Be the Change?

– Exploring the Environmental Mitigation Potential of Lifestyle Changes in Europe Using a Multi-Regional Input-Output Model

Johan Lars Ruben Lundström

Examensarbete 2017

Miljö- och Energisystem

Institutionen för Teknik och samhälle

Lunds Tekniska Högskola

LUNDS UNIVERSITET
Lunds Tekniska Högskola

Be the Change?

Exploring the Environmental Mitigation Potential of Lifestyle Changes in Europe Using a Multi-Regional Input-Output Model

Johan Lars Ruben Lundström

Supervisors: Gibran Vita & Richard Wood

Examensarbete

Februari 2017

ISRN LUTFD2/TFEM-- 16/5118--SE + (1-101)

Dokumentutgivare, Dokumentet kan erhållas från

LUNDS TEKNISKA HÖGSKOLA
vid Lunds universitet
Institutionen för teknik och samhälle
Miljö- och energisystem
Box 118
221 00 Lund
Telefon: 046-222 00 00
Telefax: 046-222 86 44

Dokumentnamn

Examensarbete

Utgivningsdatum

Februari 2017

Författare

Johan Lars Ruben Lundström

Dokumenttitel och undertitel

Be the Change? Exploring the Environmental Mitigation Potential of Lifestyle Changes in Europe Using a Multi-Regional Input-Output Model

Sammandrag

Är det möjligt för konsumenter att vara förändringen man vill se i samhället, och därmed bidra till en hållbarare framtid? Med hjälp av en modell baserad på Multi-Regional Input-Output (MRIO) analys undersöks den miljömässiga potentialen av olika livsstilar i EU. Europeiska hushålls fotavtryck för koldioxid, toxicitet, vatten och land beräknas för olika konsumtionsmönster. Modellen som används innefattar en förenklad och statisk bild av ekonomin, och bortser from de ekonomisk-strukturella förändringar en storskalig livsstilsförändring på EU-nivå skulle innebära. Därav bör resultaten inte tolkas som exakta. Majoriteten av vår mark och vattenanvändning är relaterad till utgifter på mat. En livsstil baserad på sänkt kaloriintag, undvikande av matavfall, och enbart konsumtion av ekologisk, vegansk mat kan potentiellt sänka fotavtrycket av europeiska hushåll med upp till 21% för koldioxid, 22% för land, och 34% för vatten. Genom minskad användning av transportsystem (till exempel genom att cykla) kan vårt koldioxidfotavtryck minskas med upp till 26%. Livsstilar baserade på minskad konsumtion innebär dock även en risk för att sparade pengar spenderas åter på mer utsläppsintensiva produkter (sk. *rebound effect*). En sådan oönskad effekt åtgärdas mest effektivt genom att låta sparade pengar gå till tjänstesektorn som har en låg utsläppsintensitet. Ett alternativ är en absolut minskning av hushållens konsumtion, där en viss nivå av utgiftsminskning korresponderar med motsvarande minskning av fotavtryck. Påverkan på land- och vattenanvändning huvudsakligen är placerad utanför EU. Det motsatta är sant för koldioxid- och toxicitetsfotavtryck som främst orsakas av utsläpp som sker inom EU. Sammanfattningsvis bär livsstilsförändringar en stor potential för att begränsa miljöbelastningen orsakad av europeiska hushåll, även om det krävs att negativa effekter av *rebound effect* samtidigt undviks.

Nyckelord

Hållbar konsumtion, Livsstil, Klimatpolicy, Europa, MRIO

Sidomfång	Språk	ISRN
101	Engelska	LUTFD2/TFEM-- 16/5118--SE + (1-101)

Organisation, The document can be obtained through

LUND UNIVERSITY
Department of Technology and Society
Environmental and Energy Systems Studies
Box 118
SE - 221 00 Lund, Sweden
Telephone: int+46 46-222 00 00
Telefax: int+46 46-222 86 44

Type of document

Master thesis

Date of issue

February 2017

Authors

Johan Lars Ruben Lundström

Title and subtitle

Be the Change? Exploring the Environmental Mitigation Potential of Lifestyle Changes in Europe Using a Multi-Regional Input-Output Model

Abstract

Is it possible for the EU consumer to ‘Be the Change’ and set society on a more sustainable pathway by a change of lifestyle? Using a Multi-Regional Input-Output (MRIO) model this research investigates the environmental impact reduction potential of different lifestyles in the EU, for footprints of carbon, toxicity, water, and land. 12 lifestyles are found that offer significant reduction potential without the risk of trade-offs across footprints. Half of these lifestyles are based on net reduction of consumption, and half involve shifting consumption patterns toward less environmentally intensive products. Overall, the majority of land and water footprint is associated with spending on food and thus holds a large reduction potential. A lifestyle of no food waste, reduction of calorific intake, and consuming only organic, vegan food may reduce carbon, land, and water footprint by up to 21, 22, and 34%, respectively. By low use of transportation systems (e.g. by biking) up to 26% of the EU household carbon footprint could be avoided. However, lifestyles based on reduced consumption involve a risk that the saved money is re-spent on more emission-intensive products (rebound effect). For example, a full rebound effect from decreased use of mobility would cause land and water footprint to increase significantly. The rebound effect is most effectively mitigated by ensuring that expenditure is instead redirected toward services that have a low impact intensity. An alternative is to decrease the absolute consumption, where any total expenditure reduction corresponds to the same reduction of environmental footprints. A majority of the estimated changes of land and water footprint that different lifestyles would cause are taking place outside the EU, the opposite being true for carbon and toxicity impacts. In conclusion, lifestyle changes hold a large potential for mitigation of the environmental footprint of the EU households, but the potential rebound effect has to be taken into consideration.

Keywords

Sustainable Consumption, Climate Mitigation, Lifestyle, Europe, MRIO

Number of pages	Language	ISRN
101	English	LUTFD2/TFEM-- 16/5118--SE + (1-101)

PREFACE

Starting early on in my childhood, my mother would often spend time with me in nature, and I especially remember the many mountain hiking trips we made. I have always found nature a great source of relief and positive energy, helping me rememember that there is something far greater than me out there; that I am not independent.

Motivated to serve in return, to give something back to this supreme force that I called 'nature', in 2010 I enrolled for a programme at the University of Lund in Sweden, working toward a Master of Science degree in Environmental Engineering. In 2014 I found myself in Trondheim, Norway, where I spent a year with exchange studies at the department for Industrial Ecology. Here I also met my friend and future supervisor Gibran Vita. My encounter with the exciting subject of sustainable lifestyles led me to start developing this Master thesis in the autumn of 2015. Together with Gibran, to whom I am very grateful for being so patient and understanding of my particular private life situation, this Master thesis project gradually developed from idea to implementation (through months and months of mental bushwhacking).

I would like to express how I never would have gotten through this on my own. I want to thank Sharada and Jeff for correcting my English, and all my supervisors; Gibran Vita, Richard Wood and Charlotte Malmgren, for making this master thesis possible. Most importantly, thanks to the support of my close friends and family, I've always been able to see the light in end of the tunnel.
You are all very dear to me.

I have always wanted to be able to make a difference, somehow, and I hope that this paper can be the start of something good. Hopefully, the many hours I have spent in front of the computer will contribute to creating a better world for all.

Thank you.

Table of Contents

1. Introduction

1.1 MOTIVATION

'An attitude to life which seeks fulfillment in the single-minded pursuit of wealth - in short, materialism - does not fit into this world, because it contains within itself no limiting principle, while the environment in which it is placed is strictly limited.'
E.F. Schumacher
Small is Beautiful: A Study of Economics as if People Mattered

It is growing increasingly clear that the human need for satisfaction goes further than what this material world can provide. At present, four out of nine planetary boundaries for the Earth system are exceeded. This means that the safe operating space for human societies to develop and thrive have been surpassed, causing risk of irreversible and abrupt changes in the environment. Boundaries now exceeded include that for atmospheric CO_2 concentrations, extinction rate, deforestation, and the flow of nitrogen and phosphorus (Steffen et al. 2015). The EU plays a significant role, being responsible for 18% of the world's total greenhouse gas emissions (Steen-Olsen et al. 2012). The EU economy is using nearly three times more natural resources than what is available in the region (Galli et al. 2013), and the consumption-based water use for the EU countries is more than twice as high than what the planetary boundary allows for (Lenzen et al. 2013; Nykvist et al. 2013).

The Earth may very well have entered a new geological epoch, defined as 'the Anthropocene' by Nobel prize winner Paul J. Crutzen. Mankind is now the main force shaping the environment; more nitrogen fertilizer is applied in agriculture than is fixed naturally in all terrestrial ecosystems and concentrations of greenhouse gases in the atmosphere have increased by more than 30% (CO_2) and 100% (methane) to the highest levels over the past 400 000 years (Crutzen 2002). Croplands and pastures today make up 40% of the land surface (Ramankutty and Foley 1999; Asner et al. 2004) and humans and our domesticated animals make up more than 97% of the global biomass (Smil 2011)**.** As important boundaries of the Earth system are being exceeded, the international community agreed in Cancun in 2010 to keep the global temperature rise below two degrees (UNFCCC 2017). This was previously suggested by the German Advisory Council on Global Change in order to promote early, precautionary actions of environmental impact mitigation (WBGU 1995). The European Commission (2013a) has expressed the need for a post-2015 *unified policy framework* to 'mark out a path from poverty towards prosperity and well-being, for all people and all countries, with progress remaining within planetary boundaries'. Current EU environmental policy is guided by the 7th Environment Action Programme. Having entered into force in January 2014, it underlines the need to develop the knowledge base to enable implementation of the most effective approaches toward issues such as climate change and breach of environmental thresholds (European Commission 2013b).

There is in other words a great need for exploring to what extent it is possible to satisfy the material needs in a strictly limited environment. Sustainable development as such is based on the notion of meeting current needs in a way that does not compromise the ability of future generations to meet their own needs (WCED 1987). The environmental impact related to satisfying material needs can be crudely simplified as follows;

*Impact = Population * Affluence * Technology*

or
$I = P * A * T$
(Ehrlich 1968)

or for Greenhouse Gas (GHG) emissions:

$$GHG\ Emissions = Population * \frac{Consumption}{Capita} * \frac{GHG\ Emissions}{Consumption}$$

(Girod, van Vuuren, and Hertwich 2014)

The factor of affluence is generally seen as economic growth, but can also be divided into product-specific consumption and thus represent different lifestyles and consumption choices (Hubacek, Guan, and Barua 2007). The technology parameter T measures production and processing efficiency of the 'background system' that supply certain products.

The IPAT equation visualizes the dilemma of allowing continuous economic growth (A) in a situation with steadily growing population (P); the technological improvements (doing more with less) in production processes need to outrun the growth of affluence and population so as not to generate an increase in environmental impacts. In *Prosperity without growth*, Jackson (2011) argued that such sought-after decoupling of emissions from economic growth is nothing more than a myth. Only addressing the technological aspect by efficiency improvements is not enough even to stabilize environmental impacts and resource demand (Crocker and Linden 1998; Hertwich 2008). Furthermore, technological progress may in itself increase consumption (Ayres 2008), and may be hindered by the current infrastructure that is in place. To summarize, there is a need to *also* address the question of affluence (A) or lifestyles.

Lifestyle changes where consumption patterns are altered offer a potential for immediate impact reduction. According to the 5th assessment report by the IPCC (2014, 20), 'Emissions can be substantially lowered through changes in consumption patterns (e.g., mobility demand and mode, energy use in households, choice of longer-lasting products) and dietary change and reduction in food wastes'. Such measures have an even higher mitigation potential when coupled with technological or structural change (IPCC 2014). Dietary change may especially help reverse the ongoing world food and water crisis (Goodland and Anhang 2009). Hertwich (2008) argued that implementing sustainable livelihoods is an absolute necessity in order to achieve the goal of sustainable development.

However, in a world of globally distributed production activities, often there is no clear spatial connection between production (where emissions occur) and consumption (Hubacek et al. 2014). Applying the method of multi-regional input-output (MRIO) analysis provides a connection between the two through combining trade data with production and consumption activity. This allows for investigation into how production activity is influenced by consumption. For example, using an MRIO framework Ivanova et al. (2016) showed that 27% of the EU household carbon footprint is caused by spending on mobility. Roughly half the carbon footprint is caused by direct emissions from cars, and the rest is indirect emissions occurring in the value-chain of products required for mobility. Meanwhile, there has been little research made on how much of the total EU householders' carbon footprint from mobility that is caused by emissions occurring outside the EU. Peters, Briceno, and Hertwich (2004, 1) have concluded that 'A promising way to reduce environmental impacts of consumer expenditure is through the encouragement of more sustainable consumption patterns. This requires a consistent and accurate framework to identify the most sustainable lifestyles and consumption patterns'.

1.2 OBJECTIVE

Current research within sustainable consumption is unfortunately mostly descriptive. This research aims to contribute with rough quantitative estimates of the environmental impacts of different lifestyle choices, and thus inform where the greatest potential for lifestyle changes are to be found when adopted at a large scale. Analysis is made of the rebound scenario and incorporate the backcasting method. Backcasting means defining a desirable future of a sustainable society, then analyzing what lifestyles take us toward that direction, exploring the question ‘what lifestyles are feasible today to reach a sustainable future?’. This method has previously been recommended by Hertwich (2005b). The overall objective of this research is to give a realistic picture of different mitigation options related to household consumption in the EU, by applying backcasting to find lifestyle changes with the highest impact reduction potential. One important asset of the lifestyle approach method is the implementation of environmental footprints, thus attributing the ‘blame’ for emissions from various production activities to the final consumer. The European Commission (2013b) has stated that the new environmental goal of *Living well, within the limits of our planet* is a global aim where impacts also should be reduced beyond EU borders. In reality, as Hoff, Nykvist, and Carson (2014) have pointed out, a large and increasing share of the EU environmental footprint is occurring in foreign regions. This makes it especially important to not only consider domestic emissions caused by consumer activities, but also the emissions occurring outside the EU. By implementing a footprint approach coupled to a life-cycle analysis as to where the impacts occur, this paper aims to address the issue of the so-called *carbon leakage* (emission sources moving abroad and away from the jurisdiction of domestically applied climate policies). The change of EU household footprint caused by different lifestyles is analyzed from a global supply chain perspective. The model also allows for comparison of environmental impact caused by spending in different consumption categories, such as for example food, mobility, and shelter. Another objective is to compare the potential of direct lifestyle changes (e.g. vegetarian diet) to changes related to the supply-chain of products (e.g. decreased fertilizer input to food production sector). This research aims to compare changes in environmental impacts for two scenarios; 1) assuming that no re-spending occurs with the saved money, and 2) assuming that all the money from decreased expenditure is re-spent on other products (*rebound effect*). The objective is thereby to point out specific lifestyles where it is important to take further measures to minimize the rebound effect.

With this background, the following questions were posed;

1) What is the environmental impact reduction potential of changing the consumption patterns of EU households?

2) Which consumption domains hold the greatest potential for lifestyle changes in terms of environmental impact mitigation?

3) Within each consumption domain, what are the lifestyle options that yield the largest impact reduction? Which lifestyles would lead to an increase of impacts?

4) How is the reduction of impacts affected by the rebound effect? For what lifestyles is the rebound effect especially relevant?

1.3 SCOPE

This project expands on research made by the Industrial Ecology department at NTNU, Trondheim; namely a simplified model for calculating total environmental footprint of different product interventions. I use this work but apply an analysis of broader consumption patterns or lifestyles. This analysis is guided by lifestyle visions from the EU sustainability project GLAMURS. These visions are harmonized to fit into the Input-Output product system in use (EXIOBASE). Furthermore, I apply an adjustment of expenses on food and energy products based on calorific intake and energy use. I also determine not only the total footprints, but also how much of them are caused by emissions in non-EU regions.

The analysis of environmental impact change of different lifestyles is applied to countries located in Europe. This includes for example Switzerland and Norway. For simplicity, this region as a whole is called ‘EU’ though it includes more countries than are actually part of the European Union. The base year for the economic data is 2007. Only data from the *formal economy* (that which is monitored by government and taxed) is included. This excludes the informal economy that may make up between 8-25% of the official gross domestic product in the EU countries (Schneider 2012). Changes are applied only to the household final expenditure, i.e. the consumption patterns of the EU population. However, according to Hertwich (2008, 5), ‘... consumers also have the power to influence producers and thus change how things are produced and what is being offered in the market place.’ Based on this, some changes in modelled lifestyles also cover changes in the supply chain of specific products. Environmental impacts from lifestyles are calculated from a footprint perspective, taking into consideration all impacts along the global supply chain of products consumed.

Adjustment is not made of inter-industry requirements after a certain change to the household final demand. Instead, a steady-state economy is assumed (not perturbed by the applied lifestyles). It is not within the scope of this research to supply information as to how different changes practically can take place. No consideration is made regarding socio-economic factors, rather this paper provides a generalized quantitative picture of the reduction potentials of certain lifestyles. Spending of NGOs, governments, and build-up of stocks (such as infrastructure and housing) are excluded as they are not directly linked to the lifestyles of householders.

Finally, it is worth mentioning that research on consumption also can include considerations regarding the limitations of growth. This particular research is limited to pointing out where moral evaluations are particularly needed, without going into depth on the arguments in themselves.

2. Background

2.1 SUSTAINABLE LIFESTYLES

A *sustainable lifestyle* can be defined as a consumption pattern that ‘satisfy basic needs, offer humans the freedom to develop their potential, and are replicable across the whole globe without compromising the Earth’s carrying capacity.’ (Hertwich 2005b, 4673–74). In the practical modelling of such lifestyles, several approaches are available.

The traditional way of segmentation of consumers into specific lifestyles is by using socio-demographic or economic criteria. However, due to swift and large changes in society there is an increased personalization in consumer behavior patterns (González and Bello, 2002), also within specific socio-demographic groups (Füller and Matzler 2008). This means that such criteria are less and less appropriate to explain consumer behavior. Research shows that more appropriate lifestyle segmentation methods may surpass classic demographic segmentations (Vyncke 2002), though some still defend and apply geodemographic lifestyle classifications; see for example Baiocchi, Minx, and Hubacek (2010). An alternative way to segment the market is by using the model of Activities, Interests, and Opinions (AIO), as proposed by González and Bello in 2002. This can generate both colorful and useful lifestyle typologies when combined with a cluster analysis. Vyncke (2002) argues that more general, stable concepts can be introduced with a model based on Values, Life visions, and Aesthetic styles (VLA). Both VLA and AIO belong to quantitative (traditional) life style segmentation methods. The alternative to such methods is the Consumer Culture Theory (CCT) (Arnould and Thompson 2005). CCT is a quantitative method based on qualitative research such as in-depth personal interviews with consumers and ethnography. Researchers spend extended periods of time with the people they are studying, observing their behavior and often participating in relevant activities (Ahuviar, Carroll, and Yang 2006). However whichever method is used, there is a risk that there will a difference between actual household consumption of products and the perceived lifestyles. A common way to build specific lifestyles is to take information from household consumption surveys, gathering attitudes, opinions, and intentions across a specific population. However such factors may not necessarily represent how the households actually consume different products. Newton and Meyer (2013) found few differences in the actual consumption of energy, water, domestic appliances, etc. between lifestyle segments based on an Australian household resource consumption survey. They argued that such an attitude-action gap arises due to factors such as information and organization, but also due to well ingrained practices and lack of values that promote environmental conservation.

Since the attitude-action gap may be difficult to quantify, one can alternatively take lifestyle to mean a consumption pattern of specific goods and services. Supporting this assumption, González and Bello (2002) found that generally, one can either perform market segmentation as previously suggested by the use of general lifestyle data, or by looking at how different products are purchased by householders (consumption patterns). The benefit of the former is that it to a larger extent reflects the current consumer situation and consumption patterns, and allows for an in-depth analysis of the current environmental impacts of different groups in society. This includes correlating different social factors (income, house size, age, education) to environmental footprint (see for example Baiocchi, Minx, and Hubacek (2010)). On the other hand, interpreting *lifestyle* to mean a *consumption style* offers a greater possibility in terms of backcasting; that is modelling different lifestyles from a desired future scenario (of sustainability).

Instead of only looking at the current state of affairs, analyzing consumption styles makes it possible to manipulate the model that is being used to point out the mitigation potential of certain feasible lifestyles. Furthermore, Grunert (2006) points out that lifestyles does not have to be consistent across life domain. Lifestyle descriptions should ideally be restricted to specific products or domains in life, such as food (Nie and Zepeda 2011) and housing (Thøgersen 2017).

Finally, it is important to note that there is a large potential for environmental impact mitigation by changing behaviour and consumption patterns, as it may involve a significant reduction of the environmental impact of households. Baiocchi, Minx, and Hubacek (2010) for example found that CO_2 emissions among different lifestyle groups in the UK can vary by a factor of between 2 and 3. Behavioral changes also provide a fast rate of sustainability transformation (Newton and Meyer, 2013).

2.2 MODELLING THE ENVIRONMENTAL IMPACT OF CONSUMERS

In order to quantitatively analyze the environmental impact associated with households, a number of frameworks are available. This includes the Input-Output (IO) framework, originally developed by Leontief (1936; 1941) in order to provide a more complete analysis of interrelations in the whole economic system. Important manuals and documentation were made by Miller and Blair in 1985 and United Nations in 1999. Input-Output Analysis (IOA) is a suitable tool for investigating the impacts along production chains in complex economic systems (Galli et al. 2013; Lenzen 1998). It captures direct and indirect impacts of consumption and production. In IOA, national IO tables are combined with intra-regional transaction and trade into Multi-Regional Input-Output models (MRIO). MRIO is today considered the standard for tracing environmental footprints from consumption across global value chains (Hubacek et al. 2014).

An MRIO model is often determined in the flow of money (eg. US Dollars or Euros), however it is possible to combine such models with physical data. Often, IO-tables contain 50-400 sectors, which may not be enough to capture differences in product quality or consumer preferences (Hertwich 2005b). An alternative is to use a more detailed hybrid IOA where monetary units are combined with physical units for the specific product categories of interest. Ewing et al. (2012) elaborates on how ecological and water footprint accounts can be better accounted for in this way.

EXIOBASE 2.3 is an example of a monetary-unit MRIO model (Wood et al. 2014) consistent with the System of Environmental-Economic Accounting (SEEA) guidelines (United Nations 2014) where interactions between the economy and the environment are described. The base year of economic data is 2007. It has a 200-product resolution which is especially detailed for environmentally relevant sectors, namely agriculture, renewable energy, and waste treatment. 43 countries are modelled explicitly while the rest of the countries are aggregated in five 'rest of the world' regions (Stadler, Steen-Olsen, and Wood 2014). Since there is no world-wide standard of how each product should be classified into the 200-product system, the dataset of EXIOBASE is based on harmonization of these product categories across the different regions.

2.3 PREVIOUS APPLICATIONS OF INPUT-OUTPUT ANALYSIS

In 1994, Wyckoff and Roop found that the embodied GHG emissions in manufactured traded goods are significant. They combined IO-tables with international trade flows and industrial energy industry data. It was estimated that in France, for instance, 40% of the total GHG emissions in the mid-1980s were related to imports (emissions occurring on foreign land in producing goods for French consumption).

Lenzen (1998) used IOA to calculate primary energy and GHG embodied in Australian final consumption. IO data of 45 separate industry sectors was coupled to data of fuel use and GHG emissions. It was found that the average GHG budget attributed to the average Australian was around 28 Mt CO_2-eq/cap, more than five times higher than the world average. Household purchases of goods and services made up 47% of the total GHG emissions, the rest being direct energy consumption in households (electricity, fuels, private car use), exports, and final consumption by the government. The low level of detail for the environmental data was the main shortcoming of the study.

The first study using a global input-output model to analyze household environmental impact, taking into account the different production technologies and emissions control of each region, was made by Nijdam et al. in 2005. They found that food production, room heating, and car use are the most important causes of environmental load from Dutch household consumption. Generally, impacts taking place abroad were larger than domestic, and most of impacts in terms of land use took place in developing countries.

Weber and Matthews (2008) used country-specific IO tables with manipulated import matrices to create a MRIO they coupled to environmental data from national sources, life cycle analysis projects, and the International Energy Agency. They found that 30% of the total US household CO_2 impact in 2004 occurred abroad. Consumer expenditure data was used to allocate the total impact to households of different expenditure and income levels. Using a similar methodology but applied to the Netherlands, Kerkhof, Nonhebel, and Moll (2009) found that housing and transportation are associated with the major part of environmental impacts in all household impact categories. They also concluded that the share of GHG emissions from necessities is larger than from luxury goods.

Druckman and Jackson (2009) applied a simplified MRIO model with 13 world regions to estimate the carbon footprint of households in the UK in the years 1990-2004. They implemented a socio-economic disaggregation and mapped CO_2 emissions to different functional uses. It was found that embodied CO_2 emissions account for over half of the average UK household's carbon footprint, and that approximately 40% of the embodied CO_2 emissions occur outside the UK. A quarter of the household emissions were due to activities related to recreation and leisure. In a subsequent paper, the authors showed how the average UK household GHG emissions could be reduced by 37% by following a 'minimum income standard'; including subsistence commodities as well as means to participate effectively in society (Druckman and Jackson 2010). They highlighted the important aspect of whether increased consumption (and resulting environmental pressure) actually leads us toward to goal of having a better life; 'the conclusion from this study is optimistic. A shift towards a society less focused on status-driven consumerism is essential.' '... our analysis suggests that significant reductions in GHG emissions could be achieved without jeopardizing social well-being' (Druckman and Jackson 2010, 1803).

A more disaggregated analysis was made by Baiocchi, Minx, and Hubacek (2010) who applied consumer segmentation data within an IO-framework. In a 'top-down' approach, they used consumer expenditure tables to estimate the IO household final demand vector for different lifestyle categories. Embodied CO_2 emissions in consumption were calculated for each lifestyle.

In 2014, Tukker et al. used the IO database EXIOBASE to calculate carbon, land, water, and material footprints from the final consumption in 43 countries worldwide (*Global Resource Footprint of Nations*). Their purpose was to provide insights in how consumption drives global environmental pressure. They also aimed to perform a comparison between countries to determine how quality of life can be attained with low environmental footprint. Finally, the consequences were shown of a shift in environmental impact accounting system from production-based to consumption-based.

2.4 ENVIRONMENTAL IMPACT ACCOUNTING SYSTEMS

In international policy making there are various ways of accounting for the environmental impact of society. The main systems focus either on consumption or production activity. The famous Kyoto protocol, an international treaty made in 1992 with the aim of reducing GHG emissions, follows the Production-Based Accounting (PBA) system for environmental impact. This means that reduction goals are based on the emissions from domestically located sources of individual countries (such as the production industry). PBA includes domestic emissions caused by produced goods for export, and does not take into consideration emissions embodied in imports for domestic consumption (Tukker and Dietzenbacher 2013). Though this approach has the advantage of being straightforward for policy-makers, it may lead to ‘carbon leakage’. This occurs when production (with the corresponding emissions) is shifted toward countries without or with less strict environmental impact mitigation policies. While the GHG emissions from countries that ratified the Kyoto protocol covered around 35% of the global GHG emissions in 1990, the global emissions increased by about 25% from 1990-2004 (IEA 2006). This despite the fact that ratifying countries are on target to reach the required (territory-based) emission reductions. In the trade liberalization of the late 1990's and early 2000's, many of the developed countries within the protocol moved a growing part of CO_2 intensive manufacturing industries to countries with low labour costs, and also no emission reduction obligation Peters et al. (2011). Consequently, a higher share of emissions embodied in the consumed products of the ratifying countries occurred in foreign regions. The magnitude of emissions embodied in trade also confirms this conclusion; Peters and Hertwich (2008a; 2008b) show how in 2001 as much as 23% (or ~5.7GtCO_2) of energy-related emissions were embodied in trade.

This raises the question regarding whether there is a better alternative to the PBA; whether for example the consumer should be attributed responsibility for the environmental impacts generated by his consumption. A GHG inventory based on Consumption-Based Accounting (CBA) excludes emissions embodied in export (for consumption abroad) and includes emissions embodied in imports (for domestic consumption);

$$\begin{aligned} &Consumption = \\ &= Production - Exports + Imports \end{aligned}$$

Embodied emissions are those emissions required to produce a specific product, taking into account all the stages of production from raw material processing to final sale of the finished product (Peters and Hertwich 2008a). Emissions can this way be calculated through IOA, following a system originally developed by Nobel prize winner and economist Wassily Leontief in 1970.

In recent years, CBA has been popularized due to the weakness of the PBA in allowing for carbon leakage. CBA is also superior from the perspective of addressing competitive concerns; emissions embodied in products are allocated to the specific importer and can thus lead to a ‘environmental comparative advantage’. Since it includes trade between countries, CBA encourages shifting production to where it is most environmentally preferable, through the same mechanism that trade has been exploited to reduce production costs (Peters and Hertwich 2008a). CBA may also offer the most useful and less misleading accounting system to promote local climate action (Larsen and Hertwich 2009). However, the CBA also has weaknesses. For example, it does not directly credit countries for improving eco-efficiency in the export industry since all emissions from exports are allocated to final consumers elsewhere. On the other hand, if there is demand to reduce the CBA carbon footprint, for example in the EU, exporting countries with cleaner production would be favoured. Kander et al. (2015) have proposed the use of a Technology-adjusted CBA (TCBA) as a way to take into consideration the carbon efficiency in export sectors of different countries. The change from CBA is that export-related emissions are subtracted based on the world-average carbon intensity for the sector instead of domestic carbon intensity. A country with 'cleaner' production than world-average, such as Sweden, would thus be allocated lower emissions for TCBA than for CBA. Their reasoning is that carbon footprint also should reflect upon what alternative production the specific export is replacing (in this example, clean Swedish production may replace carbon-intensive production in third-world-countries). Though additive on a global scale, TCBA suffers from a scale invariance property; carbon responsibility of a union of countries does not necessarily equal the sum of each country's individual responsibility. Correcting for this, it has been suggested to also replace the environmental impact intensity of *imports* with world average (Domingos, Zafrilla, and Lopez 2016).

Nonetheless, CBA still remains the most used accounting system due to its transparency and simplicity. It follows a clearly attributional approach in that it allocates responsibility of production systems to consumers. This stands opposite to the more consequential ('what would happen if?') approach of TCBA. Another significant difference between TCBA/PBA and CBA is that both the former reflect more on production conditions. Unlike PBA and TCBA, CBA is not primarily suitable to function, at least not on its own, as a single framework to attribute global emissions to different countries, for example in international climate mitigation agreements. On the other hand, CBA is a perfectly suitable tool to analyze potential for consumer action and mitigation potential of different lifestyle choices, as it focuses entirely on conditions of consumption.

2.5 LIFESTYLE DATA SOURCES

In the EU, two major projects exist that aim to develop frameworks and background information for consumption-based climate mitigation; GLAMURS (GLAMURS 2017) and Carbon-CAP (Carbon-CAP 2017). Both projects receive funding from the European Union's Seventh Programme for research, technological development and demonstration.

The EU project GLAMURS (Green Lifestyles, Alternative Models, and Upscaling Regional Sustainability) aims to investigate how a transition toward sustainable lifestyles can be achieved, partially through macro-economic modelling (European Commission 2014; GLAMURS 2017). It focuses on seven regions across the EU with regional research and in-depth collaborative research with citizen sustainability initiatives. These regions are (1) Banat Timis (the region of Timisoara in Romania, (2) Central Germany (the region of the city of Halle), (3) the Danube-Bohemian Forest region in Upper Austria; (4) Galicia in Spain, (5) Lazio including Rome in Italy, (6) the Rotterdam-Delft-The Hague metropolitan region in the Netherlands, (7) and Aberdeenshire in Scotland. In one of its empirical work packages, the GLAMURS project have included backcasting scenario workshops for each of the seven regions. This method is based on finding desirable future scenarios for the regions, and then working backward to identify policies that will make such a future possible. Data on environmental impact of different lifestyle options support the decision on which lifestyle changes that are sustainable (Quist and Leising 2016). GLAMURS also contain a summary of the case studies made, broad visions for 12 different relevant eco-projects in the EU. Each project suggests improvements in terms of environmental impacts, as well as future challenges, for the consumption categories food, mobility, energy, housing, consumption, and work-leisure (GLAMURS 2017).

The Carbon-CAP project (Carbon emission mitigation by Consumption-based Accounting and Policy) aims to improve the knowledge base on consumption emissions as well as to implement a more effective policy mix in moving toward a low-carbon economy in 2050 (CORDIS 2015). It has completed the work for several scientific deliverables, such as a list of life-cycle micro-level option for consumption based climate mitigation (Schanes et al. 2015). This work contained 107 specific environmental improvement suggestions on a EU level, categorized as food, transport, building, machinery and equipment, electronic goods, textiles, furniture, paper, plastics, and chemicals.

Another study that has focused on future lifestyles is a report made for the European Commission, describing lifestyles that likely will be important to the lives of people in the EU and the United States in 2020 (Wevolve 2013). Also, the European project SPREAD contains a policy brief roadmap on the transition to future sustainable lifestyles (SPREAD 2012).

2.6 IMPACT CATEGORIES

There are a number of different categories of important environmental impacts from consumption. Carbon, ecological, and water footprint were gathered together in 2012 as the 'Footprint Family', '... a suite of indicators to track human pressure on the planet and under different angles.' (Galli et al. 2012a). These particular footprint categories give decision makers a tool to track human pressure on three main life-supporting compartments of the Earth, namely *biosphere*, *atmosphere*, and *hydrosphere*. Perhaps the first footprint to be developed was the *ecological footprint*, defined in 1992 by William E. Rees. This aims to track the human pressure on the regenerative capacity of the Earth (Wackernagel et al. 1999). Thus, it includes the demand for cropland, grazing land, fishing grounds, forest, land needed for sequestration of carbon, and built-up area. The idea is to measure the total pressure that the human activities have on the biosphere (Galli et al. 2012a). A simplified way to calculate such pressure is by estimating land use. Such quantification is available in EXIOBASE through the measure of total use of pasture land, cropland, and forest land (excluding built-up area and land needed for carbon sequestration). The impacts on the hydrosphere were later quantified through the water footprint (Hoekstra and Hung 2002). This is analogous to the EXIOBASE impact category of blue water consumption, defined as the freshwater withdrawn (and not returned) from ground and surface sources in the whole supply chain of products. All use of water that arise in processing and refining of a certain product is allocated to the final consumer (Wang and Zimmerman 2016). Regarding Earth's atmospheric compartment, perhaps the most popular determinant may be Global Warming Potential (GWP) of different GHG emissions. GWP was quantified by Lashof and Ahuj (1992) who proposed an index of GWP for important greenhouse gases, relative to carbon dioxide. GWP thus measures how much energy is absorbed in the atmosphere per unit emission of a specific greenhouse, relative to that of CO_2. It also weighs the radiative properties during a given time horizon (the assumed lifetime of the greenhouse has in the atmosphere). Carbon footprint was most probably derived from the GWP and measures the total emissions contributing to GWP from the whole supply-chain of products (Čuček, Klemeš, and Kravanja 2012). Finally, the toxicity footprint may primarily reflect the human pressure on the biosphere and hydrosphere. In EXIOBASE, it is possible to estimate this through the emissions of toxicity equivalents. This measure relates the toxicity of a certain compound to that of a standard (1,4-dichlorobenzene).

In general, footprint models may help in communicating impacts and current performance to the general public, and pose a basis for policy design (McBain 2015). Galli et al. (2012) also argued that the consumption-based perspective of the carbon footprint can be used to make households more aware of the GHG emissions associated with their lifestyles, and that it is an important complement to the production-based approach considered for example in the Kyoto protocol.

2.7 THE REBOUND EFFECT

2.7.1 Background and Definition

The *rebound effect* is generally defined as '… behavioral or other systemic response to a measure taken to reduce environmental impacts that offsets the effect of the measure.' (Hertwich 2005a, 86). For instance, improvement in energy efficiency for using a product (a measure to reduce environmental impacts) may lead to a decreased price for such products. Avoided expenditure due to certain actions is thus either re-spent on other products or saved. Also saved money is associated with GHG emissions as they are used for postponed consumption or as a source of funds for investments (Chitnis et al. 2013). The GHG emissions caused by re-spending of money may be dependent for example on the emission intensity of the products for which consumption is reduced as compared for those it is increased. It may further by influenced by the characteristics of product reduced, the motivation behind the initial reduction of product spending, and the attitude of the consumers during consumption (Greening, Greene, and Difiglio 2000; Hertwich 2005a; Druckman et al. 2011; Schanes, Giljum, and Hertwich 2016). A more thorough analysis might include the needs that the products which are involved in the reduction and rebound are fulfilling for the householders (Vita et al. 2015).

