climate-adjusted travel deductions	Minskad klimatpåverkan	Reduced climate impact	yes	yes	fuel
17	Verka för att använda trängselskatten som stöd för hållbart resande	Seek to use congestion tax to support sustainable travel	Minskad klimatpåverkan	Reduced climate impact	yes	maybe	fuel, vehicles
18	Skapa ett samverkansforum för ökad användning av biogas i transportsektorn	Create a collaboration forum for increased use of biogas in the transport sector	Minskad klimatpåverkan	Reduced climate impact	yes	maybe	fuel
19	Verka för att möjliggöra gynnande av eldrift/fossilfri drift	Seek to enable favoring of electric / fossil-free operation	Minskad klimatpåverkan	Reduced climate impact	yes	maybe	fuel, vehicles
20	Testa alternativa vägbeläggningar	Test alternative road pavements	Minskad klimatpåverkan	Reduced climate impact	yes	no	
21	Autonoma fordon i hållbar stadsutveckling	Autonomous vehicles in sustainable urban development	Minskad klimatpåverkan	Reduced climate impact	yes	yes	fuel, vehicles
22	Ta fram ett godstransportprogram	Create a freight transport program	Minskad klimatpåverkan	Reduced climate impact	yes	yes	fuel, vehicles
23	Samordna leveranser till och från byggprojekt	Coordinate deliveries to and from construction projects	Minskad klimatpåverkan	Reduced climate impact	yes	yes	fuel
24	Utveckla och testa klimatsmart närlogistik	Develop and test climate-friendly proximity logistics	Minskad klimatpåverkan	Reduced climate impact	maybe	maybe	fuel
25	Utveckla vårt arbete med rättvis handel kopplat till klimatfrågan	Develop our work on fair trade linked to the climate issue	Minskad klimatpåverkan	Reduced climate impact	no	no	
26	Samverka för en hållbar destination	Collaborate for a sustainable destination	Minskad klimatpåverkan	Reduced climate impact	maybe	no	
27	Satsa på cykelturism	Invest in cycling tourism	Minskad klimatpåverkan	Reduced climate impact	maybe	maybe	fuel, vehicles
28	Metodutveckla, förankra och upprätta gröna transportplaner	Method development, anchoring and establishing green transport plans	Ökad andel hållbart resande	Increased share of sustainable travel	yes	maybe	fuel, vehicles
29	Utökad samverkan kring cykelfrågor i Göteborg	Extended cooperation on cycling issues in Gothenburg	Ökad andel hållbart resande	Increased share of sustainable travel	yes	maybe	fuel, vehicles
30	Förbättra framkomligheten för cyklister	Improve accessibility for cyclists	Ökad andel hållbart resande	Increased share of sustainable travel	yes	maybe	fuel, vehicles
31	Skapa fler cykelparkeringar	Create more bike parking	Ökad andel hållbart resande	Increased share of sustainable travel	yes	maybe	fuel, vehicles
32	Bygg säkra och attraktiva cykelparkeringsanläggningar vid tågstationer	Build safe and attractive bicycle parking facilities at train stations	Ökad andel hållbart resande	Increased share of sustainable travel	yes	maybe	fuel, vehicles

