Department of Design

A sustainable level of material footprint — Benchmark for designing one-planet lifestyles

Michael Lettenmeier

Aalto University

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Abstract

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Abstract

This thesis justifies and develops a sustainable level of Lifestyle Material Footprint (LMF) as a benchmark for designing sustainable lifestyles. It shows the application of the benchmark in a Household-level Sustainability Transition method and presents a framework for inspiring design solutions towards a Design for One Planet (Df1P).

The thesis shows how the Material Input per unit of Service (MIPS) concept has developed from product orientation to the application to household consumption and from technically-focused measurement into an integral part of methods for designing one-planet lifestyles and supporting solutions. This provides both an advanced application of the concept and its opening to new purposes and users.

The core of the thesis is the suggestion of a sustainable material footprint benchmark of 8 tonnes per person per year as a resource cap target for household consumption in Finland, an 80% (factor 5) reduction from present average. The 8 tonnes benchmark opens the possibility for a target-oriented, planned reduction of LMFs by target-setting, experimenting and up-scaling of sustainable solutions. The method enabled the participating households to perform footprint reductions of 26–54% during the one-month experiment phase. Notable footprint reductions are thus possible even in the short term, which is an important message to other households and other actors in society. Calculating households' LMFs makes visible the structures underlying household consumption and the need for change not only in household consumption but also in the supply of products, services and infrastructure, and thus systemic changes initiated by others than households.

The orientation framework of Df1P suggests measures that could be promoted by means of design, and structures them in a matrix incorporating priority action areas in the fields of housing, nutrition and mobility, and the domains of product design, service design, infrastructure planning and communication design. Mainstreaming sustainable lifestyles will potentially require a new design culture, but at least significant efforts in product design, service design and infrastructure planning as well as in making sustainable solutions attractive to consumers and disrupting existing routines. The more technology and infrastructure can be integrated into this change, the more space will be left for individual diversity in achieving sustainable household consumption. The orientation framework could provide a first step towards Df1P practice by inspiring designers to integrate the recognition of the planetary boundaries into their work.

Keywords Material Footprint, MIPS, natural resources, household, consumption, lifestyle, sustainable production and consumption, SCP, resource-efficiency, sufficiency, resource cap, transition, design

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Tekijä
Michael Lettenmeier

Väitöskirjan nimi
Materiaalijalanjäljen kestävä taso –
mittapuu yhden planeetan elämäntapojen toteuttamiseen

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Tiivistelmä
Tämä väitöskirja perustelee ja kehittää kotitalouksien materiaalijalanjäljen kestävän luonnonvarojen kulutuksen tason mittapuuksi kestävien elämäntapojen muotoiluun. Kirja näyttää, miten kotitaloudet ovat käyttäneet mittapuuta siirtyäkseen kohti yhden planeetan elämäntapoja ja esittelee kehikon, jonka avulla voidaan hakea inspiraatiota yhden planeetan elämäntapoja edistävien ratkaisujen suunnitteluun.
Kirja näyttää, miten MIPS-käsitettä (Material Input per unit of Service) on kehitetty tuotetasolta kotitaloustasolle ja samalla teknisluonteisesta mittarista kiinteäksi osaksi yhden planeetan elämäntapojen ja niitä tukevien ratkaisujen suunnittelua.
Väitöskirjan ydin on ehdotus suomalaisten kotitalouksien kestävän vuosittaisen materiaalijalanjäljen 8 tonnin mittapuuksi. Tämä edellyttää kotitalouksien luonnonvarojen käytön keskimääräisen tason pudottamista viidesosaan nykyisestä (factor 5). Kotitalouksien materiaalijalanjäljen pudottaminen etenee kotitalouksien materiaalijalanjälkien laskemisesta tiekarttojen laadintaan ja uusien toimenpiteiden ja rutiinien kokeilemiseen. Menettelyn avulla pilottiin osallistuneet kotitaloudet pudottivat materiaalijalanjälkiään 26–54 prosentilla kuukauden aikana. Kotitaloudet voivat siis pudottaa jalanjälkiään lyhyelläkin tähtäimellä huomattavasti. Kotitalouksien materiaalijalanjälkien laskenta tuo myös näkyviin kulutuksen taustalla olevia rakenteita sekä muutostarpeita tuotteiden, palvelujen ja infrastruktuurien tarjonnassa sekä laajemmalla järjestelmätasolla.
Yhden planeetan suunnittelun (Design for One Planet, Df1P) suunnittelukehikko ehdottaa toimenpiteitä, joita muotoilun ja suunnittelun keinoin voitaisiin edistää. Kehikko jäsentää toimenpiteet matriisiin, joka koostuu päätoimintalinjoista asumisen, syömisen ja liikkumisen toiminta-alueilla ja yhdistää niitä tuotesuunnitteluun, palvelumuotoiluun, infrastruktuurin suunnitteluun ja viestinnän suunnitteluun. Kestävien elämäntapojen kehittäminen valtavirraksi edellyttää mahdollisesti uutta suunnittelukulttuuria, mutta ainakin huomattavia ponnisteluja tuotesuunnittelussa, palvelumuotoilussa, infrastruktuurin suunnittelussa sekä uusien ratkaisujen saattamisessa kuluttajille houkutteleviksi, jotta nämä pystyvät muuttamaan rutiinejansa kestävälle pohjalle. Mitä enemmän tekniikkaa ja infrastruktuuria pystytään yhdistämään tähän muutokseen, sitä enemmän ja monipuolisemmin jää tilaa yksilöllisille ratkaisuille kestävissä elämäntavoissa. Suunnittelukehikon tarkoitus on innostaa muotoilijoita ja suunnittelijoita ottamaan huomioon planetaariset rajat omassa työssään ja auttaa heitä keskittymään kestävän kulutuksen olennaisiin osa-alueisiin.

Avainsanat Materiaalijalanjälki, MIPS, luonnonvarat, kestävä kulutus ja tuotanto (kultu), resurssitehokkuus, resurssiviisaus, kohtuullisuus, kotitalous, kulutus, elämäntapa, ylikulutus, kulutuskatto, siirtymä, suunnittelu, muotoilu

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Helsinki in April 2018, *Michael Lettenmeier*

Table of contents

List of figures and tables

Abbreviations

CF: Carbon Footprint

Df1P: Design for One Planet

DfS: Design for Sustainability

DMC: Direct Material Consumption

DMI: Direct Material Input

EF: Ecological Footprint

GFN: Global Footprint Network

HSA: Hot Spot Analysis

HST: Household-level Sustainability Transition

LMF: Lifestyle Material Footprint

MF: Material Footprint

MIPS: Material Input per Unit of Service

REPA: Resource Efficiency Potential Analysis

RMC: Raw Material Consumption

RMI: Raw Material Input

TMC: Total Material Consumption

TMR: Total Material Requirement

UN: United Nations

WBCSD: World Business Council for Sustainable Development

WWF: World Wildlife Fund

List of original papers

1. Liedtke, C., Bienge, K., Wiesen, K., Teubler, J., Greiff, K., Lettenmeier, M., Rohn, H. 2014. Resource Use in the Production and Consumption System—The MIPS Approach. Resources, 3(3), 544-574.

2. Liedtke, C., Baedeker, C., Kolberg, S., Lettenmeier, M. 2010. Resource intensity in global food chains: the Hot Spot Analysis. British Food Journal, 112(10), 1138-1159.

3. Mancini, L., Lettenmeier, M., Rohn, H., Liedtke, C. 2012. Application of the MIPS method for assessing the sustainability of production-consumption systems of food. Journal of Economic Behavior & Organization, 81(3), 779-793.

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6. Lettenmeier, M., Liedtke, C., Rohn, H. 2014. Eight Tons of Material Footprint—Suggestion for a Resource Cap for Household Consumption in Finland. Resources, 3(3), 488-515.

7. Laakso, S., Lettenmeier, M. 2016. Household-level transition methodology towards sustainable material footprints. Journal of Cleaner Production 132, 184-191.

8. Lettenmeier, M. 2018. Design for One Planet – An orientation framework. Unpublished, in review.

Contribution of the author to the papers

Paper 1: The author contributed in several stages of the writing and internal reviewing processes by adding his experience and examples from developing further the MIPS approach in several parts of the paper, by conducting MIPS studies and by his knowledge in data gathering, calculating and interpreting MIPS results.