The rebound is not only applicable to households, but also to industry. For example, an increase in fuel efficiency means less energy is required to produce a unit output, but also that more expensive input factors in the industry can be replaced by energy (for example capital and labor). Also, an energy price decrease for the consumer may lead to increase in production. Bentzen (2004) found that the rebound effect for the US manufacturing sector could be as high as 24%. He suggested the implementation of policies that would keep the cost of energy services constant as long as there are efficiency improvements occurring. Such improvements would otherwise reduce the price of the energy service; keeping the price constant thus prevents the rebound effect of a price decrease. Li and Yonglei (2012) studied energy efficiency rebound within China and suggested that it could be even higher than for US and other developed countries, analogous to the direct rebound effect for final consumers.

Putting the rebound effect in perspective, Hubacek and Guan (2011, 251) argued that 'Governments should never withdraw an environmental policy or slow down investment in environmentally friendly technologies because of the rebound effect'. They instead suggested that governments should understand the rebound effect to realize how far away we are from a low-carbon economy, and to appreciate the importance and difficulty they face in trying to facilitate a transition towards a more sustainable regime (Hubacek and Guan 2011).

In practice, the rebound effect is often estimated by using the proxy of price elasticity (see for example the recent UK study by Chitnis and Sorrell (2015); i.e. the degree to which the demand of a certain product or service is responsive to price. Price elasticity is considered the closest possible empirical approximation of the extent of the rebound effect (Berkhout, Muskens, and Velthuijsen 2000). However it is important to consider that price elasticity normally varies with the price level; the higher the relative price level, the higher the price elasticity (causing big changes in demand from a given price change). Hertwich (2005a) found that for energy services, the strongest rebound occurred in situations where energy services consumption was cost-constrained. For example, poor households may only maintain heating in a few rooms at a time. Introducing insulation lead such a household to gradually heat more rooms, and an absolute energy use reduction may not occur.

2.7.2 Empirical Estimates of Rebound Effect for Households

Druckman et al. (2011) estimated that the lowest possible rebound effect, under optimal circumstances, was around 12%. But the rebound effect varies greatly with different consumption categories.

In terms of domestic energy use, Chitnis et al. (2014) found that for households in the UK, the rebound effect was less than 32%. Some research indicates that rebound for residential end uses may be as high as 50% (Greening, Greene, and Difiglio 2000), while Sorrell, Dimitropoulos, and Sommerville (2009) found a rebound effect of up to 26% for consumer energy services. Moreover, reducing indoor temperature by 1°C may only lead to a rebound of 7% (Druckman et al. 2011).

For interventions that deal with mobility the rebound effect seems to be slightly larger. Most studies reviewed by Binswanger (2001) indicated a rebound effect less than 30% for personal transportation. Wang, Zhou, and Zhou (2012) showed how efficiency improvements in energy consumption for transport in urban China led to an increased spending on personal urban transportation. The rebound was around 96%, which meant that the majority of expected energy savings from urban transport was offset because increases in fuel efficiency also decreased the cost of driving. The effectiveness of the efficiency improvement policy was offset by increased driving. Meanwhile around 60% of the potential energy saving from fuel efficiency improvements in Germany may be lost due to increased demand for car travel (Frondel, Ritter, and Vance 2012). For the intervention of walking or cycling instead of using car for short-distance trips, 25% of the expected GHG reductions may not actually materialize due to rebound (some of the saved money that biking brings with it is respent, generating GHG emissions). Chitnis et al. (2014) found that the rebound for vehicle fuel use was in the range of 25-65%. Sorrell, Dimitropoulos, and Sommerville (2009) concluded that the ‘best guess’ for long-run direct rebound effect was 10-30% for personal automotive transport.

Other examples include Druckman et al. (2011) who showed that around half of the expected GHG reductions from eliminating household food waste were offset by the rebound effect. Meanwhile, Chitnis et al. (2014) found that the rebound was between 66-106% for measures that reduce food waste. Roy (2000) predicted that for developing countries, and especially in the initial stages, the rebound of any inefficiency removal could be very high. This was confirmed by Wang et al. (2012) who presented a direct rebound effect of 45% for passenger transport in Hong Kong in 1993-2009, and 35% for 2002-2009. In other words, it seems as the rebound effect decreased over time as initial efficiencies were removed.

2.8 CONSUMPTION CATEGORIES

The household consumption of products can be classified into different categories. Hertwich and Peters (2009a) suggested a division into clothing, construction, food, manufactured products, mobility, services, shelter, and trade. Disaggregating consumption in a similar way, Ivanova et al. (2016) used EXIOBASE to analyze the environmental impact of household consumption. It was found that household consumption was responsible for more than 60% of the global GHG emissions in 2007. They found a strong relationship between household expenditure and environmental impact. Figure 1 shows the intensity of carbon, land, material, and water footprint per unit expenditure, in EU households. Mobility (all kinds of personal transportation), shelter (expenses related to electricity, household fuels, and home renovation), and food were the consumption categories that contributed the most to the environmental footprint of EU households and are therefore examined individually subsequent to Figure 1. The others are described together in chapter 2.8.4 Services, Manufactured Products, Clothing, Construction.

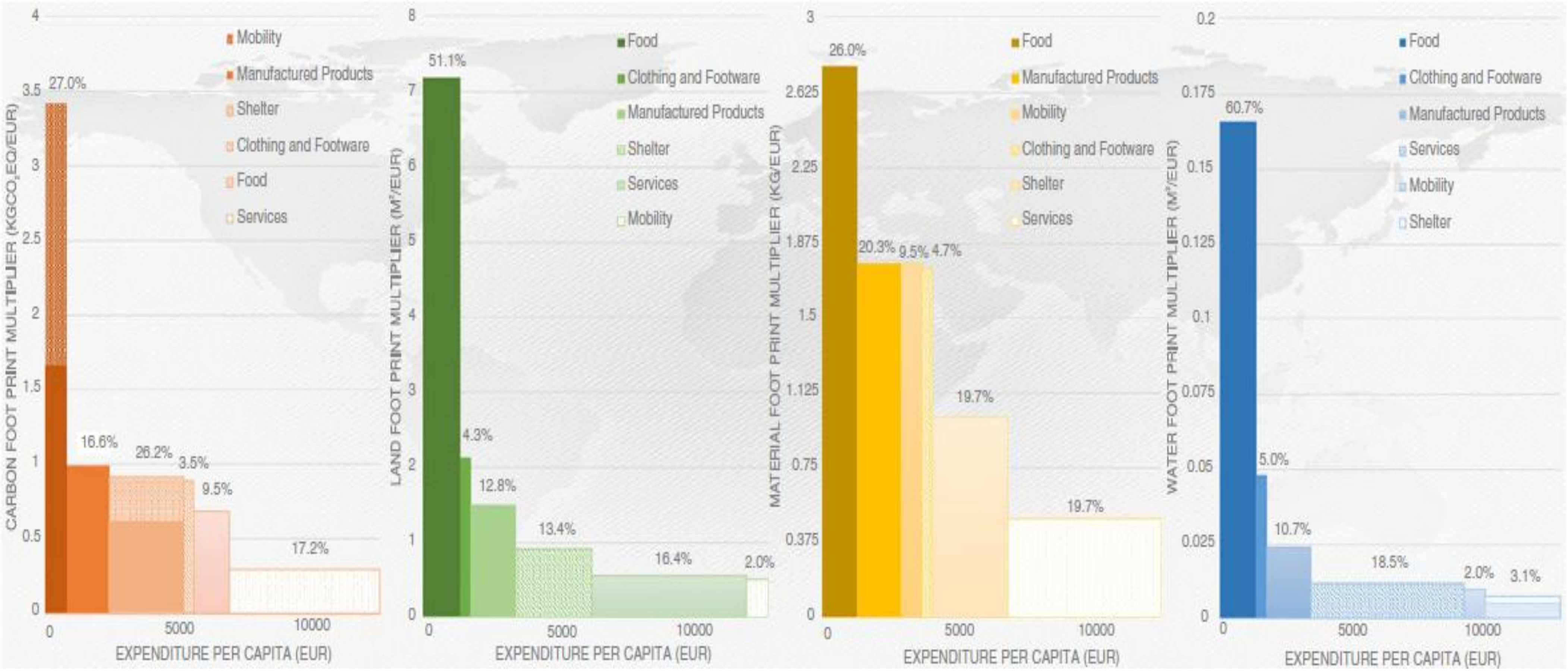

Figure 1. Contribution of consumption c2eategories to the carbon, land, material, and water footprint of EU households (Ivanova et al. 2016)

2.8.1 Food

Food consumption is one of the main drivers of environmental impacts in household impacts on land and water resources, respectively, are caused by expenditure on food (Ivanova et al. 2016). A change in dietary habits is thus often proposed as a means of mitigating the environmental impacts generated by food consumption. Wellesley, Happer, and Froggatt (2015) pointed out that a shift in diet is necessary to realize the goal of limiting the average global temperature rise to 2°C above pre-industrial levels. Above all it is vital to address meat consumption. According to estimations, 18-51% of all worldwide greenhouse gas emissions are caused by animal agriculture (Goodland and Anhang 2009; FAO 2006). Westhoek (2011) concluded that 10% of GHG emissions in EU are caused by livestock production, and that such a way of producing proteins (as opposed to consuming them directly in plant-form) is an inefficient use of resources. Notarnicola et al. (2016) used a Lifecycle Assessment (LCA)-based approach to analyze the environmental impact of different food items. Their results indicated that the most emission intensive products are meat and dairy products. Another LCA study suggest that a Mediterranean diet would yield 6.81% less dietary emissions of CO_2 from households, and a vegetarian diet 14.55% less (Pairotti et al. 2015). Halving consumption of meat, eggs, and dairy products in the EU would reduce GHG emissions from the EU agricultural sector by 25-40% (Westhoek et al. 2014). Other research also point out that processed (canned/frozen) and animal food may have a higher use of energy in production as compared to fresh produce and plant foods (Carlsson-Kanyama and Faist 2000). A decrease in consumption of animal products seems to reduce the environmental impacts, but according to Westhoek (2011) this may be a ‘slow cultural process’. On the other hand it seems already a shift in diet is occurring towards higher-quality fats, whole grains, more fruits and vegetables, and less meat (Mathijs 2015). Vranken et al. (2014) found a U-shaped relationship between meat consumption and income; indicating that at a certain level of income the meat consumption stagnates or even declines.

Potential for environmental impact reduction may also lie in food supply-chain measures. Food processing and logistics are important phases in terms of environmental impacts. However, the most important lifecycle stage in terms of environmental impact is the agricultural phase (Notarnicola et al. 2016). In this regard organic farming is an interesting practice, though burdened by the idea of it being inefficient and even contributing positively to GHG emissions from agricultural production (McGee 2015). Reviewing articles dating back more than 25 years, Reganold and Wachter (2016) found that organic farming is superior to conventional farming in terms of social wellbeing, environmental and economic sustainability, as well as certain production conditions (such as profitability). The only aspect for which conventional farming is superior to organic is in terms of yield; yield averages were found to be 8-25% lower in organic systems. However, Tuomisto et al. (2012) performed a meta-analysis of European research and found that organic farming systems have a higher land use as well as eutrophication and acidification potential than conventional farming; if estimated per product unit. They conclude that the benefits of organic farming generally are overestimated, and that organic farming only is superior to conventional from an environmental aspect if impacts are based on units of area.

Another important factor to take into consideration is the food waste, both on industrial and domestic level (Notarnicola et al. 2016). In the EU, 16% of all food reaching consumers is wasted, 80% of which is avoidable food waste. Meat accounts for the largest avoidable food waste footprint though the wasted quantity is lower than for fruits and vegetables (Vanham et al. 2015). Cutting out avoidable food waste may decrease food-related GHG emissions by 12% (Hoolohan et al. 2013). Meanwhile, globally around one-third of edible parts of food is wasted, in all parts of the value chain. Food losses in developing countries are the same as in developed countries, since developing countries have lower waste on consumer level but higher on processing levels (Gustavsson, Cederberg, and Sonesson 2011). Further reduction of overall food consumption levels can be achieved by limiting calorific intake; Vieux et al. (2012) for example showed that up to 10.7% of diet-associated GHG emissions in France could be avoided by consuming less. They found that reducing consumption of animal-based products is not sufficient to significantly reduce GHG emissions. Furthermore, it is important to consider which products that replace the reduced meat consumption, and to compensate for the possible decrease in calorie intake with a diet change.

Other supply chain measures include consuming local and/or seasonal products, which may provide significant savings, though smaller than the reduction of meat consumption and food waste (Hoolohan et al. 2013). Local food consumption may only provide a positive environmental impact reduction potential if the emission intensity of local food products is lower than that in other regions (where the food products would otherwise be imported from). However for different products there may be a difference in the footprint contribution of production versus transportation phases, making the results of local and seasonal food consumption hard to predict (Avetisyan, Hertel, and Sampson 2014). If transportation emissions for a particular food product are low compared to the production emissions, it may be beneficial to choose globally seasonal products over locally produced (MacDiarmid 2014).

2.8.2 Mobility

Mobility includes air, water, land, and water-based transportation. Within the EU it is the consumption category that has the highest amount of carbon emissions per unit of household expenditure. However, it seems to be related with a relatively low share of the total household expenditure (Figure 1), resulting in around 27% of the EU household carbon footprint in 2007 being caused by mobility expenses. Roughly half of the emissions were caused by driving personal vehicles (direct household emissions) (Ivanova et al. 2016). One popular measure that has been mentioned to decrease mobility emissions is implementing a system of car-sharing. Applied to the US, Martin and Shaheen (2011) showed how such a system can supply both mobility to carless households and be a low-emission mobility alternative for urban households in Canada and United States. The slight increase of emissions from carless households getting access to cars is small in comparison how much urban households reduce emissions, supplying a net yearly impact reduction of 0.109-0.224 Mt GHG in 2011. This is however equivalent to only 0.018-0.037% of total CO_2 footprint from household consumption in north America (Ivanova et al. 2016).

2.8.3 Shelter

The shelter consumption category contains products reflecting direct energy requirements of households (electricity, natural gas, gasoline, etc.) as well as household appliances. 34-64% of the total EU household energy requirement is direct, while the rest is embodied in goods and services (Reinders, Vringer, and Blok 2003). The consumption category of shelter contains consumption of energy, electricity, and other inter-household fuels and necessary products. 26 and 13% of EU household carbon and land footprints, respectively, are caused by expenses on shelter. Shelter has a lower carbon intensity than mobility, but higher share of household expenditure. A significant share of carbon footprint is caused by direct emissions from the burning of fuels (Ivanova et al. 2016). Nijdam and Wilting (2003) found that the largest cause of GWP impacts within housing is heating.

2.8.4 Services, Manufactured Products, Clothing, Construction

Forty-five percent of all household expenditure is spent on services, moreover it is the consumption category with the lowest carbon intensity. The contribution to carbon, land, water, and material footprint of this category is around 16-20%. Manufactured products are characterized by lower household expenditure but the second highest intensity of carbon and material footprint, and the respective contribution toward EU household impacts is 16.6 and 20.3% (Ivanova et al. 2016). As increasing research is being done on the environmental potential of leasing or sharing products, the consumption categories of services and manufactured products are becoming increasingly intertwined. Leasing and sharing is the main idea of Product-Service Systems (PSS), where the focus is shifted from product ownership toward the final user needs that are satisfied by a particular product. It has been argued that if firms are paid for the service provided by a certain product, it would provide an incentive to use the products with as high material efficiency as possible due to the lower cost associated with such use (which in turn may correlate to decreased environmental impact). However Tukker (2015) concluded that product ownership may be preferred by consumers (due to it contributing to self-esteem and supports the feeling of control), costs can be higher for PSS, and shared goods tend to be used less carefully. These factors are obstacles toward the implementation of shared-use systems and underline that the sought-after environmental benefit may not be achieved. Intlekofer, Bras, and Ferguson (2010) found that only for products with high use impacts and a steadily improving efficiency is leasing a beneficial intervention, since it reduces the product life time and increases the replacement rate of products. Products with a high share of impacts occurring in production and with only slight efficiency improvements would not be benefitted by leasing.

Clothing has the second highest intensity of land and water footprint. However, as it has the smallest share of household expenditure, spending on clothing only causes 4.3 and 5.0% of EU land and water footprint, respectively (Ivanova et al. 2016).

Regarding the building material used in renovation of one’s house, Guardigli, Monari, and Bragadin (2011) showed that the impacts of wood buildings on human health, resources, and ecosystem quality are smaller than that of a concrete structure. It is also important to keep in mind that the construction consumption category includes material for reparation and renovation, but excludes all other construction activities (such as building new houses).

3. Methodology

3.1 CONSUMPTION CATEGORIES

MRIO modelling was made using EXIOBASE 2.3 (Wood et al. 2014). The 200 products of this database were allocated to one of the seven consumption categories; namely *clothing*, *construction*, *food*, *manufactured products*, *mobility*, *services*, and *shelter*. This is analogous to the classification made by Hertwich and Peters (2009a) except that this paper merges the category of *trade* (primarily wholesale and retail trade services) with *manufactured products*. The classification was made using data from the statistical classification of economic activities in the EU community (NACE) (European Commission 2002) with the help of the OECD glossary of statistical terms (OECD 2016). This is roughly equivalent to the industry sector to consumption category characterization made by Hertwich and Peters (2009b), with a few exceptions; for example, this paper classifies *plant-based fibers as* clothing instead of food, and *tobacco products* as a manufactured product instead of food. The changes were made to reflect more correctly what the products are used for. NACE version 1.1 was used as it is the basis of the EXIOBASE-classification. A brief explanation of the consumption categories and their subcategories can be found in

Table 1. Out of the total 200 EXIOBASE products, products with no final demand and no association with a specific lifestyle change were excluded. Total EU household final demand (HHFD) from EXIOBASE 2.3 was calculated for each consumption category. The HHFD of a specific product was divided by the total EU HHFD of the consumption category. This resulted in the percentage shares of HHFD within a specific category. A mean price within each commodity category was also calculated from the EU prices of the individual products. Dividing the absolute price of a product with the mean for the consumption category, and subtracting by 1, yields the prices relative to category mean. Since prices within a specific consumption category may have different units the relative price may be slightly inaccurate, but still gives an approximate picture for comparative purposes.

Table 1. Products from EXIOBASE with modified household final demand. Shows the consumption categories, the share of total household final demand (HHFD) within each category that is spent on each product, and the absolute basic prices as well as the price relative to category mean (where number 0 means that value is equal to category mean). Information on household final demand and prices is taken from EXIOBASE 2.3 (Wood et al. 2014).

Product	Category	HHFD share (for category)	Price Rel. to Category Mean	Absolute Price	Unit
Plant-based fibers	Clothing	0.33 %	-79.77 %	1.13	EUR/kg (metric)
Wool, silk-worm cocoons	Clothing	0.00 %	-85.56 %	0.81	EUR/kg (metric)
Textiles (17)	Clothing	31.61 %	4.04 %	5.81	EUR/kg
Wearing apparel; furs (18)	Clothing	49.54 %	139.49 %	13.37	EUR/kg
Leather and leather products (19)	Clothing	18.52 %	21.80 %	6.80	EUR/kg
Stone	Construction	0.00 %	-99.377 %	0.01	EUR/kg (metric)
Sand and clay	Construction	0.00 %	-99.502 %	0.01	EUR/kg (metric)
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials (20)	Construction	14.38 %	-49.525 %	0.76	EUR/kg (wet)

Bricks, tiles and construction products, in baked clay	Construction	0.06 %	-90.414 %	0.14	EUR/kg
Cement, lime and plaster	Construction	0.53 %	-92.278 %	0.12	EUR/kg
Other non-metallic mineral products	Construction	16.21 %	-53.009 %	0.71	EUR/kg
Basic iron and steel and of ferro-alloys and first products thereof	Construction	0.01 %	-50.037 %	0.75	EUR/kg
Other non-ferrous metal products	Construction	0.20 %	567.800 %	10.07	EUR/kg
Construction work (45)	Construction	68.62 %	-33.659 %	1.00	EUR/EUR
Paddy rice	Food	0.08 %	-88.64 %	0.34	EUR/kg (metric)
Wheat	Food	1.20 %	-91.75 %	0.25	EUR/kg (metric)
Cereal grains nec	Food	0.61 %	-92.33 %	0.23	EUR/kg (metric)
Vegetables, fruit, nuts	Food	9.37 %	-75.89 %	0.72	EUR/kg (metric)
Oil seeds	Food	0.55 %	-80.80 %	0.57	EUR/kg (metric)
Crops nec	Food	1.49 %	-87.42 %	0.38	EUR/kg (metric)
Cattle	Food	0.00 %	-29.91 %	2.10	EUR/kg (metric)
Pigs	Food	0.00 %	-60.65 %	1.18	EUR/kg (metric)
Poultry	Food	2.30 %	-55.12 %	1.34	EUR/kg (metric)
Meat animals nec	Food	1.24 %	-12.64 %	2.62	EUR/kg (metric)
Animal products nec	Food	0.15 %	40.33 %	4.20	EUR/kg (metric)
Raw milk	Food	0.93 %	-86.65 %	0.40	EUR/kg (metric)
Fish and other fishing products; services incidental of fishing (05)	Food	1.25 %	-40.21 %	1.79	EUR/kg (metric)
Products of meat cattle	Food	3.30 %	9.65 %	3.28	EUR/kg (metric)
Products of meat pigs	Food	3.85 %	-48.99 %	1.53	EUR/kg (metric)
Products of meat poultry	Food	5.10 %	4.20 %	3.12	EUR/kg (metric)
Meat products nec	Food	11.09 %	1170.21 %	38.02	EUR/kg (metric)
products of Vegetable oils and fats	Food	1.10 %	-47.71 %	1.57	EUR/kg (metric)
Dairy products	Food	9.70 %	-43.66 %	1.69	EUR/kg (metric)
Processed rice	Food	0.29 %	-88.02 %	0.36	EUR/kg (wet)
Sugar	Food	1.15 %	-76.69 %	0.70	EUR/kg (metric)
Food products nec	Food	35.92 %	-56.25 %	1.31	EUR/kg (wet)
Beverages	Food	6.28 %	-76.77 %	0.70	EUR/kg (wet)
Fish products	Food	3.05 %	15.71 %	3.46	EUR/kg (wet)
Tobacco products (16)	Manufactured products	6.22 %	-56.52 %	9.00	EUR/kg (wet)
Printed matter and recorded media (22)	Manufactured products	24.62 %	-79.82 %	4.18	EUR/kg (wet)
Machinery and equipment n.e.c. (29)	Manufactured products	19.56 %	-44.05 %	11.58	EUR/kg (wet)

Office machinery and computers (30)	Manufactured products	5.45 %	95.22 %	40.41	EUR/kg (wet)
Electrical machinery and apparatus n.e.c. (31)	Manufactured products	6.05 %	-58.19 %	8.65	EUR/kg (wet)
Radio, television and communication equipment and apparatus (32)	Manufactured products	17.65 %	-10.38 %	18.55	EUR/kg (wet)
Medical, precision and optical instruments, watches and clocks (33)	Manufactured products	9.23 %	201.40 %	62.38	EUR/kg (wet)
Other transport equipment (35)	Manufactured products	11.23 %	-47.67 %	10.83	EUR/kg (wet)
Motor Gasoline	Mobility	11.95 %	-25.03 %	0.90	EUR/kg (metric)
Kerosene Type Jet Fuel	Mobility	0.07 %	-66.05 %	0.41	EUR/kg (metric)
Gas/Diesel Oil	Mobility	5.65 %	-54.72 %	0.54	EUR/kg (metric)
Heavy Fuel Oil	Mobility	0.24 %	-83.79 %	0.19	EUR/kg (metric)
Biogasoline	Mobility	0.14 %	-84.65 %	0.18	EUR/kg (metric)
Biodiesels	Mobility	0.04 %	-86.95 %	0.16	EUR/kg (metric)
Other Liquid Biofuels	Mobility	0.04 %	-91.22 %	0.11	EUR/kg (metric)
Motor vehicles, trailers and semi-trailers (34)	Mobility	29.93 %	588.34 %	8.25	EUR/kg (wet)
Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories	Mobility	20.30 %	-16.49 %	1.00	EUR/EUR
Retail trade services of motor fuel	Mobility	1.60 %	-16.56 %	1.00	EUR/EUR
Railway transportation services	Mobility	6.74 %	-9.29 %	1.09	EUR/EUR
Other land transportation services	Mobility	13.79 %	-16.98 %	0.99	EUR/EUR
Sea and coastal water transportation services	Mobility	1.47 %	-17.51 %	0.99	EUR/EUR
Inland water transportation services	Mobility	0.32 %	-2.66 %	1.17	EUR/EUR
Air transport services (62)	Mobility	7.71 %	-16.45 %	1.00	EUR/EUR
Wholesale trade and commission trade services, except of motor vehicles and motorcycles (51)	Services	10.98 %	25.53 %	1.00	EUR/EUR
Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods (52)	Services	8.92 %	25.50 %	1.00	EUR/EUR
Hotel and restaurant services (55)	Services	14.57 %	25.47 %	1.00	EUR/EUR
Supporting and auxiliary transport services; travel agency services (63)	Services	1.86 %	25.47 %	1.00	EUR/EUR
Post and telecommunication services (64)	Services	4.50 %	25.26 %	1.00	EUR/EUR
Financial intermediation services, except insurance and pension funding services (65)	Services	5.47 %	25.49 %	1.00	EUR/EUR

Insurance and pension funding services, except compulsory social security services (66)	Services	5.02 %	25.10 %	1.00	EUR/EUR
Services auxiliary to financial intermediation (67)	Services	0.50 %	25.43 %	1.00	EUR/EUR
Real estate services (70)	Services	28.18 %	25.50 %	1.00	EUR/EUR
Renting services of machinery and equipment without operator and of personal and household goods (71)	Services	0.85 %	25.43 %	1.00	EUR/EUR
Computer and related services (72)	Services	0.16 %	-90.71 %	0.07	EUR/EUR
Research and development services (73)	Services	0.00 %	-1.49 %	0.79	EUR/EUR
Other business services (74)	Services	1.41 %	-93.95 %	0.05	EUR/EUR
Public administration and defense services; compulsory social security services (75)	Services	0.43 %	25.50 %	1.00	EUR/EUR
Education services (80)	Services	2.19 %	25.50 %	1.00	EUR/EUR
Health and social work services (85)	Services	6.42 %	25.52 %	1.00	EUR/EUR
Membership organization services n.e.c. (91)	Services	0.21 %	25.54 %	1.00	EUR/EUR
Recreational, cultural and sporting services (92)	Services	4.51 %	-98.10 %	0.02	EUR/EUR
Other services (93)	Services	2.48 %	-97.44 %	0.02	EUR/EUR
Private households with employed persons (95)	Services	1.36 %	25.45 %	1.00	EUR/EUR
Products of forestry, logging and related services (02)	Shelter	2.16 %	-99.72 %	0.08	EUR/kg (metric)
Anthracite	Shelter	0.06 %	-99.67 %	0.10	EUR/kg (metric)
Coking Coal	Shelter	0.01 %	-99.79 %	0.06	EUR/kg (metric)
Other Bituminous Coal	Shelter	0.65 %	-99.75 %	0.08	EUR/kg (metric)
Sub-Bituminous Coal	Shelter	0.00 %	-99.97 %	0.01	EUR/kg (metric)
Patent Fuel	Shelter	0.01 %	-99.68 %	0.10	EUR/kg (metric)
Lignite/Brown Coal	Shelter	0.05 %	-99.97 %	0.01	EUR/kg (metric)
BKB/Peat Briquettes	Shelter	0.12 %	-99.63 %	0.11	EUR/kg (metric)
Peat	Shelter	0.00 %	-99.75 %	0.08	EUR/kg (metric)
Natural gas and services related to natural gas extraction, excl. surveying	Shelter	0.00 %	-98.81 %	0.35	EUR/kg (metric)
Chemical and fertilizer minerals, salt and other mining and quarrying products n.e.c.	Shelter	4.85 %	-99.95 %	0.02	EUR/kg (metric)
Paper and paper products	Shelter	0.00 %	-99.57 %	0.13	EUR/kg (wet)
Coke Oven Coke	Shelter	0.00 %	-99.70 %	0.09	EUR/kg (metric)
Kerosene	Shelter	0.00 %	-98.68 %	0.39	EUR/kg (metric)
Liquefied Petroleum Gases (LPG)	Shelter	0.42 %	-98.45 %	0.46	EUR/kg (metric)
Naphtha	Shelter	0.00 %	-99.11 %	0.26	EUR/kg (metric)
Non-specified Petroleum Products	Shelter	0.00 %	-99.76 %	0.07	EUR/kg (metric)
N-fertiliser	Shelter	9.80 %	-99.94 %	0.02	EUR/kg (metric)
P- and other fertiliser	Shelter	0.44 %	-99.27 %	0.22	EUR/kg (metric)

Chemicals nec	Shelter	0.00 %	-91.74 %	2.45	EUR/kg (wet)
Charcoal	Shelter	0.00 %	-99.76 %	0.07	EUR/kg (metric)
Rubber and plastic products (25)	Shelter	0.56 %	-88.72 %	3.34	EUR/kg
Ceramic goods	Shelter	0.00 %	-96.89 %	0.92	EUR/kg
Fabricated metal products, except machinery and equipment (28)	Shelter	1.67 %	-88.94 %	3.28	EUR/kg (wet)
Furniture; other manufactured goods n.e.c. (36)	Shelter	0.00 %	-86.48 %	4.00	EUR/kg (wet)
Electricity by coal	Shelter	0.00 %	-99.89 %	0.03	EUR/kWh
Electricity by gas	Shelter	0.01 %	-99.83 %	0.05	EUR/kWh
Electricity by nuclear	Shelter	0.00 %	-99.95 %	0.02	EUR/kWh
Electricity by hydro	Shelter	0.01 %	-99.84 %	0.05	EUR/kWh
Electricity by wind	Shelter	0.00 %	-99.82 %	0.05	EUR/kWh
Electricity by petroleum and other oil derivatives	Shelter	0.00 %	-99.82 %	0.05	EUR/kWh
Electricity by biomass and waste	Shelter	0.01 %	-99.92 %	0.02	EUR/kWh
Electricity by solar photovoltaic	Shelter	0.00 %	-99.84 %	0.05	EUR/kWh
Electricity by solar thermal	Shelter	0.00 %	-100.00 %	0.00	EUR/kWh
Electricity by tide, wave, ocean	Shelter	0.04 %	-99.54 %	0.14	EUR/kWh
Electricity by Geothermal	Shelter	0.25 %	-99.98 %	0.01	EUR/kWh
Electricity nec	Shelter	45.77 %	-55.02 %	13.32	EUR/kWh
Transmission services of electricity	Shelter	0.04 %	3100.02 %	947.26	EUR/kg (wet)
Distribution and trade services of electricity	Shelter	15.03 %	2911.23 %	891.38	EUR/kg (wet)
Distribution services of gaseous fuels through mains	Shelter	0.00 %	-96.13 %	1.15	EUR/EUR
Steam and hot water supply services	Shelter	0.00 %	-99.91 %	0.03	EUR/kWh
Collected and purified water, distribution services of water (41)	Shelter	4.88 %	-96.62 %	1.00	EUR/EUR
Paper waste for treatment: incineration	Shelter	0.11 %	-97.74 %	0.67	EUR/kg (metric)
Inert/metal waste for treatment: incineration	Shelter	0.00 %	-98.93 %	0.32	EUR/kg (metric)
Paper waste for treatment: biogasification and land application	Shelter	0.03 %	-98.27 %	0.51	EUR/kg (metric)
Sewage sludge for treatment: biogasification and land application	Shelter	0.00 %	-98.04 %	0.58	EUR/kg (metric)
Food waste for treatment: waste water treatment	Shelter	0.00 %	-99.98 %	0.01	EUR/kg (metric)
Other waste for treatment: waste water treatment	Shelter	0.00 %	-99.98 %	0.01	EUR/kg (metric)
Food waste for treatment: landfill	Shelter	0.00 %	-99.06 %	0.28	EUR/kg (metric)
Paper for treatment: landfill	Shelter	13.02 %	-99.03 %	0.29	EUR/kg (metric)
Plastic waste for treatment: landfill	Shelter	0.00 %	-99.01 %	0.29	EUR/kg (metric)
Inert/metal/hazardous waste for treatment: landfill	Shelter	0.00 %	-99.16 %	0.25	EUR/kg (metric)

3.2 DEVELOPMENT OF LIFESTYLES

3.2.1 Background

'Lifestyle' in this model is defined as a specific consumption pattern. This 'bottom-up' perspective allows for backcasting modelling where different *potential* lifestyles are explored. Since a classification of different commodity-categories has been made, the same categories have been used for the consumption patterns or lifestyles. Information regarding which lifestyles to model was collected and aggregated mainly from the backcasting scenario workshops of the EU project GLAMURS (GLAMURS 2017). Each region present several general visions for a possible future and within each of those, commodity-category specific lifestyles are proposed (e.g. 'Spain - Galician region, Vision 2: Sufficiency - Human scale territories, Less meat is consumed and products have less packaging and labels'). Information on relevant lifestyles to be included was also supported by case studies from the GLAMURS (GLAMURS 2017). A Carbon-CAP (C-CAP) deliverable made by Schanes et al. (2015) has also been included to give input for the determination of which lifestyles to model. Finally, relevant lifestyles were taken from a collection of studies that categorize consumer behavior patterns into lifestyles in different domains (other studies). Full lifestyle data from which aggregation was made (GLAMURS, GLAMURS GCS, C-CAP, other studies) can be found in the supplementary information to this paper. From these four sources, relevant lifestyles were developed and clustered from common information and ideas in the sources. Some lifestyles come directly from a specific vision. A general description of each lifestyle was made through synthesizing the different sources used ( ). In addition to lifestyles within each consumption category, modelling was made of a *Parttime Work* lifestyle.

3.3.2 Specification of Reductions & Increases

This research develops general descriptions of each lifestyle, and thereafter the actual material implications are established. This includes what products will be reduced, what products will be substituted for, and if there are any industrial sectors affected by the changes. Using this information, the type of change the lifestyle implies was classified as one of the following:

1) Change at household level (Y in)
This implies a direct consumer change in which products are reduced and/or increased. This is the most common type of lifestyle implication. It applies if the lifestyle implies no change in the industry requirement of different products. A special case is food lifestyles where all changes at the household level cause the restaurant and hospitality sector to be affected; none of the food lifestyles were therefore classified into this category.

2) Change at industry level (A in)
This applies if the consumers have no direct ability to consume differently, but still have power to change the industry demand of products. Due to the aggregation in the model, for example in the textile industry as a sector there is no differentiation between synthetic and natural textile fibers. In this way, the *Fossil Free* clothing lifestyle can only be modelled if there is a change in the textile industry to reduce synthetic fibers and increase natural fibers. This model deals with lifestyle environmental impact changes, primarily focused on the consumer. Scenarios entirely focused on industrial sectors (background system) were therefore discarded if the link to lifestyles was not well represented.

3) Change at both household and industry level
If none of the above options apply, the change is a mixture of household demand and industry requirement changes. If this is the case it was assumed that the products reduced in the affected sector(s) were the same as products reduced by household final demand.

The modelling of lifestyle environmental impact changes also included determining whether products reduced were substituted by other products or not. *Product reduction* implies that the spending on (final demand of) the specified products is reduced. *Product substitution* means that the current spending on specified products is shifted towards the products substituted for. This can apply both to sectors changes and household changes. A minimum of one product needs to be reduced. If the lifestyle change also affects one or several industry sectors, this was specified. The particular sector(s) would thus be induced to reduce/increase demand of products as specified.

Technical Potential (TP) for industry and households, respectively, was also determined. Meanwhile, the Uptake Rate (UR) (portion of consumers/industries that actually implement the changes) was assumed to be 100%. TP determines how much it is practically possible to reduce the industry/household demand of specified products. The parameter should be in the interval of between 0 and 1 where 1 means a complete reduction, and 0 means no reduction made or not affected. Specific values were assigned to industry and households, respectively (Table 2).