No.	Swedish	English	Category	Category (English)	Relevant to material or rf?	Related to hotspots?	Material flow
33	Skapa fler gång- och cykelförbindelser över älven	Create more walking and cycling links across the river	Ökad andel hållbart resande	Increased share of sustainable travel	yes	maybe	fuel, vehicles
34	Bygg ut pendlingscykelnätet	Expand the commuting cycle network	Ökad andel hållbart resande	Increased share of sustainable travel	yes	maybe	fuel, vehicles
35	Förbered för ett nytt lånecykelsystem	Prepare for a new loan cycle system	Ökad andel hållbart resande	Increased share of sustainable travel	maybe	maybe	fuel, vehicles
36	Samordna och förbättra drift och underhåll av gång- och cykelbanor	Coordinate and improve operation and maintenance of pedestrian and cycle tracks	Ökad andel hållbart resande	Increased share of sustainable travel	maybe	maybe	fuel, vehicles
37	Utöka prioriterad vinterväghållning av viktiga gång- och cykelbanor	Extend priority winter road maintenance of key pedestrian and cycle tracks	Ökad andel hållbart resande	Increased share of sustainable travel	maybe	maybe	fuel, vehicles
38	Gör det attraktivt och säkert att gå och cykla till skolor	Make it attractive and safe to walk and bicycle to school	Ökad andel hållbart resande	Increased share of sustainable travel	maybe	maybe	fuel, vehicles
39	Skapa fler attraktiva gångstråk i centrala Göteborg och andra stadsmiljöer	Create more attractive walkways in central Gothenburg and other urban environments	Ökad andel hållbart resande	Increased share of sustainable travel	no	no	
40	Sänk trafikhastigheten i staden	Lower the traffic speed in the city	Ökad andel hållbart resande	Increased share of sustainable travel	yes	yes	fuel
41	Verka för att utveckla ett kombinerat reskort	Work to develop a combined travel card	Ökad andel hållbart resande	Increased share of sustainable travel	maybe	maybe	fuel, vehicles
42	Använd flexlinjen för minskat fritidsresande med bil	Use the flex line for reduced leisure travel by car	Ökad andel hållbart resande	Increased share of sustainable travel	yes	yes	fuel, vehicles
43	Verka för ökad elektrifiering av kollektivtrafiken	Work for increased electrification of public transport	Ökad andel hållbart resande	Increased share of sustainable travel	maybe	maybe	fuel, vehicles
44	Skapa hållbara mobilitetslösningar vid nyproduktion av bostäder	Create sustainable mobility solutions for new home production	Ökad andel hållbart resande	Increased share of sustainable travel	maybe	maybe	fuel, vehicles
45	Underlätta laddning för boende i flerbostadshus	Facilitate charging for those living in multi-family houses	Ökad andel hållbart resande	Increased share of sustainable travel	yes	yes	fuel, vehicles
46	Stötta utvecklingen av fordonspooler	Support the development of vehicle pools	Ökad andel hållbart resande	Increased share of sustainable travel	yes	yes	fuel, vehicles
47	Minska söktrafiken	Reduce search traffic	Ökad andel hållbart resande	Increased share of sustainable travel	maybe	maybe	fuel, vehicles
48	Undersöka förutsättningar för automatiska parkeringsgarage	Examine the conditions for automatic parking garage	Ökad andel hållbart resande	Increased share of sustainable travel	maybe	maybe	fuel, vehicles
49	Verka för möjligheten att ta ut parkeringsavgifter på privat tomtmark	Seek the opportunity to charge parking fees on private land	Ökad andel hållbart resande	Increased share of sustainable travel	no	no	
50	Kartlägg Göteborgs materialflöden för att sluta kretsloppen	Map Göteborg's material flows to "close the loop"	Ökad resurshushållning	Increased resource management	yes	yes	several
51	Främja uppstarten av en eller flera återbyggdepåer i Göteborg	Promote the start-up of one or more building material re-use in Gothenburg	Ökad resurshushållning	Increased resource management	yes	no	
52	Erbjud en ny sorterande grovavfallsinsamling	Offer a new sorting coarse waste collection	Ökad resurshushållning	Increased resource management	maybe	no	