Paper 2: The author presented the preliminary version of the paper at the 2nd International European Forum on System Dynamics and Innovation in Food Networks. The author was responsible for redrafting the paper for the British Food Journal, for writing the MIPS- and LCA-related parts and for compiling Table 1 of the paper.

Paper 3: The author contributed strongly in designing the research and the paper and in editing the text during the internal and external review rounds.

Paper 4: The author designed the research together with the co-authors. He designed and wrote the paper. He presented the preliminary version of the paper at the World Resources Forum 2011 and was the corresponding author to the conference and the journal.

Paper 5: The author designed the paper together with the co-authors. The author wrote sections 1.1, 1.2, 2.1 and 3.1 and made the material footprint calculations for the paper. He contributed in editing, internal reviews and writing conclusions together with the co-authors.

Paper 6: The author developed the idea and the concept of the resource cap. He did the calculations and the best practice collection behind the paper, and has contributed in different forms to most of the research related to the best practice examples. He wrote the vast part of the paper. He coordinated the internal and official review rounds, edited the revisions except the very last confirmation round and was the corresponding author to the journal.

Paper 7: The author was main responsible for designing and coordinating the project, as well as the household consumption surveys and the material footprint calculations during different stages of the project. The author and the co-author together designed and wrote the paper, with a special responsibility of the author for the material footprint results and of the co-author for the households' interviews' results. Both author and co-author participated in several internal and official review rounds.

Paper 8: The author developed the Df1P orientation framework and solely authored the paper.

1. Introduction

During the coming years and decades, we are going to face one of the biggest lifestyle changes in human history, the transition to sustainable lifestyles. This transition has to build up the ability of using natural resources within the earth's ecological limits while allowing a good life for all humans on earth. Natural resource use by the human economy has been constantly growing for decades, and the overconsumption of natural resources is obvious in terms of environmental impacts (e.g. Krausmann et al. 2009, Dittrich et al. 2012, Wiedmann et al. 2015, Schandl et al. 2016).

We have to manage a huge transition in a relatively short time period. This calls for decisions that can be made relatively speedily on the basis of existing knowledge. This knowledge would benefit from a sufficiently scientific basis in order to allow relevant and effective decisions into the right direction. For instance, Cooper (2000) calls for improved data in order to quantify the scale of the substantial change we are going to face and remembers that sustainable consumption requires attention to the impacts of all instead of just a limited range of products. Therefore, in order to design and implement solutions for this transition, we need an indicator system that is comprehensive and understandable, as well as suitable for setting targets and implementing action on different levels. This purpose of this thesis is to show that the creation of such a system is possible. The MIPS (material input per unit of service) indicator this thesis is based on covers a relevant and understandable measure of environmental sustainability, the material use by the human economy (papers 1, 2). It can be applied on lifestyles on the level of both overview (paper 4) and detailed insights (papers 3, 4). It allows setting overall (papers 6 and 7) and detailed (papers 5 and 6) targets which can be used for implementation with households (paper 7) and other relevant actors (paper 8).

The thesis shows the conceptual development of the MIPS indicator from the product-focused (papers 1, 2, 3) to the household and lifestyle (papers 3, 4) level. It describes the setting of the eight tonnes sustainability target (papers 5, 6) and ways for implementing the target in households (paper 7). As households are not just drivers of their own but influenced by numerous external factors and actors, the thesis culminates in the introduction of a Design for One Planet (Df1P) orientation framework for both inspiring designers and evaluating design solutions from a one-planet perspective (paper 8).

1.1 Background

This thesis is the results of a long development and research process. It started in the mid 1990s. I worked on waste prevention and its implementation into society with the team of Eija Koski at the Finnish Association for Nature Conservation when I read Schmidt-Bleek's (1993c) first book on MIPS (Material Input Per unit of Service). While discussing the content and message of the book with the team we noticed that MIPS and resource-efficiency could be useful concepts for making waste prevention concrete by shifting the focus from the output of waste to the resource input into the human economy. We quickly started co-operation with the Wuppertal Institute and utilising the MIPS concept in our communication and advocacy projects. My Finnish translation and edition (Schmidt-Bleek and Lettenmeier 2000) of Schmidt-Bleek's MIPS books (Schmidt-Bleek 1993c, Schmidt-Bleek and Bierter 1997) was published at the kick-off event of the Factor X project with 25 Finnish companies and other organisations testing the application of the MIPS concept (Autio and Lettenmeier 2002). Based on the experiences of that project we[1] started to further improve the conditions for using the MIPS concept in Finland by producing new and improving existing data, providing guidance and applying MIPS calculation on new fields like construction, transportation and waste prevention and management (e.g. Ritthoff et al. 2004, Sinivuori and Saari 2006, Lähteenoja et al. 2006, Lettenmeier and Salo 2009).

On the basis of those projects with different sectors and companies involved, I started to realize that in order to effectively reduce natural resource use, the viewpoint on single companies, products or activities might not be sufficient. In order to shape a bigger picture of the relevance and the potentials of different products and activities in terms of sustainable resource use, I started to ask about their relevance in terms of household consumption. I initiated and coordinated the project FIN-MIPS Household (Kotakorpi et al. 2008). Here, we still had to establish a database for the MIPS calculation of households by calculating MIPS values for numerous household-related goods and activities. On the basis of this we were able to calculate the Lifestyle Material Footprints (LMFs) of 27 Finnish households – and to become surprised by the huge differences in the level and composition of these households' footprints (at that time called ecological backpacks). In the focus group discussions at the end of the project households asked for target levels to reduce their material footprints but at that time we only were able to make general statements like the requirement for a factor 4 or factor 10 reduction at least from the average Finnish household's level.

A couple of years later I was invited to participate in different parts of the SPREAD project on European sustainable lifestyles in 2050. During a workshop at the Politecnico di Milano I found myself confronted with a huge amount of

1 In the course of this thesis, I am frequently writing about different things we have done. 'We' means myself in cooperation with many people involved in the different projects as researchers and partners. I have listed many of them in the acknowledgements section and some of them have been co-authors in the publications of this thesis and other publications. I am using the term 'we' because it would be unfair to replace it by 'me' although I have been playing a central role in many of these projects.

suggestions for making lifestyles sustainable without having a sufficient idea of their relevance. This somehow uncomfortable situation inspired me to have a closer look at the global limits of resource use in order to find out a sustainable Lifestyle Material Footprint level and to provide a more concrete idea of what sustainable lifestyle could include. Bringezu's (2009) book chapter provided a basis in terms of sustainable resource use and after testing the idea of a sustainable LMF in a couple of projects and publications (Leppänen et al. 2012, papers 5 and 4) we published a detailed paper on the eight tonnes benchmark for LMF (paper 6). Thanks to this benchmark we were now able to work in a much more focused manner with households and to make transition concrete, again with surprising results concerning the huge and even immediate potentials for decreasing material footprints while even improving quality of life (paper 7, Vähähiilinen 2016, Lettenmeier et al. 2017).

Lifestyle Material Footprints are not only influenced by households but also by a variety of other factors in society, e.g. companies, authorities and infrastructure (Kotakorpi et al. 2008, papers 4, 6, 7). One profession with great influence on our lifestyles are designers because they shape the products, services and infrastructure we are using, as well as the communication on them. Already for years I have had the opportunity of participating one day per year in design students' education at Aalto University (and the former University of Arts and Design Helsinki) and these sessions have always been inspiring. During my years at the Wuppertal Institute (2008 and 2009) I intensified cooperation with designers. Therefore, I applied and was accepted a doctoral candidate at the Department of Design of Aalto University to compile a thesis that combines my earlier work on developing MIPS and the Lifestyle Material Footprint (papers 1, 2, 3, 4) and its eight tonnes benchmark (papers 5, 6, 7) with additional considerations on how designers could approach and support one-planet lifestyles (paper 8).

Haberl et al. (2009) state that the whole humanity cannot become industrialized societies because already with one third of the human population being industrialized, physical constraints in terms of energy, material and land use and the related environmental impacts are materializing. The transition to a new age of human societies is thus inevitable. Haberl et al. (2011) state that the post-industrial society does not provide a sufficient model for that because it has not been able to decrease material and energy flows. They quote Netting's (1993) four attributes characterizing sustainable agro-ecosystems but state that at present it is hard to say what the next transition would look like although it has to happen. This dissertation tries to describe a landing point or, in Brinegzu's (2015) words, a target corridor for that new sociometabolic regime from the perspective of consumption-based material flows. My intention is to show the magnitude, the direction and the feasibility of the transition, give concrete examples of what this transition could mean in terms of consumption, and thus support design actions with a vision of a sustainable future, as called for by Manzini (2015a).