Finally, if the lifestyle is based on a substitution of particular products for others, the price difference between reduced products as compared to the substituted ones was determined by the parameter Price Deflation (PD) (Table 2). The value of this parameter is in the interval of 1 to 0, indicating the multiplier by which the old price should be modified to achieve the new price. Thus if the products substituted for are 5 times cheaper, PD should be 0.2. Only 20% of the reduced final demand will go to final demand of the products substituted for. The default setting of the value 1 means that there is no price difference. The PD variable was also used to specify a certain substitute rate (for example, 20% of reduced final demand from reduced energy use in lifestyle *Passive House* is re-spent in construction).

Table 2 Consumption categories with the specified lifestyles within each category. The sources used for developing lifestyles are the GLAMURS backcasting workshops (GLAMURS), GLAMURS project case studies (GCS), Carbon-CAP project (C-CAP), and other sources (Others). Price deflation (PD) and uptake rate (UR) are developed from the information in the sources. Where information on UR is missing, as well as where the lifestyle was developed independently in this paper (sources are missing), this is specified with a dash ('-'). The technical potential (TP) is separated into households (Y) and industry (A).

Category	Name	Description	Product implications	Type of Change	UR	Sources	TP	PD
Clothing	Low Use	Do-it-yourself (DIY), second hand and buys for need. Buys raw material and produces clothes in the household. Reduces overall consumption of textiles by reusing, repairing, making own clothing, buying clothes of recycled fiber, increasing lifetime of clothes, donating or recycling old clothes. Uses library for clothes to further reduce demand, and rents clothes when needed.	Reduce finished products (textiles and wearing apparel) by 80%. Substitute 20% of spending by textile materials (fibers and wool) and leather.	Change in Y; partial substitution	30-80%	GLAMURS SP2, SP3. MAPI 5, 9. Carbon-CAP 72, 78, 79, 81, 81, 82.	Y: 0.8 A: 0	0.2
	Vegan	No textiles with animal origin, only synthetic fibers and plant fibers (in line with vegan lifestyle).	Reduce wool, furs, leather, and replace with textiles and plant-based fibers. Textile and wearing apparel sectors affected.	Change in A and Y; substitution	-	MAPI 5	Y: 1 A: 1	1
	Natural Fiber	No petroleum-based clothes. Only demands clothes with natural fibers such as wool, fur, plants and leather.	Reduce plastic, rubber to sectors textile and wearing apparel by 90%. Replace with natural fibers.	Change in A; substitution	90%	GLAMURS ITA1, AUT1. MAPI 10. Carbon-CAP 71.	Y: 0 A: 0.9	1
	Local Clothing	Only local clothing and manufactured products.	Reduce by 50% the inputs of air & water transport to sectors of clothing and manufactured products	Change in A; reduction	-	GLAMURS SP1, SP4-5, AUT1, AUT14-15, AUT21, NL15	Y: 0 A: 0.5	

Construction	Repair Renovate	Spends a significant amount of income on refurbishment and renovation of old residential buildings. Never buys new housing, instead renovates older structures.	Reallocate 5% of all overall product spending, except that on food, to increases of construction products.	Change in Y; substitution	30%	GLAMURS SP64. MAPI 7, 11. Carbon-CAP 56, 57.	Y: 0.05 A: 0.9	1
	No Renovation	Almost no refurbishment of the house or purchase of new material.	Reduce all construction products by 90%	Change in Y and A; reduction	-	-	Y: 0.9 A: 0.9	1
	Natural Materials	Uses natural, and renewable materials in renovation and refurbishment of housing.	90% decrease in clay products, cement, and steel. Increase in stone, sand and clay, wood, and non-metallic mineral products.	Change in A and Y; substitution	30%	GLAMURS SP63. MAPI 4, 5. Carbon-CAP 35, 36, 37, 40, 43.	Y: 0.9 A: 0.9	1
	Concrete Renovation	Renovation based on concrete, metal, and glass. No wood, stone, sand, clay, or non-metallic mineral products.	Reduce products wood, stone, sand, clay, and non-metallic mineral products by 90%. Increase products concrete, baked clay, glass, and metal.	Change in A and Y; substitution	-	Carbon-CAP 53.	Y: 0.9 A: 0.9	1
Food - Diet	Mediterranean Diet	High consumption of olive oil, legumes, fruits, vegetables, and unrefined cereals. Moderate consumption of fish, dairy products, and wine. Low consumption of non-fish meat and meat products.	Decrease non-fish meat products by 80%, increase all others foodstuffs. H/R affected.	Change in Y and A; substitution	50%	GLAMURS SP13, NL3. MAPI 10. Carbon-CAP 5, 10.	Y: 0.8 A: 0.8	1
	Unprocessed	No processed meat products. Buys the animal alive and does the slaughtering himself. Does not eat any processed food, just direct agricultural products.	Reduce all ready-made meat products by 80%, replace with increase in live animals.	Change in Y; substitution	80%	GLAMURS SP23	Y: 0.8 A: 0	1
	Vegetarian	Vegetarian food (without red/white meat). With dairy and eggs.	Reduce products with meat and fish to 100%. Replace with plant-based	Change in Y and A; substitution	-	GLAMURS SP13, NL3. MAPI 5.	Y: 1 A: 1	1

			food, diary, and food n.e.c. H/R affected.			Carbon-CAP 4, 10, 12.		
	Vegan	Vegan food (without red/white meat, eggs, and dairy products).	Decrease all meat, fish, and dairy products to 100%. Increase all other food. H/R affected.	Change in Y and A; substitution	-	GLAMURS SP13, NL3. MAPI 5. Carbon-CAP 3, 5, 6, 9, 10, 11.	Y: 1 A: 1	1
	Healthy Vegan	Vegan food. Healthy food consumption and no food with low nutritional value; tea, coffee, beverages. Mainly unprocessed food.	Decrease all meat, fish, dairy, and sugary/unhealthy products to 100%. Increase all other food. H/R affected.	Change in Y and A; substitution	-	GLAMURS SP13, NL3. MAPI 5, 7, 10. Carbon-CAP 1, 2, 3, 4, 9, 10, 12. Others 1, 4.	Y: 1 A: 1	1
	Careless Consumer	Doesn't care about health at all. Convenience and taste the only importance. Ready-made fast-food and meat-products.	Reduce all raw plant-based foods, as well as live animals, by 80%. Replace with processed food products.	Change in Y and A; substitution	-	Others 5	Y: 0.8 A: 0	1
	Eat Less	Limits food consumption to 2586 kcal/day.	Reduce all food product spending by 27%.	Change in Y; reduction	-	-	Y: 0.27 A: 0	1
Food - Supply Chain	Restaurant Food	Only consume food from restaurants, never buys raw food products from the market.	Reduce all food products, substitute with hotel & restaurant services.	Change in Y; substitution	-	-	Y: 1 A: 0	1
	Local Food	Shift toward locally produced food in households and in hotel/restaurant sector. Focus on food sovereignty.	Reduce goods-related mobility and transport services in food and H/R products by 50%.	Change in A; reduction	50-100%	GLAMURS SP7, SP8, SP10-12, SP14, SP17. AUT2-4, AUT6-7, AUT21, NL1, NL5, NL7-9, NL15, ITA2-3, GER2, 4.	Y: 0 A: 0.5	1
	Organic Food	Food is organically grown (without artificial fertilizers added).	Reduce fertilizer input to food and H/R products by 100%.	Change in A; reduction	80%	GLAMURS SP15, SP19, SP21, AUT3, AUT5, AUT7. ITA4, RO1. MAPI 2, 6, 8, 10.	Y: 0 A: 1	1

	Seasonal Food	Reduced need for vegetables grown in greenhouses through seasonal food consumption	Reduce inputs of fuels and electricity to vegetable sector by 30%.	Change in A; reduction	50-80 %	GLAMURS NL2, ITA2, SP12, SP19.	Y: 0 A: 0.3	1
	No Waste	Doesn't waste any of the purchased food products.	Reduce all food product spending by 12%.	Change in Y; reduction	-	-	Y: 0.12 A: 0	1
Manufactured Products	No Chemicals	Reduces number of plastic items, bottled water, buys bio-based plastics, uses textile bag when shopping. Bio-based chemicals, efficient use, chemical leasing, and only compost to his garden.	Reduced fertilizer and other chemicals. Reduced plastic, rubber, and petroleum-based products. 80% reduction.	Change in Y; reduction	-	Carbon-CAP 84, 99, 100, 101, 102, 104, 105, 106.	Y: 0.9 A: 0	1
	Low Tech	Minimizes purchase of personal and household electronic products.	80% reduction of machinery and electric apparatus	Change in Y; reduction	-	-	Y: 0.8 A: 0	1
	No Media	No consumption of media or Internet, and doesn't have any telecommunication device or computer.	80% reduction of media, machinery, electric apparatus, telecommunication devices, and services related.	Change in Y; reduction	-	MAPI 11.	Y: 0.8 A: 0	1.0
	Share Repair	Shared use of material goods. Second-hand buying. Life extension and repairs. Shift from ownership of product to buying service provided by product. Reduce surpluses, consume less intensely. Repair tax breaks, longer life of products.	Reduced consumption of manufactured products and retail/trade by 50%. 10% of reductions go to increase of renting services.	Change in Y; partial substitution	70-80%	GLAMURS SP28, SP30, SP58, SP75, SP77, SP85-86, SP88, AUT12-13, AUT20, NL10-14, NL16, NL28-29, ITA6, ITA10, RO6, RO8.	Y: 0.5 A: 0	0.1
Mobility	Bike Walk Full	Bikes or walks everywhere by land. Keeps expenditure on flying constant.	100% reduction of products related to mobility by land	Change in Y; reduction	80%	GLAMURS SP34, SP41-42, ITA9, GER9, GER16, GER18, GER22, RO9-10. MAPI 10. Carbon-CAP 30.	Y: 1 A: 0	1

	Flex Work Half	Reduces need for mobility by working from home, living close to work, teleworking, and having shared services in neighborhood. Digital trips instead of physical, local tourism. Less time spent in mobility. Tax advantages. Sustainable mobility education. Only commute to/from work.	Reduces spending on mobility by land by 50%	Change in Y; reduction	75-100%	GLAMURS SP31-32, SP36, SP44, AUT22, AUT30, AUT33, AUT47, NL18, NL20-22, GER8, GER12, GER19, GER20. MAPI 1, 2, 4, 6, 8. Carbon-CAP 7, 11, 29, 39, 45, 86	Y: 0.5 A: 0	1
	Flex Work Half ER	Reduces need for mobility by working from home, living close to work, teleworking, and having shared services in neighborhood. Digital trips instead of physical, local tourism. Less time spent in mobility. Tax advantages. Sustainable mobility education. Only commute to/from work. More time spent in the home means electricity and fuel spending increases. ER (Energy Rebound).	Reduces spending on mobility by land by 50%, increase electricity and fuel spending by 20%	Change in Y; partial substitution	75-100%	GLAMURS SP31-32, SP36, SP44, AUT22, AUT30, AUT33, AUT47, NL18, NL20-22, GER8, GER12, GER19, GER20. MAPI 1, 2, 4, 6, 8. Carbon-CAP 7, 11, 29, 39, 45, 86	Y: 0.5 A: 0	0.2
	Less Mobility Half	Overall decreased spending on mobility	50% reduction of all products related to mobility	Change in Y; reduction	80%	GLAMURS SP34, SP41-42, ITA9, GER9, GER16, GER18, GER22, RO9-10. MAPI 10. Carbon-CAP 30.	Y: 0.5 A: 0	1
	Collective Transport	Land mobility by public transport. Simulates a car-free life. When car is needed, co-ownership and ride share is used.	Substitutes 50% of income spent on products used for car travel with public transportation (bus, train, boats, etc.)	Change in Y; substitution	30%	GLAMURS SP33, SP37, SP39, AUT23-24, AUT27,-28, AUT31, AUT36-37, AUT39, GER6. MAPI 4, 5, 11.	Y: 0.5 A: 0	1

						Carbon-CAP 16, 27, 28, 30, 31, 32.		
	Renewable Fuels	Public transport and private vehicles all use liquid biofuels. Fossil-free transport.	Decrease fossil fuel input to retail sale of motor fuel and urban transport by 90%, substitute by renewable fuels. Also for households.	Change in Y and A; substitution	50%	GLAMURS SP38, AUT25, GER 13-15.	Y: 0.9 A: 0.9	1
	No Flying	Stops flying.	100% reduced air transport, increased land and water.	Change in Y; substitution	-	GLAMURS SP40, SP46, AUT26, AUT38, NL19. Carbon-CAP 8.	Y: 1 A: 0	1
	No Flying TR	Replaces air transportation with land- and water based. Transport rebound (TR).	100% reduced air transport, increased land and water.	Change in Y; substitution	-	GLAMURS SP40, SP46, AUT26, AUT38, NL19. Carbon-CAP 8.	Y: 1 A: 0	1
	Flying Biker	Biker saves money by biking but flies with the saved money.	50% reduction of products related to local land mobility, substitute with air mobility	Change in Y; substitution	-	-	Y: 0.5 A: 0.0	1
	Frequent Flyer	Flies internationally frequently.	Reallocate 2% of all product spendings, except on food, towards air transport.	Change in Y; substitution	-	-	Y: 0.02, A: 0	1
	Green Cars	Only uses electrical mobility.	Reduce mobility by land by 100%, substitute with electricity use and treatment of hazardous waste	Change in Y substitution	-	AUT29, AUT32, NL17. ITA7-8, GER7.	Y: 1 A: 0	1
Services	Local	Local service supply. Decentralized service when possible. Services-based local economies.	Reduce household spending on local transport by 20%. Reduce input of local mobility into all services by 30%.	Change in Y and A; reduction	80%	GLAMURS SP51, SP60-62	Y: 0.2 A: 0.3	1

	Hedonist	Live fast, die young. A lot of travelling, restaurant food, spa, culture events, etc. Focus on enjoying life, no need for health services or financial security.	80% reduction in services related to business, education, health, and similar. Substituted by recreational activities and retail services.	Change in Y; substitution	-	-	Y: 0.8 A: 0	1
	Play It Safe	Large spending of financial and personal safety and health (insurance, pension, healthcare, etc.).	Reallocates 80% of services spendings, towards health, defence, and insurance services.	Change in Y; substitution	-	-	Y: 0.8 A: 0	1
	Home Based	Passive, homebased activities and interests. Like gardening and consuming a lot of media, but never long-distance travels. Enjoy local cultural activities and engagements in organizations.	Decrease leisure services as well as long-distance travel by 90%, substitute with recreational and membership organization services.	Change in Y; substitution	-	Others 2, 3.	Y: 0.8 A: 0	1
	Low Services	Highly dependent on inter-community exchange, low use of commercial services. Frequently volunteers within the local community.	80% lower use of all services	Change in Y; reduction	50%	GLAMURS SP56.	Y: 0.8 A: 0	1
	High Services	High use of all services.	Reallocates 5% of overall product spending, except that on food, toward services.	Change in Y; substitution	-	-	Y: 0.05 A: 0	1
Shelter	Green Home	Off the grid in terms of energy (electricity and fuels). Respends some of savings to solar panels and biofuels.	Decrease spending on electricity and fuels by 100%. Respends 20% into renewable fuels and PV's.	Change in Y; partial substitution	-	SP65, 70. AUT48, 52	Y:1 A: 0	0.2
	Green Electricity	Renewable supply of energy; wind, photovoltaic, solar, geothermal and tidal. PV roofs. Less fossil fuels used for heating.	Reduce fossil electricity by 100%, replace with renewable electricity.	Change in Y; substitution	-	-	Y: 1 A: 0	1

	Fossil Fuel	Replaces renewable fuels and electricity with fossil fuel based sources.	Full replacement of renewable electricity and energy with fossil sources	Change in Y; substitution	-	-	Y: 1 A: 0	1
	Tecno Ecovillage	Off the electricity and gas grid. Decentralized, local, and small-scale energy production by renewable sources. All other fossil fuels for heating remain the same.	Decrease spending on non-renewable electricity as well as on grid services. Substitute with renewable electricity.	Change in Y; substitution	-	SP65, 70. AUT48, 52	Y: 1 A: 0	1
	Full Ecovillage	Off the grid in terms of energy (electricity and fuels). Low-tech means no respending of savings within the shelter commodity category. Off-the-market energy sourcing.	Decrease spending on energy, fuels, and other shelter-related services by 100%	Change in Y; reduction	-	GLAMURS SP65, SP70, AUT48, AUT52.	Y: 1 A: 0	1
	Water Off Grid	Doesn't use the conventional water distribution network. Gathers drinking water from external sources.	100% reduced expenditure on collected and purified water, distribution services of water	Change in Y; reduction	-	-	Y: 1 A: 0	1
	Passive House	Eco-efficient dwellings. Lower energy consumption and remaining use of energy is much more efficient.	Reduce spending on energy by 43% (equivalent to energy reduction by 40%). Respend 20% into construction work and insulation.	Change in Y; partial substitution	80%	GLAMURS SP73, AUT50-51. MAPI 1, 5, 11. Carbon-CAP 34, 46, 47, 48, 49, 50, 52, 55, 73, 74, 75, 76, 77, 83, 84, 85, 88, 89, 90.	Y: 0.43 A: 0	0.2
Non-specified	Parttime Work	Works only 75%, thus spends 25% less	Put technical potential in Y = 0.25 reduction	Change in Y; reduction	-	-	Y: 0.25 A: 0	1

3.2.3 Calorie Intake and Energy Use Adjustments

Lifestyles within the food as well as within the energy (household fuels and electricity) consumption category required additional data processing. When consumption is shifted from certain (reduced) calorie or energy-related products to other products substituted for (increased), it is possible that the calorie intake or energy use change significantly. For all lifestyles, the calorie intake and energy use before and after intervention was calculated. Thus it was possible to determine whether drastic changes in calorie intake or energy use were implied for a specific intervention, which may be relevant for interpreting the results. For lifestyles within the shelter and food consumption category, a specific modelling was applied where energy use and calorie intake was adjusted. This was made in four steps, and the results for modelling types 2 and 3 for carbon, toxicity, water, and land footprint are included in chapter 4. Results and Discussion. Results for step 1 and 4 were obtained for carbon footprint, and are presented in Table 9 in the Appendix.

1. *Without rebound, no food/energy changes applied.* Without any calorie or energy adjustments made. Calculations were based on the new final demand obtained from the reductions or substitution specified in the specific lifestyle. No rebound effect was taken into consideration. Household final demand is balanced, but there is a change in energy use or calorific intake after as compared to before intervention.

2. *Without rebound, adjustment of energy/food.* Results were obtained from the original no-rebound final demand and changes were applied to food/energy products so that calorie intake or energy use stayed constant in the intervention. No rebound effect was taken into consideration. Household final demand may be different after as compared to before intervention.

3. *Excess spending on energy/food rebounding to other products.* Energy/food spending was adjusted as in previous steps. This step also takes into account the money corresponding to an excess of calories/energy after as compared to before the intervention. The excess final demand was shifted toward all other products in a general rebound scenario. A lifestyle that would typically lead to such results is the 'Vegetarian' lifestyle that exchanges meat products for cheaper food products like vegetables and cereals. When final demand was substituted for the new food products, i.e. the money is spent on cheaper food products, the result was a higher calorie intake after the intervention. Household final demand and calorie intake / energy use may be different after as compared to before intervention if the lifestyle actually has a deficit of calories, since that is not taken into consideration.

4. *Deficit spending on energy/food taken from other products.* Energy/food spending were adjusted as before. These estimations also take into account the money corresponding to a deficit of calories/energy with the intervention. The additional money required to be spent on food/energy to make calorie intake / energy use balanced was taken from all other products. There is simply not enough calories/energy bought for the money available from the product reduce change. This could happen for example for the 'Careless Consumer' where expensive ready-made and processed products are consumed to a higher extent than before. In this scenario, a certain expenditure was taken from all other products that are not already reduced and redistributed toward the increased food products to balance the calorie intake. Household final demand and calorie intake / energy use will be balanced, i.e. same before as after the intervention.

For each of the food products, the calorific output (in kilocalories) per monetary unit (million Euros) was calculated as

$$Calorific\ output \left[\frac{kcal}{MEuro}\right] = Calorie\ content \left[\frac{kcal}{ton}\right] * Price^{-1} \left[\frac{ton}{MEuro}\right]$$

Information on the calorie content in each food product was taken from the National Nutrient Database of the United States Department of Agriculture (USDA 2016). Supplementary data was taken from the Finnish National Food Composition Database (Fineli 2016). See Table 3 for a summary. Assumptions were made to approximate how much of the weight of each raw product, for example pigs, is eligible to be consumed as calories (since prices are weight based). This is presented as *ER* (edible ratio) in Table 3. Estimated calorific intake share calculated from household final demand was compared to data from the Food and Agriculture Organization of the United Nations (FAO 2016), presented as *FAO share* in Table 3.

For the *No Waste* food lifestyle, it was necessary to estimate the amount of food wasted by EU households. The avoidable consumer food waste was in 2015 estimated to be 12% of the food reaching consumers, based on weight units (Vanham et al. 2015). This research assumes that the same was valid for year 2007 and that the weight units roughly reflect the monetary demand reduction. A 12% reduction of food-product spending was therefore applied to this lifestyle. For the *Eat Less* food lifestyle it was assumed that dietary intake is equal to that of the EU country with the lowest calorific intake; namely the Republic of Moldova with 2586 kcal/cap/day (FAO 2016). This is within the range of calorie need for a moderately active male (USDA/HSS 2010). The average dietary intake in EU is 3370 kcal/cap/day. Calorie reduction was thus assumed as

$$Reduction\ of\ Demand = 1 - \frac{Minimum\ Calorific\ Intake}{Actual\ Calorific\ Intake} = 1 - \frac{2586}{3370} = 0.233$$

By the method of trial and error, it was found that a calorie reduction of 23.3% corresponds approximately to a household final demand reduction of 27%. Household technical potential for *Eat Less* was therefore set to 0.27. *Eat Less* does not include calorie reduction from hotel and restaurant spending. Therefore, because some of the actual calorie supply is coming from the hotel and restaurants, the calorie reduction of *Eat Less* was lower than the total final demand reduction.

A maximum reduction potential for food lifestyles was calculated by combining the lifestyles of vegan diet, organic food, no food waste, and reduced calorific intake. The sum of the reduction potential of each of these lifestyles was compared to the total EU household impact in 2007 (see Table 7).

Table 3. Estimated calorie content of the EXIOBASE food products (Fineli 2016; USDA 2016). Each EXIOBASE product is compared to a similar product from the sources of the calorie information. Edible ratio (ER) is assumed. Calorific intake of each product by EU households is shown as the share of household final demand (HHFD share). FAO share shows the calorific distribution of each product in EU as of 2007 (FAO 2016). N.e.c stands for not elsewhere classified.

EXIOBASE product	Explanation	Equivalent product(s)	Calories (kcal/g)	ER	Calories (kcal/g)	HHFD share	FAO share
Paddy rice	Raw rice. Natural, unprocessed stage. From paddy fields.	Wild rice, raw	3.57	0.9	3.23	0.5 %	0%
		Rice, white, medium-grain, raw, unenriched	3.60				
Wheat	Raw wheat	Wheat, durum	3.39	0.4	1.36	4.5 %	27.2%
Cereal grains nec	Raw rye, barley, oats, maize, rice, etc.	Rye, grain	3.38	0.7	2.53	4.6 %	3.8%
		Barley, hulled	3.54				
		Oats	3.89				
		Corn grain, yellow	3.65				
Vegetable, fruit, nuts	Vegetables (tomatoes, cabbage, beans, sweet corn, etc.), edible nuts incl. coconut, fruit (apples, berries, bananas, etc.).	Average selection of vegetables	0.40	0.9	1.05	29.3 %	10.7%
		Average selection of raw nuts	4.00				
		Average selection of fruits	0.55				
Oil seeds	Raw peanuts, soya, colza	Peanuts, all types, raw	5.67	0.8	4.05	2.7 %	1.2%
		Soybeans, mature seeds, raw	4.46				
Sugar cane, sugar beet	Raw sugar cane and sugar beet	Syrup, Cane	2.69	0.7	1.88	0%	0%
Crops nec	Other crops	Assume average for potato, pumpkin, sugar beet	0.50	0.9	0.45	1.2 %	0%
Cattle	Cattle	Beef, carcass, separable lean and fat, select, raw	2.78	0.5	1.39	0%	0%
Pigs	Swine (pigs)	Pork, fresh, carcass, separable lean and fat, raw	3.76	0.5	1.88	0%	0%
Poultry	Eggs, turkeys, ducks, chickens, geese and guinea fowl or guinea hens	Average selection of chicken	1.50	0.6	0.88	1.0 %	1.4%
		Egg, whole, raw, fresh	1.43				
Meat animals nec	For meat; horses and other equines, camels, sheep, goats. Ostriches, emus, non-poultry birds, insects, rabbits and other fur animals.	Average selection of meat animals neck	1.50	0.5	0.75	0.2%	0%
Animal products nec	Other crude, primary animal products. Animal oils.	Lard	9.02	0.9	4.29	0.1 %	2.6%

		Blood	0.52				
Raw milk	Raw milk from cows, buffaloes, sheep, goat, camels, horses, asses, etc.	Milk, Raw Milk, 4.4 % Fat, Without Added Vitamin D	0.71	1	0.71	1.1 %	0%
Fish and other fishing products; services incidental of fishing (05)	Raw fish, crustaceans, mollusks, natural pearls, algae, oysters, seaweeds. Servies naturally related to fishing.	Fish, Average, Baltic Herring/Vendace/Perch/Pike	0.99	0.6	0.59	0.3 %	1.4%
Products of meat cattle	Beef meat in cuts or carcasses.	Beef, variety meats and by-products, mechanically separated beef, raw	2.76	1	2.76	1.9 %	2.0%
Products of meat pigs	Pork meat in cuts or carcasses.	Pork, fresh, variety meats and by-products, mechanically separated, raw	3.04	1	3.04	5.2 %	5.2%
Products of meat poultry	Fresh or frozen poultry meat in individual portions, edible poultry fats. Rabbit meat, feathers, down.	Poultry, mechanically deboned, from mature hens, raw	2.43	1	2.43	2.7 %	2.1%
Meat products nec	Dried, salted or smoked meat. Prepared meat dishes. Sausages, salami, puddings, ’andouillettes’, saveloys, bolognas, pâtés, galentines, rillettes, boiled ham, meat extracts and juices.	Sausage, Fresh Sausage, Kabanossi, Rapeseed Pork, Average, Hk	1.95	1	2.18	0.4 %	0.6%
		Ham, sliced, regular (approximately 11% fat)	1.63				
		Bratwurst, beef and pork, smoked	2.97				
products of Vegetable oils and fats	Crude and refined vegetable oils and fat. Margarine. Olive oil, soya-bean oil, palm oil, sunflower-seed oil, cotton-seed oil, rape, colza or mustard oil, linseed oil, etc.	Margarine, margarine-like vegetable oil spread, 67-70% fat, tub	6.06	1	7.91	3.8 %	11.8%
		Oil, sunflower, linoleic, (partially hydrogenated)	8.84				
		Oil, industrial, soy (partially hydrogenated), all purpose	8.84				

Dairy products	Processed milk and cream (homogenized, pasteurized, sterilized and/or UHT). Butter, yoghurt, cheese, whey, casein or lactose, ice cream and sorbet, milk drinks, dried milk.	Milk, Average, 1 Ug Added Vitamin D	0.48	1	3.75	14.7 %	11.2%
		Butter	7.27				
		Cheese, cream	3.50				
Processed rice	Milled, polished, glazed, parboiled or converted rice. Rice flour and starch	Rice, White	3.42	1	3.54	1.9 %	1.3%
		Rice flour, white, unenriched	3.66				
Sugar	Refined sugar and sugar substitutes from juice of cane, beet, maple, and palm	Syrups, table blends, corn, refiner, and sugar	3.19	1	3.63	4.1 %	11.0%
		Sugar	4.06				
Food products nec	Soups and broths. Yeast, powdered or reconstituted eggs, etc. Food products enriched by vitamins, proteins, etc.	Average selection of broth	0.10	1	0.53	9.9 %	0.2%
		Chicken soup	0.44				
		Leavening agents, yeast, baker's, compressed	1.05				
Beverages	Whisky, brandy, gin, liqueurs, wine, cider, beer, malt, soft drinks, mineral water. Ethyl alcohol and neutral spirits.	Average selection of cider and beer	0.40	0.7	0.69	4.3 %	6.2%
		Average selection of wine	0.80				
		Spirit, Brandy/Rum/Whisky 40% Volume	2.29				
		Soft Drink, Cola, Average	0.45				
Fish products	Fish and marine mammal oils.	Average selection of fish oils	9.02	1	9.02	5.4 %	0.1%

For the energy-related products, data was obtained directly on energy (TJ) output per monetary unit for the different kinds of electricity products. For household fuels such as coal, gas, and liquid petroleum, lower heating value (net calorific value) was obtained from OECD/IEA (2005). Energy content for peat was obtained from Ekono (1981). Unlike electricity, the energy content of household fuels does not directly correspond to the usable heat that is possible to extract. Each fuel product therefore required the assumption of a heating efficiency equal to one of four types of a least efficient home-heating system (EIA 2013; EPA 2015; Pisupati 2016; Stovax 2017). By multiplying the heating efficiency with the lower heating value, the useful energy (TJ/ton) of each fuel was estimated. See Table 4 for the estimated values. From the EU weight price of the fuels, the energy price was obtained as

$$Energy\ price_{household\ fuel}\ \left[\frac{MEuro}{TJ}\right] = \frac{Weight\ price\left[\frac{MEuro}{ton}\right]}{HE * LHV\left[\frac{TJ}{ton}\right]}$$

where HE is the heating efficiency and LHV the lower heating value for a specific fuel.

For the *Passive House* lifestyle, it was assumed that it is possible to reduce energy consumption by 40%. This was based on 1) comparing theoretical maximum reduction potential for example by comparing current average space heating needs to a passive house standard (15 kWh/m^{2}yr), 2) a study of maximum achievable potential of energy efficiency measures in the U.S (Mosenthal and Socks 2015), 3) on assuming that people live in the most efficient type of buildings (flats, apartment buildings, etc.) (Statistics Norway 2012). By the trial and error method, it was found that a 40% energy consumption reduction was obtained by reducing final demand by 43%. Because a share of the total final demand reduction is for product *distribution services of gaseous fuels* which does not have energy use associated with it, a higher final demand reduction was required than the 40% energy consumption reduction.

Table 4. Estimation of useful energy in household fuels. NCV (Net Calorific Value or Lower Heating Value) measures the amount of energy released in combustion of specific fuel. The least effective heating system (HS) for each fuel is assumed, namely 1) non-catalytic wood stove Pacific Energy fireplace (EPA 2015), 2) non-condensing furnace (EIA 2013), 3) steam furnace for fuel oil (Pisupati 2016), and 4) Stockton 14HB high output boiler stoves (Stovax 2017). Heating Efficiency (HE) determines the efficiency of the heating system. Useful Energy is obtained from the NCV and HE of each fuel.

EXIOBASE Product	Description	NCV (GJ/t)	HS	HE	Useful Energy (GJ/t)
Products of forestry, logging and related services (02)	Raw products from forestry. Services related to logging (transport of logs within the forest)	16.0	1	0.65	10.4
Liquefied Petroleum Gases (LPG)	LPG for mobility included in another product category. LPG used for daily cooking in developed countries. Also heating.	50.1	2	0.80	40.1
Natural gas and services related to natural gas extraction, excluding surveying	Crude gaseous hydrocarbon. Services: Directional drilling and redrilling; 'spudding in'; derrick erection in situ, repairing and dismantling; cementing oil and gas well casings; pumping of wells; plugging and abandoning wells, etc.	39.0	2	0.80	31.2
Kerosene	-	43.9	3	0.825	36.2
Naphtha	Paint thinner, cleaning agent	47.7	3	0.825	39.4
Anthracite	Rank 1 coal. Hard, compact variety of coal . It has the highest carbon content, the fewest impurities, and the highest calorific content of all types of coal except for graphite.	29.7	4	0.72	21.3
Coking Coal	Essential ingredient in steel production. It is different to thermal coal which is used to generate power. Coking coal, also known as metallurgic coal, is heated in a coke oven which forces out impurities to produce coke, which is almost pure carbon.	28.2	4	0.72	20.3
Other Bituminous Coal	Rank 2 coal. Bituminous coal or black coal is a relatively soft coal containing a tarlike substance called bitumen. It is of higher quality than lignite coal but of poorer quality than anthracite.	24.1	4	0.72	17.3
Patent Fuel	A composition fuel manufactured from hard coal fines with the addition of a binding agent.	27.3	4	0.72	19.7
Lignite/Brown Coal	Rank 4 coal. Lignite or brown coal is a soft brown combustible sedimentary rock formed from naturally compressed peat. It is considered the lowest rank of coal due to its relatively low heat content.	16.3	4	0.72	11.7
BKB/Peat Briquettes	Composition fuels manufactured from lignite/brown coal. Virtually smokeless, slow-burning, easily stored and transported. Can be used as domestic fuel for houses.	17.0	4	0.72	12.2
Peat	Accumulation of partially decayed vegetation or organic matter. First step in formation of other fossil fuels.	17.2	4	0.72	12.3
Coke Oven Coke	Coke for coke ovens. The solid product obtained from the carbonization of coal, principally coking coal, at high temperature.	27.5	4	0.72	19.8
Carola	Charcoal is a light, black residue, consisting of carbon and any remaining ash, obtained by removing water and other volatile constituents from animal and vegetation substances.	29.6	4	0.72	21.3

3.3 MULTI-REGIONAL INPUT-OUTPUT SYSTEM

The following section on MRIO system modelling is based on Rodrigues et al. (2015) and a working paper by Wood and colleagues where the basis of the implemented method is introduced (Wood et al. 2015). Peters and Hertwich (2004) explains in detail how to use IOA to calculate pollution in trade, and the MRIO implications are further described by Peters (2007). MRIO is based on an estimation of the total output of the economy from final and intermediate consumption in a region r:

$$x_r = A_r x_r + y_r \tag{1}$$

where x_r is the total output in region r and A_r is the inter-industry requirements matrix showing the input from each industry to produce one unit output in each industry (the so-called 'production recipes' for different industries). y_r is the vector of final demands on the economy (exports, changes in inventories and valuables, gross fixed capital formation, and final consumption expenditure by households, NGO's, and government).