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53	Minska förpackningsavfallet	Reduce packaging waste	Ökad resurshushållning	Increased resource management	maybe	no	
54	Utveckla en metod och verktyg för att säkerställa att ytor för avfall inkluderas i den fysiska planeringen	Develop a method and tool to ensure that areas for waste are included in the physical planning	Ökad resurshushållning	Increased resource management	no	no	
55	Genomför kampanj för att synliggöra det hållbara utbudet på stan	Carry out campaign to make visible the sustainable supply in town	Ökad resurshushållning	Increased resource management	maybe	no	
56	Underlätta för delningsekonomin i Göteborg	Facilitate the sharing economy in Gothenburg	Ökad resurshushållning	Increased resource management	yes	maybe	electronics, vehicles
57	Underlätta för ett cirkulärt Göteborg	Facilitate a circular Gothenburg	Ökad resurshushållning	Increased resource management	yes	maybe	several
58	Öka biblioteksverksamhetens miljöfokus	Increase the library's environmental focus	Ökad resurshushållning	Increased resource management	maybe	maybe	several
59	Undersök möjligheten att etablera ett hållbarhetshus	Examine the possibility of establishing a sustainability house	Ökad resurshushållning	Increased resource management	no	no	
60	Inför konceptet ”Det avfallssnåla kontoret”	Introduce of the concept "The waste-efficient office"	Ökad resurshushållning	Increased resource management	maybe	maybe	electronics, machinery
61	Genomför kommunikationskampanj för minskat matsvinn, grovavfall och elavfall	Conduct communication campaign for reduced food waste, bulky waste and electrical waste	Ökad resurshushållning	Increased resource management	yes	yes	electronics, machinery
62	Bygg en ny kretsloppspark	Build a new reycling/reuse park	Ökad resurshushållning	Increased resource management	yes	maybe	several
63	Utveckla och starta upp minikretsloppsparker	Develop and start up mini-recycling parks	Ökad resurshushållning	Increased resource management	maybe	maybe	several
64	Öka insamlingen av textilier	Increase the collection of textiles	Ökad resurshushållning	Increased resource management	maybe	no	
65	Öka återanvändningen på stadens återvinningscentraler	Increase reuse at city recycling centers	Ökad resurshushållning	Increased resource management	yes	yes	electronics, machinery
66	Utveckla miljöstyrande avfallstaxa	Develop environmental management waste tax	Ökad resurshushållning	Increased resource management	maybe	maybe	several (waste)
67	Minska byggavfallet	Reduce construction waste	Ökad resurshushållning	Increased resource management	yes	no	
68	Inkludera cirkulära lösningar i den fysiska planeringen	Include circular solutions in the physical planning	Ökad resurshushållning	Increased resource management	maybe	maybe	construction materials
69	Öka utsorteringen av förpackningar och tidningar	Increase the sorting of packages and newspapers	Ökad resurshushållning	Increased resource management	yes	no	
70	Förebygg och sortera avfall vid evenemang	Prevent and sort waste at events	Ökad resurshushållning	Increased resource management	maybe	no	
71	Utöka källsorteringen på kommunens anläggningar för allmänheten	Expand recyclables sorting at municipal facilities for the public	Ökad resurshushållning	Increased resource management	maybe	no	
72	Öka antalet miljörum för insamling av elavfall och farligt avfall	Increase the number of environmental resources for the collection of waste and hazardous waste	Ökad resurshushållning	Increased resource management	yes	yes	electronics
73	Öka användningen av anläggningsjord från avloppsslam i staden	Increase the use of soil? from sewage sludge in the city	Ökad resurshushållning	Increased resource management	yes	no	
74	Öka fosforåterföringen till jordbruk med avloppsslam	Increase phosphorus return to agriculture with sewage sludge	Ökad resurshushållning	Increased resource management	no	no	
75	Rena dagvatten från kraftigt förorenade områden	Clean water from heavily polluted areas	En sundare livsmiljö	A healthier habitat	no	no	
76	Verka för att minska läkemedel i avlopp	Work to reduce medicine in sewage	En sundare livsmiljö	A healthier habitat	no	no	
77	Anlägg gröna tak på kommunens fastigheter	Build green roofs on the municipality's properties	En sundare livsmiljö	A healthier habitat	no	no	
78	Tillämpa grönytefaktor i nyproduktion	Apply green factor in new production	En sundare livsmiljö	A healthier habitat	no	no	
79	Skapa förutsättningar för fartyg att få tillgång till alternativa bränslen	Create conditions for ships to access alternative fuels	En sundare livsmiljö	A healthier habitat	yes	yes	fuel