1.2 Objectives and scope

The purpose of this thesis is to determine the basic prerequisites for sustainable lifestyles, products and services in terms of natural resource use and to develop a method for applying them to the design of lifestyles and the services, products and infrastructures contributing to them. The overarching research question is therefore:

What kinds of measures and tools could support design and action for sustainable lifestyles?

In order to answer this question, the following questions have to be answered:

1. What is a scientifically sound and still practicable way of determining the pressure consumption and its components cause on the natural environment?

   The method must be able to indicate impacts of lifestyles as well as single products and services. In order to avoid burden-shifting the method has to cover the entire life-cycle of products, services and lifestyles, and it should be broad in terms of impacts covered.
2. How can this measuring methodology be applied to the complex consumption patterns of private households?

   The methodology must be able to be applied on various levels of production and consumption and must be able to cope with uncertainties and data gaps arising in a field as complex as households and their lifestyles.
3. In which way can sufficiently unambiguous targets for sustainable lifestyles be determined both for household consumption as a whole and for its components? Can these targets be achieved?

   The sustainable level of household consumption has to be allocated to the different consumption components or areas of needs. For the different consumption components, feasibility indications have to be found and assessed while taking into account possible trade-offs and rebound effects between different areas of needs.
4. In which way can that target be applied to households in order to facilitate the concrete transition to sustainable lifestyles?

   The method has to be useful for considering the feasibility of changes in behaviour and lifestyles. The question of how to mainstream changes that early adopters are pioneering has to be taken into account.
5. How can that sustainable lifestyle target be implemented or integrated in design?

   Planetary boundaries have to be made operationable to designers in a way that can support designers' work and inspires designers to develop solutions that facilitate one-planet lifestyles.

The thesis includes eight papers that provide answers to the research questions. Papers 1 and 2 are related to research question 1, with paper 1 introducing the MIPS approach and paper 2 including a comparison of different approaches to assess the life-cycle of products. Papers 3 and 4 mainly respond to question 2 with paper 3 showing the application of MIPS on food products and diets and paper 4 assessing the material footprint of 18 households. Papers 5 and 6 tackle question 3. While paper 5 concentrates on the example of nutrition, paper 6 provides the eight tonnes resource cap benchmark for lifestyles. Paper 7 shows the application of the resource cap benchmark on households in a project context, thus answering research question 4. Paper 8 presents an orientation framework for Design for One Planet, which is a response to question 5.

Figure 1 shows how the eight papers build on and relate to each other. Papers 1 and 2 deal with the assessment of environmental pressure and especially resource use. Papers 3 and 4 show the application of the MIPS concept on nutrition and lifestyles as a whole. Papers 5, 6 and 7 deal with the determination and application of the eight tonnes target and paper 8 reflects possible implications of the target on design. Figure 1 also shows that the eight tonnes resource cap benchmark (paper 6) is the core of this thesis, grounding on papers 1, 2, 3, 4 and 5 and providing the foundation for the methodology developed in paper 7 and the Orientation Framework for Design for One Planet (paper 8).

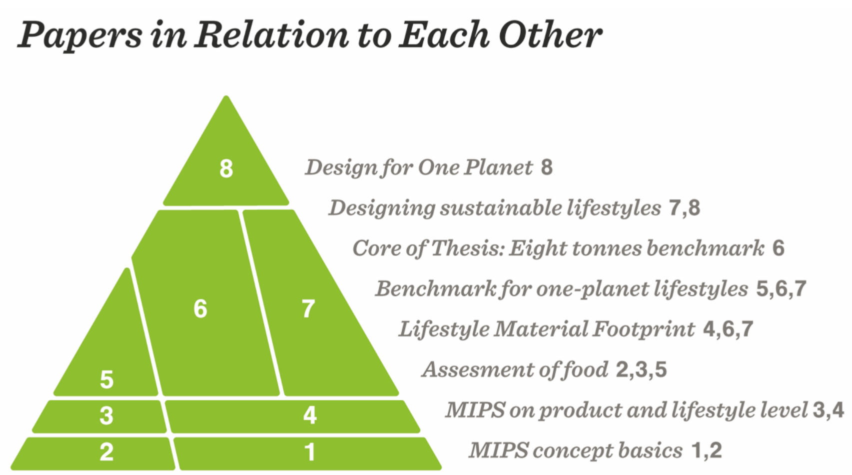

Figure 1. Relation of the thesis' papers to each other. (Own compilation. Graphics: Michael Lettenmeier and Heidi Konttinen)

Papers 2, 3 and 5 deal with the nutrition sector as an example. This is related to the projects and people I have been working with. Together with housing and mobility, nutrition is one of the three most relevant consumption components that have been identified in numerous studies using different indicators (e.g. Kotakorpi et al. 2008, Tukker et al. 2010, Moore 2015, Nissinen et al. 2015). In addition, nutrition is probably the most basic human need, the role of which is especially visible when studying households (paper 4) and countries (WBCSD 2016a,b,c) with lower incomes.

Several papers (4, 5, 6, 7, 8) point out that it is definitely not only households that affect the material footprint of household consumption. Numerous external actors greatly influence how and how much households are consuming, e.g. companies, authorities and infrastructures, as already stated by, e.g., Lorek and Spangenberg (2001). Paper 8 suggests an approach designers could use to facilitate one-planet lifestyles. The role of design for promoting sustainability has been acknowledged already decades ago (e.g. Papanek 1984) and a variety of approaches have been presented to integrate sustainability aspects into design (Ceschin and Gaziulusoy 2016). However, explicit research on the role design could play in achieving one-planet lifestyles can be found only recently (e.g. Pettersen 2016). Therefore, design appeared a reasonable field for focusing on in this thesis.

Nutrition and design are two special foci of the thesis that do not appear having so much relations to each other. However, during the recent years, increasing focus has been put on the potential role of design and nutrition also in the field of sustainability (e.g. Hahn et al. 2013, Durall et al. 2015). This thesis provides another contribution to strengthen that connection because the framework presented in paper 8 shows various ways for a contribution of design to make nutrition sustainable.

Although the main focus of this thesis is on lifestyles, it addresses the role and possibilities of both production and consumption in several ways. Footprint indicators are related to both production and consumption (Hoekstra and Wiedmann 2014, see section 2.3 for details). Papers 2 and 3 deal with the material footprint indicator rather from a production perspective, papers 4 and 7 rather from a consumption perspective. Papers 1 and 5 integrate production and consumption aspects, and so do paper 6 by using production-related resource intensities and absolute consumption levels as a basis for calculating the sustainable material footprint benchmark and paper 8 by proposing a consumption-based orientation framework to design which is traditionally part of production processes but actually situates at the interface of production and consumption.

1.3 Research process and thesis structure

The thesis is based on a decade of research. During this period, I contributed to developing the MIPS concept from production-oriented (paper 2) to a holistic tool for the assessment (papers 1 and 4) and basis for the transition (papers 7 and 8) of household consumption. This process covered the establishment and development of both a database for calculating LMFs (Kotakorpi et al. 2008, paper 3) and a methodology for gathering household consumption data (Kotakorpi et al. 2008, papers 4 and 7) as well as determining targets for a sustainable level of the LMF and its components (papers 5, 6, 7) and utilising these targets in the context of transition of lifestyles in relation to demand (paper 7) and supply (paper 8).

The compiling part of the thesis is structured in the following way. The introduction shows the motivation and development of the thesis, the research questions and how the papers of the thesis respond to them, as well as the position of the papers and their relation to the research process. Section 2 provides the theoretical background of the thesis, which is related to social metabolism, material flow accounting, sustainability, indicators and design. Section 3 deals with the methodological choices of the thesis in terms of indicating environmental pressure, applying material flow accounting on micro level, determining sustainable levels and processing them to be used by actors. The results of the work are given in section 4 where they are divided into the assessment methodology, the resource cap benchmark and its application on experimentation and design. Section 5 summarizes the findings and limitations of the thesis, provides conceptual implications and reflects on its implications on design and policy as well as on its scientific contribution and options for new research.

2. Theoretical background

This section presents the theoretical background of the thesis (see also Figure 2). Section 2.1 introduces social metabolism as a background theory of material flow accounting, the development of which is presented in section 2.2. Section 2.3 deals with aspects of sustainability and section 2.4 focuses on sustainability from a design point of view. Social metabolism (the human production and consumption system) has grown to a volume that exceeds the natural resources and environmental boundaries of one planet (section 2.1). For redirecting production and consumption towards sustainable volumes, Material Flow Accounting (MFA) and the related indicators can perform assessment, provide targets and benchmark success by means of science (sections 2.2 and 2.3) while design can provide creativity and necessary tools and solutions (section 2.4).