This is analogous to

$$x_r = (I - A_r)^{-1} y_r \tag{2}$$

where I is the identity matrix. From this environmental impacts occurring in a specific region r can be calculated as

$$f_r = F_r * x_r = F_r (I - A_r)^{-1} y_r \tag{3}$$

where f_r is the total impacts and F_r the environmental impact per unit industry output. Domestic consumption in products produced domestically and imports can be estimated from

$$y_r = y_{rr} + \textstyle\sum_s e_{rs} \tag{4}$$

where y_{rr} is the final demand vector of domestic products and $\sum_s e_{sr}$ is the sum of all exports from countries s into the region of interest r. The latter is constructed from bilateral trade data. Likewise the inter-industry requirements can be estimated as

$$A_r = A_{rr} + \textstyle\sum_s A_{sr} \tag{5}$$

where A_{rr} shows the industry input of domestically produced products and $\sum_s A_{sr}$ the industry input of products to region r coming from all other countries. With these definitions, (1) is reformulated as

$$x_r = A_{rr} x_r + y_{rr} + \textstyle\sum_s e_{sr} \tag{6}$$

In order to calculate emissions embodied in consumption, for a country s exporting to country r, exports going to final demand has to distinguished from inter-industry demand,

$$e_{sr} = e_{sr}^{ii} + y_{rs} \tag{7}$$

where y_{rs} is the final demand in region r coming from region s and e_{sr}^{ii} the exports to industry which can be expressed as

$$e_{sr}^{ii} = A_{sr} * x_s \tag{8}$$

When (8) is combined with (6), the resulting total output is

$$x_r = A_{rr} x_r + y_{rr} + \textstyle\sum_{s \neq r} A_{sr} x_s + \sum_{s \neq r} y_{rs} \tag{9}$$

For a specific region, denoted number 1, the output in each region for the total demand in region 1 can thus be expressed as

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_m \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} & A_{13} & \cdots & A_{1m} \\ A_{21} & A_{22} & A_{23} & \cdots & A_{2m} \\ A_{31} & A_{32} & A_{33} & \cdots & A_{3m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_{m1} & A_{m2} & A_{m3} & \cdots & A_{mm} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_m \end{pmatrix} + \begin{pmatrix} y_{11} + \sum_{i \neq 1} y_{1i} \\ y_{21} \\ y_{31} \\ \vdots \\ y_{m1} \end{pmatrix} \tag{10}$$

where the first element in the demand vector (y) represents final demand on domestic production (for domestic consumption; y_{11}, and for exports to regions i; $\sum_{i \neq 1} y_{1i}$). The other elements are imports into final demand of region 1. The elements A_{mm} are the domestic inter-industry requirements, while each element A_{ir} and y_{ir} is estimated using trade shares (Lenzen, Pade, and Munksgaard 2004; Peters and Hertwich 2004; Peters and Hertwich 2009). $\{s_{ir}\}_g$ shows the share of trade flows of good g from regions i to region r;

$$\{s_{ir}\}_g = \frac{\{m_{ir}\}_g}{\{m_{total}\}_g} \tag{11}$$

where $\{m_{total}\}_g$ is the total import of good g into region r and $\{m_{ir}\}_g$ is the total import of good g from region i to r. With this, vector A_{ir} and y_{ir} can be estimated as

$$A_{ir} = s_{ir} A_i^{im} \tag{12}$$

and

$$y_{ir} = s_{ir} y_i^{im} \tag{13}$$

where A_i^{im} is the inter-industry requirement (intermediate consumption) of goods from i, and y_i^{im} is the final demand of products from region i. Solving (10) for x gives

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_m \end{pmatrix} = \left(I - \begin{pmatrix} A_{11} & A_{12} & A_{13} & \dots & A_{1m} \\ A_{21} & A_{22} & A_{23} & \dots & A_{2m} \\ A_{31} & A_{32} & A_{33} & \dots & A_{3m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_{m1} & A_{m2} & A_{m3} & \dots & A_{mm} \end{pmatrix} \right)^{-1} * \begin{pmatrix} y_{11} + \sum_{r \neq 1} y_{1r} \\ y_{21} \\ y_{31} \\ \vdots \\ y_{m1} \end{pmatrix} \tag{14}$$

or simplified

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_m \end{pmatrix} = L \begin{pmatrix} y_{11} + \sum_{r \neq 1} y_{1r} \\ y_{21} \\ y_{31} \\ \vdots \\ y_{m1} \end{pmatrix} \tag{15}$$

Combining (15) with (3), environmental footprint (global impacts due to consumption in a specific region) can thus be calculated using regional outputs and emission intensities;

$$FP = \sum_i F_i x_i = \mathrm{F}^{\mathrm{s}}_{\mathrm{Global}} * \mathrm{L}_{\mathrm{Global}} * \begin{pmatrix} y_{11} + \sum_{r \neq 1} y_{1r} \\ y_{21} \\ y_{31} \\ \vdots \\ y_{m1} \end{pmatrix} + \sum \mathrm{F}^{\mathrm{s}}_{\mathrm{hh}} \tag{16}$$

where F^s_{Global} is the emission intensity of stressor s for production of all goods in all regions, L_{Global} the Leontief inverse (originating from the global inter-industry requirements matrix A as seen in eq. 10), and F^s_{hh} is the direct household (hh) emission of stressor s from each product. This methodology disregards the trade going directly to industry (imports required to produce exports) and thus allocates all the embodied impacts to the final consumers of a given region. In other words, y_r is the final demand from both domestically produced products and imports.

To calculate and disaggregate footprint into showing where the actual impact reduction occurs, (16) is reformulated as $FP_{disagg} =$ $\widehat{\mathrm{F}^{\mathrm{s}}_{\mathrm{Global}}} * \mathrm{L}_{\mathrm{Global}} *$

$$* \begin{pmatrix} y_{11} + \sum_{r \neq 1} y_{1r} \\ y_{21} \\ y_{31} \\ \vdots \\ y_{m1} \end{pmatrix} + \sum \mathrm{F}^{\mathrm{s}}_{\mathrm{hh}} \tag{17}$$

where $\widehat{\mathrm{F}^{\mathrm{s}}_{\mathrm{Global}}}$ is the diagonalized emission intensity stressor.

The direct household emissions (DHE) of (16) and (17) are adjusted by calculating a DHE multiplier, through dividing DHE for each emission category and product by the original final demand of that product. The new DHE is calculated as a product of the DHE multiplier and the new final demand. For products where there is no household final demand linked to the DHE, that DHE is adjusted according to the total relative change of household final demand.

The MRIO database used in this paper is EXIOBASE 2.3 (Wood et al. 2014) (for more information, see chapter 2.2 Modelling the Environmental Impact of Consumers). The environmental intensity vector of EXIOBASE 2.3 contains 124 stressors. Results were calculated for 1) global warming potential (GWP100) (Mt CO_2 eq.) which includes emissions in the whole supply chain of products as well as direct emissions from combustion of fossil fuels, 2) human toxicity potential (HTP100) (Mt 1,4-dichlorobenzene eq.) where like the GWP, time horizon was defined as 100 years, 3) blue water consumption (Gm^3) which also includes direct household use of water, and 4) land use (1000 km^2). Impacts were calculated for the EU as a region, including Norway, Switzerland, and other non-specified European countries (classified in EXIOBASE as ‘rest of the world Europe’).

3.4 FINAL DEMAND MODELLING

The model is based on a redistribution of the original final demand of different products toward other products. A balance in expenditure is therefore assumed, and not in the service that products may provide the householder with (such as kilometers travelled, kilograms of clothes used, etc.). When reduced consumption of specific products (i, *reduced products*) is replaced by spending on others (g, *increased products*) this was classified as a substitution. Results for the substitution effect are presented as *No Rebound*. The current demand of (spending on) reduced products was redistributed toward increased products. The products for which final demand was increased were explicitly specified. The total amount of spending that is redistributed was reduced if there was a price difference. If there was price difference only part of the reduced demand was redistributed. Where there was no price difference, this was modelled with a unitary value. Any price difference p was defined as

$$p = \frac{p_g}{p_i} \qquad (18)$$

The relative price difference thus defines how much of a certain expenditure should be re-spent on the products with increased final demand. A value of 0.2 means that 20% of the expenditure of reduced products is re-spent on increased products, or that the reduced products are 5 times more expensive than the increased products. A lower price for the new products will result in money being available for re-spending. This demand is distributed proportionately across all the products not affected by the substitution. Since final demand of new products cannot be larger than the substituted final demand, the maximum (and default) value for price difference is 1. This means that the new products have the same price as the old products. The model does therefore not take into consideration situations where the new products are more expensive than the old ones.

The reduced final demand y^{red} is modified as

$$y^{red} = \mathrm{y} \cdot (1 - \mathrm{q}^{\mathrm{y}}) \qquad (19)$$

where y is the final demand per product (column vector of 200 products), $\cdot$ represents elementwise multiplication, and the vector q^{y} specifies the technically possible reduction for the consumer goods (ranging from 0 to 1).

In the substitution, the added final demand $\mathrm{y}_o^{\mathrm{sub}}$ is estimated as

$$y_o^{\mathrm{sub}} = p * \left(\sum y - \sum y^{red}\right) * \frac{y_o}{\sum_{\mathrm{g}} y} \qquad \forall(\mathrm{o} \in \mathrm{g}) \qquad (20)$$

$$y_o^{\mathrm{sub}} = 0 \qquad \forall(\mathrm{o} \notin \mathrm{g}) \qquad (21)$$

where y is the original final demand and o an index specifying a region-product combination of the Cartesian product of the 48 regions and 200 products.

Rebound occurs when there are no specified products for which demand is increased. Though broadly defined as behaviroral or systematic response to climate migitation action, this research only includes the direct rebound effect in terms of expenditure saving. Dynamics of behavioral response or macro-economic price propogation is disregarded. Only lifestyles dealing with household demand is affected by rebound effect. It is assumed that industrial sectors, as opposed to consumers, generally either try to make a profit out of the savings, or are compelled to pass on savings to consumers. Therefore, for lifestyles exclusively addressing industry changes, the rebound effect is disregarded.

In rebound cases, spending from selected products was redistributed to increased consumption of all products from all countries where there was no product reduction. The saved money due to reduction of consumption of certain products went towards increased consumption of all other products from countries outside the EU. If there was a price difference, for lifestyles dealing with substitution, the saved money due to the new products being cheaper was also redistributed according to this logic. Thus for lifestyles that deal with substitution, there is no difference in results between including and excluding rebound unless there was a price deflation specified.

The added final demand due to the rebound effect, y_o^{reb}, is estimated as

$$y_o^{\mathrm{reb}} = \left(\sum y - \sum (\mathrm{y}^{\mathrm{red}} + \mathrm{y}^{\mathrm{sub}})\right) * \frac{y_o}{\sum_g \mathrm{y}}$$

$$\forall (\mathrm{o} \notin \mathrm{i} \cup \mathrm{g}) \qquad (22)$$

$$y_o^{\mathrm{reb}} = 0 \qquad \forall (\mathrm{o} \in \mathrm{i} \cup \mathrm{g}) \qquad (23)$$

A specific rebound (e.g. if newly available money are supposed to be spent on specific products) can be modelled with the substitution mechanism described in Equation 5.

The new total final demand vector $\mathrm{y}^{\mathrm{tot}}$, combining substitution and rebound effect, is given by

$$\mathrm{y}^{\mathrm{tot}} = \mathrm{y}^{\mathrm{red}} + \mathrm{y}^{\mathrm{sub}} + \mathrm{y}^{\mathrm{reb}} \qquad (24)$$

3.5 LIMITATIONS

The EXIOBASE framework requires homogenization between different countries, as separate country-specific IO tables may aggregate differently into the variety of products and sectors. Also, it is assumed that the industry sectors have a fixed set of inputs (technology) to produce both primary and secondary products. This is called the industry technology assumption of IO. Since the technology assumed for by-products is not accurately assumed, emissions associated with each product may also be somewhat inaccurate. A static MRIO model is also applied, which does not take into consideration secondary rebound effects (IO-effects). These effects include the change of inter-industry requirements of different products that could arise from a change in household demand. The rebound effect is also assumed to be negligible for industry when in reality it may be that production techniques change as demand (and thus price of different production factors) is altered. The rebound included is a non-specific, overall increase of all products not effected by the intervention, which does not take into consideration how much money one realistically would re-spend on certain products. Also for almost all non-shelter and non-food lifestyles, rebound is partially distributed toward shelter and food consumption categories. The resulting increases in total energy use and calorific intake circumvent the adjustments otherwise made to maintain energy use and calorific intake constant. Finally, results are presented for the worst-case scenario of 100% rebound effect. Another method would be to try to estimate specific degrees of rebound for each lifestyle intervention.

The functional unit is another limitation of this research. This research assumes a balance in monetary spending, not in the actual service that the products provide. This means that the lifestyles may involve large changes in terms of for example in time spent travelling, weight of clothes purchased, energy use for shelter expenses, calorie intake, etc. In an attempt to partially address this issue, this paper adjusts the spending on shelter and food in terms of energy use and calorific intake, respectively. This is however made in a simplified way, leading to some uncertainties. The largest uncertainties are related to the assumed calorie/energy content of each product, as well as to assuming that each individual maintains the same calorific intake and energy with the change of lifestyle. For fuels used as part of the shelter consumption category, assumption has been made for numbers of heating value and efficiency of heating value, to obtain the usable energy embodied in the fuels. Food products on the other hand include both processed and crude products such as raw cereals and live animals. Therefore a parameter was determined for each food item giving the actual edible fraction (that contains the calories). Also there is no adjustment or control for other parameters such as nutritional value or proteins, which could mean that some lifestyles also assume an improper diet change. Balancing for such factors would probably yield more correct footprint reduction results. Finally, it is assumed that the hotel and restaurant sector is the only sector affected by the change in diets. Though this sector has the largest intermediate demand of food products, food products are also required in sectors such as *health and social work* and retail/wholesale trade sectors.

The environmental impact estimations within food also have various sources of uncertainty;
1) some EXIOBASE food products had to be disaggregated into several products for which specific calorie content data was available (thereafter obtaining a mean calorie content of the products),
2) the edible fraction of each food item was assumed without reliable data as a support,
3) each food product contains several different products within them which makes the specification uncertain (for example, *food products n.e.c.* contains broth, soup, and vitamin-enriched food products that are both vegetarian and non-vegetarian),
4) there is a large household spending (35.9%) on the mixed product of *food products nec*, that has an especially uncertain calorie content information (ranging from 0.1 kcal/g for broth to 1.05 kcal/g for leavening agents and yeast) and as previously mentioned is difficult to allocate to different low-meat lifestyles,
5) the model does not run with a Computational General Equilibrium (CGE) and thus does not take into consideration macro-economic effects of the diet change. In reality, if the whole EU turned vegan the large increase in demand for vegan products would potentially decrease their prices (leading to more money available for rebounds to other products). Furthermore, a full vegan shift in EU would probably have effects on sectors that deal with for example leather; the decrease in demand of the co-product of meat would probably cause the EU leather industry to lose income, get replaced by foreign leather industry, or replace the leather by synthetic products (changing the inter-industry requirements, environmental intensity of each industry, etc.).

A more general source of error is the aggregation of several products into one and the same category, to make up in total 200 products. Decreasing the variation of products in this way may lead to slight errors when allocating products that correspond to each lifestyle change. For example, lifestyle *Vegetarian* increases consumption of *Food products nec*, a part of which is soups and broths. Some of the soups and broths could be meat-based which does not correspond with a vegetarian lifestyle. Allocation errors on a larger scale occur in the EXIOBASE global harmonization of product categories into the 200 products specified. Different regions may have a larger or smaller level of detail in number of products, in which case there is a chance that the attribution made within that region does not match the EU classification exactly. Information of environmental impact of production of that product in the region may therefore be incorrectly attributed to the EXIOBASE product categories.

Also, environmental impacts are assigned to households, leaving out public spending. For some products, such as *health and social work services*, there may be variations within EU whether households consume this directly or whether it is part of government spending (in which case it will be excluded from the footprint calculations). Results of environmental impact changes may therefore have higher certainty when applied to EU as a whole, rather than to any specific country within the region. Another issue with disregarding public spending is that households are not held accountable for environmental impacts embodied in infrastructure they use, such as houses and roads. These impacts are discarded as a part of public spending.

Product attribution errors also arise in specification of lifestyles. The model in use cannot distinguish between changes in specific products relating to households, and relating to industry. This means that some lifestyles have a slightly larger impact reduction potential than what would realistically be the case. For example, the lifestyle *Natural Fiber* in the clothing consumption category reduces demand of rubber and plastic products, when actually this product reduction should only occur in the textile sectors.

It should be noted that the rebound results are especially uncertain. This research applies a general rebound effect, assuming that expenditure is equally distributed toward all other products. This may not be the case in reality. Specifically the rebounds also go toward food and shelter products with resulting increased calorie intake and energy use. Such changes have not been controlled for. A 'worst-case' of full rebound have also been assumed (i.e. that all final demand is re-spent).

Furthermore, as Baiocchi, Minx, and Hubacek (2010) pointed out regarding the methodology applied in this research, the results obtained can mainly function as descriptive; they do not investigate how the suggested lifestyle changes practically can be implemented. There is no closer look at the connection between environmental impact and important socioeconomic factors such as income, education, living situation, and health.

4. Results and Discussion

In chapter 4.1 Background Calculations, results are presented for household demand shares and emission intensity of different consumption categories. Each consumption category is also linked to a certain share of the total EU household carbon, toxicity, water, and land footprint. Finally, results are presented for the environmental mitigation potential within each consumption category, when the rebound effect is taken into consideration.

The lifestyle-based modelling, described in chapter 4.2 Lifestyle Results, is based upon the main area for which the lifestyle is applied to.

4.1 BACKGROUND CALCULATIONS

Background calculations are based on consumption categories as described in Table 1. In terms of the share of the household demand in the different consumption categories, 59.20% of spendings is in services (Figure 2). The second highest expenditure is related to mobility, closely followed by food and shelter. Construction has the smallest household demand (1.11%).

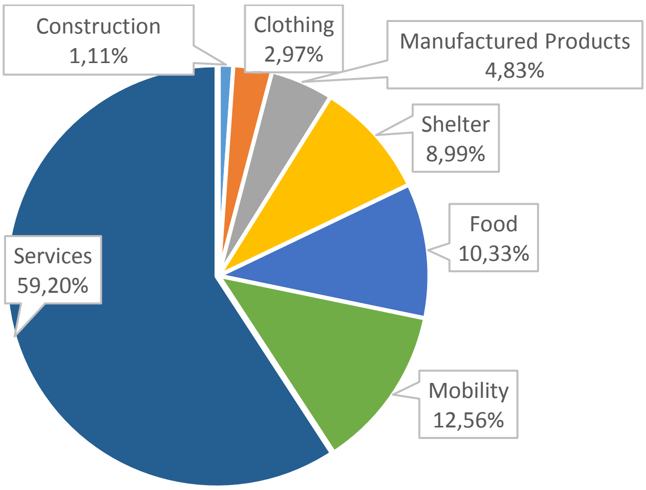

Figure 2. Share of EU household final demand in different consumption categories.

The share of total EU household footprint caused by each consumption category is shown in Figure 3. The absolute numbers indicate how much each footprint would change if all products within a certain category were not produced nor consumed. The largest environmental impact of households in the EU on land and water comes from spending on food. 46.10% of total land footprint and 59.09% of total water footprint is related to food expenses (Figure 3). This is close to the values estimated by Ivanova et al. (2016). The difference is explained by a different correspondence between products and consumption categories (what consumption category each product is assumed to belong to). Mobility spending is the cause of the majority of footprints for carbon (28.96%) and toxicity (40.88%) (Figure 3). Other major causes of impacts are the consumption categories of services and of shelter. Only minor impact reductions are obtained from reducing total EU household spendings (as of 2007) on clothing, construction, and manufactured products.

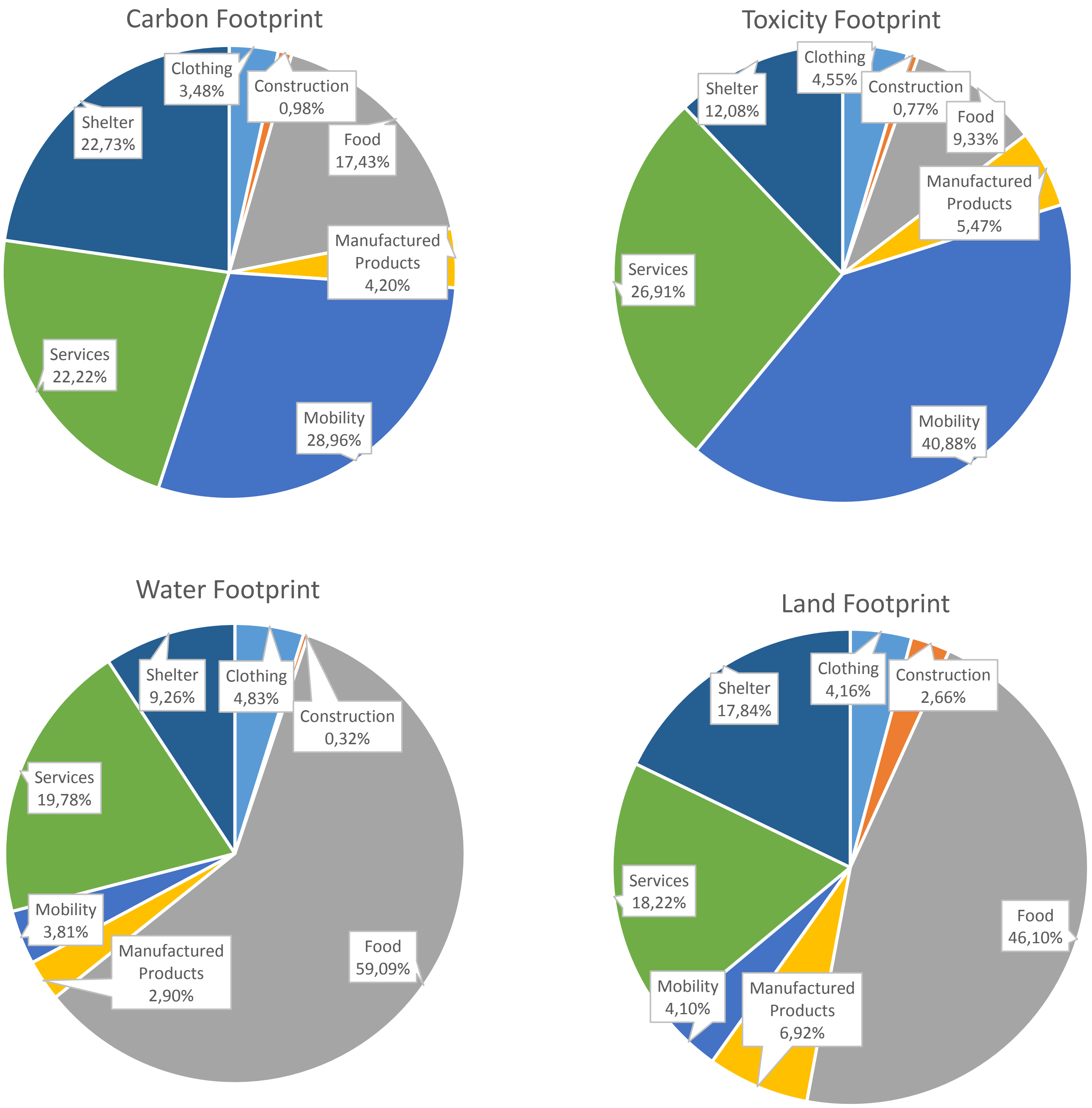

Figure 3. Breakdown of European household footprint in 2007 on different consumption categories. In percent the share of total footprint. Footprints include carbon, toxicity, water, and land.

The results for the rebound effect indicate a difference in impact intensity of each consumption category (Figure 4). The changes in environmental impact are the combination of impact intensity and the total household demand. For example, due to a high household final demand and low impact intensity, rebounding service spending to all other categories leads to large impact increases; 101.74% for land and 90.51% for carbon (Figure 4Figure 4). For land and water impacts, most of it occurs outside the EU (Figure 4, non-EU impact ratio indicated by white bars). This is especially true for the land footprint. The trend is most likely caused by imported products from foreign regions, where land and water is used to produce exported goods for final and intermediate (industry) demand. For the carbon footprint, a smaller but still significant part is due to non-EU emissions of GHG. This is probably due to direct emissions from combustion of fossil fuels, that inevitably occurs in the EU. The transportation of goods also causes domestic emissions. The latter also explains why the majority of toxicity footprint is caused by emissions in the EU; direct (or tailpipe) emissions per definition occur where the vehicles for mobility are used.

Figure 5 confirms that services generally have a low impact intensity. Meanwhile, food has the highest impact intensity in terms of land and water use. For carbon footprint the largest emission multipliers (impact per Euro) are found for mobility and shelter. Mobility is also related to the highest impact intensity in terms of toxicity (Figure 5).

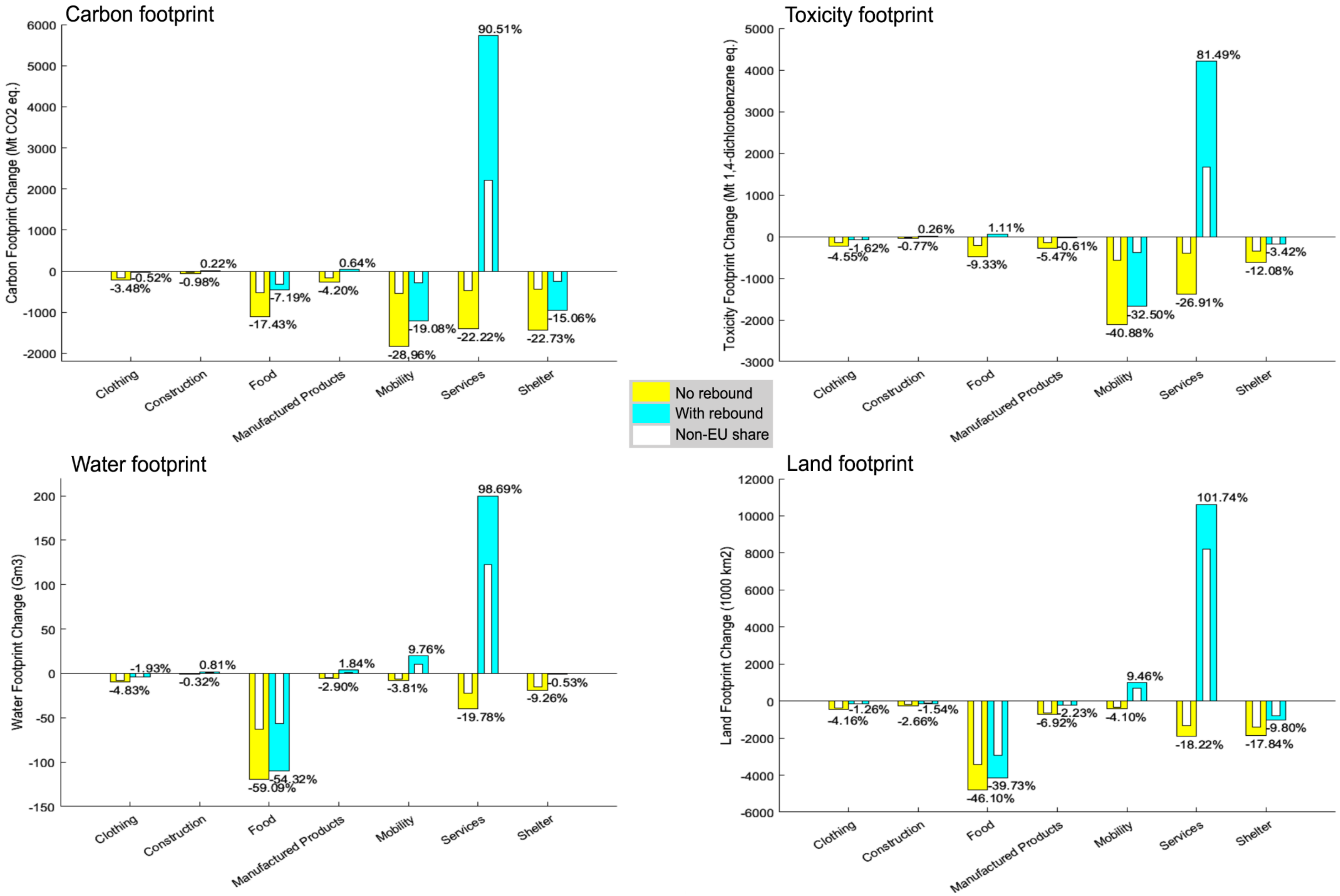

Figure 4. Change of total EU household footprint as a result of full reduction of demand of each consumption category. Footprints include carbon, toxicity, water, and land. Percent values indicate reduction as compared to total EU household footprint in 2007.

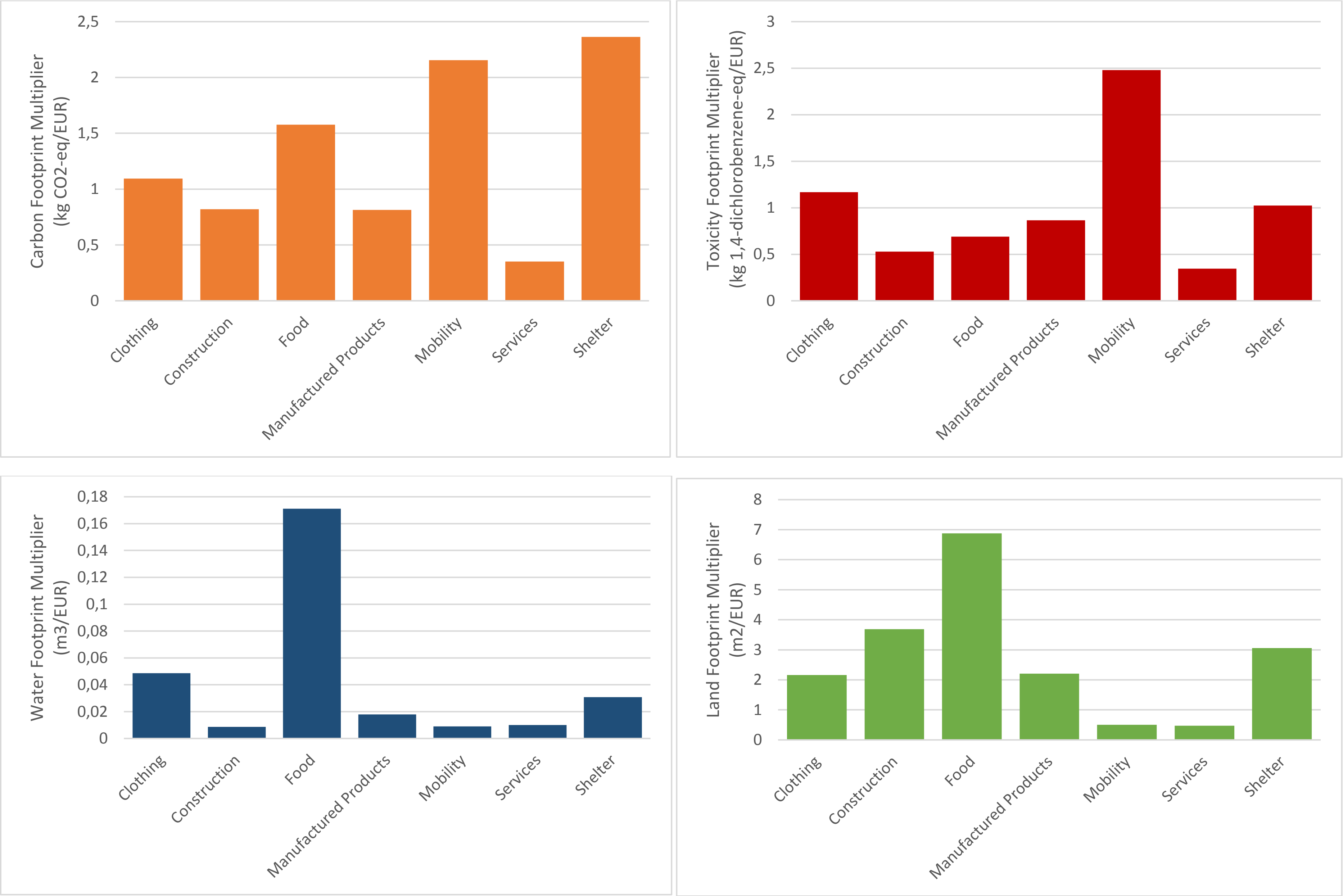

Figure 5. Footprint multiplier (impact per EUR) for each consumption category, measured as kg CO_2-eq/EUR (carbon), kg 1,4-dichlorobenzene-eq/EUR (toxicity), m^3/EUR (water), and m^2/EUR (land).

4.2 LIFESTYLE RESULTS

The EU household change of environmental impact caused by different lifestyles is presented and analyzed in the the following chapter. Relative (percent) values are based on comparison to the total EU household impacts in 2007. The results are separated into the main consumption category that the lifestyles are concerned with. However, a certain lifestyle may have repercussions in more than one consumption category. There can be substitutions occurring across consumption categories. For example, manufactured products may be reduced in favour of services, which is still classified as a lifestyle within Manufactured Products. For a complete summary of results, see chapter A2. Lifestyle Results.

4.2.1 Clothing

Figure 6 shows the change of total EU household footprint of different lifestyles within clothing. The *Low Use* lifestyle involves an 80% reduction of new purchase of clothing articles, as well as a respending of 20% of this demand toward buying material for making clothes for one's own use. This lifestyle has the largest footprint reduction potential of all lifestyles within the clothing sector; from 1.7 up to 2.5% of the total EU household footprint. The large change is due to the lower impact intensity of clothing material products (plant-based fibers, leather and leather products) as compared to finished clothing products (textiles, wearing apparel; furs). If the saved money due to low use is redistributed toward all other products (i.e. rebound) the reduction potential is smaller but still significant. Purchasing local clothing would also provide a significant impact reduction for all footprints, especially regarding toxicity (1.71% reduction) since mobility is a particularly toxic-intensive category (Figure 5).

Lifestyles *Vegan* and *Natural Fibers* show a different pattern; all footprints increase with these lifestyles. For example, by the *Vegan* lifestyle the land footprint is increased by 1.23%. The *Vegan* involve a change where both households and industry to 100% substitute the use of furs and leather with textiles and plant-based fibers. Since all demand is replaced with other demand, there is no rebound effect. The results are most likely explained by the lower environmental impact per unit expenditure for furs and leather products as compared to plant-based fibers, the former being more expensive. The lifestyle *Natural Fibers* has a smaller but significant increase of environmental footprint, the result of substituting rubber and plastic inputs to textile industries by leather, plant-based fibers, and wool.

A majority of the change in impacts occur outside the EU. This indicates that a majority of the clothing products are imported into the EU. The higher non-EU share for land and water use impacts indicate that the imported clothing products are also more intensive in water and land use as compared to the regional products. For example, when the money saved from low use is redistributed to other products with a higher domestic share, the result is a net increase of impacts within the EU (though not visible in Figure 6). Therefore all the impact reductions that occur are located outside the EU.

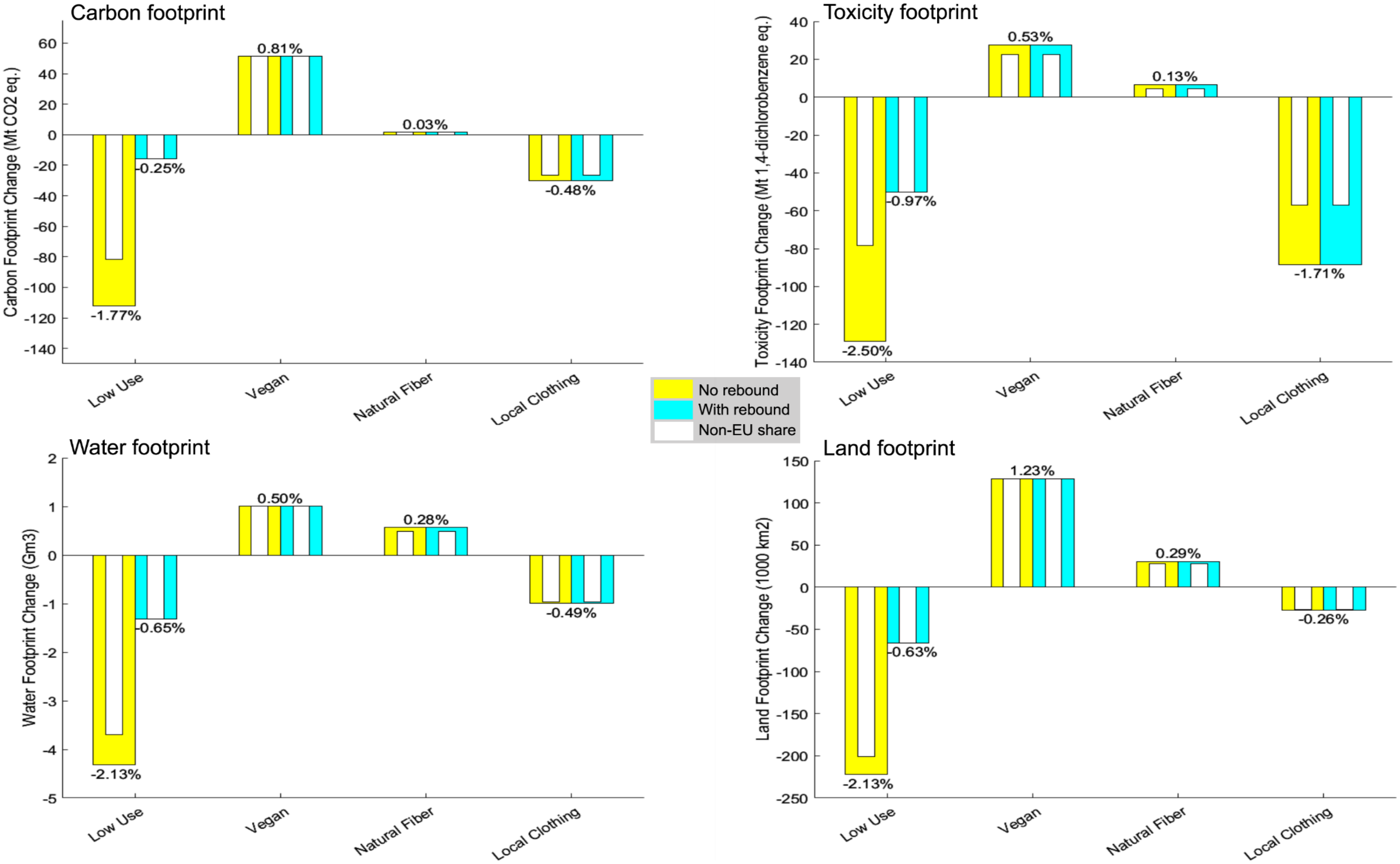

Figure 6. Change of total EU household footprint as a result of lifestyle changes within clothing. Percent values indicate share of the total household footprint. Yellow bar excluding rebound, teal bar including rebound, white bar showing the share of impacts that occur outside the EU. Including carbon footprint (Mt CO_2-eq), toxicity footprint (Mt 1,4-dichlorobenzene-eq), water footprint (billion m^3), and land footprint (1000 km^2).