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80	Fortsätt arbetet med att elansluta fartyg i hamn	Continue work on connecting ships in port	En sundare livsmiljö	A healthier habitat	maybe	maybe	unclear
81	Utveckla den miljödifferentierade hamntaxan	Develop the environmentally differentiated port tax	En sundare livsmiljö	A healthier habitat	maybe	maybe	unclear
82	Utred incitament för minskad miljöpåverkan från lastbilar till och från Göteborgs Hamn	Investigate incentives for reduced environmental impact from trucks to and from Gothenburg Harbor	En sundare livsmiljö	A healthier habitat	maybe	maybe	fuel
83	Verka för differentierad trängselskatt för tunga fordon	Apply for differentiated congestion tax for heavy vehicles	En sundare livsmiljö	A healthier habitat	maybe	maybe	fuel
84	Verka för att minska dubbdäcksanvändningen	Work to reduce the double-deck usage	En sundare livsmiljö	A healthier habitat	no	no	
85	Tillämpa miljöanpassad halkbekämpning	Apply environmentally friendly anti-slip control	En sundare livsmiljö	A healthier habitat	no	no	
86	Verka för ökad användning av arbetsmaskiner med elhybriddrift	Work for increased use of electric operating machines	En sundare livsmiljö	A healthier habitat	maybe	maybe	vehicles, machinery, fuel
87	Följ upp anmälningspliktiga verksamheters kemikalieredovisningar	Follow up the reporting requirements of reporting activities	En sundare livsmiljö	A healthier habitat	no	no	
88	Konkretisera insatser kopplade till den regionala vattenförsörjningsplanen	Concrete efforts related to the regional water supply plan	En sundare livsmiljö	A healthier habitat	no	no	
89	Utveckla stadens arbete för god vattenstatus	Develop the city's work for good water status	Främjad biologisk mångfald	Promoting biodiversity	no	no	
90	Ta fram en plan för restaurering och anläggning av våtmarker	Develop a plan for restoration and construction of wetlands	Främjad biologisk mångfald	Promoting biodiversity	no	no	
91	Motverka igenväxning av viktiga biotoper	Counteract the growth of important biotopes	Främjad biologisk mångfald	Promoting biodiversity	no	no	
92	Gör biotopförbättrande åtgärder i sjöar och vattendrag	Make biotope enhancing measures in lakes and streams	Främjad biologisk mångfald	Promoting biodiversity	no	no	
93	Tillämpa hållbar dagvattenhantering i alla byggprojekt inom staden	Apply sustainable water treatment in all construction projects within the city	Främjad biologisk mångfald	Promoting biodiversity	no	no	
94	Skapa fler vattenspeglar i staden	Create more water mirrors in the city	Främjad biologisk mångfald	Promoting biodiversity	no	no	
95	Skapa miniparker med fjärilstema	Create mini-parks with butterfly theme	Främjad biologisk mångfald	Promoting biodiversity	no	no	
96	Öka andelen död ved på skogsmark	Increase the proportion of deadwood on woodland	Främjad biologisk mångfald	Promoting biodiversity	no	no	
97	Bevara äldre träd i parkmiljö	Preserve older trees in the park environment	Främjad biologisk mångfald	Promoting biodiversity	no	no	
98	Utveckla skötsel av ängs- och gräsytor	Develop care of meadow and grass areas	Främjad biologisk mångfald	Promoting biodiversity	no	no	
99	Anlägg dagvattenrening på trafikintensiva vägar	Install water drainage on traffic-intensive roads	Främjad biologisk mångfald	Promoting biodiversity	no	no	
100	Genomför åtgärder utifrån plan för utbyggnad av VA-ledningssystem	Implement measures based on plans for the expansion of the VA management system	Främjad biologisk mångfald	Promoting biodiversity	no	no	
101	Minska utsläppen av spillvatten från ledningsnätet	Reduce emissions of waste water from the mains	Främjad biologisk mångfald	Promoting biodiversity	no	no	
102	Minska tillskottsvatten till spillvattenförande ledningar	Reduce additive water to spillwastewires	Främjad biologisk mångfald	Promoting biodiversity	no	no	
103	Verka för ett utökat skyddsområde för Göta älv	Work for an extended protection area for Göta River	Främjad biologisk mångfald	Promoting biodiversity	no	no	
104	Värdera ekosystemtjänster i staden	Evaluate ecosystem services in the city	Främjad biologisk mångfald	Promoting biodiversity	no	no	
105	Planera för öppna vattendrag	Plan for open watercourses	Främjad biologisk mångfald	Promoting biodiversity	no	no	
106	Identifiera naturliga stråk för dagvattenavledning	Identify natural streams for water drainage	Främjad biologisk mångfald	Promoting biodiversity	no	no	
107	Utred hur olika föroreningskällor påverkar badkvaliteten i centrala Göteborg	Examine how different sources of pollution affect the quality of baths in central Gothenburg	Främjad biologisk mångfald	Promoting biodiversity	no	no	