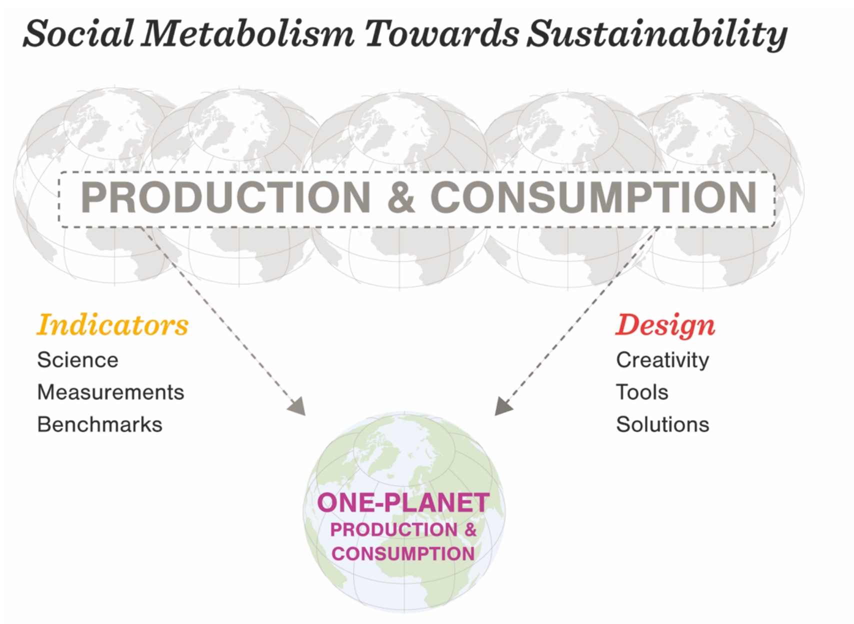

Figure 2. Theoretical framework of this thesis. (Own compilation. Graphics: Heidi Konttinen.)

2.1 Grasping social metabolism

The role and impacts of the human economy as a sub-system of nature have been an object of scientific debate for long. While there is broad understanding of humans being part of nature, a separation between ecosphere/nature/biogeosphere and technosphere/economy/ anthroposphere has been made in order to at least technically facilitate the description and monitoring of human activities and their impacts to (the rest of) nature (e.g. Ayres and Knees 1969, Baccini and Brunner 1991, Lehmann and Schmidt-Bleek 1993, Bringezu 1993b, Willamo 2005, Schröter et al. 2005, Steffen et al. 2007). In biology, metabolism is a central concept and refers to the physiological processes related to energy turnover in relation to the conversion of matter whereas social metabolism adopts this concept to the analysis of physical interaction between the human society and nature (Schandl et al. 2015). Social metabolism is thus not just a metaphor but a powerful interdisciplinary concept for the empirical analysis of the interaction between human society and nature (Fischer-Kowalski 1998).

The volume of human and human-related activities in comparison to (other) natural activities has grown to a remarkable extent, for instance in terms of human energy and material use (Krausmann et al. 2009, Haberl et al. 2011), human appropriation of net primary production (Erb et al. 2009a), freshwater run-off use (Postel et al. 1996), land transformation (Vitousek et al. 1997), and mineral flows (Bringezu 2015). The continuous growth of natural resource use for sustaining human society has resulted in environmental impacts like climate change, ecosystems degradation and biodiversity loss (Haberl et al. 2011). Large-scale use of fossil energy facilitated changes in population, material flows and land use that led to the exponential "Great Acceleration" of roughly all human-related activities after 1945, as well as their environmental impacts, which made Crutzen and Steffen (2003) declare a new geological epoch called the Anthropocene. The approach of social metabolism, or sociometabolism, seeks to explore the use of natural resources by and their flow through the human system (Haberl et al. 2011) and can help to understand future developments towards or away from sustainability.

Some authors stress the importance of energy availability and consumption for achieving present levels of sociometabolism (e.g. Krausmann et al. 2009, Haberl et al. 2011). Others emphasize material flows as the basis of the interactions between human economy and the rest of nature. Already Ayres and Knees (1969) stated that environmental impacts are not likely to cease while material flows in general are growing. Baccini and Brunner (1991) called a reduction of material flows prudent in order to ensure the long-term functioning of natural processes. Schmidt-Bleek (1993a,c) proposed the total amount of material flow from the biogeosphere into the human technosphere to be used as a basic measure of the human impact on the environment, because any input into the human economy will sooner or later become an output back to (the rest of) nature (see also Ayres and Knees 1969, Baccini and Brunner 1991). These ideas led to the concept of material flow accounting (MFA) later on (Bringezu et al. 2003, Bringezu and Moriguchi 2002).

Although material flows and environmental impacts are interconnected in many ways, it is not irrelevant which flows and impacts are used as indicators of environmental pressure. The choice of indicators and the framing of environmental problems determine the way we look at and react to things (e.g. Lehtonen et al. 2016). For instance, ecological footprints and human appropriation of net primary production both measure human draw on nature in an aggregate way but the former measures human utilization of bioproductive areas while the latter measures the intensity of that utilization (Haberl et al. 2004). Material flow indicators measure the aggregate amount of material used by the human economy while substance flows measure the flow of certain substances like carbon or nitrogen through the human economy, and specific emissions or impacts are measured by numerous specific indicators (Bringezu et al. 2003, Bringezu and Moriguchi 2002).

Indicators also influence the appreciation and understanding of scientific observations outside the scientific community. Erb et al. (2009a) call footprint approaches “oversimplified” for relating sociometabolism to ecosystem functioning. However, Sanderson et al. (2002) suspect that scientists’ tendency to express themselves in terms that are hard to understand by public (e.g. ‘appropriation of net primary productivity’ or ‘exponential population growth’) may be a reason for the lack of acceptance of their messages. Haberl et al. (2004) argue that a major factor behind the success of the ecological footprint is its ability to communicate ecological constraints and their potential consequences. Lyytimäki et al. (2013) stress understandability by stating that indicators identifying key issues (see also Bilharz and Schmitt 2011, Steinmann et al. 2017) and the development in sustainability transition can be “powerful pedagogical and communicative tools”.

Schmidt-Bleek (1993a,c) advocates the use of the aggregated amount of material tonnes that humans take from ecosphere as a measure for the general pressure of human activities on the environment because it both is easier to understand for the public than nanogrammes of specific substances and covers the whole material flow through the human society regardless of the question of how well we yet know about the specific impacts. Risku-Norja and Mäenpää (2007) call for an evaluation of physical inputs into the product chains as a whole because sustainability requires a reduction of material throughputs in the economies. This is consistent with the matter-energy conservation law assuming quantitative equivalent inputs and outputs (paper 1).

The concept of social metabolism offers a range of benefits and opportunities in terms of the sustainability transition. Already Fischer-Kowalski and Hüttler (1999) predicted sociometabolism to become one of the most powerful tools for describing and analysing environmental and sustainability problems because of its simplicity and its transferability to the fields of economy and technology. Van der Voet (2011) stresses the usefulness of the methods of sociometabolism in detecting problem shifting on a global level. She calls for developing future pathways while taking into account both side effects and the effectiveness potential of solutions. Schandl et al. (2015) attribute the growing impact of sociometabolism not only in science but also in political and economic decision-making to the strength of its conceptual framework. This framework links the traditionally fragmented disciplines of social, economic and biophysical science by using fundamental physical principles of mass and energy conservation and establishing meaningful data.

For this thesis, social metabolism is a central framework because of its ability of assessing complex problems in a comprehensive and understandable manner while maintaining the view on the interaction of humans and the rest of nature and enabling the assessment of burden-shifting in a global context. Lifestyles and their impacts should be discussed in a holistic way and social metabolism offers an important framework for considering the interaction between humans and (the rest of) nature as well as global impacts and global burden-shifting. The latter is especially important because of the currently very uneven global distribution of natural resource use.