4.2.2 Construction

Within construction the changes for each lifestyle are especially inconsistent for the different footprint categories (Figure 7). The *No Renovation* lifestyle assumes a reduction of all construction products by 90% which provides a reduction potential of 3.50 and 1.80% for land and carbon footprint, respectively. Taking into consideration the rebound effect, the water footprint would instead increase due to this lifestyle. This indicates that construction products have a relatively low water use intensity. This is confirmed by the results of lifestyle *Repair Renovate* where 5% of all non-construction spendings are shifted toward construction products. Such lifestyle change would decrease water footprint of EU households by 0.95%. However, it leads to an increase of 10.78 and 0.68% of the total EU household land and carbon footprint, respectively. These results disregard any potential benefit that may result from renovating to a higher degree, such for example a decrease in energy use. It also excludes the probability that renovating would lead to a prolonged lifetime of buildings, which would decrease the construction activites needed in society. However, the latter is not included in the household final demand but as a capital formation final demand. Thus, no credit is given for such potential positive side-effects. This explains why Pauliuk, Sjöstrand, and Müller (2013) argued that to reduce the environmental footprint of housing, the best option may be ambitious renovation to passive standards. According to the authors this would lead to reductions in GHG emissions from an early point, contrary to the results of this research paper.

In terms of materials used, key elements in a low carbon built environment include materials with low embodied carbon and increased reuse of carbon-intensive materials (Pomponi and Moncaster 2016). An example from India and China highlighted that many rural households in developing countries rebuild houses with concrete bricks and tiles instead of natural materials (Hubacek, Guan, and Barua 2007). If this would be applied to the EU (lifestyle *Concrete Renovation*), land footprint may be decreased by 2.94%. Meanwhile carbon footprint would increase by 0.77%. Concrete in other words use little land to produce, but cause emissions of GHG both directly (from the calcination process in concrete production) and indirectly (from the energy used in concrete production) (Pade and Guimaraes 2007). Lifestyle *Natural Materials* on the other has a carbon footprint reduction of 0.46% but an increase of land footprint by 1.44%. Using natural materials such as wood, stone, sand, and clay has higher land requirements (for example from forests) but lower GHG emissions since less processing is required for using these products. Neither toxicity nor water footprint would change significantly with implementing any of these two lifestyles on a EU level. Guardigli, Monari, and Bragadin (2011) performed an LCA study and found that wood structures, as compared to those based on concrete, had a lower impact on human health, resources, and ecosystem quality. They simultaneously warned for the negative side-effects of the extensive use of wood. The results obtained in this research paper point toward an increased land use from wood renovation than for concrete renovation. At the same time, there is no difference in impacts on human health (approximated by toxicity footprint) between renovation with wood versus concrete.

A majority of the changes in land and water footprint that the lifestyles cause is due to impact reductions (or increases) occuring outside the EU. For carbon and toxicity footprint the majority of the impact change is located domestically (emission sources located within the EU). For example, lifestyle *Repair Renovate* causes a decrease in emissions of GHG outside the EU but leads to a net increase of total carbon footprint due to increase of domestic emissions. All lifestyles except *No Renovation* are based on full substitution of final demand, therefore there is no rebound effect for these lifestyles.

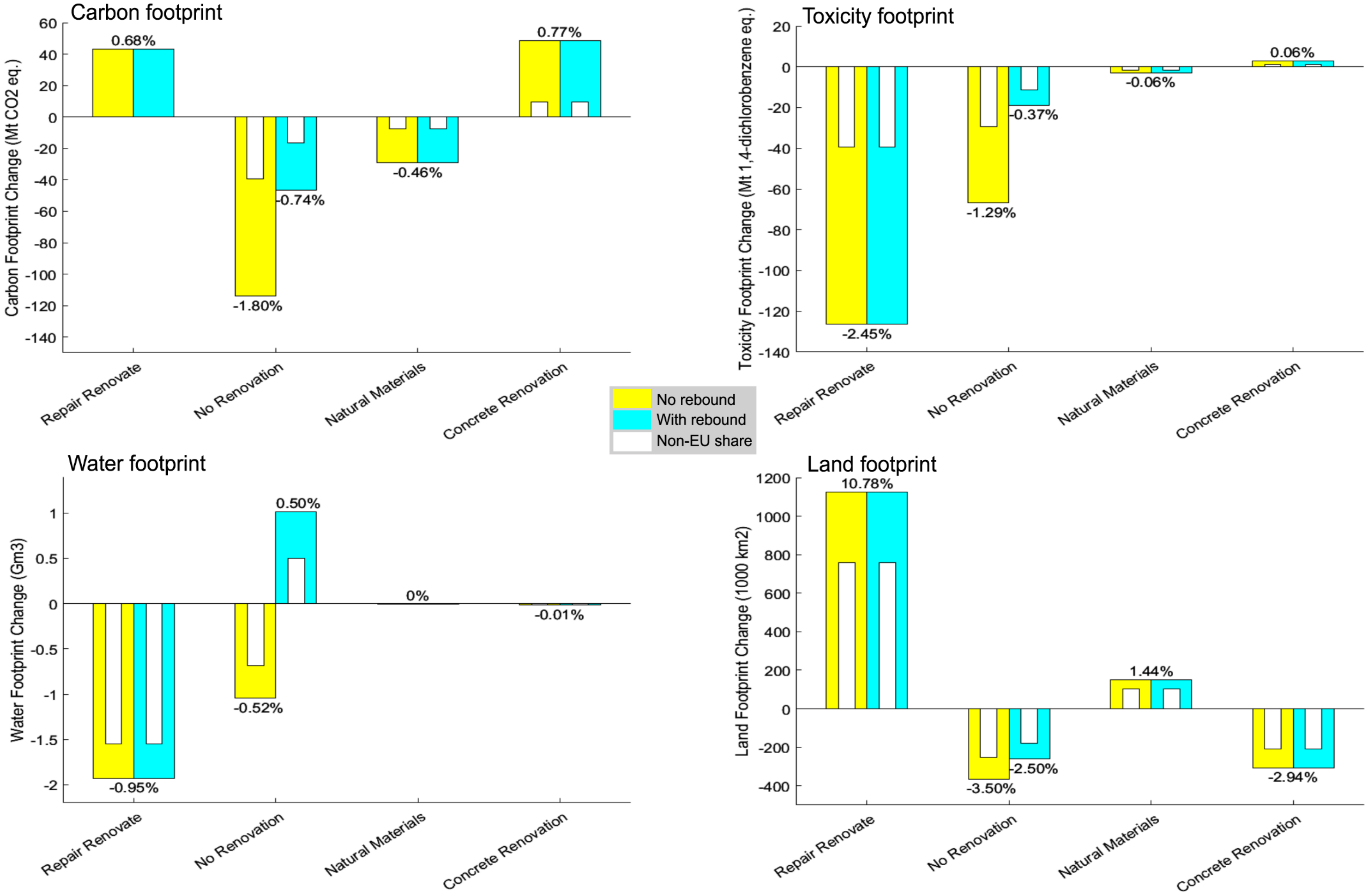

Figure 7. Change of total EU household footprint as a result of lifestyle changes within construction. Percent values indicate share of the total household footprint. Yellow bar excluding rebound, teal bar including rebound, white bar showing the share of impacts that occur outside the EU. Including carbon footprint (Mt CO_2-eq), toxicity footprint (Mt 1,4-dichlorobenzene-eq), water footprint (billion m^3), and land footprint (1000 km^2).

4.2.3 Food – Diet

The upscaling of a vegan diet has the largest potential to reduce total land and water footprint; by 4.7 and 14.8%, respectively (Figure 8). All the low-meat lifestyles provide very significant environmental footprint reductions for EU households. *Mediterranean Diet* (decreased intake of non-fish meat products) has a carbon footprint reduction potential of 2.73% but a slight increase in land and water footprint. Cutting out meat consumption completely (*Vegetarian* lifestyle) would reduce carbon and toxicity footprint by EU households by 6.44 and 3.00%, respectively. Also removing dairy products and eggs (*Vegan* lifestyle) yields an even higher reduction potential of carbon footprint (13.93%) and also a reduction of toxicity and water footprint by 9.04 and 14.80%, respectively. If all EU households followed a *Healthy Vegan* lifestyle (like vegan but also no sugar and no processed food products), the carbon and toxicity footprint would be further decreased (by 15.69 and 12.04%, respectively). However, it requires a trade-off where reduction potential of water would be lowered as compared to the vegan diet, and land use would have a net increase. This indicates that the products refused by the *Healthy Vegan* (processed rice, sugar, and beverages) have a lower land and water use intensities (impact per expenditure) as compared to other vegan products, but higher toxicity and carbon intensities. Finally it is important to note that both kinds of vegan diet lifestyles assume that consumers purchase raw plant-based products such as raw rice and wheat and do the processing required for consumption themselves. This disregards emissions in home-processing and also the possible technological and knowledge barriers towards doing this. The uncertainty introduced by this assumption is largest for the vegan lifestyles but may also be significant for the vegetarian and mediterrenean diet.

Furthermore it is found that by limiting the calorific intake of the EU population to 2586 kcal/day (a calorie decrease of 23%), total carbon footprint may be reduced by 4.2% (lifestyle *Eat Less*). This is more than twice as high as the approximate 1.87% reduction found by Vieux et al. (2012) (applying to the whole EU an estimated 10.7% reduction of diet-associated GHG emissions in France when decreasing calorific intake). As eating less yields a decrease in total agricultural land needed, the water and land footprint may be decreased by 16% and 14.4%, respectively.

When household final demand is balanced, that is, when the reduction of spending on food is reallocated to other products, lower environmental impact reduction potentials are found for all low-meat lifestyles. This is because fruits and vegetables generally have a lower price than meat products; since they are normally less processed (for example crude grains, oil seeds, and crops). Especially the *Vegan* lifestyle involves freeing a lot of money which could potentially be respent within other consumption categories, reducing the environmental benefits. Assuming full rebound for the vegan lifestyle, roughly 65% of the expected GHG reductions would be offset. It has been shown that rebound within food spendings could offset up to 50% of expected GHG reductions (Druckman et al. 2011), slightly lower than the approximations in this research paper. Duarte et al. (2015) on the other hand suggested that in Spain, shifting toward a vegetable-based (and more healthy) diet may yield a net increase of GHG emissions due to the rebound effect. The results obtained in this paper do not point in the same direction. With rebound, the *Vegan* still has the highest reduction potential and could decrease carbon and water footprint by 4.89 and 11.17%, respectively (Figure 8). The *Healthy Vegan* on the other hand would lead to lower land and water footprint reductions, and increases of toxicity and land footprint by 1.54 and 10.72%, respectively. The drastic land footprint increase for *Healthy Vegan* is explained by the low price but relatively high calorie content of all vegan products, especially for products *sugar* and *beverages*. To maintain a constant calorie intake with the lifestyle change, since the vegan products are much cheaper than other products, only a fraction of the original EU household spendings on food is required. That leaves the majority of the original expenditure on food (10.33% of total EU expenditure; see Figure 2) open for being redistributed as rebound. Therefore there is a large change in footprints from the no-rebound scenario. It also seems that compared to other products, the land use intensity of products *sugar* and *beverages* is relatively low. Generally, whether rebound is taken into consideration or not is of big importance when estimating the environmental benefits of a plant-based diet. If consumers could be stimulated toward *not* respending the income 'freed' by following a cheaper low-meat lifestyle, this would provide a great impact reduction potential for the EU household (remember, rebound from reduced food spendings could potentially offset up to 50% of the expected GHG reductions of food lifestyle changes (Druckman et al. 2011)).

The lifestyles *Unprocessed* and *Careless Consumer* depict alternative future pathways. *Unprocessed* includes changes where processed meat products are substituted for live animals. *Careless Consumer* represents a lifestyle of reducing raw products, plant-based as well as meat-based, and replacing with processed food products. The *Unprocessed* lifestyle leads to increased footprints in all categories (e.g. 7.65% for carbon footprint) since live animal products are more emission intensive per monetary unit than the ready-made meat products. On the other hand, the uncertainties are large. Firstly, estimated methane emissions from cattle may vary greatly. This is due to the limitations in quantification methods, the variety of methods available, and the many factors in cattle farming that may change the emissions (Johnson and Johnson 1995; Kebreab et al. 2008). Secondly, some of the live products have no or very low final demand (*cattle*, *pigs*, and *poultry*). Emission intensities are therefore assumed from industrial animal raising, meant for producing inputs to the food industry. These emissions may be different than the case of private animal farming. Thirdly, if all EU households shifted spending toward live animals there would realistically also be a reduced demand of co-products such as manure, milk, and leather, which is not taken into consideration. Compared to *Unprocessed*, the *Careless Consumer* leads to larger water use and toxicity footprint but to a decrease of land footprint. These two lifestyles include changes where the new diet is more expensive that the old diet, leading to a deficit of calories when final demand is substituted for new products. To balance calorific intake in these cases, the total amount of money spent on food has been increased. The increased spending on food would realistically have to be balanced by a decreased spending on other products, so that total expenditure does not exceed the money actually available to the households. Since such decreased spending on non-food products is not applied, the impact increases from lifestyles *Unprocessed* and *Careless Consumer* are slightly overrated.

Generally, a majority of the impacts on emissions of CO2-eq. as well as on land and water use occur outside the EU. This means that a large share of the food comes from imports. Most of the impacts on toxicity seem to take place within EU, perhaps due to the transportation of food products that inevitably also occur inside the region. This conlusion is supported by the fact that mobility has the highest toxicity multiplier of all the consumption categories (Figure 5).

The results obtained in this research are coherent with those of Schanes, Giljum, and Hertwich (2016); the largest reduction of GHG emissions is achieved by a completely meat-free diet (vegan or vegetarian), followed by a diet with meat of lower carbon intensity (*Mediterranean Diet*). The finding that avoiding meat and dairy products reduces emissions significantly is supported by Westhoek et al. (2014), Pairotti et al. (2015), and Notarnicola et al. (2016).

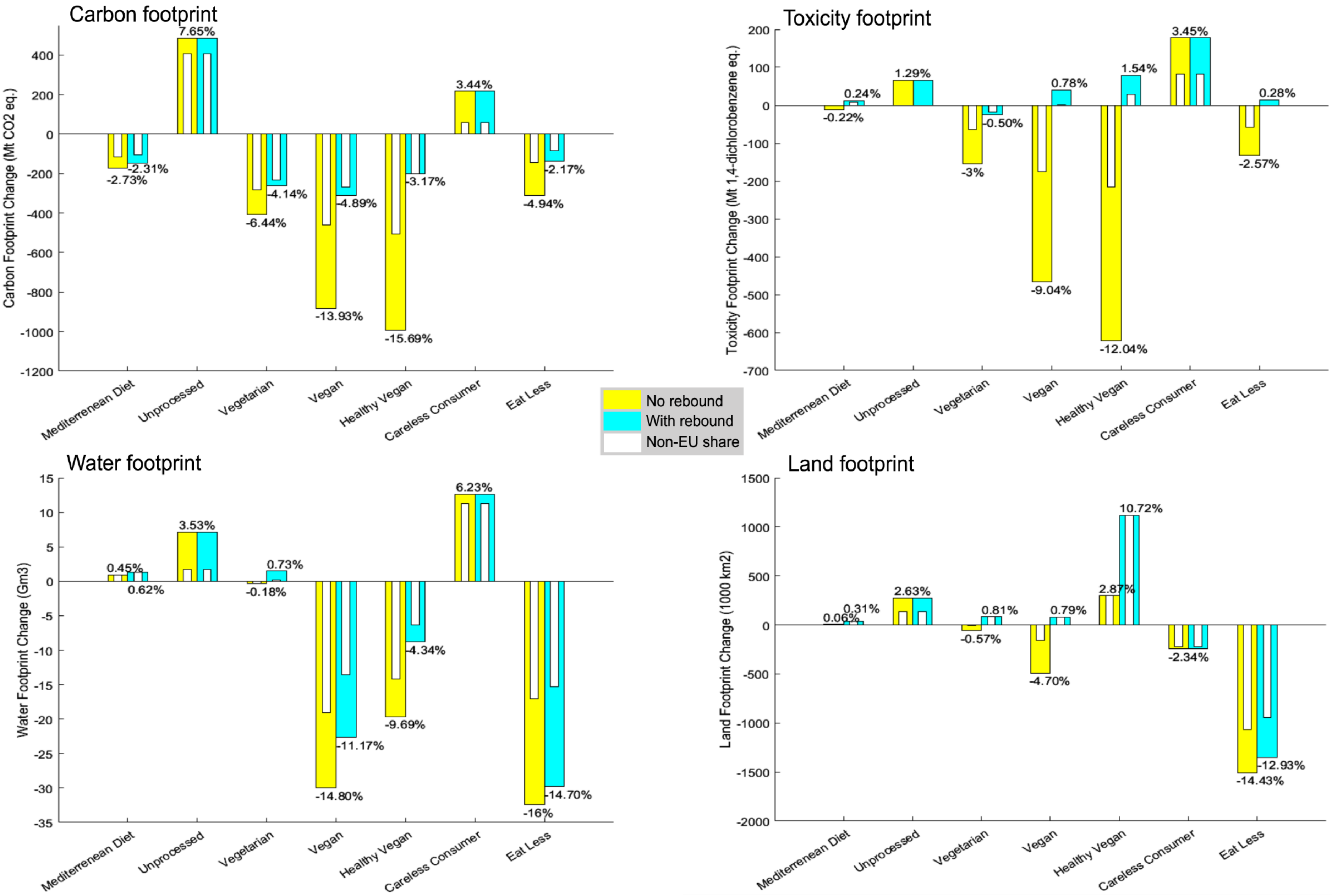

Figure 8. Change of total EU household footprint as a result of lifestyle changes within food-diet. Percent values indicate share of the total household footprint. Yellow bar excluding rebound, teal bar including rebound, white bar showing the share of impacts that occur outside the EU. Including carbon footprint (Mt CO_2-eq), toxicity footprint (Mt 1,4-dichlorobenzene-eq), water footprint (billion m^3), and land footprint (1000 km^2).

4.2.4 Food – Supply Chain

The results presented for food lifestyles in this section have not been adjusted for calories, since they address changes on the supply chain level. Regarding how the supply and production of food is being made, lifestyle *Organic Food* would provide the largest reduction potential of carbon (1.75%), land (0.82%), and water (1.27%) (Figure 9). *Local Food* would on the other hand be more effective in terms of toxicity footprint, reducing the EU household impact by 3.63%. The model of lifestyle *Seasonal Food*, where inputs of fuels and electricity to vegetable sector is reduced by 30% due to less use of vegetable greenhouses, does not cause a major change in environmental impact for any of the footprint categories. This may be because vegetable greenhouses do not have large inputs of fuels and electricity, or that the fuel and electricity used is embodied in products that were not detected in this research paper (for example in products demanded by vegetable sectors in order to generate the final products).Research indicates that whether locally manufactured food or imported seasonal food should be preferred depends mainly on the emission intensity of the food production system; the transportation plays a minor role (Macdiarmid 2014; Avetisyan, Hertel, and Sampson 2014). The same trend is found in this paper; implementing the low impact production system of organic food has a larger reduction potential than decreasing the food transportation necessary by consuming local food. However, the current research adds to the picture the missing piece of toxicity impacts; local food is preferable to avoid emissions of toxic compounds. For this footprint category, similar reduction are found for buying local food as following a vegetarian diet. For the rest of the footprints there is a larger benefit in a low-meat diet shift as compared to local food, as also found by Weber and Matthews (2008a).

Eliminating all food waste (*No Waste*) would cause demand of food to be reduced by 12%. This leads to a reduction of total EU household expenditure by 1.24% (Appendix, Table 7), and a 5.53 and 7.09% reduction of land and water footprint, respectively (Figure 9). Half or more of the decreased land and water use in located outside the EU. For toxicity footprint the impact reduction is turned to an increase when the rebound effect is taken into consideration. This is a result of food products being associated with lower toxicity intensities as compared to other products. Hoolohan et al. (2013) found that food-related carbon footprint could be reduced by 12% by eliminating food waste, which corresponds to 2.09% of total EU household carbon footprint, assuming that 17.43% of total household carbon footprint is caused by food spendings. The results in this paper are very similar; namely that food waste reduction would decrease total EU household carbon footprint by 2.09%. Schanes, Giljum, and Hertwich (2016) also found that a food waste intervention delivers considerable emission savings, larger than for example if not eating food grown in greenhouses (seasonal food). In other words, promoting food waste reduction may be more important than convincing consumers to purchase only seasonal food.

The lifestyle of only eating in restaurants (*Restaurant Food*) has the highest overall footprint reduction potential, which is probably a result of the aggregation level in the model. Only part of the product *hotel and restaurant services* is actually related to food, and therefore the emission intensity of this product may be lower than for food products overall. Notwithstanding, as services are generally the least carbon intensive per expenditure of all consumption categories (see Figure 5) it is still clear that a respending of demand toward this category (from food products) would be beneficial for reducing the EU environmental footprint of households.

.

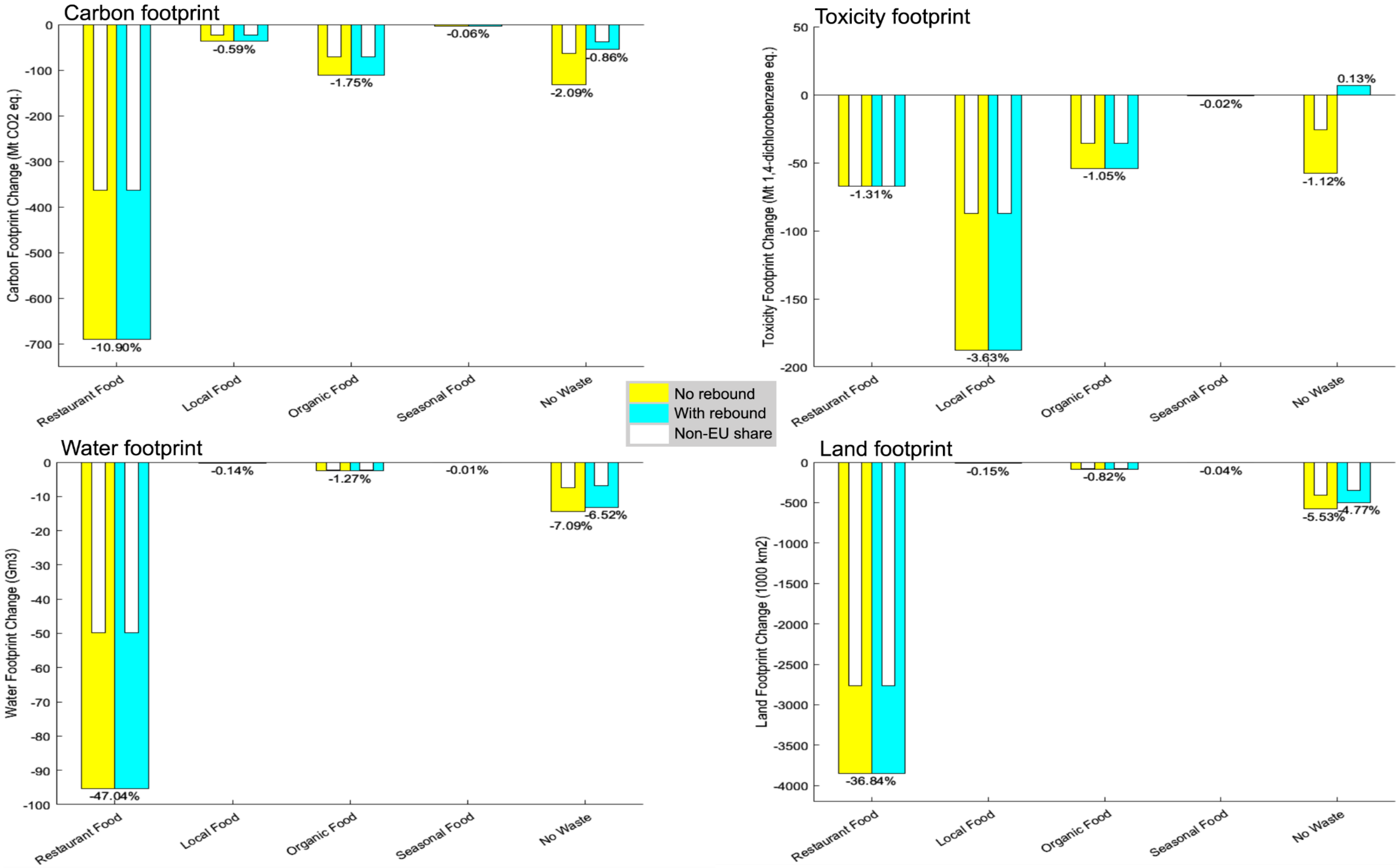

Figure 9. Change of total EU household footprint as a result of lifestyle changes within food-supply chain. Percent values indicate share of the total household footprint. Yellow bar excluding rebound, teal bar including rebound, white bar showing the share of impacts that occur outside the EU. Including carbon footprint (Mt CO_2-eq), toxicity footprint (Mt 1,4-dichlorobenzene-eq), water footprint (billion m^3), and land footprint (1000 km^2).

4.2.5 Manufactured Products

All the modelled lifestyles within the consumption category of manufactured products show a big reduction potential when rebound is not taken into consideration (Figure 10). This is because they involve reduction of consumption of specific products, and not a full substitution of final demand.

Lifestyle *No Chemicals* depicts a person who reduces by 80% the expenditure on household chemicals, artificial fertilizers, and petroleum-based products. This would decrease the EU carbon footprint by 3.91% (Figure 10). Even if the money saved from the reduction in consumption is re-spent (rebound scenario) there is still a significant reduction potential. A larger reduction potential for both carbon and toxicity is achieved by the lifestyle *Share Repair*. This assumes methods of sharing use, second-hand, repairs, etc. to reduce consumption of manufactured products and retail/trade by 50%. 10% of reductions are re-spent in renting services. Such an intervention has a reduction potential of 4.28% (carbon) and 6.16% (toxicity). Water and land footprints would be reduced by 2-3% (Figure 10).

Lifestyles *No Media* and *Low Tech* have similar footprint reduction potentials. *No Media* assumes a person who reduces spendings on media and telecommunication devices by 80%, replacing with eg. automobile expenses. *Low Tech* reduces spending only on electricial products by 80%, achieving a footprint reduction of 1.53, 2.01, 0.61, and 0.59% for carbon, toxicity, water, and land, respectively. *No Media* causes slightly larger reductions in land (1.01%) and water (0.71%) footprint than *Low Tech*, but a lower reduction of carbon and toxicity footprint (Figure 10).

The rebound effect may offset any potential benefit of the *Low Tech*, *No Media*, or *Share Repair* lifestyles. Especially in terms of land and water footprint, the rebound effect causes significant increase of footprint for these lifestyles. This suggests that manufactured products are less intensive in impact as compared to other products, especially for land and water use impacts. This is probably because of rebounds toward food products.

A majority of footprint changes are caused by impacts occurring outside of the EU. For example, reducing the use of chemicals (lifestyle *No Chemicals*) only causes a very small reduction of land and water use within the EU. If the reduced expenditure is respent on other products the effect would be an increase of land and water use in EU but a net effect of decreasing footprint due to non-EU reductions (Figure 10). *Share Repair* on the other hand significantly reduces the impact occurring in the EU, especially in terms of carbon and toxicity. This is probably caused by a high share of domestic emissions for services related to retail and trade.

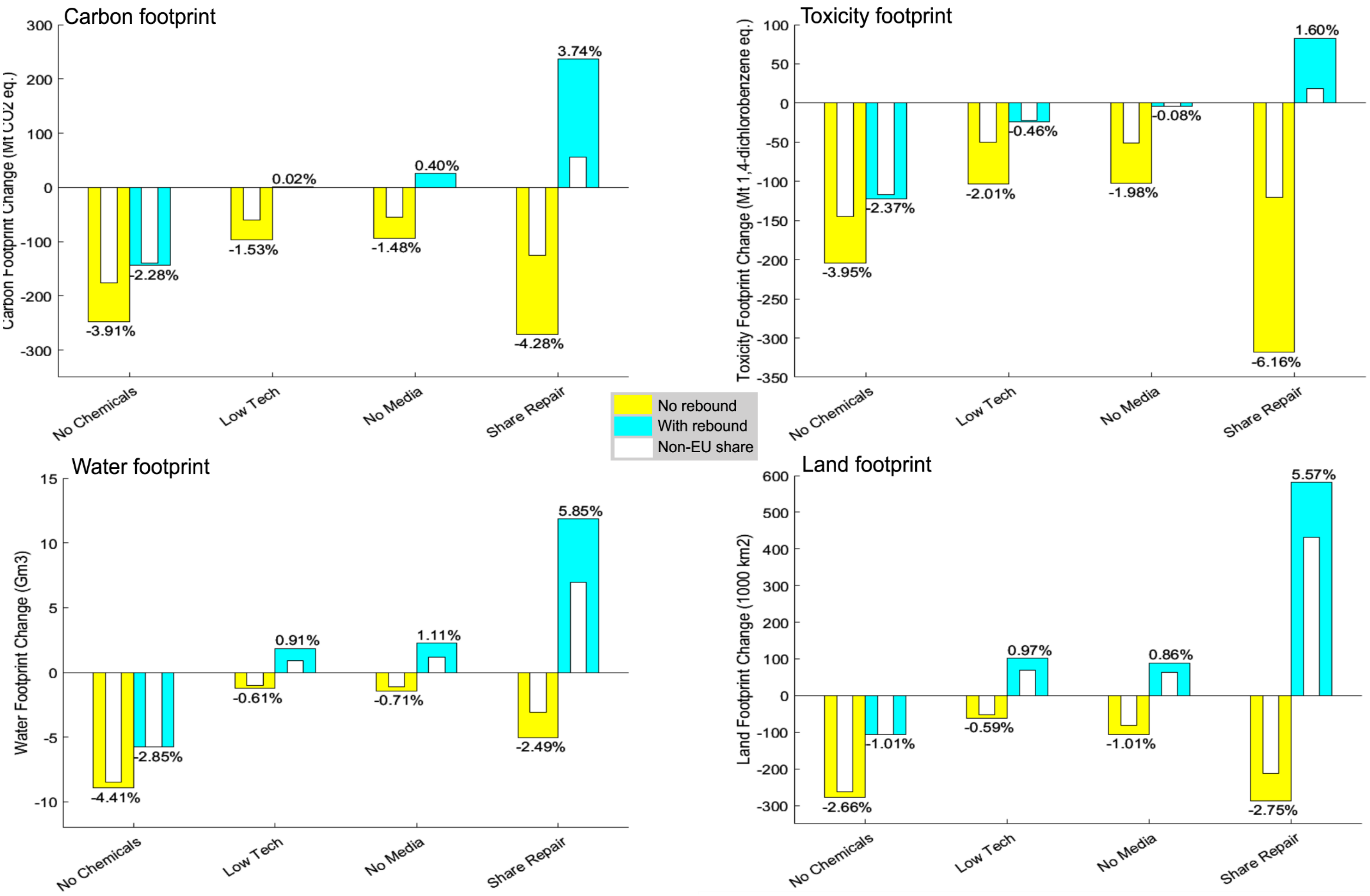

Figure 10. Change of total EU household footprint as a result of lifestyle changes within manufactured products. Percent values indicate share of the total household footprint. Yellow bar excluding rebound, teal bar including rebound, white bar showing the share of impacts that occur outside the EU. Including carbon footprint (Mt CO_2-eq), toxicity footprint (Mt 1,4-dichlorobenzene-eq), water footprint (billion m^3), and land footprint (1000 km^2).

4.2.6 Mobility

The largest carbon footprint of EU households is caused by spendings on mobility (personal transportation by car, bus, train, airplane, boat, etc.). Mobility is responsible for 28.96% of the total carbon impacts (see Figure 4), which is close to the 27.0% of total footprint calculated by Ivanova et al. in 2016. With large impact changes for carbon, Figure 11 shows how products related to mobility especially have a high footprint in terms of carbon. Through the drastic measure of eliminating the need for land transport by biking and walking (*Bike Walk)*, it is possible to achieve a 25.7% reduction of total impacts. This would also reduce the EU household toxicity footprint by 14.24%. For a more feasible yet still optimistic lifestyle, applying flex-work measures such as working close to home and teleworking to reduce by 50% the spending on all mobility by land (*Flex Work Half*) shows the same pattern for all footprints but with smaller reductions. Flex-working could however lead to an increased use of fuel and electricity due to more time spent at home. This is explored in lifestyle *Flex Work Half ER* (ER standing for Energy Rebound). Footprint reduction is hereby decreased to the levels of 8.86% for carbon, 6.10% for toxicity, and to -1.01% for land. In other words, in terms of land footprint the increase of energy use would offset the benefit of flex-working and lead to an overall impact increase. Decreasing not just land transportation but all kinds of mobility by 50%, lifestyle *Less Mobility Half* provides the highest toxicity footprint reduction for EU households (20.44%) and second highest carbon footprint reduction potential (14.48%).

In terms of modal shift to public transport, Duarte et al. (2016) applied a case study of private and public transport systems in Madrid. It was found that a higher modal share of public transport would cause transport emissions to be decreased by 220% as compared to the baseline. In this paper, such modal shift is summarized in lifestyle *Collective Transport*. A total EU household carbon footprint reduction of 8.07% is obtained (Figure 11), which corresponds to 28% of the total carbon impacts from mobility. Though the results obtained in this paper thereby point in the same direction as those from Duarte et al. (2015), they are not directly comparable since this research includes all kinds of mobility emissions (not just emissions from private and public transportation as studied by Duarte and colleagues). Duarte et al. (2015) also found a reduction in emissions of sulfur dioxide, which would contribute to a lower impact on toxicity. To the contrary, the results herein suggest that the toxicity footprint would increase by 41.69% due to the increased use of public transportation. This could be because the present collective mobility systems of EU countries (wherein expenditure is increased for the *Collective Transport* lifestyle) are likely using a high share of diesel fuels (ICCT 2016). Diesel vehicles contribute significantly to emissions of toxic compounds (Nelson, Tibbett, and Day 2008).

In the scenario of a shift toward renewable fuels in private and public transportation (*Renewable Fuels*) there would be a significant decrease of carbon footprint (12.08%), and a slight decrease of toxicity footprint (1.39%). This however comes at the cost of land and water footprint that increase by 5.85 and 5.28%, respectively. The potential of *No Flying* is also explored, that is 100% reduction of air transport, with and without transportation rebound (TR) where spendings increase in other means of transportation. The option of not flying is only beneficial if the money saved is not respent, and even without such rebounds it only leads to a minor reduction of carbon footprint of EU households (2.30%). Toxicity footprint would be increased by 3.15% if all spendings on air transport are shifted toward land- and water based modes of transport.

Flying Biker lifestyle adds to *Flex Work Half* a substitution of local land mobility spendings with air mobility. It shows that if each EU household would reduce local land mobility by 50% and instead spend that money on flying, the EU household carbon footprint would not increase significantly, however toxicity, land, and water footprint would increase slightly (eg. 1.33% for toxicity footprint). The opposite pattern is found for the lifestyle *Frequent Flyer*, where 2% of all product spendings are reallocated toward air transport. This would actually reduce the land and water footprint, most likely since the product a*ir transport services* is not very intensive from this aspect. The carbon footprint would on the other hand increase by 2.45%. The scenario of a decrease in land mobility and substitution with use of electricity (demanded for lifestyle *Green Cars* where electric vehicles are assumed) finally provides a significant carbon and toxicity footprint reduction (9.20 and 4.71%, respectively).