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108	Analysera marina ansvarsbiotoper	Analyze marine liability biotopes	Främjad biologisk mångfald	Promoting biodiversity	no	no	
109	Gör ekologisk landskapsanalys för fler arter	Make organic landscape analysis for more species	Främjad biologisk mångfald	Promoting biodiversity	no	no	
110	Sammanställ information om invasiva främmande arter	Summarize information about invasive alien species	Främjad biologisk mångfald	Promoting biodiversity	no	no	
111	Ta fram checklistor om artskydd och kompensationsåtgärder	Provide checklists for protection and compensation	Främjad biologisk mångfald	Promoting biodiversity	no	no	
112	Digitalisera kartläggningen av kulturhistoriskt värdefulla odlingslandskap	Digitize the mapping of culture-historically valuable farming landscapes	Främjad biologisk mångfald	Promoting biodiversity	no	no	
113	Utvärdera nya hållbara anläggningar för dagvatten	Evaluate new sustainable facilities for daytime water	Främjad biologisk mångfald	Promoting biodiversity	no	no	
114	Utred möjligheten att öppna upp kulverterade vattendrag	Determine the possibility of opening up watered streams	Främjad biologisk mångfald	Promoting biodiversity	no	no	
115	Undersök föroreningsbelastningen i recipienter av dagvatten	Examine pollutant load in recipients of water	Främjad biologisk mångfald	Promoting biodiversity	no	no	
116	Testa alternativa materialval vid ny- och ombyggnation av konstgräsplaner	Test alternative materials for new and rebuilding artificial turf	Främjad biologisk mångfald	Promoting biodiversity	no	no	
117	Ändrade skötselmetoder för konstgräsplaner syftande till minskad spridning av mikroplast	Changed care methods for artificial turf aimed at reduced microspread dispersion	Främjad biologisk mångfald	Promoting biodiversity	no	no	
118	Informera föreningar med egna konstgräsplaner om miljöproblematiken	Inform associations with their own artificial turf about environmental issues	Främjad biologisk mångfald	Promoting biodiversity	no	no	
119	Utred hur mikroplaster fångas upp i småbåtshamnarnas dagvattenanläggningar	Determine how microplasts are caught in the marina's waterworks	Främjad biologisk mångfald	Promoting biodiversity	no	no	
120	Utbilda anställda i kommunens hamnar när det gäller skötsel av båtbottentvättar med efterföljande rening och hantering av avfall	Educate employees in the municipality's ports when it comes to the care of boat bottles with subsequent treatment and waste management	Främjad biologisk mångfald	Promoting biodiversity	no	no	
121	Undersök förekomsten av mikroskräp från trafik	Examine the presence of microscopic waste (nanowaste?) from traffic	Främjad biologisk mångfald	Promoting biodiversity	no	no	
122	Ta fram riktlinjer om att inte använda konstgräs i trafikmiljöer	Provide guidelines for not using artificial turf in traffic environments	Främjad biologisk mångfald	Promoting biodiversity	no	no	
123	Utöka strandstädningen	Expand beach cleaning	Främjad biologisk mångfald	Promoting biodiversity	no	no	
124	Öka kunskapen om marint skräp i ett maritimt besökscenter vid Askimsbadet	Increase knowledge of marine junk in a maritime visitor center at Askimsbadet	Främjad biologisk mångfald	Promoting biodiversity	no	no	
125	Öka kunskapen om spridning av mikroplaster i kretsloppet via avloppsvatten	Increase the knowledge of the spread of microplaster in the circuit through wastewater	Främjad biologisk mångfald	Promoting biodiversity	no	no	
126	Inkludera utsläpp av mikroplaster från anläggningar i tillsyn	Include discharges of micro-waste (nanowaste?) from supervised installations	Främjad biologisk mångfald	Promoting biodiversity	no	no	
127	Öka andelen multifunktionella ytor i parker för att hantera skyfall	Increase the proportion of multifunctional areas in parks to handle clouds	Tillgängliga och varierade parker och naturområden	Available and varied parks and natural areas	no	no	
128	Utveckla information om parker och naturområden	Develop information about parks and nature areas	Tillgängliga och varierade parker och naturområden	Available and varied parks and natural areas	no	no	
129	Förbättra tillgängligheten till parker och naturområden	Improve accessibility to parks and natural areas	Tillgängliga och varierade parker och naturområden	Available and varied parks and natural areas	no	no	
130	Anlägg ”Jubileumsparken” – en ny stadspark i Frihamnen	Plant "Jubileumsparken" - a new city park in Frihamnen	Tillgängliga och varierade parker och naturområden	Available and varied parks and natural areas	no	no	