2.2 The evolution and the levels of material flow analysis: From products and processes to lifestyles

Material flow analysis (MFA) is one approach under the framework of social metabolism. It deals with the material throughput of the human economy which is a subsystem of the biogeosphere. Humans take materials from natural systems into their processes (input) and return them after use (output). MFA analyzes the flows of both specific substances and bulk materials in a systemized way. MFA can analyse flows of substances, materials or products within companies, sectors or regions (Bringezu and Moriguchi 2002). Eurostat contributed to systemize economy-wide MFA by publishing a methodology guide (Eurostat 2000). In addition to the direct assessment of material flows, MFA is utilized as a basis of further analysis, e.g. lifestyles' ecological footprints (Moore 2013) or energy saving assessments (Kanianska et al. 2011).

Table 1 shows the different material flows covered by different indicators (material flows covered are marked green). Direct material input (DMI) and direct material consumption (DMC) are macro-level indicators of the direct use of materials in an economy, without considering material flows behind these directly used materials. Raw material input (RMI) and raw material consumption (RMC) on macro-level as well as cumulated raw material demand (CRD) on product-level are life-cycle-wide indicators based on the used extraction of raw materials and omitting unused extraction. Total material requirement (TMR) and total material consumption (TMC) cover all material resources and include both used and unused extraction. Used extraction means materials used by the human economy while unused extraction (earlier also called 'hidden material flows', see Matthews et al. 2000) means materials moved from their original place in nature without having been used by the economy. During the past decade, statistical systems have widely started to cover used extraction so that vast databases for RMC calculation have been established. Macro-level RMC is also called material footprint (Giljum et al. 2015, Wiedmann et al. 2015). DMI, RMI and TMR include, while DMC, RMC and TMC exclude the materials ending up in goods for export (Table 1). Table 1 also gives the different material flow indicator values for the example of Germany. The values show that direct material flow indicators (DMC and DMI) produce lower, and total material flow indicators (TMC and TMR) higher absolute values than raw material flow indicators (RMC and RMI), and that indicators including exports (DMI, RMI, TMR) provide higher values than consumption-based indicators (DMC, RMC, TMC).

Table 1. Material flow indicators and values for the German economy in 2008. (Own compilation, values from Bringezu and Schütz 2013)

Material flows		**Indicators**							
		DMC	**DMI**	**RMC**	**RMI**	**TMC**	**TMR**	**MIPS**	**LMF**
Abiotic		■	■	■	■	■	■	■	■
Biotic		■	■	■	■	■	■	■	■
Earth movement in agriculture						■	■	■	■
Air								■	
Water								■	
Direct material use	Domestic	■	■	■	■	■	■	■	■
	Imported	■	■	■	■	■	■	■	■
Used extraction	Domestic	■	■	■	■	■	■	■	■
	Abroad			■	■	■	■	■	■
Unused extraction	Domestic					■	■	■	■
	Abroad					■	■	■	■
Export			■		■		■		
Life-cycle-wide				■	■	■	■	■	■
Germany 2008 (tonnes/cap./a)		**15.8**	**20.5**	**22.0**	**51.0**	**47.2**	**73.3**		

Unused extraction (earlier also called "hidden material flows", (Matthews et al. 2000) can constitute considerable material flows and related environmental impacts, e.g. overburden in mining or rock moved in construction (Aachener Stiftung 2011). In the case of metals the share of unused extraction can be huge. For example, most of the abiotic material intensity of copper (348 kg abiotic resources per 1 kg of copper, Wuppertal Institute 2014) and platinum (320,000 kg abiotic resources per 1 kg of platinum, Wuppertal Institute 2014) relates to unused extraction. With biotic materials, for instance by-catch in fishing can easily be 40 per cent of the biomass fished (Davies et al. 2009). A computer imported to a country is considered only in terms of its mass in DMC, while RMC considers the raw materials of the whole value chain of the computer, and TMC also the unused extraction behind the raw materials. A kilogramme of copper included in a dish-washer imported from abroad would thus form 1 kg of DMC, 128 kg of RMC (Umweltbundesamt 2009) and 348 kg of TMC (Wuppertal Institute 2014).

Schmidt-Bleek and his team proposed the material input per unit of service (MIPS) as a system-wide proxy indicator for the environmental pressure caused by a certain benefit ("service") for the consumer. MIPS is input-oriented. Based on the matter-energy conservation law, input and output flows are equivalent in quantitative terms (see also Figure 3). Therefore, the total of input flows can serve as a preliminary estimation of the environmental impact potential of the services provided by products (Schmidt-Bleek 1993a,c).

From the beginning, the MIPS approach has been applied on both a macro-economic (TMR, see Bringezu 1993a, Hinterberger and Welfens 1994) and micro-economic (Kranendonk and Bringezu 1993, Tischner and Schmidt-Bleek 1993) level. Schmidt-Bleek et al. (1998) presented a systemized approach that still forms the basis for the different applications of MIPS. The MIPS concept includes all material inputs into the human economy, including the materials required for the provision of energy. However, all these material inputs are not summed up as one material flow but separated into five categories of material resources: abiotic raw material, biotic raw material, water, air, and soil movement in agriculture and forestry: Abiotic raw materials include metallic and non-metallic minerals (ores, rocks, sand etc.) and fossil energy carriers (such as coal, mineral oil, natural gas). Biotic materials comprise wild or cultivated plants harvested and wild animals caught. Grown animals are considered on the basis of the plant biomass they have eaten. Soil movement in agriculture and forestry is separated into erosion and earth movement. Water consumption in the MIPS concept means any water flows diverged from their natural cycle by human activities, thus including e.g. drinking water, water for irrigation and run-off water from buildings, roads and streets. Air consumption means the parts of the air that are chemically transformed by human activities. Most of this is oxygen used for combustion but also nitrogen from the air used in fertilizer production is considered (Schmidt-Bleek et al. 1998, Ritthoff et al. 2002).

The MIPS concept measures the natural resource use during the whole life-cycle (resource extraction, manufacturing, transport, packaging, operating, re-use, re-cycling, and re-manufacturing, final waste disposal) of technologies, processes, products, services or systems. MIPS takes into account both direct and indirect material use as well as both resources used in the human economy (used extraction) and unused extraction. Thus, all material flows caused by humans are calculated regardless of whether and how they are valuated in the economic system (paper 1).

The five different resource categories are displayed separately from each other. The only categories that can be added up are the categories of abiotic resources, biotic resources and erosion. In terms of resource categories covered by different indicators, the economy-wide MFA indicators TMR (total material requirement, which includes the materials required for exported goods) and TMC (total material consumption, which excludes materials required for exported goods, Bringezu et al. 2003) are therefore consistent with the micro-level applications of MIPS and the Material Footprint (Ritthoff et al. 2002, Lettenmeier et al. 2009, paper 1, paper 4, paper 6, for methodological details see section 3.1).

Figure 3 shows the position of MIPS and the Material Footprint in the context of social metabolism and related indicators. MIPS covers all flows of matter from the biogeosphere into the human production and consumption system. Output flows (wastes and emissions) and environmental impacts of input and output flows are not directly represented by MIPS but they are basically dependent on the scale of the inputs because of the mass-energy-conservation law. It is worthy to mention that any indicator can cover only parts of the environmental impacts of human activities because only a part of the output flows is known at all, not to mention the environmental impacts they cause (Schmidt-Bleek 1993a,c, Robert 2000, Robert et al. 2002). Even life-cycle assessment (LCA) covers only a part of the known human outputs and impacts on the environment (paper 1).

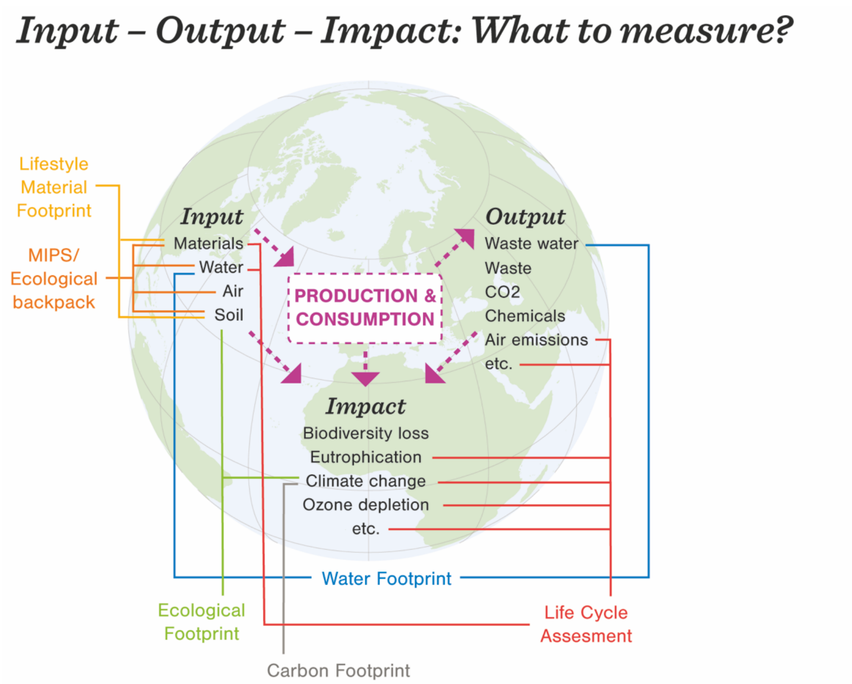

Figure 3. Social metabolism and selected indicators. (Source: Own compilation, influenced by Bringezu 1993b, Schmidt-Bleek 1993c, Autio and Lettenmeier 2002. Graphics: Heidi Konttinen.)