The rebound results indicate that although mobility products may have high carbon-intensity, the same is not true for land and water intensity. In general, large trade-offs are found in the mobility consumption category, where positive effects on a certain footprint lead to negative effects for another footprint. All lifestyles that include a reduction of mobility usage show large increases in land and water footprint, ranging from 4.22% (*Flex Work Half*) to 8.44% (*Bike Walk Full*) for land footprint when considering the rebound effect. This means that mobility products are lower in land and water intensity as compared to other products, underlining the importance of considering rebounds for any interventions that deal with reduction of mobility use. The results are calculated from the assumption of 100% rebound effect. Meanwhile, the rebound effect may only be around 30% for mobility interventions (Chitnis et al. 2014; Sorrell, Dimitropoulos, and Sommerville 2009) in which case there would be no major negative impacts on land and energy footprint but a significant reduction of carbon footprint for the lifestyles of reduced mobility. This is explained by the fact that most kinds of mobility involve combustion and thus direct household emissions of GHG. Reduced use of mobility also decreases the direct household emissions. This conclusion is supported by the fact that most of the mobility reductions of GHG emissions occur inside the EU.

Furthermore, the increase of land and water use for the rebound scenario is mostly located outside the EU. Especially externalized are the land and water use increases caused by renewable fuels, that almost exclusively occur in foreign regions. This indicates that biofuels to a large extent are imported into the EU, and underlines the importance of considering such displacement of environmental impact for any intervention directed towards the use of renewable fuels.

Lifestyles that include a substitution of one means of transportation for another (such as *Collective Transport*, *Renewable Fuels*, *No Flying TR*, *Flying Biker*, and *Green Cars*) demonstrate the flaw of modelling transportation lifestyles in terms of monetary units. Public transportation for example is generally less expensive than automobile ownership and may lead to an increase of total kilometers travelled (Ornetzeder et al. 2008) Hence, a full shift of final demand according to the lifestyle of *Collective Transport* would then also include an increase of distance travelled. On the other hand, shifting toward more expensive modes of transport, such as probably is the case for the flying biker, the result will be a net decrease in travelling distance. This may lead to changes in time spent in transportation. Meanwhile, at least on an aggregated level it may be that individual's travel time expenditures should be fairly constant (Mokhtarian and Chen 2004). Another issue is that in the model applied in this paper, households are not held accountable for the infrastructure required to make certain kind of mobility possible. Emissions embodied in highways, railways, tunnels, etc. are instead allocated to public spendings. This may give a comparative advantage to modes of transport that have high infrastructure requirements but lower operating emissions, such as trains. Federici, Ulgiati, and Basosi (2009) found that the thermodynamic and environmental costs of railway and road infrastructure is important to consider in analyzing their environmental performance, seen from a life cycle perspective. In certain cases, road and railway transportation systems may be less sustainable than those based on air, due to the lower infrastructure requirement for the latter. The results already point in the same direction. A transport rebound from decreasing flying would even yield slight increases of environmental footprint in all categories except that of carbon.

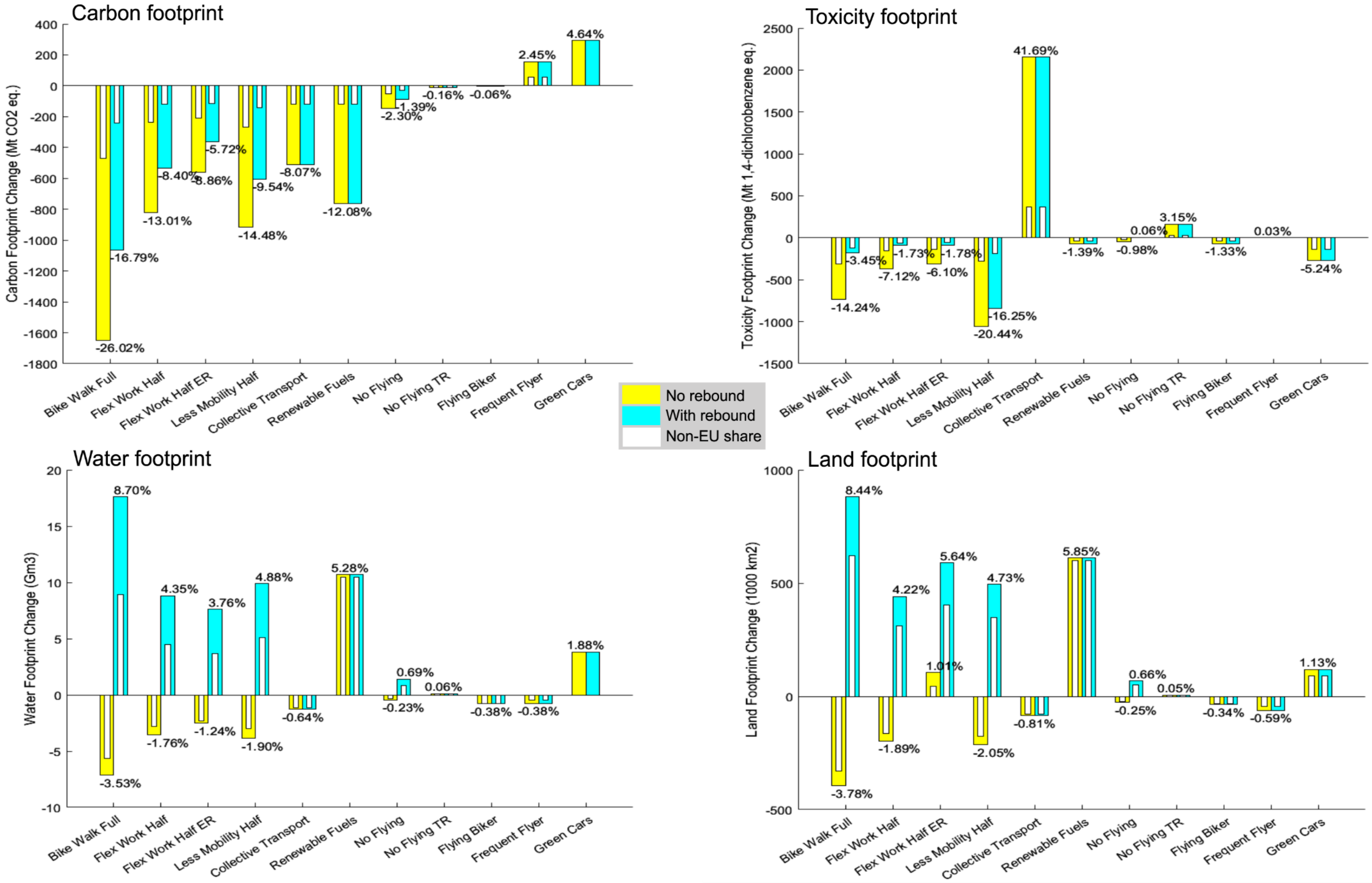

Figure 11. Change of total EU household footprint as a result of lifestyle changes within mobility. Percent values indicate share of the total household footprint. Yellow bar excluding rebound, teal bar including rebound, white bar showing the share of impacts that occur outside the EU. Including carbon footprint (Mt CO_2-eq), toxicity footprint (Mt 1,4-dichlorobenzene-eq), water footprint (billion m^3), and land footprint (1000 km^2).

4.2.7 Services

As much as 59.20% of all household expenditure is spent in services (Figure 2). Since the consumption category is also low in emission intensity (Figure 5), any lifestyle including a connection to other consumption categories is especially important to consider; i.e. *Local*, *Home-Based*, and *High Services*. The lifestyle *Local* mixes elements from mobility and services by reducing both household spending on local transport and input of local transport into all services. This provides significant reduction potentials especially for carbon (5.33%) and toxicity (2.87%) footprint (Figure 12). Since reduced spendings on local transport may rebound partially to food products that have a high water and land use, the net effect with rebound is an increase of land and water footprint. The results from mobility lifestyles have already shown this to be a risk of reducing mobility spendings (Figure 11).

Lifestyle *Home Based* is also a mixture of services and mobility, where spendings on long-distance transport as well as leisure services are reduced and substituted by recreational and membership organization services. This has a reduction potential for toxicity footprint of 23.79%. The high reduction potential is probably an effect of a high final demand being shifted away from highly toxicity-intensive products related to water and train transport (part of *Collective Transport* explored in chapter 4.7 Mobility). *Home Based* also has a high water footprint reduction potential (6.64%). This may be because of relatively high water footprint in either long-distance transport or leisure services.

High Services assumes a 5% reallocation of overall product spendings, except that on food, toward services. Interestingly enough such a change does not provide a large mitigation potential. Since services generally are relatively low impact-intensive (Figure 5), the low reductions achieved can only be explained by the low household final demand that is being shifted. Since a majority of expenditure is related to services, and food spendings are excluded, only a small amount of final demand is shifted toward services in lifestyle *High Services*. The reduction of water and land use is especially moderate due to the exclusion of food products that have the highest emission intensity in terms of land and water use (Figure 5).

An opposite scenario is explored by lifestyle *Low Services*, instead reducing spending on all services by 80%. For the carbon, water, and land footprint, this provides the largest reduction potentials (17.77, 15.83, and 14.58%, respectively). This is a result of the large final demand reduction it involves. On the other hand, the simultaneous low emission intensity of service products mean that if all the final demand is rebound toward non-service products, the environmental footprint for EU households will drastically increase. All footprints would increase from around 65-82% if full rebound is assumed. Since lifestyle *Low Services* provides a large mitigation potential when rebound is excluded, and a significant impact increase if rebound is included, this particular lifestyle is highly interesting to consider further.

Lifestyles that include a shift of final demand within services include *Play-It-Safe* and *Hedonist. A* large reduction potential for toxicity (7.64%) and land (5.16%) footprint would be achieved by following the *Play It Safe* lifestyle, shifting all service expenditure toward health, defence, and insurance services. This lifestyle also has significant reductions of water and carbon footprint. The *Hedonist* assumes a lifestyle of cultural events and enjoying life by reducing services related to business, education, and health by 80%, substituted by recreational activities and retail services. This would cause all footprints to increase slightly. The lifestyle does not include increases in mobility expenses which possibly is a result of such a lifestyle. Including that would make the increases of footprints more significant.

To sum up the findings, mitigation of environmental footprint through service-related measures has a large potential if focused on a shift of overall spending toward services, especially toward low-emission intensive services such as health, defence, and insurance services. Such lifestyles also do not cause any offset of reductions by the rebound effect. On the other hand, decreasing overall service expenditure may potentially cause footprint increases much larger than the mitigation potential if assuming no rebound effect. To be on the safe side, such a lifestyle change should be avoided.

The results for the non-EU share indicate that services are mostly related to domestic emissions, especially in terms of toxicity and carbon. However, though the services themselves may be purchased locally, there is also a significant non-EU land and water use embodied in them. This is probably caused by the variety of imported products needed to supply the services in the EU, such as food products, minerals, etc. The non-EU share is largest for land use footprint. This implies that is may be especially difficult to motivate service lifestyle changes in EU from the perspective of it decreasing land use, since most of the land use reduction does actually not occur in the region. The share of impact reduction occurring in EU is generally high for the *Play It Safe* lifestyle. This means that health, defence, and insurance services mainly use domestically produced goods (causing emissions to occur inside the EU).

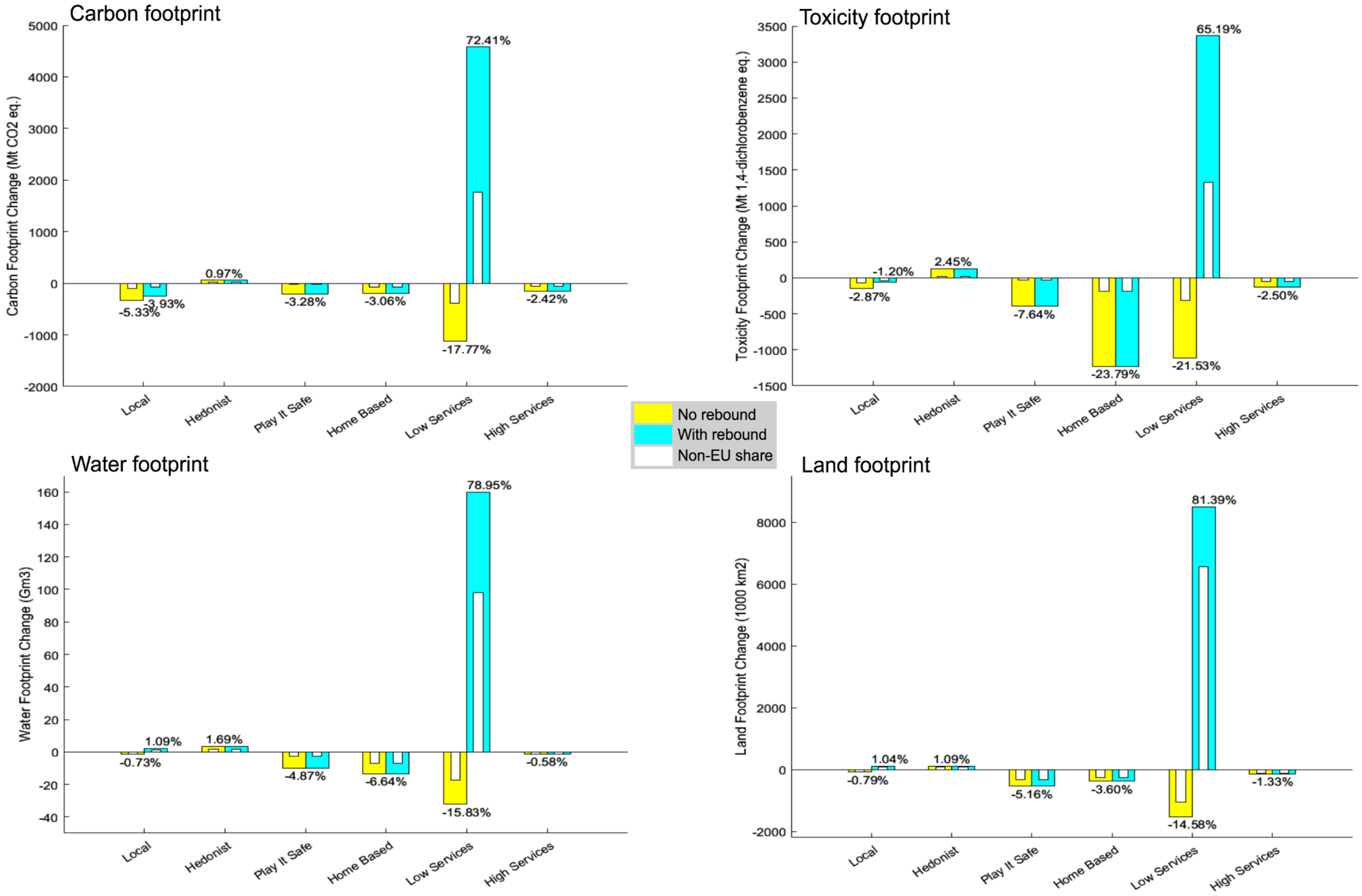

Figure 12. Change of total EU household footprint as a result of lifestyle changes within services. Percent values indicate share of the total household footprint. Yellow bar excluding rebound, teal bar including rebound, white bar showing the share of impacts that occur outside the EU. Including carbon footprint (Mt CO_2-eq), toxicity footprint (Mt 1,4-dichlorobenzene-eq), water footprint (billion m^3), and land footprint (1000 km^2).

4.2.8 Shelter

Some lifestyles within the shelter consumption category have been adjusted to keep total energy use constant. This includes lifestyles where one source of energy is substituted by another, namely *Green Home*, *Green Electricity*, *Fossil Fuel*, and *Tecno Ecovillage* (Figure 13). *Green Home* depicts a person not using the grid for electricity or household fuels and instead partially shifts income toward solar panels and products of forestry. Since almost 9% of household final demand is directed toward shelter expenses, this lifestyle includes a large shift of final demand. Also, the products increased include forestry products that have a high land-use intensity, globally being the cause of almost 24% of the total land footprint (Ivanova et al. 2016). This is probably why the land footprint increases so drastically (112.77%). *Green Home* also, however, involves a 6.89% decrease of carbon footprint, entirely due to emission reduction within the EU. This may be because the energy supply is mainly from EU regions. *Green Electricity* shows the effect of shifting from fossil to renewable electricity. Slight (externalized) impact increases in terms of land and water use are found, but also a significant decrease of carbon footprint (2.91%). Since lifestyle *Green Home* causes increased land and water footprint, it is concluded that land requirement of fossil fuels is lower than for renewable fuels (i.e. forestry products). For that reason the lifestyle *Fossil Fuel* yield significant decreases of land footprint along with an expected increase of carbon footprint since renewable fuels and electricity are substituted by fossil alternatives. Lifestyle *Tecno Ecovillage* assumes local, small scale energy production without need for grid services, and a shift from fossil to renewable electricity. This would decrease carbon footprint but cause a large increase of land usage, mainly occurring in foreign regions.

The lifestyle *Full Ecovillage* explores the environmental consequences of an ecovillage where net energy use is reduced fully (without energy adjustment). Without rebound such a lifestyle would reduce land (4.92%) and especially carbon footprint (13.76%). However with rebound there would be no significant decrease of land or toxicity footprint and a net increase of water footprint. Carbon reduction potential would however still be significant (9.53%). This is explained by the fact that shelter is the most carbon intense consumption category of all but only moderate in terms of land, water, and toxicity footprint multiplier (see Figure 5). Reducing use of conventional drinking water system (*Water Off Grid*) similarly has no positive effect in case of 100% rebound, though it may provide slight reduction potentials without rebound. Finally, the lifestyle *Passive House* roughly assumes a feasible energy use reduction of 40% through eco-efficient dwellings and low energy consumption, while 20% of the reduction is re-spent within construction work and insulation. This would especially have a potential of reducing the EU household carbon (5.58%) and land (5.02%) footprint, with significant reduction potentials even when full rebound is assumed. In reality the rebound effect for residential end-uses is probably in the range of 7-50% (Greening, Greene, and Difiglio 2000; Sorrell, Dimitropoulos, and Sommerville 2009; Druckman et al. 2011; Chitnis et al. 2014). This, at least for the carbon footprint, would assure a significant net impact reduction for all lifestyles except *Fossil Fuel.*

In conclusion, the mitigation potential of most individual shelter lifestyles is not consistent for different footprint categories. Though a shift to renewable electricity and fuels would decrease carbon footprint, the land and water use would increase. This is especially significant for shifting toward forestry products, as for lifestyles *Green Home* and *Tecno Ecovillage*. For these two lifestyles, an important factor is the characteristics of the estimated land use change. When land is increased due to expenditure in forestry products, in practice a larger area is designated for forests. An increase of forest area does not necessarily translate to a negative mitigation potential since forests may also provide the benefit of carbon sequestration. Such an effect is not taken into consideration for the estimations of land use, and could be better estimated by using the Ecological Footprint (Galli et al. 2012a). Overlooking the resulting increase of land use, a full shift toward living as a technological ecovillage (characterized by locally produced, renewable energy) has a large mitigation potential. The potential is however even larger for the full ecovillage where all spendings on energy and fuels are reduced fully.

The accuracy of the results for *Green Home* may be low due to the approximation of purchase and use of solar panels by expenditure in the single product *electrical machinery and apparatus n.e.c*. Also, the lifestyle involves a large increase of expenditure on forestry products, required to maintain the total energy use when spendings on electricity and household fuels are reduced. Since the energy contained in forestry products cannot be used for the same purposes as electricity (i.e. domestic appliances), it may be more feasible only to exchange energy used for space heating (household fuels) with increased use of forestry products. The energy use of electricity should perhaps therefore not translate to increase of forestry spendings.

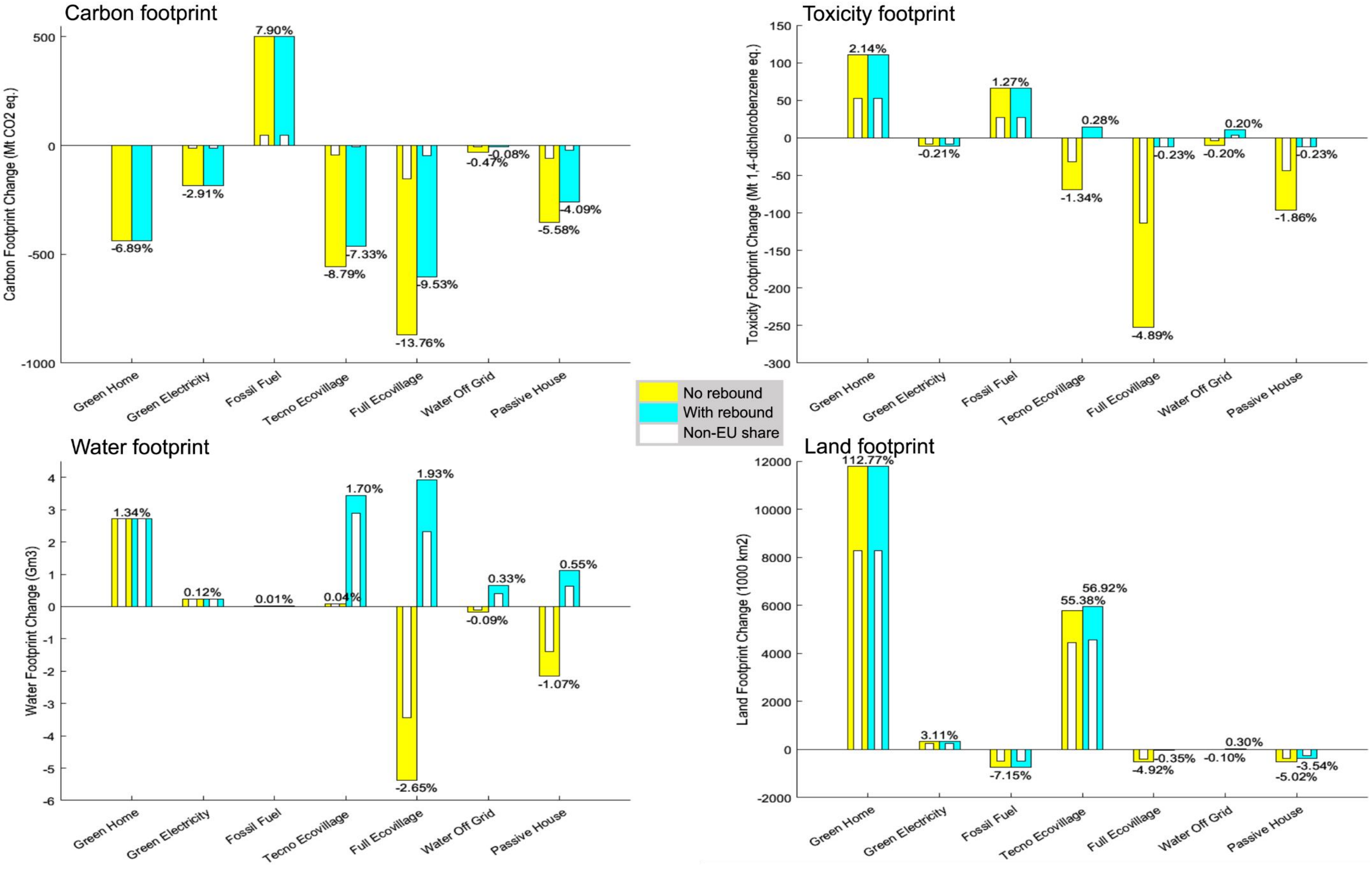

Figure 13. Change of total EU household footprint as a result of lifestyle changes within shelter. Percent values indicate share of the total household footprint. Yellow bar excluding rebound, teal bar including rebound, white bar showing the share of impacts that occur outside the EU. Including carbon footprint (Mt CO_2-eq), toxicity footprint (Mt 1,4-dichlorobenzene-eq), water footprint (billion m^3), and land footprint (1000 km^2).

5. Conclusion

5.1 SUMMARY OF LIFESTYLES

Table 5 summarizes the 18 lifestyles with highest mitigation potential within each footprint category. The results shown are without rebound effect. Reducing total expenditure by 25% by only working part-time (*Parttime Work*) is the most beneficial intervention. Also reduced expenditure in certain products has a large potential. Out of the 18 most promising lifestyle changes, 9 involve expenditure reduction without substitution. This includes low use of services (*Low Services*), reduced use of mobility (*Bike Walk Full*, *Less Mobility (50%)*, and *Flex-Work Half*), reduced energy use (*Full Ecovillage* and *Passive House*), reduced use of manufactured products (*Share Repair*) or specifically chemicals (*No Chemicals*), and reduced food consumption (*No Waste (Food)* and *Eat Less*). The potential of these lifestyles is however subject to the extent of the rebound effect. In many cases, a full rebound of the reduced final demand toward other products would cause one or more of the different types of household footprints to increase. For example, with rebound the lifestyle of *Low Services* causes all footprints to increase significantly. Lifestyles reducing use of mobility all cause higher land and water use when rebound is taken into consideration, especially located in non-EU regions.

On the other hand, lifestyles involving a full substitution of final demand do not cause potential rebound effects, since demand is simply shifted toward other products. Implementation of these lifestyles on a large scale are the safest bet for decreasing the environmental footprint of EU households. Largest impact reductions are achieved by the dietary change of following a vegan or healthy vegan diet. *Restaurant Food* is high on the list due to the low impact intensity and high price of the hotel and restaurant product. However as mentioned earlier, the results for this lifestyle may not be reliable. Also shifting long-distance mobility expenses toward local recreational and membership organization services (*Home Based*) has a significant mitigation potential. The same is true for shifting service spendings toward services of personal safety and health (normally supplied by public sector) as for lifestyle *Play It Safe*. Renewable fuels are generally associated with lower carbon and toxicity footprint as compared to non-renewable fuels, but higher land and water footprint. This is illustrated by a substitution of renewable household fuels with fossil fuels (*Fossil Fuel*) that cause carbon footprint to increase but land footprint to decrease, and shifting from fossil to renewable car fuels for which carbon footprint is reduced significantly but land and water use is increased (*Renewable Fuels*).

Reducing household energy use has a large potential to decrease land and carbon footprint, even though part of the expenditure is shifted toward increasing construction requirements (*Passive House*). Similarly, reducing spending on manufactured products by sharing and repairing (*Share Repair*) has a significant reduction potential despite a 10% substitution for renting services. This is explained by the generally low impact intensity of service products. However, when the remaining 90% of final demand is respent toward other products, all footprints are increased due to the relatively low impact intensity of manufactured products (Figure 5).

Table 5. Collection of lifestyles with top-ten mitigation potentials in each footprint category. Sorted by maximum reduction potential for a specific footprint category. Increases of other footprints and rebound results are not taking into consideration. Percent values indicate change relative to the total EU household footprint in 2007, without rebound effect.

Top Mitigation Pot.	**Category**	**Type**	**Carbon**	**Toxicity**	**Water**	**Land**
Parttime Work	General	Reduction	-25.0 %	-25.0 %	-25.0 %	-25.0 %
Low Services	Services	Reduction	-17.8 %	-21.5 %	-15.8 %	-14.6 %
Restaurant Food	Food - Supply Chain	Substitution	-10.9 %	-1.3 %	-47.0 %	-36.8 %
Healthy Vegan	Food - Diet	Substitution	-15.7 %	-12.0 %	-9.7 %	2.9 %
Bike Walk Full	Mobility	Reduction	-26.0 %	-14.2 %	-3.5 %	-3.8 %
Vegan	Food - Diet	Substitution	-13.9 %	-9.0 %	-14.8 %	-4.7 %
Eat Less	Food - Diet	Reduction	-4.9 %	-2.6 %	-16.0 %	-14.4 %
Less Mobility (50%)	Mobility	Reduction	-14.5 %	-20.4 %	-1.9 %	-2.0 %
Home Based	Services	Substitution	-3.1 %	-23.8 %	-6.6 %	-3.6 %
No Waste (Food)	Food - Supply Chain	Reduction	-2.1 %	-1.1 %	-7.1 %	-5.5 %
Play It Safe	Services	Substitution	-3.3 %	-7.6 %	-4.9 %	-5.2 %
Fossil Fuel	Shelter	Substitution	7.9 %	1.3 %	0.0 %	-7.1 %
Full Ecovillage	Shelter	Reduction	-13.8 %	-4.9 %	-2.6 %	-4.9 %
Flex Work Half	Mobility	Reduction	-13.0 %	-7.1 %	-1.8 %	-1.9 %
Passive House	Shelter	Part. substitution	-5.6 %	-1.9 %	-1.1 %	-5.0 %
Renewable Fuels	Mobility	Substitution	-12.1 %	-1.4 %	5.3 %	5.9 %
No Chemicals	Manufactured Products	Reduction	-3.9 %	-4.0 %	-4.4 %	-2.7 %
Share Repair	Manufactured Products	Part. substitution	-4.3 %	-6.2 %	-2.5 %	-2.7 %

In Table 6 lifestyles with the top mitigation potential are presented, also taking into consideration the rebound effect. The reduction potential is generally slightly lower than for the selection of lifestyles presented in Table 5. However, the lifestyles presented below can be seen as ‘safe options’ in terms of mitigation of EU household environmental impacts. No negative effects are obtained even when taking into consideration 100% rebound effect. Additional to the ‘no-brainer’ lifestyles presented in Table 5, more lifestyle changes are found to have a large potential, namely; decreased purchase of clothes (*Low Use*), shifting expenditure toward services (*High Services*), buying food that is organic (*Organic Food*) and seasonal (*Seasonal Food*), and purchase of local products in terms of food (*Local Food*) and clothing (*Local Clothing*). Decreasing expenditure on mobility by land by biking and walking potentially increases total land and water footprint (Figure 11). This is an effect of an increase of highly land and water use intensive food products. However, if the decreased mobility expenditure is specifically respent on increased flying (*Flying Biker*), all footprints would be slightly reduced (Table 6). It is probable that deeper cuts in environmental impact from EU households would be achieved by instead respending expenditure in the least emission-intensive products; namely services.

Table 6. Lifestyles with reductions for all footprints in terms of both no-rebound as well as rebound scenario (i.e. without any trade-off). Percent value indicates change relative to total EU household footprint in 2007.

		Carbon		Toxicity		Water		Land	
Lifestyle	**Category**	**No reb.**	**Reb**	**No reb.**	**Reb.**	**No reb.**	**Reb.**	**No reb.**	**Reb**
Parttime Work	General	-25.0 %	-25.0 %	-25.0 %	-25.0 %	-25.0 %	-25.0 %	-25.0 %	-25.0 %
Restaurant Food	Food-SC	-10.9 %	-10.9 %	-1.3 %	-1.3 %	-47.0 %	-47.0 %	-36.8 %	-36.8 %
Home Based	Services	-3.1 %	-3.1 %	-23.8 %	-23.8 %	-6.6 %	-6.6 %	-3.6 %	-3.6 %
Play It Safe	Services	-3.3 %	-3.3 %	-7.6 %	-7.6 %	-4.9 %	-4.9 %	-5.2 %	-5.2 %
No Chemicals	Man. Prod.	-3.9 %	-2.3 %	-4.0 %	-2.4 %	-4.4 %	-2.8 %	-2.7 %	-1.0 %
Low Use	Clothing	-1.8 %	-0.2 %	-2.5 %	-1.0 %	-2.1 %	-0.6 %	-2.1 %	-0.6 %
High Services	Services	-2.4 %	-2.4 %	-2.5 %	-2.5 %	-0.6 %	-0.6 %	-1.3 %	-1.3 %
Organic Food	Food-SC	-1.8 %	-1.8 %	-1.0 %	-1.0 %	-1.3 %	-1.3 %	-0.8 %	-0.8 %
Local Food	Food-SC	-0.6 %	-0.6 %	-3.6 %	-3.6 %	-0.1 %	-0.1 %	-0.1 %	-0.1 %
Local Clothing	Clothing	-0.5 %	-0.5 %	-1.7 %	-1.7 %	-0.5 %	-0.5 %	-0.3 %	-0.3 %
Flying Biker	Mobility	-0.1 %	-0.1 %	-1.3 %	-1.3 %	-0.4 %	-0.4 %	-0.3 %	-0.3 %
Seasonal Food	Food-SC	-0.1 %	-0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %

5.2 GENERAL FINDINGS

The consumption category of food is responsible for the majority of water and land footprint, and a significant share of carbon footprint (17.43%) (Figure 3). Addressing food supply-chain measures may provide an additional mitigation potential to that of changing diet. Combining a vegan lifestyle with elimination of food waste, reduction of calorific intake, and consuming only organic food could potentially reduce the EU household footprints of up to 20.8, 21.6, and 33.9%, for carbon, land, and water footprint, respectively (Table 7). This is in accordance with previous research that show how vegetarians and consumers of organic food have a lower environmental impact than consumers following an ordinary diet (Duchin 2005; Foster et al. 2007; Garnett 2008; Weber and Matthews 2008a; Tukker et al. 2009; Hoolohan et al. 2013; Notarnicola et al. 2016; Reginald and Wachter 2016)). However, such a lifestyle potentially generates a large monetary saving that may be re-spent on other products. This may drastically reduce the potential savings of a sustainable dietary lifestyle. The same effect is seen for lifestyles decreasing the overall use of mobility. Such lifestyles have the largest potential of decreasing EU household carbon footprint, but may cause increased land and water use especially in non-EU regions. Up to 26% of EU household's carbon footprint could be avoided if mobility by land was completely reduced; for example by biking, walking, flex-working, and an overall decreased use of mobility (Figure 11). Decreasing expenses on flying has a low impact reduction potential for EU households.

For shelter lifestyles, only *Full Ecovillage* provides significant reduction potentials that are consistent across all footprint categories (Figure 12). This lifestyle assumes an overall reduction in spendings on electricity, fuels, and other shelter-related products by 100%, made possible by sourcing energy and fuels off the grid. A more realistic scenario of increasing expenses in renewable electricity and fuels instead (*Tecno Ecovillage*) may potentially reduce the carbon footprint by up to 8.79%. It also results in a drastic increase of land use, required for the renewable fuels (forestry products). The increased demand of land used to grow forest may at least partially translate to positive side-effects such as carbon sequestration.

Footprints of land and water are to a large extent caused by impacts occuring in non-EU regions. Toxicity impacts mainly occur domestically, probably due to domestic transportation of products. A significant share of carbon impacts also occur outside the EU. Direct emissions (for example from cars and burning of household fuels) causes a majority of carbon impacts of mobility and shelter expenditure to occur inside the EU.

Regarding the model in use, an MRIO model has some clear advantages despite the many limitations. One is that monetary data always is obtained in basic prices. This reflects the actual value of product and removes potential demand effects and price fluctuations. Since it is a constant model it also removes the impact of economic inflation.

5.3 POLICY IMPLICATIONS AND RECOMMENDATIONS

There is significant impact reduction potential in reducing consumption of impact-intensive products. To decrease the EU household water and land footprint, a very effective intervention is to reduce meat consumption. Decreased use of mobility may however be an even more attractive option since the popularized carbon footprint can be reduced significantly. Also, the emissions reduction to a large extent occur inside the EU. However, such lifestyles may backfire to increase land and water in non-EU countries if the monetary savings are re-spent. The ideal scenario is if consumers could be motivated to shift final demand toward less emission-intensive products, such is the case for example for the vegetarian and vegan diets. This is confirmed by Kawajiri, Tabata, and Ihara (2015), who further argued that lifestyles based on a re-spending toward low GHG-intensive and expensive products (lowering marginal consumption) may be the most sustainable from environmental, economic, and quality-of-life perspectives. Realistically, for different reasons (eg. convenience or the feeling of having to sacrifice something of value), people may be unwilling to undertake lifestyle changes for example by reducing food waste, calorie intake, and automobile usage, without the added enjoyment involved in re-spending the saved money for other types of consumption. In terms of policy development, the best scenario would be to stimulate consumers to undergo an absolute reduction of consumption. But in practice, consumers could also be motivated to re-spend the saved money into the least impact-intensive consumption category; namely services.

When it comes to mitigation of footprints from mobility, this research points to that a shift of final demand between flying and other modes of long-distance transport only has a minor effect on environmental footprint. This supports the conclusion made by Federici, Ulgiati, and Basosi (2009); instead of directing the attention at long distance transport infrastructure, focus should be shifted toward making local transport systems more sustainable. Such systems should include public transportation, if additional measures are also undertaken to avoid a drastic increase of toxicity footprint. Another pathway is that of implementing renewable fuels in automobiles and buses. Though such measure could very effectively reduce the carbon footprint of households in EU, it may carry with it a less visible effect of increased land and water use in non-EU regions. In terms of climate justice, such effects also need to be taken into consideration. This can be done by adopting consumption-based accounting system in decision-making processes.