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131	Skapa en promenadvänlig och varierad upplevelsemiljö längs kajkanterna inom Älvstaden	Create a walk-friendly and varied experience environment along the quayside of Älvstaden	Tillgängliga och varierade parker och naturområden	Available and varied parks and natural areas	no	no	
132	Ersätt parkeringsplatser vid kanalerna med aktivt stadsliv och grönska	Replace parking spaces on the canals with active city life and greenery	Tillgängliga och varierade parker och naturområden	Available and varied parks and natural areas	no	no	
133	Realisera ett varierat växt- och djurliv i bostadsnära natur	Realize a varied plant and wildlife in residential nature	Tillgängliga och varierade parker och naturområden	Available and varied parks and natural areas	no	no	
134	Ta fram områdesbeskrivningar för friluftsområden	Get area descriptions for outdoor areas	Tillgängliga och varierade parker och naturområden	Available and varied parks and natural areas	no	no	
135	Utveckla Kvillebäcksstråket	Develop Kvillebäcksstråket	Tillgängliga och varierade parker och naturområden	Available and varied parks and natural areas	no	no	
136	Öka tillgängligheten till bostadsnära natur	Increase accessibility to residential nature	Tillgängliga och varierade parker och naturområden	Available and varied parks and natural areas	no	no	
137	Tillgängliggöra Hisingens kustremsa	Accessible to Hisingen's coastal strip	Tillgängliga och varierade parker och naturområden	Available and varied parks and natural areas	no	no	
138	Öka tillgängligheten och naturvärden på mindre öar	Increase accessibility and natural values in smaller islands	Tillgängliga och varierade parker och naturområden	Available and varied parks and natural areas	no	no	
139	Placera ut fler toaletter i skärgården	Place more toilets in the archipelago	Tillgängliga och varierade parker och naturområden	Available and varied parks and natural areas	no	no	
140	Ta fram ett nytt strategiskt styrdokument för miljöområdet för Göteborg Stad	Create a new strategic governance document for the environmental area of Göteborg City	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	no	no	
141	Presentera och visualisera miljöinformation	Present and visualize environmental information	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	no	no	
142	Ta fram stadengemensam miljöövervakningsplan	Obtain city-wide environmental monitoring plan	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	no	no	
143	Samla och synliggör resultat från miljöövervakning	Collect and visualize results from environmental monitoring	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	no	no	
144	Vidareutveckla GreenhackGBG	Further develop GreenhackGBG	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	no	no	
145	Utveckla stadens arbete med hållbara livsstilar	Develop the city's work with sustainable lifestyles	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	maybe	maybe	several
146	Inför miljöledningssystem eller miljöcertifiering i alla kommunens verksamheter	Environmental management system or environmental certification in all municipalities	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	no	no	
147	Utse miljösamordnare på alla förvaltningar och bolag	Appoint environmental coordinators to all administrations and companies	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	no	no	
148	Miljöutbilda kommunens personal	Environmental education of the municipality's staff	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	no	no	
149	Samordna uppföljning av miljömålen med uppföljningen av översiktsplanen	Coordinate follow-up of environmental goals with the follow-up of the overview plan	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	no	no	
150	Utreda flexibel arbetsplats	Investigate flexible workplace	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	maybe	maybe	fuel, vehicles
151	Ta fram avfallsplaner i alla förvaltningar och bolag	Create waste plans in all administrations and companies	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	maybe	maybe	fuel
152	Utse avfallssamordnare	Appointing waste coordinator	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	maybe	maybe	several (waste)
153	Inventera och utveckla verksamheternas utrymmen för avfallshantering	Investigate and develop the activities of waste management	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	maybe	maybe	several (waste)

No.	Swedish	English	Category	Category (English)	Relevant to material or rf?	Related to hotspots?	Material flow
154	Minska elektronikavfallet i stadens verksamheter	Reduce the electronic waste in the city's operations	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	yes	electronics
155	Kvalitetssäkra insamlingen av farligt avfall i stadens verksamheter	High-quality collection of hazardous waste in the city's operations	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	maybe	no	
156	Implementera samordnad utskriftshantering i stadens verksamheter	Implement coordinated print management in city operations	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	maybe	no	
157	Inför rutiner vid införskaffande och avyttrande av möbler och inredning	Procedures for the procurement and disposal of furniture and furnishings	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	no	
158	Utveckla TAGE	Develop TAGE	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	no	several
159	Inred nya lokalerna i Alelyckan hållbart	Decorate new premises in Alelyckan sustainable	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	no	
160	Inför konceptet "Det avfallssnåla äldreboendet"	Initiate of the concept "The waste-poor retirement home"	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	maybe	no	
161	Dokumentera och redovisa användningen av utfasningsämnen i märkningspliktiga kemiska produkter	Document and report the use of phase-out substances in labeling chemical products	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	no	
162	Begränsa produkter med utfasningsämnen i Winst	Restrict products with phase-out substances in Winst	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	no	
163	Koppla samman Winst med Chemsoft - underlätta rätt val vid inköp	Connect Winst with Chemsoft - facilitate the right choice when purchasing	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	no	
164	Skapa nätverk för kreativa återvinningscenter	Create Network for Creative Recycling Center	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	maybe	several (waste)
165	Minska miljöpåverkan från livsmedelsinköp	Reduce environmental impact from food purchases	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	no	
166	Öka utbudet av ekologiskt och vegetariskt samt minska matsvinnet på restauranger, caféer och evenemang i stadens verksamheter	Increase the range of organic and vegetarian foods as well as reduce food habits in restaurants, cafes and events in the city's activities	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	no	
167	Utbilda måltidspersonal i vegetarisk matlagning	Educate meal staff in vegetarian cooking	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	no	
168	Upphandla fler ekologiska livsmedel	Purchase more organic foods	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	no	
169	Energieffektivisera energianläggningar	Energy-efficient energy plants	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	no	no	
170	Underlätta för energibesparing av IT-utrustning i stadens verksamheter	Facilitate energy saving of IT equipment in city operations	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	no	no	
171	Genomför planen för avveckling av fossila bränslen	Implement the plan for the disposal of fossil fuels	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	yes	fuel
172	Avveckla kylmaskiner	Discontinue refrigerators	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	yes	machinery
173	Erbjud energiutbildning till nyckelpersoner	Offer energy education to key personnel	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	maybe	maybe	unclear
174	Inför fossilfri kommunal maskinpark	Facing fossil-free municipal machinery	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	yes	fuel, vehicles
175	Kartlägg IT:s klimatpåverkan	Map the IT climate impact	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	yes	electronics
176	Inför en modell för kommuninterna gröna hyresavtal	Introducing a model for municipal green leases	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	maybe	maybe	unclear
177	Underlätta för resfria möten	Enable travel-free meetings	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	maybe	maybe	fuel, vehicles
178	Utred hur vi kan främja att semestra lokalt	Investigate how we can encourage local vacations	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	maybe	maybe	fuel, vehicles