A controversially discussed aspect of MIPS is the relation of the material flow and their environmental impacts (e.g. Kleijn 2000, Voet et al. 2004, Müller et al. 2017). Jungbluth et al. (2012) conclude that the only environmental impact MIPS covers is material use. Traditionally, environmental protection focused rather on the hazardous impact of substances, especially outputs, than on the material input. However, the need for reducing material flows in general in order to reduce general environmental pressure has been acknowledged for long (Ayres and Kness 1969, Baccini and Brunner 1991). As the specific environmental impact of most substances humans release to nature is even partly known only for a limited amount of substances, the amount of materials dislocated from their natural location can be considered a proxy measure for the potential environmental impact of natural capital use by humans (Hinterberger 1993, Hinterberger et al. 1997). In addition, even the elimination of substances well known for being hazardous (e.g. lead or DDT) has been so slow that precautionary environmental policy calls for a more holistic material flow approach than only focusing on especially hazardous substances (Schmidt-Bleek 1993c, Robert et al. 2002, paper 1).

Originally, the micro-level application of MIPS has mainly focused on material, product and service level (Schmidt-Bleek 1993a). Before the year 2006, private households were covered mainly as one sector in macroeconomic TMR and TMC calculations (e.g. Adriaanse et al. 1997, Mäenpää and Juutinen 2001). However, these calculations do not provide insight in the resource use of specific households and the factors that influence resource use (paper 3, Teubler et al. 2018). With improvements in the data basis, MIPS has also been applied on household level (paper 1, Kotakorpi et al. 2008, paper 4, paper 7).

From a design perspective, MIPS is also interesting because it includes the idea of the fulfilment of a service to the consumer as the final purpose of products (products as service-delivering machines). Thus, Schmidt-Bleek (1993c) already introduced the basic idea of product-service systems replacing the thinking in products, which has later on been taken up in numerous design approaches (e.g. Manzini 1999, Mont 2002, Spangenberg et al. 2010, Vezzoli et al. 2012, Vezzoli et al. 2014).

For this thesis, input-based MFA indicators provide a suitable framework because they can provide a picture of the global impacts of household consumption while covering the whole field of activities. MIPS does not focus on specific output or environmental impacts but as a concept covers the whole range of material inputs including unused extraction. Thus, global sociometabolic interactions can be covered and considered.

2.3 Sustainable consumption, indicators and planetary boundaries

Already Smith (1776 / 2005) called the welfare and consumption of households the ultimate purpose of economic activities. The share of households in the impacts of production and consumption is considerable. According to Watson et al. (2013) household consumption contributes 55 per cent to final use in the European Union, which exceeds public consumption and capital formation. Globally, household consumption is growing because affluence and population are growing faster than technology increases in efficiency (Lorek and Spangenberg 2014). The reduction of environmental pressure from household consumption requires changes in both production and consumption patterns and are heavily influenced by the infrastructures and politics provided by governments (Hoekstra and Wiedmann 2014, Tukker et al. 2010, Lettenmeier et al. 2012).

The way we frame environmental problems influences the way we perceive them and which potential solutions we identify (Bardwell 1991). For example, if we see plastic bags as a problem of littering, we might see the use of biodegradable plastic or paper bags as a solution to decrease plastic accumulation in oceans or elsewhere in nature. If we see them as part of consumers' logistics, we might focus on easily available reusable bags as a solution. If we see plastic bags as a part of the life-cycle of food products, we might rather care about food waste than about plastic bags. If we see them as part of consumers' lifestyles, we might address their content or the way they are transported home to reduce environmental impacts. Barr and Gilg (2006) call for placing households' environmental action into a holistic context instead of sectoring on the basis of specific issues.

Lähteenoja et al. (2013) point out the great need for imagination to understand how present overconsumption can be turned into sustainable lifestyles on the large scale. Therefore we need a deeper understanding on how to scale up current promising practices, and we have to know how far these practices will take us towards sustainable living (Lähteenoja et al. 2013). This can be supported by simple, reliable and robust accounting instruments that are based on aggregated information and show resource efficiency and reduction potentials without being too costly or time intensive (paper 1).

Indicators summarize or simplify, quantify, measure and communicate relevant information. Depending on the variable, different hierarchical levels of perception (local, national, regional, global) may require different indicators. Indicators are operational representatives of attributes chosen to describe developments or performance in relation to benchmarks, targets or goals. (Gallopin 1996). "Indicators are not an end in themselves. Their purpose is to alert the public and policymakers about the existence and cause of problems so that they might be solved" (Cobb and Rixford 1998, according to Karjalainen 2013). Gallopin stresses the need for holistic indicators representing basic system properties that are critical for sustainability. He names the available resources an obvious factor making socio-ecological systems more robust or more vulnerable (Gallopin 1996).

Indicators serve, amongst others, awareness-rising, performance monitoring and evaluation, control and accountability, target-setting, as well as carrying of messages, and they are expected to simplify and facilitate communication (Lehtonen et al. 2016). Indicators are anchored in theory on the basis of an underlying conceptual framework and can have various intended functions depending on their role as descriptive, performance or composite indicators. Composite indicators draw attention to important issues and present the 'big picture' in an understandable way. In addition to just delivering information especially composite indicators can carry with them implicit worldviews and hide conflicts between alternative visions, and they can be used to influence agenda-setting and problem-definition, which widens their potential influence also to originally unintended issues. Thus, the "pathways between indicator design processes, indicators, indicator use, and indicator influence are complex and largely unpredictable", and indicators can empower either the experts providing the data or the citizens through simplification of complex issues and by making policy-makers accountable. When indicators play conceptual and political roles, they can have huge systemic impacts and shape worldviews and visions of society (Lehtonen et al. 2016). However, literature has mostly focused on improving the technical quality of indicators, and therefore Lehtonen et al. (2016) argue that indicators should also be examined in a broader context taking into account the characteristics of indicator producers and users as well as the political framework conditions that not only shape indicators but are also shaped by them. For example, the use of the ecological footprint indicator has been opposed by some actors because of the fear of the radical change the indicator would call for (Sébastien et al. 2014).

With an increasing amount of international trade and interdependence, human production and consumption systems have increasingly been spatially disconnected from each other so that the consequences of consumption are less and less visible to the consumer (Erb et al. 2009a,b, Rushforth et al. 2013, Hoekstra and Wiedmann 2014). The purpose of footprint indicators is to illustrate the hidden links between human consumption and the use of resources and its environmental impacts (Rushforth et al. 2013, Hoekstra and Wiedmann 2014). Hoekstra and Wiedmann (2014) call footprint different concepts developed during the recent decades that "quantify the human appropriation of natural capital as a source or a sink", thus indicating human pressure on the environment. According to Rushforth et al. (2013) understanding and managing embedded resources and footprints in "Coupled Natural and Human systems" is a fundamental part of sustainability science.