This research also highlights a key issue in international decision-making; who should be held accountable for the emissions occurring to generate exports?. Following a consumption-perspective that allocates such impacts to the final consumer of the products, it has been found that a large share of the embodied impacts of EU household consumption occur in foreign regions. Many of the suggested lifestyle changes carry with them an externalized impact increase, which is especially significant for land and water use. In this context, Sahakian and Steinberger (2011, 15) have argued that ‘International negotiations related to sustainable consumption issues must also recognize the role of elite populations within developing countries and their responsibilities regarding resource depletion and pollution.’ EU plays a key role in this regard as a developed region with major import flows from non-EU regions.

Regarding the practical implementation of the suggested lifestyle changes in the EU, there are a number of barriers in place. Hubacek, Guan, and Barua (2007) suggested that resource addictive ‘North’ may find it harder to develop sustainable consumption and production patterns, as compared to developing countries. The EU may to a larger extent be stuck with wasteful infrastructure, institutions, and habits which would make it difficult to implement the proposed lifestyles. Also, at a personal level, concerns about climate change does not always translate to lifestyle changes. A number of factors have been mentioned to explain such knowledge-concern-action paradox, including; status pressure to use resources, convenience/financial constraints, the perception that 'it's just a drop in the ocean', lack of trust in authorities, and shortage of physical opportunities to perform the change (i.e. public transport) (Lenzen and Cummins 2011).

5.4 FUTURE WORK

In this simplified model of lifestyles, the question of time consumption for different lifestyles has not been explored. Incorporating such a dimension would translate the consumption pattern lifestyles studied herein to actual lifestyles, where people are defined from what they do with their time rather than only from what they spend their money on. Balancing for time use may also yield more meaningful results for the rebound effect. Possibly it is more feasible to assume that time use is constant, rather than monetary spending. As Jalas (2008, 132) points out, 'time, unlike economic resources, is absolutely finite, and thus increases in a certain type of time use must be matched with decreases in others.'. Future research should explore the possibility of incorporating average time use in different activities (linked to certain products). With a rebound-scenario based on keeping average time use constant, changes in environmental impacts caused by different lifestyles could be estimated. Time-use data could also provide useful insights when analyzing how specific lifestyles would require an increase or decrease of time spent on certain activities. Furthermore, the freed expenditure for rebound should ideally be distributed with a specific share in each consumption category (instead of being re-spent equally on all products). Such shares could be based on estimations of price elasticity, which is the most accurate way to estimate the rebound effect (Berkhout, Muskens, and Velthuijsen 2000). Other possibly methods for determining rebounds could also be used, such as Computable General Equilibrium (CGE) models of the macroeconomy that measures economy-wide rebound effects (Sorrell 2007). Finding behavioural rebound using psychology models is another alternative.

Another important aspect to increase the accuracy of lifestyle impact changes is that of how calorie intake and energy use adjustments are made. Calorie intake adjustments should not only take into consideration the hotel and restaurant sectors, but also the sectors *wholesale trade and commission trade (except of motor vehicles and motorcycles)*, *retail trade (except of motor vehicles and motorcycles*), *repair of personal and household goods*, and *health and social work*. All these sectors supply the households with a small percentage of the total calorie intake, which should ideally be taken into consideration when diets are changed. For example, a person following a vegan diet would probably also consume such a diet when hospitalized (spending money within sector *health and social work*). Also, household spending on food could be simultaneously adjusted not only for calorie intake, but also for example for protein intake and nutritional levels. Furthermore, the calorie content of each food item could be determined with higher accuracy by finding a reliable data source on how many calories each EXIOBASE food product contains. Energy use adjustments could be made more accurate for example by improving the estimations of the useful energy in household fuels.

5.5 PERSONAL REFLECTIONS

During the course of the development of this paper, it has grown increasingly clear to me that an accurate estimation of absolute environmental impact reduction of different lifestyles is difficult to make. Due to a high degree of uncertainties and simplifications in the IO framework, the results should therefore mainly be used for comparing different lifestyle options with each other. I wish to express my concern that the footprint results should *not* be used as exact measurements on how much the footprints of the EU households would change by implementing specific lifestyles. On the other hand, since the largest sources of error are similar across lifestyle options, the current paper allows for comparison of one lifestyle with another to find the lifestyles with the highest mitigation potential.

Nonetheless, the accuracy of the impact reduction results is high enough to conclude that changing lifestyles may significantly reduce the environmental impact caused by the EU households. But that assumes both quite drastic and also extensive lifestyle changes. I have assumed an uptake rate of 100%, meaning that all EU citizens implement the suggested lifestyles, which is clearly an ideal scenario that would be practically impossible to achieve. Also, for example by combining the diet changes with the largest impact reduction potential, 'only' a 20-30%

reduction of household footprints would be achieved. To obtain larger reductions, changes need to be simultaneously applied across several lifestyle domains. This leads us straight to the elephant in the living room; the rebound effect. If consumers after all were induced, or partially forced, to eat and waste less and only eat organic, vegan food, what would they do with the money they would save? Is it not probable, and perhaps even likely, that the feeling of having made a big personal sacrifice in terms of diet spills over to increased consumption of material goods in another lifestyle domain? I have shown that the rebound effect can offset any potential gains of lifestyle changes, or even turn what seems a positive lifestyle change into one that causes large impact increases. And to refer to the elephant again; why is it that we practically hear nothing about the rebound effect? Is it perhaps linked to the fact that the whole economic system is dependent on a constant turn-over and a steadily increasing consumption?

Regardless, I believe that we need to help people make their own change in their life, to find their own personal motivation of undergoing a drastic change of lifestyle. That would ensure that in the long run, we don't simply stimulate people to exchange one type of material pacifier for another. After all, if we force people to stop using (or reducing) personal automotive transport, and they replace these savings by increased meat consumption, what is the gain? I have even shown that the seemingly benevolent (or at least harmless) act of reducing spending on services, by volunteeringly supplying services within the local community, wreaks havoc on the environment if the saved money is respent to other consumption categories. Indeed, the issue inevitably has a philosophical or even spiritual aspect to it. As the Vedic literature puts it; 'Because of their uncontrolled senses, persons too addicted to materialistic life make progress toward hellish conditions and repeatedly chew that which has already been chewed' (Srimad-Bhagavatam 7.5.30). If material consumption is the ends by which we achieve happiness, the one solution to ensure long-term lifestyle benefits is to help people realize the importance of non-material values in life; such as the inner spiritual journey, realizing the meaning of love, developing ones relationships to others, etc. Meanwhile, I have shown that the most effective antidote to a negative rebound effect is simply working less and earning less money. If you don't have the money in the pocket in the first place, you don't need to worry where you spend that money either. And after all, is it not true that we would all like to have more time free to spend with family and friends?

I believe we need to take into consideration the intrinsic human need to strive for happiness, since lifestyle changes may be associated with trade-offs in terms of comfort and well-being. Fortunately, it seems that happiness does not *require* a negative environmental impact to occur. In a case study in Canada, Wilson, Tyedmers, and Spinney (2013) found that the degree of life satisfaction and happiness is not related to GHG emissions. Zidanšek (2007) similarly proved a positive relationship between different indices of happiness and environmental sustainability. He also suggested that people with post-materialistic values, like valuing love instead of money, were happier than those with materialistic values. This suggests that there may be a possibility of shifting toward a more sustainable lifestyle without compromising the quality of life for the EU population. In other words, we may find a large impact reduction potential in 'being the change' we want to see in the world; if we are ready to be such a change in our own world first.

References

Ahuviar, A., Barbara Carroll, and Yi Yang. 2006. ‘Consumer Culture Theory and Lifestyle Segmentation’. *Innovative Markets* 2: 33–43.

Arnould, Eric J., and Craig J. Thompson. 2005. ‘Consumer Culture Theory (CCT): Twenty Years of Research’. *Journal of Consumer Research* 31 (4): 868. doi:10.1086/426626.

Asner, Gregory P., Andrew J. Elmore, Lydia P. Olander, Roberta E. Martin, and A. Thomas Harris. 2004. ‘GRAZING SYSTEMS, ECOSYSTEM RESPONSES, AND GLOBAL CHANGE’. *Annual Review of Environment and Resources* 29 (1): 261–99.

Avetisyan, Misak, Thomas Hertel, and Gregory Sampson. 2014. ‘Is Local Food More Environmentally Friendly? The GHG Emissions Impacts of Consuming Imported versus Domestically Produced Food’. *Environmental and Resource Economics* 58 (3): 415–62. doi:10.1007/s10640-013-9706-3.

Ayres, Robert U. 2008. ‘Sustainability Economics: Where Do We Stand?’ *Ecological Economics* 67 (2): 281–310. doi:10.1016/j.ecolecon.2007.12.009.

Baiocchi, Giovanni, Jan Minx, and Klaus Hubacek. 2010. ‘The Impact of Social Factors and Consumer Behavior on Carbon Dioxide Emissions in the United Kingdom: A Regression Based on Input–Output and Geodemographic Consumer Segmentation Data’. *Journal of Industrial Ecology* 14 (1): 50–72. doi:10.1111/j.1530-9290.2009.00216.x.

Bentzen, Jan. 2004. ‘Estimating the Rebound Effect in US Manufacturing Energy Consumption’. *Energy Economics* 26 (1): 123–34. doi:10.1016/S0140-9883(03)00047-1.

Berkhout, Peter HG, Jos C. Muskens, and Jan W. Velthuijsen. 2000. ‘Defining the Rebound Effect’. *Energy Policy* 28 (6): 425–432.

Binswanger, Mathias. 2001. ‘Technological Progress and Sustainable Development: What about the Rebound Effect?’ *Ecological Economics* 36 (1): 119–132.

Carbon-CAP. 2017. ‘Carbon-CAP. Consumption-Based Accounting and Policy’. European Union’s Seventh Programme, grant agreement No 603386. http://www.carboncap.eu/.

Carlsson-Kanyama, Annika, and Mireille Faist. 2000. *Energy Use in the Food Sector: A Data Survey*. Swedish Environmental Protection Agency Stockholm, Sweden. http://mmm.comuv.com/wordpress/wp-content/uploads/2010/06/Energy-use-in-the-food-sector-Carlsson-Kanyama-and-Fiest.pdf.

Chitnis, Mona, and Steve Sorrell. 2015. ‘Living up to Expectations: Estimating Direct and Indirect Rebound Effects for UK Households’. *Energy Economics* 52 (December): S100–116. doi:10.1016/j.eneco.2015.08.026.

Chitnis, Mona, Steve Sorrell, Angela Druckman, Steven K. Firth, and Tim Jackson. 2013. ‘Turning Lights into Flights: Estimating Direct and Indirect Rebound Effects for UK Households’. *Energy Policy* 55 (April): 234–50. doi:10.1016/j.enpol.2012.12.008.

———. 2014. ‘Who Rebounds Most? Estimating Direct and Indirect Rebound Effects for Different UK Socioeconomic Groups’. *Ecological Economics* 106 (October): 12–32. doi:10.1016/j.ecolecon.2014.07.003.

CORDIS. 2015. ‘Carbon CAP Report Summary’. *Community Research and Development Information Service (CORDIS)*. European Commission. http://cordis.europa.eu/result/rcn/169161_en.html.

Crocker, David A., and Toby Linden. 1998. *Ethics of Consumption: The Good Life, Justice, and Global Stewardship*. Rowman & Littlefield.

Crutzen, Paul J. 2002. ‘Geology of Mankind’. *Nature* 415 (6867): 23–23.

Čuček, Lidija, Jiří Jaromír Klemeš, and Zdravko Kravanja. 2012. ‘A Review of Footprint Analysis Tools for Monitoring Impacts on Sustainability’. *Journal of Cleaner Production* 34 (October): 9–20. doi:10.1016/j.jclepro.2012.02.036.

Domingos, Tiago, Jorge E. Zafrilla, and Luis A. Lopez. 2016. ‘Consistency of Technology-Adjusted Consumption-Based Accounting’. *Nature Clim. Change* 6 (8): 729–30.

Druckman, Angela, Mona Chitnis, Steve Sorrell, and Tim Jackson. 2011. 'Missing Carbon Reductions? Exploring Rebound and Backfire Effects in UK Households'. *Energy Policy* 39 (6): 3572–81. doi:10.1016/j.enpol.2011.03.058.

Druckman, Angela, and Tim Jackson. 2009. 'The Carbon Footprint of UK Households 1990–2004: A Socio-Economically Disaggregated, Quasi-Multi-Regional Input–output Model'. *Ecological Economics* 68 (7): 2066–77. doi:10.1016/j.ecolecon.2009.01.013.

———. 2010. 'The Bare Necessities: How Much Household Carbon Do We Really Need?' *Ecological Economics* 69 (9): 1794–1804. doi:10.1016/j.ecolecon.2010.04.018.

Duarte, Rosa, Kuishuang Feng, Klaus Hubacek, Julio Sánchez-Chóliz, Cristina Sarasa, and Laixiang Sun. 2016. 'Modeling the Carbon Consequences of pro-Environmental Consumer Behavior'. *Applied Energy* 184 (December): 1207–16. doi:10.1016/j.apenergy.2015.09.101.

Duchin, Faye. 2005. 'Sustainable Consumption of Food: A Framework for Analyzing Scenarios about Changes in Diets'. *Journal of Industrial Ecology* 9 (1–2): 99–114.

Ehrlich, Paul R. 1968. *The Population Bomb*. Cutchogue, N.Y.: Sierra Club/Ballantine Books.

EIA. 2013. 'Gas Furnace Efficiency Has Large Implications for Residential Natural Gas Use'. U.S. Energy Information Administration. http://www.eia.gov/todayinenergy/detail.php?id=14051.

Ekono. 1981. 'Report on Energy Use of Peat'. Contribution to U.N. Conference on New and Renewable Sources of Energy. Nairobi.

EPA. 2015. 'List of EPA Certified Wood Heaters'. Heaters Certified as Meeting the 2015 Standards of Performance for New Residential Wood Heaters. United States Environmental Protection Agency (EPA). https://www.epa.gov/sites/production/files/2015-12/documents/list_of_epa-certified_wood_stoves_oct_2015.pdf.

European Commission. 2002. 'Statistical Classification of Economic Activities in the European Community, Rev. 1.1 (2002) (NACE Rev. 1.1)'. Eurostat. http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_CLS_DLD&StrNom=NACE_1_1#.

———. 2013a. 'A Decent Life for All: Ending Poverty and Giving the World a Sustainable Future'. Communication from the commission to the European parliament, the council, the European economic and social committee and the committe of the regions. Brussels.

———. 2013b. 'Living Well, within the Limits of Our Planet, 7th EAP: The New General Union Environment Action Programme to 2020'. Decision No 1386/2013/EU of the European Parliament and of the Council.

———. 2014. 'EU Researchers Explore Pathways for Transition to Sustainable Lifestyles'. *CORDIS (Community Research and Development Information Service)*, November 26. http://cordis.europa.eu/news/rcn/122152_en.html.

Ewing, Brad R., Troy R. Hawkins, Thomas O. Wiedmann, Alessandro Galli, A. Ertug Ercin, Jan Weinzettel, and Kjartan Steen-Olsen. 2012. 'Integrating Ecological and Water Footprint Accounting in a Multi-Regional Input–output Framework'. *Ecological Indicators* 23 (December): 1–8. doi:10.1016/j.ecolind.2012.02.025.

FAO. 2006. *Livestock's Long Shadow. Environmental Issues and Options*. Rome: Food and Agriculture Organization of the United Nations.

———. 2016. 'FAOSTAT Statistics Database. Food and Agriculture Data'. Food and Agriculture Organization of the United Nations. Rome, Italy.

Federici, M., S. Ulgiati, and R. Basosi. 2009. 'Air versus Terrestrial Transport Modalities: An Energy and Environmental Comparison'. *11th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction* 34 (10): 1493–1503. doi:10.1016/j.energy.2009.06.038.

Fineli. 2016. 'National Food Composition Database in Finland'. Helsinki, Finland: National Institute for Health and Welfare. https://fineli.fi/fineli/en/index.

Foster, C., K. Green, M. Bleda, P. Dewich, B. Evans, and A. Flynn. 2007. 'Environmental Impacts of Food Production and Consumption: A Report to the Department of Environment, Food and Rural Affairs'. London: DEFRA.

Frondel, Manuel, Nolan Ritter, and Colin Vance. 2012. ‘Heterogeneity in the Rebound Effect: Further Evidence for Germany’. *Energy Economics* 34 (2): 461–67. doi:10.1016/j.eneco.2011.10.016.

Füller, Johann, and Kurt Matzler. 2008. ‘Customer Delight and Market Segmentation: An Application of the Three-Factor Theory of Customer Satisfaction on Life Style Groups’. *Tourism Management* 29 (1): 116–26. doi:10.1016/j.tourman.2007.03.021.

Galli, Alessandro, Jan Weinzettel, Gemma Cranston, and Ertug Ercin. 2013. ‘A Footprint Family Extended MRIO Model to Support Europe’s Transition to a One Planet Economy’. *Science of The Total Environment* 461–462 (September): 813–18. doi:10.1016/j.scitotenv.2012.11.071.

Galli, Alessandro, Thomas Wiedmann, Ertug Ercin, Doris Knoblauch, Brad Ewing, and Stefan Giljum. 2012a. ‘Integrating Ecological, Carbon and Water Footprint into a “Footprint Family” of Indicators: Definition and Role in Tracking Human Pressure on the Planet’. *Ecological Indicators* 16 (May): 100–112. doi:10.1016/j.ecolind.2011.06.017.

———. 2012b. ‘Integrating Ecological, Carbon and Water Footprint into a “Footprint Family” of Indicators: Definition and Role in Tracking Human Pressure on the Planet’. *The State of the Art in Ecological Footprint: Theory and Applications* 16 (May): 100–112. doi:10.1016/j.ecolind.2011.06.017.

Garnett, Tara. 2008. ‘Cooking up a Storm’. *Food, Greenhouse Gas Emissions and Our Changing Climate. Guildford, UK: Food Climate Research Network, Centre for Environmental Strategy, University of Surrey*. http://www.unscn.org/layout/modules/resources/files/Cooking_up_a_Storm.pdf.

Girod, Bastien, Detlef Peter van Vuuren, and Edgar G. Hertwich. 2014. ‘Climate Policy through Changing Consumption Choices: Options and Obstacles for Reducing Greenhouse Gas Emissions’. *Global Environmental Change* 25 (March): 5–15. doi:10.1016/j.gloenvcha.2014.01.004.

GLAMURS. 2017. ‘GLAMURS. Supporting Green Lifestyles.’ *European Commission 7th Framework Programme for Research and Technological Development*. Green Lifestyles, Alternative Models, and Upscaling Regional Sustainability. http://glamurs.eu/.

González, Ana M., and Laurentino Bello. 2002. ‘The Construct “lifestyle” in Market Segmentation: The Behaviour of Tourist Consumers’. *European Journal of Marketing* 36 (1/2): 51–85. doi:10.1108/03090560210412700.

Goodland, Robert, and Jeff Anhang. 2009. ‘Livestock and Climate Change’. *World Watch Magazine* 22, No. 6 (November).

Greening, Lorna A., David L. Greene, and Carmen Difiglio. 2000. ‘Energy Efficiency and Consumption — the Rebound Effect — a Survey’. *Energy Policy* 28 (6–7): 389–401. doi:10.1016/S0301-4215(00)00021-5.

Grunert, Klaus G. 2006. ‘Future Trends and Consumer Lifestyles with Regard to Meat Consumption’. *Meat Science* 74 (1): 149–60. doi:10.1016/j.meatsci.2006.04.016.

Guardigli, Luca, Filippo Monari, and Marco Alvise Bragadin. 2011. ‘Assessing Environmental Impact of Green Buildings through LCA Methods: Acomparison between Reinforced Concrete and Wood Structures in the European Context’. *2011 International Conference on Green Buildings and Sustainable Cities* 21 (January): 1199–1206. doi:10.1016/j.proeng.2011.11.2131.

Gustavsson, Jenny, Christel Cederberg, and Ulf Sonesson. 2011. *Global Food Losses and Food Waste: Extent, Causes and Prevention ; Study Conducted for the International Congress Save Food! At Interpack 2011, [16 - 17 May], Düsseldorf, Germany*. Rome: Food and Agriculture Organization of the United Nations.

Hertwich, Edgar G. 2005a. ‘Consumption and the Rebound Effect: An Industrial Ecology Perspective’. *Journal of Industrial Ecology* 9 (1–2): 85–98.

———. 2005b. ‘Life Cycle Approaches to Sustainable Consumption: A Critical Review’. *Environmental Science & Technology* 39 (13): 4673–84. doi:10.1021/es0497375.

———. 2008. ‘Consumption and Industrial Ecology’. *Journal of Industrial Ecology* 9 (1–2): 1–6. doi:10.1162/1088198054084536.

Hertwich, Edgar G., and Glen P. Peters. 2009a. ‘Carbon Footprint of Nations: A Global, Trade-Linked Analysis’. *Environmental Science & Technology* 43 (16): 6414–6420.

———. 2009b. ‘Carbon Footprint of Nations: A Global, Trade-Linked Analysis. Supporting Information.’ *Environmental Science & Technology* 43 (16): 6414–20. doi:10.1021/es803496a.

Hoekstra, Arjen Y., and Pin Q. Hung. 2002. ‘Virtual Water Trade’. *A Quantification of Virtual Water Flows between Nations in Relation to International Crop Trade. Value of Water Research Report Series* 11: 166.

Hoff, Holger, Björn Nykvist, and Marcus Carson. 2014. ‘“Living Well, within the Limits of Our Planet”? Measuring Europe’s Growing External Footprint’. *Stockholm Environment Institute*, no. Working Paper No. 2014-5. https://www.researchgate.net/profile/Marcus_Carson2/publication/272488205_Living_well_within_the_limits_of_our_planet_Measuring_Europes_growing_external_footprint/links/54eefe800cf2e55866f3d01a.pdf.

Hoolohan, C., M. Berners-Lee, J. McKinstry-West, and C.N. Hewitt. 2013. ‘Mitigating the Greenhouse Gas Emissions Embodied in Food through Realistic Consumer Choices’. *Energy Policy* 63 (December): 1065–74. doi:10.1016/j.enpol.2013.09.046.

Hubacek, Klaus, Kuishuang Feng, Jan C. Minx, Stephan Pfister, and Naijun Zhou. 2014. ‘Teleconnecting Consumption to Environmental Impacts at Multiple Spatial Scales: Research Frontiers in Environmental Footprinting’. *Journal of Industrial Ecology* 18 (1): 7–9. doi:10.1111/jiec.12082.

Hubacek, Klaus, and Dabo Guan. 2011. ‘Behaviour: The Net Effect of Green Lifestyles’. *Nature Climate Change* 1 (5): 250–51. doi:10.1038/nclimate1181.

Hubacek, Klaus, Dabo Guan, and Anamika Barua. 2007. ‘Changing Lifestyles and Consumption Patterns in Developing Countries: A Scenario Analysis for China and India’. *Futures* 39 (9): 1084–96. doi:10.1016/j.futures.2007.03.010.

ICCT. 2016. ‘NOx Emissions from Heavy-Duty and Light-Duty Diesel Vehicles in the EU: Comparison of Real-World Performance and Current Type-Approval Requirements’. Briefing. The International Council on Clean Transportation.

IEA. 2006. ‘CO2 Emissions from Fuel Combustion : 1971 / 2004: 2006 Edition (Complete Edition - ISBN 9264110003)’. *SourceOECD Energy*, International Energy Agency, 2006 (22): i-556.

Intlekofer, Koji, Bert Bras, and Mark Ferguson. 2010. ‘Energy Implications of Product Leasing’. *Environmental Science & Technology* 44 (12): 4409–15. doi:10.1021/es9036836.

IPCC. 2014. ‘Summary for Policymakers.’ Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA: Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.).

Ivanova, Diana, Konstantin Stadler, Kjartan Steen-Olsen, Richard Wood, Gibran Vita, Arnold Tukker, and Edgar G. Hertwich. 2016. ‘Environmental Impact Assessment of Household Consumption: Environmental Impact Assessment of Household Consumption’. *Journal of Industrial Ecology* 20 (3): 526–36. doi:10.1111/jiec.12371.

Jackson, Tim. 2011. *Prosperity without Growth: Economics for a Finite Planet*. Routledge.

Jalas, Mikko. 2008. ‘The Everyday Life Context of Increasing Energy Demands: Time Use Survey Data in a Decomposition Analysis’. *Journal of Industrial Ecology* 9 (1–2): 129–45. doi:10.1162/1088198054084644.

Johnson, Kristen A., and De E. Johnson. 1995. ‘Methane Emissions from Cattle.’ *Journal of Animal Science* 73 (8): 2483–2492.

Kander, Astrid, Magnus Jiborn, Daniel D. Moran, and Thomas O. Wiedmann. 2015. ‘National Greenhouse-Gas Accounting for Effective Climate Policy on International Trade’. *Nature Clim. Change* 5 (5): 431–35.

Kawajiri, Kotaro, Tomohiro Tabata, and Tomohiko Ihara. 2015. 'Using a Rebound Matrix to Estimate Consumption Changes from Saving and Its Environmental Impact in Japan: Consumption Changes from Saving and Its Environmental Impact'. *Journal of Industrial Ecology* 19 (4): 564–74. doi:10.1111/jiec.12275.

Kebreab, E., K. A. Johnson, S. L. Archibeque, D. Pape, and T. Wirth. 2008. 'Model for Estimating Enteric Methane Emissions from United States Dairy and Feedlot cattle1'. *Journal of Animal Science* 86 (10): 2738–48. doi:10.2527/jas.2008-0960.

Kerkhof, Annemarie C., Sanderine Nonhebel, and Henri C. Moll. 2009. 'Relating the Environmental Impact of Consumption to Household Expenditures: An Input–output Analysis'. *Ecological Economics* 68 (4): 1160–70. doi:10.1016/j.ecolecon.2008.08.004.

Larsen, Hogne N., and Edgar G. Hertwich. 2009. 'The Case for Consumption-Based Accounting of Greenhouse Gas Emissions to Promote Local Climate Action'. *Environmental Science & Policy* 12 (7): 791–98. doi:10.1016/j.envsci.2009.07.010.

Lashof, Daniel A., and Dilip R. Ahuja. 1990. 'Relative Contributions of Greenhouse Gas Emissions to Global Warming'. *Nature* 344 (6266): 529–31. doi:10.1038/344529a0.

Lenzen, Manfred. 1998. 'Primary Energy and Greenhouse Gases Embodied in Australian Final Consumption: An Input–output Analysis'. *Energy Policy* 26 (6): 495–506.

Lenzen, Manfred, and Robert A. Cummins. 2011. 'Lifestyles and Well-Being Versus the Environment'. *Journal of Industrial Ecology* 15 (5): 650–52. doi:10.1111/j.1530-9290.2011.00397.x.

Lenzen, Manfred, Daniel Moran, Anik Bhaduri, Keiichiro Kanemoto, Maksud Bekchanov, Arne Geschke, and Barney Foran. 2013. 'International Trade of Scarce Water'. *Ecological Economics* 94 (October): 78–85. doi:10.1016/j.ecolecon.2013.06.018.

Lenzen, Manfred, Lise-Lotte Pade, and Jesper Munksgaard. 2004. 'CO_2 Multipliers in Multi-Region Input-Output Models'. *Economic Systems Research* 16 (4): 391–412. doi:10.1080/0953531042000304272.

Leontief, Wassily. 1936. 'Quantitative Input and Output Relations in the Economic Systems of the United States'. *The Review of Economics and Statistics* 18 (3): 105. doi:10.2307/1927837.

———. 1941. 'The Structure of American Economy'. *New York: Oxford University Press*.

———. 1970. 'Environmental Repercussions and the Economic Structure: An Input-Output Approach'. *The Review of Economics and Statistics* 52 (3): 262. doi:10.2307/1926294.

Li, Li, and Han Yonglei. 2012. 'The Energy Efficiency Rebound Effect in China from Three Industries Perspective'. *Energy Procedia* 14: 1. doi:10.1016/j.egypro.2011.12.887.

Macdiarmid, Jennie I. 2014. 'Seasonality and Dietary Requirements: Will Eating Seasonal Food Contribute to Health and Environmental Sustainability?' *Proceedings of the Nutrition Society* 73 (03): 368–75. doi:10.1017/S0029665113003753.

Martin, Elliot W., and Susan A. Shaheen. 2011. 'Greenhouse Gas Emission Impacts of Carsharing in North America'. *IEEE Transactions on Intelligent Transportation Systems* 12 (4): 1074–86. doi:10.1109/TITS.2011.2158539.

Mathijs, Erik. 2015. 'Exploring Future Patterns of Meat Consumption'. *Meat Science* 109 (November): 112–16. doi:10.1016/j.meatsci.2015.05.007.

McBain, Darian. 2015. 'Is Social Footprinting Relevant to Industrial Ecology?' *Journal of Industrial Ecology* 19 (3): 340–42. doi:10.1111/jiec.12260.

McGee, Julius Alexander. 2015. 'Does Certified Organic Farming Reduce Greenhouse Gas Emissions from Agricultural Production?' *Agriculture and Human Values* 32 (2): 255–63. doi:10.1007/s10460-014-9543-1.

Miller, Ronald E., and Peter D. Blair. 1985. *Input-Output Analysis. Foundations and Extensions*. 2nd ed. Cambridge: Cambridge University Press.

Mokhtarian, Patricia L., and Cynthia Chen. 2004. 'TTB or Not TTB, That Is the Question: A Review and Analysis of the Empirical Literature on Travel Time (and Money) Budgets'. *Transportation Research Part A: Policy and Practice* 38 (9–10): 643–75. doi:10.1016/j.tra.2003.12.004.

Mosenthal, Phil, and Matt Socks. 2015. ‘Potential for Energy Savings in Affordable Multifamily Housing’. Final Report. Energy Efficiency For All Project. Optimal Energy.

Nelson, Peter F., Anne R. Tibbett, and Stuart J. Day. 2008. ‘Effects of Vehicle Type and Fuel Quality on Real World Toxic Emissions from Diesel Vehicles’. *Atmospheric Environment* 42 (21): 5291–5303. doi:10.1016/j.atmosenv.2008.02.049.

Newton, Peter, and Denny Meyer. 2013. ‘Exploring the Attitudes-Action Gap in Household Resource Consumption: Does “Environmental Lifestyle” Segmentation Align with Consumer Behaviour?’ *Sustainability* 5 (3): 1211–33. doi:10.3390/su5031211.

Nie, Cong, and Lydia Zepeda. 2011. ‘Lifestyle Segmentation of US Food Shoppers to Examine Organic and Local Food Consumption’. *Appetite* 57 (1): 28–37. doi:10.1016/j.appet.2011.03.012.

Nijdam, D. S., and Harm Christiaan Wilting. 2003. ‘Milieudruk Consumptie in Beeld’. http://rivm.openrepository.com/rivm/handle/10029/9101.

Nijdam, Durk S., Harry C. Wilting, Mark J. Goedkoop, and Jacob Madsen. 2005. ‘Environmental Load from Dutch Private Consumption: How Much Damage Takes Place Abroad?’ *Journal of Industrial Ecology* 9 (1–2): 147–68. doi:10.1162/1088198054084725.

Notarnicola, Bruno, Giuseppe Tassielli, Pietro Alexander Renzulli, Valentina Castellani, and S. Sala. 2016. ‘Environmental Impacts of Food Consumption in Europe’. *Journal of Cleaner Production* 140 (June): 753–65. doi:10.1016/j.jclepro.2016.06.080.

Nykvist, Björn, Åsa Persson, Fredrik Moberg, Linn Persson, Sarah Cornell, and Johan Rockström. 2013. *National Environmental Performance on Planetary Boundaries:. A Study for the Swedish Environmental Protection Agency*. Stockholm: Swedish Environmental Protection Agency.

OECD. 2016. ‘Glossary of Statistical Terms’. https://stats.oecd.org/glossary/index.htm.

OECD/IEA. 2005. ‘Energy Statistics Manual’. International Energy Agency (IEA), Organisation For Economic Co-Operation And Development (OECD), Eurostat.

Ornetzeder, Michael, Edgar G. Hertwich, Klaus Hubacek, Katarina Korytarova, and Willi Haas. 2008. ‘The Environmental Effect of Car-Free Housing: A Case in Vienna’. *Ecological Economics* 65 (3): 516–30. doi:10.1016/j.ecolecon.2007.07.022.

Pade, Claus, and Maria Guimaraes. 2007. ‘The CO2 Uptake of Concrete in a 100 Year Perspective’. *Cement and Concrete Research* 37 (9): 1348–56. doi:10.1016/j.cemconres.2007.06.009.

Pairotti, Maria Beatrice, Alessandro Kim Cerutti, Fiorenzo Martini, Enrica Vesce, Dario Padovan, and Riccardo Beltramo. 2015. ‘Energy Consumption and GHG Emission of the Mediterranean Diet: A Systemic Assessment Using a Hybrid LCA-IO Method’. *Carbon Emissions Reduction: Policies, Technologies, Monitoring, Assessment and Modeling* 103 (September): 507–16. doi:10.1016/j.jclepro.2013.12.082.

Pauliuk, Stefan, Karin Sjöstrand, and Daniel B. Müller. 2013. ‘Transforming the Norwegian Dwelling Stock to Reach the 2 Degrees Celsius Climate Target: Combining Material Flow Analysis and Life Cycle Assessment Techniques’. *Journal of Industrial Ecology* 17 (4): 542–54. doi:10.1111/j.1530-9290.2012.00571.x.

Peters, G. P., J. C. Minx, C. L. Weber, and O. Edenhofer. 2011. ‘Growth in Emission Transfers via International Trade from 1990 to 2008’. *Proceedings of the National Academy of Sciences* 108 (21): 8903–8. doi:10.1073/pnas.1006388108.

Peters, Glen, Tania Briceno, and Edgar Hertwich. 2004. ‘Pollution Embodied in Norwegian Consumption’. http://www.diva-portal.org/smash/record.jsf?pid=diva2:122108.

Peters, Glen, and Edgar Hertwich. 2004. ‘Production Factors and Pollution Embodied in Trade: Theoretical Development’. https://brage.bibsys.no/xmlui/handle/11250/242583.

Peters, Glen P. 2007. ‘Opportunities and Challenges for Environmental MRIO Modeling: Illustrations with the GTAP Database’. In *16th International Input-Output Conference*. http://www.iioa.org/conferences/16th/files/Papers/Peters_LP.pdf.

Peters, Glen P., and Edgar G. Hertwich. 2008a. 'Post-Kyoto Greenhouse Gas Inventories: Production versus Consumption'. *Climatic Change* 86 (1–2): 51–66. doi:10.1007/s10584-007-9280-1.

———. 2008b. 'CO $_2$ Embodied in International Trade with Implications for Global Climate Policy'. *Environmental Science & Technology* 42 (5): 1401–7. doi:10.1021/es072023k.

———. 2009. 'The Application of Multi-Regional Input-Output Analysis to Industrial Ecology'. In *Handbook of Input-Output Economics in Industrial Ecology*, 847–863. Springer. http://link.springer.com/chapter/10.1007/978-1-4020-5737-3_38.

Pisupati, Sarma. 2016. 'Heating Efficiency'. EGEE 102: Energy Conservation and Environmental Protection. The Pennsylvania State University. https://www.e-education.psu.edu/egee102/node/2066.

Pomponi, Francesco, and Alice Moncaster. 2016. 'Embodied Carbon Mitigation and Reduction in the Built Environment – What Does the Evidence Say?' *Journal of Environmental Management* 181 (October): 687–700. doi:10.1016/j.jenvman.2016.08.036.

Quist J., and Leising E. 2016. 'GLAMURS Deliverable 4.3'. GLAMURS: EU SSH.2013.2.1-1. Grant agreement no: 613169: Green Lifestyles Alternative Models and Up -scaling Regional Sustainability / GLAMURS.

Ramankutty, Navin, and Jonathan A. Foley. 1999. 'Estimating Historical Changes in Global Land Cover: Croplands from 1700 to 1992'. *Global Biogeochemical Cycles* 13 (4): 997–1027.

Rees, W. E. 1992. 'Ecological Footprints and Appropriated Carrying Capacity: What Urban Economics Leaves out'. *Environment and Urbanization* 4 (2): 121–30. doi:10.1177/095624789200400212.

Reganold, John P., and Jonathan M. Wachter. 2016. 'Organic Agriculture in the Twenty-First Century'. *Nature Plants* 2 (2): 15221. doi:10.1038/nplants.2015.221.