No.	Swedish	English	Category	Category (English)	Relevant to material or rf?	Related to hotspots?	Material flow
179	Vidareutveckla stadens klimatkompensation	Further develop the city's climate compensation	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	no	no	
180	Samordna fordonspooler inom Göteborgs stad	Coordinate vehicle pools in the city of Gothenburg	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	yes	fuel, vehicles
181	Öka andelen miljöfordon	Increase the proportion of environmental vehicles	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	yes	fuel, vehicles
182	Ställ högre krav på miljöfordonsanvändning i upphandling	Set higher demands on environmental use in procurement	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	yes	fuel, vehicles
183	Handla upp varor separat från transporter	Procure goods separately from transport	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	yes	fuel
184	Minska miljöpåverkan från stadens inköp	Reduce environmental impact from city purchases	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	maybe	several
185	Minska klimatpåverkan från stadens byggnation	Reduce climate impact from the city's construction	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	no	
186	Ha ett tydligt miljöfokus i inköps- och beställarutbildningar	Have a clear environmental focus in purchasing and ordering programs	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	yes	several
187	Tydliggör miljöanpassade produkter i Winst	Explain environmentally adapted products in Winst	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	yes	yes	electronics, machinery
188	Samla och tillgängliggör kunskapen från planprocessens miljöutredningar	Collect and make available the knowledge from the planning process's environmental investigations	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	no	no	
189	Utred hur miljökvalitet säkerställs i nyplanerade områden	Investigate how environmental quality is ensured in newly planned areas	Göteborgs stad som föregångare	The city of Gothenburg as a forerunner	no	no	

Appendix C: Questionnaire to workshop attendees

Do you use quantitative data for monitoring environmental goals?

- Yes
- No
- Partly

If so, which environmental aspects are evaluated quantitatively?

- Climate impact
- Acidification
- Eutrophication
- Resource use
- PM10 / PM2.5 (Air quality)
- Biodiversity

Do you use tools to calculate consumption-based emissions?

- Yes
- No
- Partly

If you use tools, which one or which ones do you use? (Eg REAP, Environmental Spend Analysis, LCA)

Appendix D: Popular Science Summary of Workshop

Sammanfattning: Seminariet om konsumtionsbaserade utsläpp

Alexandra Lavers Westin, Chalmers & Tomas Rydberg, IVL

12 november 2020

Den 12 november 2020 samlades 18 praktiker från åtta olika kommunala miljökontor och flera miljöorganisationer i Sverige för en diskussion om ett beräkningsverktyg utvecklat av Chalmers och IVL som uppskattar kommuners och regioners konsumtionsbaserade miljöpåverkan. Syftet var att diskutera resultat från verktyget och huruvida verktyget skulle kunna modifieras och utvecklas för att kunna tillämpas av flera.

Konsumtionsbaserade miljöpåverkan är den miljöpåverkan som uppstår när en vara produceras i ett land (Sverige eller i andra länder) och konsumeras i Sverige. Den inkluderar inte varor som produceras i Sverige men exporteras och konsumeras i andra länder. Miljöpåverkans kategorier som verktyget beräknar inkluderar klimatpåverkan, försurning, övergödning, fotokemisk ozonformation samt resursutarmning. Verktyget har använts för att beräkna konsumtionsbaserade miljöpåverkan i storstadsregionerna Stockholm, Göteborg, och Malmö.