Footprints are closely related to the concept of planetary boundaries, and environmental sustainability can be achieved when global footprints range below their maximum sustainable level (Hoekstra and Wiedmann 2014). The term planetary boundaries was introduced be Rockström et al. (2009) and specifies biophysical thresholds the crossing of which would move the biophysical Earth system irreversibly out of the Holocene state of the last 11,700 years, which would drastically decrease the operating space for human life on Earth. Planetary boundaries have been suggested for nine biophysical processes, the core processes of which are climate and biodiversity (Rockström et al. 2009). Presently two of nine systems, biodiversity and biochemical phosphorous and nitrogen flows, have already been assessed being at high risk beyond uncertainty and two of them, climate change and land-system change are at increasing risk in zone of uncertainty (Steffen et al. 2015). Basis of the planetary boundary concept is that many subsystems of Earth react in a nonlinear way and are sensitive to threshold levels (Rockström et al. 2009). Planetary boundary levels are set upstream of threshold levels in order to allow humanity to react before it's too late. The planetary boundary framework relates to biophysical processes on Earth or its susbystems. It is not designed to be disaggregated to, e.g., national or local level nor does it provide guidance on how to achieve social change to keep the impacts of human activity below global thresholds (Steffen et al. 2015). Similar intentions of providing information on the guardrails for human activities within the ecological limits of Earth have earlier been published by, e.g. Opschoor and colleagues around the concept of environmental space (Opschoor and Reinders 1991, Weeterings and Opschoor 1992, Buitenkamp et al. 1992), Schmidt-Bleek (1993b,c) with the Factor 10 concept, and Wacknagel and Rees (1998) with the ecological footprint.

Footprint indicators form a link between production and consumption, or the pursuit of sustainable production and consumption. On a global level, the overall footprints of production and consumption are equal and constitute the sum of all footprints of human activities. This means that for a transition to sustainability both production and consumption activities are relevant and have to be addressed in order to make footprints more sustainable. Footprint levels per capita are determined by both the eco-efficiency of production and the level of consumption (Hoekstra and Wiedmann 2014). As Figure 4 shows, lifestyle footprint calculation situates at the interface of production and consumption. Consumption footprints like the LMF include the resource use of the corresponding production both within and outside the object of scrutiny (e.g. consumers in Finland). They are not limited to a specific territory (e.g. only resource use or only CO2 emissions within Finland), which helps avoid burden-shifting from one country to another.

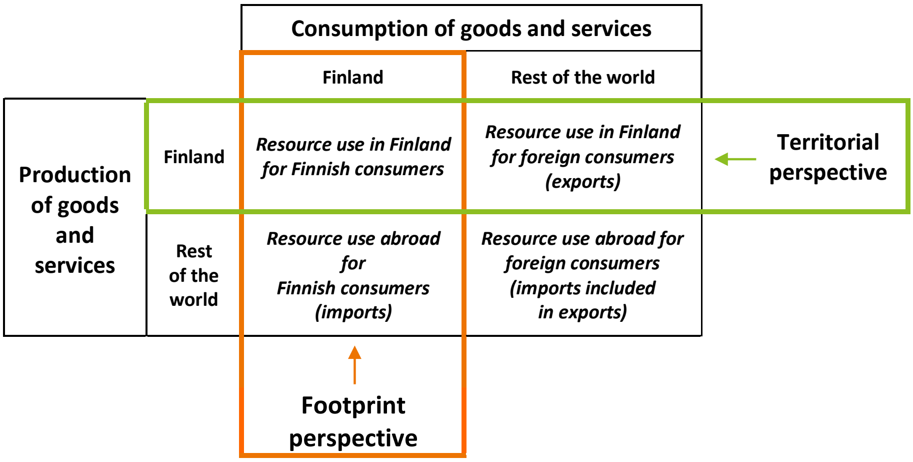

Figure 4. Perspectives of different indicators of resource use. (Source: Adapted from Dao et al. 2015.)

Different footprints quantify the use of natural resources and its consequences in different ways. For instance, the material footprint and the phosphorous footprint measure resource appropriation alone, the carbon footprint and the nitrogen footprint measure emissions from the human economy to the environment, and the ecological footprint and the water footprint measure human appropriation of resources both directly (land use and water consumption) and in their function to assimilate waste by the appropriation of land to assimilate carbon emissions and water to assimilate waste water emissions (Hoekstra and Wiedmann 2014). In terms of material flow accounting, the material and phosphorous footprints measure input flows from the biogeosphere into its susbystem human economy, carbon and nitrogene footprint output flows from human economy back to the environment, and ecological and water footprint combine input and output considerations.

Rushforth et al. (2013) discuss the ecological, water and carbon footprints from the viewpoints of mass balances and resource stocks. They stress the concept of equivalence for governing resources. Footprint indicators enable "a process manager to act outside of its narrow self-interests and to consider external indirect impacts as decision making information that is equally relevant and important to information about the direct impacts of its process", thus making hidden impacts equally relevant with direct impacts. The concept of equivalence works slightly differently with different footprint indicators. "The ecological footprint methodology is specifically designed to include and emphasize the indirect/outsourced impacts of a process on external biocapacity in distant ecosystems" (Rushforth et al. 2013). Water and carbon footprints assume that the "resource stocks impacted" are fully equivalent to each other. With carbon dioxide equivalents this "universal locality" is justified because of the physical connectivity of the global atmosphere. On the other hand, the water footprint assumes that the user of the information given by the indicator recognizes the relevance of an integrated global water stock concept and shared global solutions to local water problems. This can be seen "as a means of transforming the conceptual paradigm of water management toward a more global and interconnected paradigm of governance", which does not yet commonly exist in the minds of water managers and the public (Rushforth et al. 2013).

The Material Footprint as used in this thesis is based on the MIPS (material input per unit of service) concept (Lettenmeier et al. 2009). MIPS considers all primary material moved by human activities from their original location in nature. MIPS defines resources as primary raw materials, including materials used for energy carriers and transports (Schimdt-Bleek 1993a,c). In Rushforth's et al. (2013) terms, the Material Footprint according to the MIPS concept considers as equivalent any kind of material dislocated from its original place in nature and thus relates any primary material mobilized to produce, for instance, a kg of steel, a kWh of electric power or a km of transportation (incl. infrastructure, transport carriers and their energy consumption) to the global stock of material resources.

Contrary to the concept of equivalence (Rushforth et al. 2013) referred above, the MIPS indicator has also been questioned for defining as equivalent, on the basis of their mass, different material resources with different environmental impacts (Kleijn 2000, Voet et al. 2004, Müller et al. 2017). The justification for the MIPS concept, however, is that it is even theoretically impossible to know, much less to analyse all the environmental impacts of all substances released back to the environment by the human economy (Schmidt-Bleek 1993a,c, Robert 2000, see also Steinmann et al. 2017). As all inputs from the biogeosphere into its subsystem of human production and consumption (technosphere) are finally turning into outputs with environmental impacts, such as climate change, eutrophication and acidification but also impacts unknown so far and future impacts, only the reduction of resource inputs from nature can lead to a decrease of outputs (e.g. emissions, waste) and potential impacts (Schmidt-Bleek 1993a,c). This helps maintain the precautionary principle that has been a central basis of environmental decision-making (e.g. Robert et al. 2002, Persson 2016) since it is considered unlikely that unassailable evidence of environmental cause-effect relations could ever cover all known and unknown environmental impacts in their entirety. "The need to make subtle distinctions between various materials does in no way contradict the applicability of a rough estimate of the overall need to dematerialize modern society" (Robert et al. 2000).

Additionally, Steinmann et al. (2017) found that resource footprints are good proxies of environmental damage in terms of damage to health and biodiversity[2].

MIPS and the Material Footprint correspond to the call for reducing the material throughput of the human economy in order to reduce environmental problems that has been formulated through decades in research contributing to the social metabolism perspective (Ayres and Kneese 1969, Baccini and Brunner 1991, Schandl et al. 2016). The input focus of MIPS follows the idea of the matter-energy conservation law (first rule of thermodynamics) assuming quantitative equivalent inputs and outputs. Accounting input material flows thus allows a preliminary estimation of the environmental impact potential of products and services.

For this thesis, the relation of consumption, footprint indicators and planetary boundaries is an important framework because indicators play conceptual roles beyond providing information and thus can have systemic impacts and shape worldviews (Lehtonen et al. 2016). Therefore, although indicators for sustainable consumption take into account global planetary boundaries they still should be understandable for consumers on a conceptual basis. While nine different planetary boundaries (Rockström et al. 2009) could be seen extremely complex in terms of communication to and decision-making of consumers, the Material Footprint according to the MIPS concept can provide an understandable unit that is still related to the ecological limits our planet is providing and, with global mass equivalents of material resource input, also represents a relevant aspect in terms of social metabolism.