Reinders, A.H.M.E., K. Vringer, and K. Blok. 2003. 'The Direct and Indirect Energy Requirement of Households in the European Union'. *Energy Policy* 31 (2): 139–53. doi:10.1016/S0301-4215(02)00019-8.

Rodrigues, Joao, Valentina Prado, Ester van der Voet, Daniel Moran, and Richard Wood. 2015. 'Effectiveness of Improvement Options to Reduce GHG Emissions in a Consumption Based Approach'. Seventh Framework Program - Theme FP7-ENV-2013 D 6.2. Carbon-Cap. European Union.

Roy, Joyashree. 2000. 'The Rebound Effect: Some Empirical Evidence from India'. *Energy Policy* 28 (6): 433–438.

Sahakian, Marlyne D., and Julia K. Steinberger. 2011. 'Energy Reduction Through a Deeper Understanding of Household Consumption: Staying Cool in Metro Manila'. *Journal of Industrial Ecology* 15 (1): 31–48. doi:10.1111/j.1530-9290.2010.00305.x.

Schanes, Karin, Stefan Giljum, and Edgar Hertwich. 2016. 'Low Carbon Lifestyles: A Framework to Structure Consumption Strategies and Options to Reduce Carbon Footprints'. *Journal of Cleaner Production* 139 (December): 1033–43. doi:10.1016/j.jclepro.2016.08.154.

Schanes, Karin, Stefan Giljum, Friedrich Hinterberger, Hanspeter Wieland, and Ester van der Voet. 2015. 'List of Life-Cycle Micro-Level Options for Consumption Based Climate Mitigation'. Seventh Framework Program - Theme FP7-ENV-2013 D 6.1. Carbon-Cap. European Union.

Schneider, Friedrich. 2012. 'The Shadow Economy and Work in the Shadow: What Do We (Not) Know?' http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2031951.

Smil, Vaclav. 2011. 'Harvesting the Biosphere: The Human Impact'. *Population and Development Review* 37 (4): 613–636.

Sorrell, Steve. 2007. 'The Rebound Effect: An Assessment of the Evidence for Economy-Wide Energy Savings from Improved Energy Efficiency'. UK Energy Research Centre. London: UKERC.

Sorrell, Steve, John Dimitropoulos, and Matt Sommerville. 2009. 'Empirical Estimates of the Direct Rebound Effect: A Review'. *Energy Policy* 37 (4): 1356–71. doi:10.1016/j.enpol.2008.11.026.

SPREAD. 2012. ‘Roadmap: The Transition to Future Sustainable Lifestyles. Policy Recommendations for the Development of Pathways to More Sustainable Living in Europe from Today to 2050.’ European Policy Brief. SPREAD Sustainable Lifestyles 2050.

Stadler, Konstantin, Kjartan Steen-Olsen, and Richard Wood. 2014. ‘THE “REST OF THE WORLD” – ESTIMATING THE ECONOMIC STRUCTURE OF MISSING REGIONS IN GLOBAL MULTI-REGIONAL INPUT–OUTPUT TABLES’. *Economic Systems Research* 26 (3): 303–26. doi:10.1080/09535314.2014.936831.

Statistics Norway. 2012. ‘Energy Consumption in Households. Energy and Manufacturing’. Energy Consumption in Households, 2012. Division for Energy and Environmental Statistics. http://www.ssb.no/en/husenergi.

Steen-Olsen, Kjartan, Jan Weinzettel, Gemma Cranston, A. Ertug Ercin, and Edgar G. Hertwich. 2012. ‘Carbon, Land, and Water Footprint Accounts for the European Union: Consumption, Production, and Displacements through International Trade’. *Environmental Science & Technology* 46 (20): 10883–91. doi:10.1021/es301949t.

Steffen, W., K. Richardson, J. Rockstrom, S. E. Cornell, I. Fetzer, E. M. Bennett, R. Biggs, et al. 2015. ‘Planetary Boundaries: Guiding Human Development on a Changing Planet’. *Science* 347 (6223): 1259855–1259855. doi:10.1126/science.1259855.

Stovax. 2017. ‘Stockton 14HB High Output Boiler Stoves’. http://www.stovax.com/stove-fire/high-output-boiler-stoves/stockton-14hb-boiler-stove/.

Thøgersen, John. 2017. ‘Housing-Related Lifestyle and Energy Saving: A Multi-Level Approach’. *Energy Policy* 102 (March): 73–87. doi:10.1016/j.enpol.2016.12.015.

Tukker, A., S Bausch-Goldbohm, M. Verheijden, A. de Koning, R. Kleijn, O. Wolf, and I. Pérez Domínguez. 2009. ‘Environmental Impacts of Diet Change in the European Union’. Seville, Spain: Institute of Prospective Studies.

Tukker, Arnold. 2015. ‘Product Services for a Resource-Efficient and Circular Economy – a Review’. *Journal of Cleaner Production* 97 (June): 76–91. doi:10.1016/j.jclepro.2013.11.049.

Tukker, Arnold, Tatyana Bulavskaya, Stefan Giljum, Arjan de Koning, Stephan Lutter, Moana Simas, Konstantin Stadler, and Richard Wood. 2014. ‘The Global Resource Footprint of Nations’. *Carbon, Water, Land and Materials Embodied in Trade and Final Consumption Calculated with EXIOBASE* 2: 8.

Tukker, Arnold, and Erik Dietzenbacher. 2013. ‘GLOBAL MULTIREGIONAL INPUT–OUTPUT FRAMEWORKS: AN INTRODUCTION AND OUTLOOK’. *Economic Systems Research* 25 (1): 1–19. doi:10.1080/09535314.2012.761179.

Tuomisto, H.L., I.D. Hodge, P. Riordan, and D.W. Macdonald. 2012. ‘Does Organic Farming Reduce Environmental Impacts? – A Meta-Analysis of European Research’. *Journal of Environmental Management* 112 (December): 309–20. doi:10.1016/j.jenvman.2012.08.018.

UNFCCC. 2017. ‘The Cancun Agreements: Key Steps of the United Nations Climate Change Conference’. *United Nations Framework Convention on Climate Change*. http://cancun.unfccc.int/cancun-agreements/significance-of-the-key-agreements-reached-at-cancun/#c45.

United Nations. 1999. *Handbook of Input-Output Table Compilation and Analysis*. Handbook of National Accounting. Studies in Methods Series F, No 74. United Nations.

———. , ed. 2014. *System of Environmental-Economic Accounting 2012: Central Framework*. New York, NY: United Nations.

USDA. 2016. ‘USDA Branded Food Products Database’. United States Department of Agriculture Agricultural Research Service. https://ndb.nal.usda.gov/ndb/search/list?fgcd=Branded+Food+Products+Database&ds=Branded+Food+Products.

USDA/HSS. 2010. ‘Dietary Guidelines for Americans’. 7th Edition. Washington, DC: U.S. Government Printing Office: U.S. Department of Agriculture and U.S. Department of Health and Human Services.

Vanham, D, F Bouraoui, A Leip, B Grizzetti, and G Bidoglio. 2015. ‘Lost Water and Nitrogen Resources due to EU Consumer Food Waste’. *Environmental Research Letters* 10 (8): 084008. doi:10.1088/1748-9326/10/8/084008.

Vieux, F., N. Darmon, D. Touazi, and L.G. Soler. 2012. ‘Greenhouse Gas Emissions of Self-Selected Individual Diets in France: Changing the Diet Structure or Consuming Less?’ *Ecological Economics* 75 (March): 91–101. doi:10.1016/j.ecolecon.2012.01.003.

Vita, Gibran, Edgar G. Hertwich, Konstantin Stadler, and Richard Wood. 2015. ‘The Environmental Impact of Human Needs’. In .

Vranken, Liesbet, Tessa Avermaete, Dimitrios Petalios, and Erik Mathijs. 2014. ‘Curbing Global Meat Consumption: Emerging Evidence of a Second Nutrition Transition’. *Environmental Science & Policy* 39 (May): 95–106. doi:10.1016/j.envsci.2014.02.009.

Vyncke, Patrick. 2002. ‘Lifestyle Segmentation from Attitudes, Interests and Opinions, to Values, Aesthetic Styles, Life Visions and Media Preferences’. *European Journal of Communication* 17 (4): 445–463.

Wackernagel, Mathis, Larry Onisto, Patricia Bello, Alejandro Callejas Linares, Ina Susana López Falfán, Jesus Méndez Garcı´a, Ana Isabel Suárez Guerrero, and Ma Guadalupe Suárez Guerrero. 1999. ‘National Natural Capital Accounting with the Ecological Footprint Concept’. *Ecological Economics* 29 (3): 375–90. doi:10.1016/S0921-8009(98)90063-5.

Wang, H., D.Q. Zhou, P. Zhou, and D.L. Zha. 2012. ‘Direct Rebound Effect for Passenger Transport: Empirical Evidence from Hong Kong’. *Applied Energy* 92 (April): 162–67. doi:10.1016/j.apenergy.2011.10.027.

Wang, H., P. Zhou, and D.Q. Zhou. 2012. ‘An Empirical Study of Direct Rebound Effect for Passenger Transport in Urban China’. *Energy Economics* 34 (2): 452–60. doi:10.1016/j.eneco.2011.09.010.

Wang, Ranran, and Julie Zimmerman. 2016. ‘Hybrid Analysis of Blue Water Consumption and Water Scarcity Implications at the Global, National, and Basin Levels in an Increasingly Globalized World’. *Environmental Science & Technology* 50 (10): 5143–53. doi:10.1021/acs.est.6b00571.

WBGU. 1995. ‘Scenario for the Derivation of Global CO2 Reduction Targets and Implementation Strategies. Statement on the Occasion of the First Conference of the Parties to the Framework Convention on Climate Change in Berlin’. German Advisory Council on Global Change (WBGU). http://sss.sagepub.com/content/28/2/291.short.

WCED. 1987. *Report of the World Commission on Environment and Development: Our Common Future (The Brundtland Report)*. World Commission on Environment and Sustainable Development. Bungay, Suffolk, UK: Oxford University Press, Oxford. http://www.ask-force.org/web/Sustainability/Brundtland-Our-Common-Future-1987-2008.pdf.

Weber, Christopher L., and H. Scott Matthews. 2008a. ‘Food-Miles and the Relative Climate Impacts of Food Choices in the United States’. *Environmental Science & Technology* 42 (10): 3508–13. doi:10.1021/es702969f.

———. 2008b. ‘Quantifying the Global and Distributional Aspects of American Household Carbon Footprint’. *Ecological Economics* 66 (2–3): 379–91. doi:10.1016/j.ecolecon.2007.09.021.

Wellesley, Laura, Catherine Happer, and Antony Froggatt. 2015. *Changing Climate, Changing Diets: Pathways to Lower Meat Consumption:*

Westhoek, Henk. 2011. *The Protein Puzzle: The Consumption and Production of Meat, Dairy and Fish in the European Union*. The Hague: PBL Netherlands Environmental Assessment Agency.

Westhoek, Henk, Jan Peter Lesschen, Trudy Rood, Susanne Wagner, Alessandra De Marco, Donal Murphy-Bokern, Adrian Leip, Hans van Grinsven, Mark A. Sutton, and Oene Oenema. 2014. ‘Food Choices, Health and Environment: Effects of Cutting Europe’s Meat and Dairy Intake’. *Global Environmental Change* 26 (May): 196–205. doi:10.1016/j.gloenvcha.2014.02.004.

Wevolve. 2013. ‘Future Lifestyles in Europe and in the United States in 2020’. Trend report for the Horizon 2020 programme. European Commission.

Wilson, Jeffrey, Peter Tyedmers, and Jamie E. L. Spinney. 2013. ‘An Exploration of the Relationship between Socioeconomic and Well-Being Variables and Household Greenhouse Gas Emissions: Drivers of Household Greenhouse Gas Emissions’. *Journal of Industrial Ecology* 17 (6): 880–91. doi:10.1111/jiec.12057.

Wood, Richard, Daniel Moran, Konstantin Stadler, Diana Ivanova, Kjartan Steen-Olsen, and Edgar G. Hertwich. 2015. ‘Prioritizing Consumption-Based Carbon Policies Based on the Evaluation of Mitigation Potential’. In review.

Wood, Richard, Konstantin Stadler, Tatyana Bulavskaya, Stephan Lutter, Stefan Giljum, Arjan de Koning, Jeroen Kuenen, et al. 2014. ‘Global Sustainability Accounting—Developing EXIOBASE for Multi-Regional Footprint Analysis’. *Sustainability* 7 (1): 138–63. doi:10.3390/su7010138.

Wyckoff, Andrew W., and Joseph M. Roop. 1994. ‘The Embodiment of Carbon in Imports of Manufactured Products: Implications for International Agreements on Greenhouse Gas Emissions’. *Energy Policy* 22 (3): 187–194.

Zidanšek, Aleksander. 2007. ‘Sustainable Development and Happiness in Nations’. *Third Dubrovnik Conference on Sustainable Development of Energy, Water and Environment Systems* 32 (6): 891–97. doi:10.1016/j.energy.2006.09.016.

Appendix

A1. SPECIFICATION OF APPLIED CHANGES

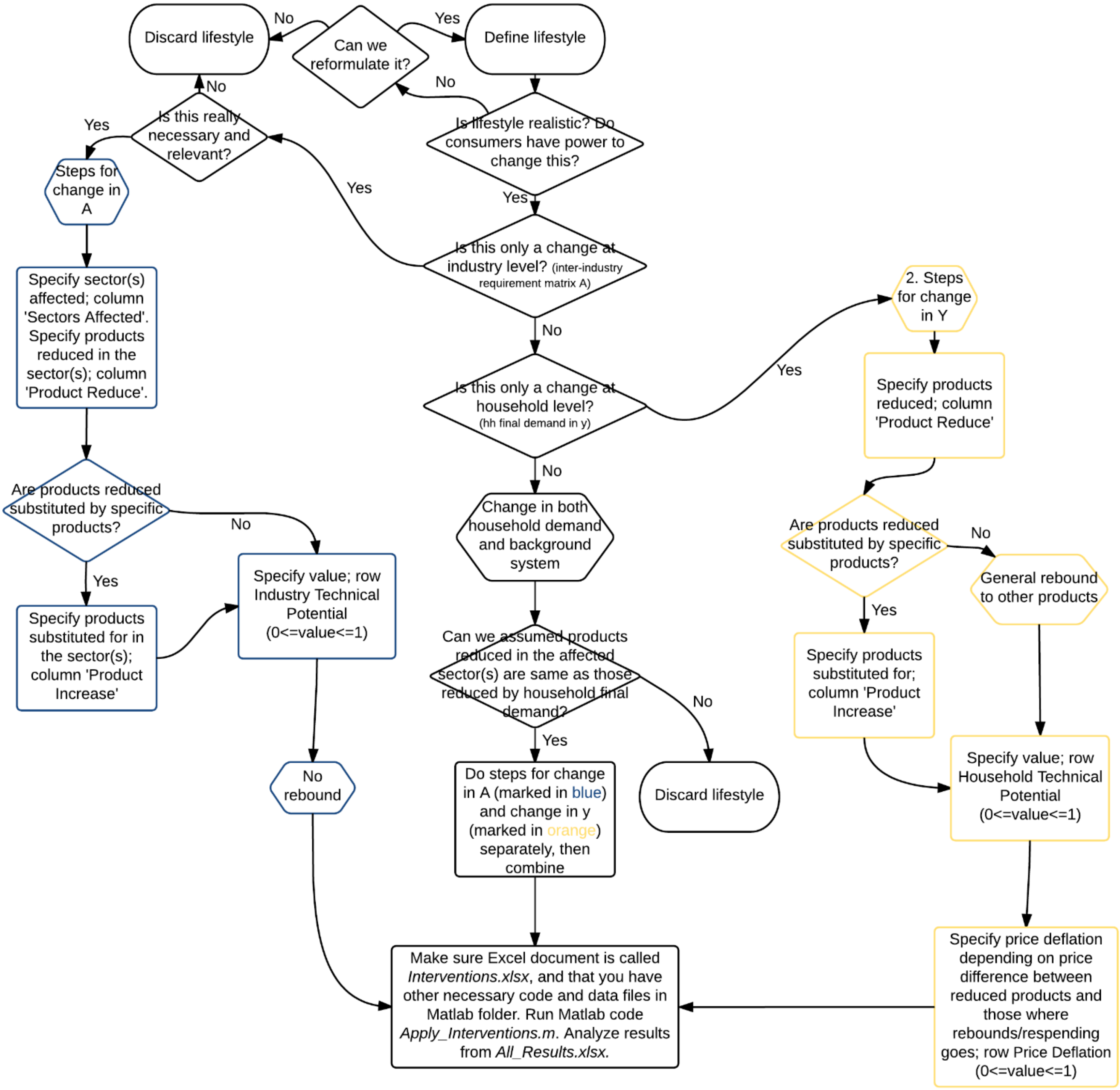

Figure 14. Flowchart for application and use of the model

A2. LIFESTYLE RESULTS

Table 7. Change in EU household carbon, toxicity, water, and land footprint, as well as household final demand (HHFD), caused by different lifestyles. ***No rebound effect****.*

	Carbon (kg CO_2-eq)		Toxicity (kg 1,4-dichlorobenze)		Water (Mm^3)		Land (km^2)		HHFD (Million Euros)	
Low Use	-1,12E+11	-1,77%	-1,29E+11	-2,50%	-4320	-2,13%	-2,22E+05	-2,13%	-1,04E+05	-1,54%
Vegan	5,13E+10	0,81%	2,76E+10	0,53%	1003	0,50%	1,29E+05	1,23%	0	0
Natural Fiber	1,67E+09	0,03%	6,62E+09	0,13%	568	0,28%	3,05E+04	0,29%	0	0
Local Clothing	-3,03E+10	-0,48%	-8,85E+10	-1,71%	-999	-0,49%	-2,72E+04	-0,26%	0	0
Repair Renovate	4,33E+10	0,68%	-1,26E+11	-2,45%	-1927	-0,95%	1,13E+06	10,78%	0	0
No Renovation	-1,14E+11	-1,80%	-6,68E+10	-1,29%	-1044	-0,52%	-3,66E+05	-3,50%	-6,78E+04	-1,00%
Natural Materials	-2,91E+10	-0,46%	-2,96E+09	-0,06%	-4	0%	1,50E+05	1,44%	0	0
Concrete Renovation	4,87E+10	0,77%	2,98E+09	0,06%	-17	-0,01%	-3,07E+05	-2,94%	0	0
Mediterranean Diet	-1,73E+11	-2,73%	-1,1E+10	-0,22%	918	0,45%	6,37E+03	0,06%	-3,01E+04	-0,44%
Unprocessed	4,84E+11	7,65%	6,65E+10	1,29%	7145	3,53%	2,75E+05	2,63%	2,85E+04	0,42%
Vegetarian	-4,07E+11	-6,44%	-1,5E+11	-3,00%	-358	-0,18%	-5,97E+04	-0,57%	-1,64E+05	-2,42%
Vegan	-8,82E+11	-13,93%	-4,7E+11	-9,04%	-29990	-14,80%	-4,91E+05	-4,70%	-6,45E+05	-9,52%
Healthy Vegan	-9,93E+11	-15,69%	-6,2E+11	-12,04%	-19626	-9,69%	3,00E+05	2,87%	-8,91E+05	-13,16%
Careless Consumer	2,18E+11	3,44%	1,78E+11	3,45%	12630	6,23%	-2,45E+05	-2,34%	2,45E+05	3,62%
Eat Less	-3,12E+11	-4,94%	-1,3E+11	-2,57%	-32415	-16,00%	-1,51E+06	-14,43%	-1,91E+05	-2,82%
Restaurant Food	-6,90E+11	-10,90%	-6,74E+10	-1,31%	-95298	-47,04%	-3,85E+06	-36,84%	0	0
Local Food	-3,72E+10	-0,59%	-1,88E+11	-3,63%	-279	-0,14%	-1,53E+04	-0,15%	0	0
Organic Food	-1,11E+11	-1,75%	-5,41E+10	-1,05%	-2567	-1,27%	-8,59E+04	-0,82%	0	0
Seasonal Food	-3,57E+09	-0,06%	-8,43E+08	-0,02%	-19	-0,01%	-4,24E+03	-0,04%	0	0
No Waste	-1,32E+11	-2,09%	-5,78E+10	-1,12%	-14366	-7,09%	-5,78E+05	-5,53%	-8,40E+04	-1,24%
No Chemicals	-2,47E+11	-3,91%	-2,04E+11	-3,95%	-8938	-4,41%	-2,78E+05	-2,66%	-1,14E+05	-1,69%
Low Tech	-9,69E+10	-1,53%	-1,04E+11	-2,01%	-1235	-0,61%	-6,13E+04	-0,59%	-1,05E+05	-1,56%
No Media	-9,35E+10	-1,48%	-1,02E+11	-1,98%	-1431	-0,71%	-1,05E+05	-1,01%	-1,26E+05	-1,87%
Share Repair	-2,71E+11	-4,28%	-3,18E+11	-6,16%	-5041	-2,49%	-2,87E+05	-2,75%	-4,97E+05	-7,34%
Bike Walk Full	-1,65E+12	-26,02%	-7,35E+11	-14,24%	-7142	-3,53%	-3,95E+05	-3,78%	-7,69E+05	-11,36%
Flex Work Half	-8,24E+11	-13,01%	-3,68E+11	-7,12%	-3571	-1,76%	-1,97E+05	-1,89%	-3,85E+05	-5,68%

Flex Work Half ER	-5,61E+11	-8,86%	-3,15E+11	-6,10%	-2518	-1,24%	1,06E+05	1,01%	-3,08E+05	-4,54%
Less Mobility Half	-9,17E+11	-14,48%	-1,06E+12	-20,44%	-3859	-1,90%	-2,14E+05	-2,05%	-4,25E+05	-6,28%
Collective Transport	-5,11E+11	-8,07%	2,15E+12	41,69%	-1293	-0,64%	-8,46E+04	-0,81%	0	0
Renewable Fuels	-7,65E+11	-12,08%	-7,17E+10	-1,39%	10688	5,28%	6,11E+05	5,85%	0	0
No Flying	-1,45E+11	-2,30%	-5,06E+10	-0,98%	-458	-0,23%	-2,66E+04	-0,25%	-6,63E+04	-0,98%
No Flying TR	-1,01E+10	-0,16%	1,63E+11	3,15%	122	0,06%	5,32E+03	0,05%	0	0
Flying Biker	-3,96E+09	-0,06%	-6,86E+10	-1,33%	-772	-0,38%	-3,54E+04	-0,34%	0	0
Frequent Flyer	1,55E+11	2,45%	1,53E+09	0,03%	-770	-0,38%	-6,15E+04	-0,59%	0	0
Green Cars	2,94E+11	4,64%	-2,70E+11	-5,24%	3808	1,88%	1,19E+05	1,13%	0	0
Local	-3,38E+11	-5,33%	-1,48E+11	-2,87%	-1478	-0,73%	-8,24E+04	-0,79%	-1,19E+05	-1,76%
Hedonist	6,14E+10	0,97%	1,27E+11	2,45%	3420	1,69%	1,14E+05	1,09%	0	0
Play It Safe	-2,08E+11	-3,28%	-3,95E+11	-7,64%	-9869	-4,87%	-5,39E+05	-5,16%	0	0
Home Based	-1,94E+11	-3,06%	-1,23E+12	-23,79%	-13451	-6,64%	-3,76E+05	-3,60%	0	0
Low Services	-1,13E+12	-17,77%	-1,11E+12	-21,53%	-32065	-15,83%	-1,52E+06	-14,58%	-3,21E+06	-47,36%
High Services	-1,53E+11	-2,42%	-1,29E+11	-2,50%	-1172	-0,58%	-1,39E+05	-1,33%	0	0
Green Home	-4,37E+11	-6,89%	1,1E+11	2,14%	2711	1,34%	1,18E+07	112,77%	3,46E+04	0,51%
Green Electricity	-1,84E+11	-2,91%	-1,1E+10	-0,21%	233	0,12%	3,24E+05	3,11%	1,25E+04	0,19%
Fossil Fuel	5,00E+11	7,90%	6,58E+10	1,27%	30	0,01%	-7,46E+05	-7,15%	2,08E+04	0,31%
Tecno Ecovillage	-5,57E+11	-8,79%	-6,9E+10	-1,34%	89	0,04%	5,78E+06	55,38%	-1,10E+05	-1,62%
Full Ecovillage	-8,71E+11	-13,76%	-2,5E+11	-4,89%	-5369	-2,65%	-5,14E+05	-4,92%	-3,15E+05	-4,65%
Water Off Grid	-2,99E+10	-0,47%	-1,1E+10	-0,20%	-173	-0,09%	-1,01E+04	-0,10%	-2,72E+04	-0,40%
Passive House	-3,53E+11	-5,58%	-9,6E+10	-1,86%	-2160	-1,07%	-5,24E+05	-5,02%	-1,10E+05	-1,63%
Consumption Categories:										
Clothing	-2,20E+11	-3,48%	-2,35E+11	-4,55%	-9787	-4,83%	-4,35E+05	-4,16%	-2,01E+05	-2,97%
Construction	-6,18E+10	-0,98%	-3,99E+10	-0,77%	-656	-0,32%	-2,78E+05	-2,66%	-7,54E+04	-1,11%
Food	-1,10E+12	-17,43%	-4,82E+11	-9,33%	-119714	-59,09%	-4,81E+06	-46,10%	-7,00E+05	-10,33%
Manufactured Products	-2,66E+11	-4,20%	-2,83E+11	-5,47%	-5875	-2,90%	-7,22E+05	-6,92%	-3,27E+05	-4,83%
Mobility	-1,83E+12	-28,96%	-2,11E+12	-40,88%	-7719	-3,81%	-4,28E+05	-4,10%	-8,51E+05	-12,56%
Services	-1,41E+12	-22,22%	-1,39E+12	-26,91%	-40081	-19,78%	-1,90E+06	-18,22%	-4,01E+06	-59,20%
Shelter	-1,44E+12	-22,73%	-6,24E+11	-12,08%	-18764	-9,26%	-1,86E+06	-17,84%	-6,09E+05	-8,99%
Total household emissions	**6,33+12**	100%	**5,16E+12**	100%	**202596**	100%	**1,04E+07**	100%	**6,77E+06**	100%

Table 8. Change in EU household carbon, toxicity, water, and land footprint, as well as household final demand (HHFD), caused by different lifestyles. ***With rebound effect.***

	Carbon (kg CO_2-eq)		Toxicity (kg 1,4-dichlorobenze)		Water (Mm^3)		Land (km^2)		HHFD (Million Euros)	
Low Use	-1,58E+10	-0,25%	-5,02E+10	-0,97%	-1312	-0,65%	-6,58E+04	-0,63%	0	0
Vegan	5,13E+10	0,81%	2,76E+10	0,53%	1003	0,50%	1,29E+05	1,23%	0	0
Natural Fiber	1,67E+09	0,03%	6,62E+09	0,13%	568	0,28%	3,05E+04	0,29%	0	0
Local Clothing	-3,03E+10	-0,48%	-8,85E+10	-1,71%	-999	-0,49%	-2,72E+04	-0,26%	0	0
Repair Renovate	4,33E+10	0,68%	-1,26E+11	-2,45%	-1927	-0,95%	1,13E+06	10,78%	0	0
No Renovation	-4,67E+10	-0,74%	-1,89E+10	-0,37%	1016	0,50%	-2,62E+05	-2,50%	0	0
Natural Materials	-2,91E+10	-0,46%	-2,96E+09	-0,06%	-4	0%	1,50E+05	1,44%	0	0
Concrete Renovation	4,87E+10	0,77%	2,98E+09	0,06%	-17	-0,01%	-3,07E+05	-2,94%	0	0
Mediterranean Diet	-1,46E+11	-2,31%	1,24E+10	0,24%	1253	0,62%	3,29E+04	0,31%	0	0
Unprocessed	4,84E+11	7,65%	6,65E+10	1,29%	7145	3,53%	2,75E+05	2,63%	2,85E+04	0,42%
Vegetarian	-2,62E+11	-4,14%	-2,59E+10	-0,50%	1482	0,73%	8,48E+04	0,81%	0	0
Vegan	-3,10E+11	-4,89%	4,04E+10	0,78%	-22638	-11,17%	8,21E+04	0,79%	0	0
Healthy Vegan	-2,01E+11	-3,17%	7,95E+10	1,54%	-8792	-4,34%	1,12E+06	10,72%	0	0
Careless Consumer	2,18E+11	3,44%	1,78E+11	3,45%	12630	6,23%	-2,45E+05	-2,34%	2,45E+05	3,62%
Eat Less	-1,37E+11	-2,17%	1,43E+10	0,28%	-29785	-14,70%	-1,35E+06	-12,93%	0	0
Restaurant Food	-6,90E+11	-10,90%	-6,74E+10	-1,31%	-95298	-47,04%	-3,85E+06	-36,84%	0	0
Local Food	-3,72E+10	-0,59%	-1,88E+11	-3,63%	-279	-0,14%	-1,53E+04	-0,15%	0	0
Organic Food	-1,11E+11	-1,75%	-5,41E+10	-1,05%	-2567	-1,27%	-8,59E+04	-0,82%	0	0
Seasonal Food	-3,57E+09	-0,06%	-8,43E+08	-0,02%	-19	-0,01%	-4,24E+03	-0,04%	0	0
No Waste	-5,46E+10	-0,86%	6,88E+09	0,13%	-13205	-6,52%	-4,98E+05	-4,77%	0	0
No Chemicals	-1,44E+11	-2,28%	-1,22E+11	-2,37%	-5774	-2,85%	-1,06E+05	-1,01%	0	0
Low Tech	1,04E+09	0,02%	-2,39E+10	-0,46%	1838	0,91%	1,01E+05	0,97%	0	0
No Media	2,53E+10	0,40%	-3,95E+09	-0,08%	2239	1,11%	8,93E+04	0,86%	0	0
Share Repair	2,37E+11	3,74%	8,24E+10	1,60%	11852	5,85%	5,81E+05	5,57%	0	0
Bike Walk Full	-1,06E+12	-16,79%	-1,78E+11	-3,45%	17619	8,70%	8,81E+05	8,44%	0	0
Flex Work Half	-5,32E+11	-8,40%	-8,91E+10	-1,73%	8809	4,35%	4,41E+05	4,22%	0	0
Flex Work Half ER	-3,62E+11	-5,72%	-9,17E+10	-1,78%	7619	3,76%	5,89E+05	5,64%	0	0
Less Mobility Half	-6,04E+11	-9,54%	-8,39E+11	-16,25%	9884	4,88%	4,94E+05	4,73%	0	0
Collective Transport	-5,11E+11	-8,07%	2,15E+12	41,69%	-1293	-0,64%	-8,46E+04	-0,81%	0	0

Renewable Fuels	-7,65E+11	-12,08%	-7,17E+10	-1,39%	10688	5,28%	6,11E+05	5,85%	0	0
No Flying	-8,79E+10	-1,39%	3,11E+09	0,06%	1397	0,69%	6,85E+04	0,66%	0	0
No Flying TR	-1,01E+10	-0,16%	1,63E+11	3,15%	122	0,06%	5,32E+03	0,05%	0	0
Flying Biker	-3,96E+09	-0,06%	-6,86E+10	-1,33%	-772	-0,38%	-3,54E+04	-0,34%	0	0
Frequent Flyer	1,55E+11	2,45%	1,53E+09	0,03%	-770	-0,38%	-6,15E+04	-0,59%	0	0
Green Cars	2,94E+11	4,64%	-2,70E+11	-5,24%	3808	1,88%	1,19E+05	1,13%	0	0
Local	-2,49E+11	-3,93%	-6,22E+10	-1,20%	2200	1,09%	1,08E+05	1,04%	0	0
Hedonist	6,14E+10	0,97%	1,27E+11	2,45%	3420	1,69%	1,14E+05	1,09%	0	0
Play It Safe	-2,08E+11	-3,28%	-3,95E+11	-7,64%	-9869	-4,87%	-5,39E+05	-5,16%	0	0
Home Based	-1,94E+11	-3,06%	-1,23E+12	-23,79%	-13451	-6,64%	-3,76E+05	-3,60%	0	0
Low Services	4,58E+12	72,41%	3,37E+12	65,19%	159947	78,95%	8,50E+06	81,39%	0	0
High Services	-1,53E+11	-2,42%	-1,29E+11	-2,50%	-1172	-0,58%	-1,39E+05	-1,33%	0	0
Green Home	-4,37E+11	-6,89%	1,10E+11	2,14%	2711	1,34%	1,18E+07	112,77%	34593	0,51%
Green Electricity	-1,84E+11	-2,91%	-1,08E+10	-0,21%	233	0,12%	3,24E+05	3,11%	12542	0,19%
Fossil Fuel	5,00E+11	7,90%	6,58E+10	1,27%	30	0,01%	-7,46E+05	-7,15%	20756	0,31%
Tecno Ecovillage	-5,57E+11	-7,33%	1,46E+10	0,28%	89	1,70%	5,94E+06	56,92%	0	0
Full Ecovillage	-8,71E+11	-9,53%	-1,21E+10	-0,23%	-5369	1,93%	-3,61E+04	-0,35%	0	0
Water Off Grid	-2,99E+10	-0,08%	1,03E+10	0,20%	-173	0,33%	3,18E+04	0,30%	0	0
Passive House	-3,53E+11	-4,09%	-1,17E+10	-0,23%	-2160	0,55%	-3,69E+05	-1,26%	0	0
Clothing	-2,20E+11	-0,52%	-2,35E+11	-1,62%	-3912	-1,93%	-1,31E+05	-1,26%	0	0
Construction	-6,18E+10	0,22%	-3,99E+10	0,26%	1638	0,81%	-1,61E+05	-1,54%	0	0
Food	-1,10E+12	-7,19%	-4,82E+11	1,11%	-110043	-54,32%	-4,15E+06	-39,73%	0	0
Manufactured Products	-2,66E+11	0,64%	-2,83E+11	-0,61%	3733	1,84%	-2,33E+05	-2,23%	0	0
Mobility	-1,83E+12	-19,08%	-2,11E+12	-32,50%	19769	9,76%	9,88E+05	9,46%	0	0
Services	-1,41E+12	90,51%	-1,39E+12	81,49%	199933	98,69%	1,06E+07	101,74%	0	0
Shelter	-1,44E+12	-15,06%	-6,24E+11	-3,42%	-1084	-0,53%	-1,02E+06	-9,80%	0	0

Table 9. Change in EU household footprint of carbon for different scenarios including/excluding rebound and adjustment of calories/energy use (for full explanation, see chapter 3.2.3 Calorie Intake and Energy Use Adjustments).

	Carbon (kg CO_2-eq)				**Carbon (%)**			
	No Rebound, No Food/Energy Adj	No Rebound, Food/Energy Adj	With Rebound, Food/Energy Adj	Rebound & Inv. Rebound, Food/Energy Adj	No Rebound, No Food/Energy Adj	No Rebound, Food/Energy Adj	With Rebound, Food/Energy Adj	Rebound & Inv. Rebound, Food/Energy Adj
Mediterranean Diet	-1,45E+11	-1,73E+11	-1,46E+11	-1,46E+11	-2,29%	-2,73%	-2,31%	-2,31%
Unprocessed	4,22E+11	4,84E+11	4,84E+11	4,59E+11	6,67%	7,65%	7,65%	7,25%
Vegetarian	-2,28E+11	-4,07E+11	-2,62E+11	-2,62E+11	-3,59%	-6,44%	-4,14%	-4,14%
Vegan	-1,68E+11	-8,82E+11	-3,10E+11	-3,10E+11	-2,65%	-13,93%	-4,89%	-4,89%
Healthy Vegan	3,15E+10	-9,93E+11	-2,01E+11	-2,01E+11	0,50%	-15,69%	-3,17%	-3,17%
Careless Consumer	-1,25E+11	2,18E+11	2,18E+11	2,48E+08	-1,97%	3,44%	3,44%	0,00%
Green Home	-5,26E+11	-4,37E+11	-4,37E+11	-4,66E+11	-8,31%	-6,89%	-6,89%	-7,36%
Green Electricity	-2,45E+11	-1,84E+11	-1,84E+11	-1,95E+11	-3,87%	-2,91%	-2,91%	-3,08%
Fossil Fuel	2,76E+11	5,00E+11	5,00E+11	4,82E+11	4,36%	7,90%	7,90%	7,62%
Tecno Ecovillage	-2,56E+11	-5,57E+11	-4,64E+11	-4,64E+11	-4,05%	-8,79%	-7,33%	-7,33%