Först diskuterades hur deltagarna arbetade med konsumtionsbaserade miljöpåverkan i dagsläget. Flera praktiker arbetade med konsumtionsbaserade miljöpåverkan relaterade till offentlig upphandling, mestadels livsmedelsrelaterade, genom att använda sig av upphandlingsspecifika verktyg såsom Compare/Mashie eller Miljöspendanalys från Upphandlingsmyndigheten. En kommun kopplade upphandlingar till LCA i viss mån. En annan kommun använde ett verktyg för att beräkna miljöpåverkan från byggprojekt. Enstaka kommuner hade mål med avseende på konsumtionsbaserade utsläpp, dock oftast kopplad till den offentliga verksamheten och inte för hushåll eller företag. I Västra Götaland finns ett regionalt mål att minska västsvenskarnas konsumtionsbaserade utsläpp med 30% jämfört med 2010 till 2030. Det fanns ett stort intresse för att kunna beräkna konsumtionsbaserade miljöpåverkan för att kunna uppnå exempelvis FN:s hållbarhetsmål samt Sveriges generationsmål.

Deltagarna var överens om att verktyget skulle vara användbart för att prioritera åtgärder riktade mot konsumtion och konsumtionsbaserade miljöpåverkan. Praktikerna utryckte ett behov av ett enkelt verktyg som ger vägledning om vilka produktgrupper som ska prioriteras samt bidrar till evidensbaserad policy. Dock måste data vara kommun- eller regionspecifikt och inte baserat på generaliserade per capitaberäkningar. Det är viktigt att kunna både prioritera åtgärder men viktigast är att kunna följa upp och kvantifiera hur effektivt åtgärderna hade minskat konsumtionen. Det är således viktigt att resultaten från verktyget ska kunna uppdateras med aktuella konsumtionsdata. Konsumtionsdata måste därför vara tillgängliga och lätt kvantifierbara. Verktyget i sig bör vara enkel eftersom det oftast finns inte tid eller resurser för komplicerade programvaror eller beräkningar som kommuner ska utföra själva. Dessutom finns ett behov av integration med befintliga databaser och rapporteringsprogramvara (t.ex. Kolada, där kommunernas nyckeltal samlas). Det finns dessutom en risk för överlappning med andra verktyg såsom exempelvis Climate Views, Transition Targets samt Future Proofed cities.

Det diskuterades även vilken del av konsumtion var väsentlig för praktikerna. Konsumtion kan delas upp i tre sektorer, offentlig konsumtion dvs upphandlingar, hushållens konsumtion, samt företagens konsumtion. Den totala konsumtionen var relevant för praktiker, men det fanns ett behov av att kunna beräkna den offentliga upphandlingens inverkan specifikt eftersom detta är det område där det finns störst rådighet. Hushållens konsumtion är också intressant eftersom flera åtgärder riktar sig mot hushåll och man vill kunna mäta resultat. Verktyget skulle således vara till mest hjälp om det kunde ge en samlad bedömning av påverkan från totala konsumtionen som kan delas upp i de tre konsumtionssektorerna (offentlig, hushåll, och företag).

I dagsläget räknar verktyget ut så kallade ”hotspots”, dvs produktgrupper med särskilt hög miljöpåverkan som kan prioriteras för att uppnå miljömål fortare. Dessa hotspots sågs som användbara men begränsade av behovet av att veta vilka aktiviteter som drev konsumtionen. För att rikta åtgärder krävs mer information om vilket eller vilka konsumenter eller aktiviteter driver konsumtionen. Hotspots kan också ha ett högt kommunikativt värde som lyfter konsumentens eget ansvar för att minska konsumtionen.

Verktyget kan också användas för att beräkna möjlig konsumtionsminskning till följd av olika åtgärder med så kallade ”scenarios”. Det var delade åsikter om det skulle vara hjälpsamt att beräkna hur långt man kan nå med åtgärderna. Information inom områden som kommunerna inte har rådighet är inte särskilt hjälpsamt, dock tyckte vissa att det kan vara intressant att veta om planerade åtgärder kan ta kommunen hela vägen till målet.

Verktyget var utvecklad för att stötta kommuners arbete med konsumtionsbaserade miljöpåverkan. I framtiden kommer verktyget att utvecklas med avseende på förslagen som lyftes fram under seminariet.

Frågor som ställdes till deltagarna:

- Hur arbetar ni med konsumtionsbaserad miljöpåverkan idag?
- Finns det ett behov att utveckla ett Excelverktyg eller liknande?
- Vilken information är viktigast: Totalkonsumtion (hushåll + offentlig verksamhet + företag), Offentlig konsumtion, Hushållens konsumtion, eller Företagens konsumtion
- Krävs regionspecifika konsumtionsdata eller skulle per capita räcka för era behov?
- Är “hotspots” dvs produktgrupper med särskilt stor påverkan till hjälp för ert arbete? I så fall varför/varför inte?
- Är ett verktyg mer användbart vid planering/prioritering av åtgärder eller för uppföljning?
- Är uppskattningar av hur långt man kan nå (dvs hur mycket minskning i miljöpåverkan till följd av minskad konsumtion) med åtgärder användbart?