2.4 Design as a facilitator of sustainable lifestyles

Increasing material and energy efficiency have been identified central in terms of sustainable business models (e.g. Bocken et al. 2014, Krarup and Ramesohl 2002). Approaches have been developed for integrating resource use aspects in business on the basis of either direct (e.g. Schmidt and Schneider 2013, Schmidt et al. 2016) or life-cycle-wide (e.g. Lettenmeier et al. 2009, Geibler et al. 2016) resource consumption. Experiences from practice show that on the basis of consulting activities companies can easily save 2 % of their annual turnover by quick resource efficiency interventions, and institutional structures have been established to foster such resource-efficiency gains in the production sector (paper 1). However, higher magnitudes of resource-efficiency improvements are necessary for redirecting social metabolism, including both production and consumption, on a sustainable path (Schmidt-Bleek 1993c, Haberl et al. 2011, Bringezu 2015, see also section 2.1). Therefore, the focus has to broaden from eco-efficient processes and greener products towards consumption, as well as to the total amount of consumption as a whole (e.g. Marchand et al. 2010) Design works at the interface of lifestyles and business, or consumption and

[2] While Steinmann et al. (2017) found an especially good correlation for the energy and land footprints, it's worth to mention that the material footprint they used excluded fossil fuels and biotic resources both of which are especially related to the (best-performing) energy and land footprints.

production (e.g. Thorpe 2010), and can therefore play a crucial role in developing system-wide sustainability approaches that consider both production and consumption.

Sustainability can be realized through transitions on different scales and in multiple dimensions, such as technological, material, institutional, politic, economic, and socio-cultural (Rotmans and Loorbach 2009, Schneidewind and Scheck 2012, Shove and Walker 2007). Overcoming barriers to a sustainability transition requires not only long-term strategies, but also processes of individual and social learning, as well as experimenting with ways to achieve these targets. (Loorbach and Rotmans 2010.) For the transition to sustainability, in addition to scientific facts also designerly mindsets are required in order to develop and explore alternative futures (Edelholt 2012). Design approaches that target at improving sustainablity have continuously developed from addressing technically-oriented product solutions towards holistic systemic change (Ceschin and Gaziulusoy 2016). Design can thus be a facilitator of future-oriented development processes (e.g. Gaziulusoy and Ryan 2017a,b).

The role of design for promoting sustainability has been acknowledged for decades (e.g. Papanek 1984, Tischner and Schmidt-Bleek 1993, Cooper 2000). Numerous approaches have been launched to integrate sustainability aspects into design (e.g. Schmidt-Bleek and Tischner 1995, Manzini 1999, Knight and Jenkins 2009, Cooper 2010, Lindsey 2011, Liedtke et al. 2013, Manzini 2015b). Marchand and Walker (2008) point out that design "can realistically and concretely contribute to imagining and proposing new ways of organising daily life" and sustainability "provides exceptional opportunities for designers to imaginatively and creatively develop new concepts for material culture". They see the opportunities for product and service designers in promoting the benefits of sustainable consumption to the individuals as one starting point for "making sustainable lifestyles more attractive" and increase the activeness of actors in making their lifestyles sustainable. Additionally, Thorpe (2010) sees a role for designers in facilitating a way towards less commercialized lifestyles where people can regain consciousness tunes from less material- and more community-oriented lifestyle because there is plenty of need for design "strategies that help us meet needs with fewer purchased solutions". Ehrenfeld (2008) even calls design for sustainability a subversive strategy for transforming the consumer culture. In a similar vein, Edelholt (2012) calls on designers for producing visions of alternative futures and enable to go beyond the growth economy instead of facilitating economic growth regardless of whether a product is really needed. Going even further in terms of the role of design, Manzini (2015a) calls for design to become an "agent of change toward resilient and sustainable ways of living and producing". Vezzoli et al. (2015) add the notion of planetary boundaries by underlining the role of design in developing product-service systems that create well-being "while operating within the limits of our planet". In addition, Haemmerle et al. (2012) stress the potential from the interdisciplinarity of design because wicked problems require radical innovation.

However, the success of design in improving sustainability has also been doubted. Ryn and Cowan (1996) understand the environmental crisis as a design crisis because it is closely related to the way of thinking, constructing and using things. In a similar way, Thorpe (2010) states that design is struggling with the challenges the transition to sustainable lifestyles raises and asks if design can acquire “a substantial role in supporting sustainable consumption” instead of “being a cog in the wheel of consumerism”. In her analysis of different discourses, she has identified the question to which extent consumers or informed individuals make sovereign decisions on the market and to which extent they are dependent on the marketing and symbolizing decisions business and designers are making in order to keep consumption growing. She tends to see designers on the problem side, not only because the design stage fixes 90 per cent of a product’s environmental impacts but also because eco-design tends to overemphasize the “voting-with-your-wallet approach” and because eco-design has not sufficiently linked consumers to upstream environmental and social impacts.

Several authors stress the need for a fundamental change in design in order to take a leading role in sustainability transitions in front of the wicked problems we are facing. For example, Irwin (2015) calls for a design for transition because there is a need for fundamental changes at all levels of society and for new approaches to problem solving. Tonkinwise (2014) argues that design should move from business-as-usual revisionism (“merely improving existing lifestyles”) to being more explicit or ambitious about undertaking transformation by seeking to change from one system to another. As this is inherently wicked (i.e. resistant to resolution), he states that it will never be sufficient to make onething based design interventions. Popplow and Dobler (2015) reflect on a design for degrowth that could help turn our visual culture away from the aesthetics of growth.

While Thorpe (2010) questions whether existing design methods are sufficient and whether designers are adequately educated for new, sustainable-consumption-oriented approaches, Manzini (2015a) states that the specific skills and the culture of design can play a major role in the transition to sustainable living: The new design culture is built up by the interaction with bottom-up social innovation[3]. He sees that “emerging design in transition” is “the capability to support design activities with long horizons of time and visions of a sustainable future” that feeds co-design processes with ideas, visions and proposals. The transition is a context in which design is embedded so that design is influenced by the transition while design also can provide tools and ways for influencing and facilitating the transition (Manzini 2015a). Manzini (2015b) calls for intentional conventions that emerge from a broad social learning process and that people can adopt for their lifestyle-related choices. He underlines that this learning process cannot be designed as such but designers can spread a design culture that is capable of building scenarios and of making new ideas of well-being tangible and visible. Design thus can help everyone to find a convergence between well-being and sustainability by “collaborating in the creation of shared images and stories that underlie a new idea of well-being” (Manzini 2015b). Hyysalo et

3 Manzini (2015b) calls design for social innovation “everything that expert design can do to activate, sustain, and orient processes of social change toward sustainability”.

al. (2017, 2018) provide an impressive example of how effective active users can be in the diffusion and further development of sustainable products and technologies.

Ceschin and Gaziulusoy (2016) show how design approaches have integrated sustainability transition in the course of time. On the basis of a profound, basically chronological review of the development of design approaches incorporating environment and sustainability aspects, they provide an evolutionary framework on how the different approaches of Design for Sustainability have evolved from technical to people-orientation and from product-level and insular solutions to socio-technical system orientation, which means that design has reacted to the increasing and ever more complex challenges of sustainability.

Liedtke et al. (2015) have identified a design-oriented, resource-light scenario "Society of Creation" within four future scenarios along the borderlines of low vrs. heavy resource consumption and practice- vrs. design-orientation. In this scenario, design plays a role in resource management, especially in relation to the reconstruction, new design and redesign of product management with reference to product design as well as business models for low-resource use of product-service systems. They further stress the importance of a resource culture including people in a future-oriented transition management instead of excluding people through technology. They emphasize the role of change agents, i.e. "individuals and institutions with greater capacities to initiate sustainable transformation, into the field of production and consumption" and refer to the design competencies of people in general when facing spontaneous struggles in everyday life. These design competencies can be utilized to increase the system-efficacy of the self on micro-level in order to overcome the environmental challenges during the coming years and decades. In a similar way, Manzini (2006) calls for enabling solutions in order to facilitate people's move from passive users to active co-designers. Going even further, Manzini (2015b) emphasizes a new, sustainable design culture that helps people in constantly co-designing lifestyles supporting both their own and the planet's well-being by collaborating in the creation of underlying images and stories.

With their proposal for a "Design for Sustainability (DfS)" Spangenberg et al. (2010) represent a broad, design-based approach for tackling the transition to sustainable lifestyles. They consider DfS the missing link between sustainable production and consumption because it adds a strong consumption perspective to the rather production-oriented approaches of eco-design. Also Cooper (2000) calls for a design focus beyond product orientation towards meeting people's needs sustainably. While Spangenberg et al. (2010) use a broad understanding of sustainability with its ecological, social, economic and institutional dimensions, the theoretical background of their DfS including the terminology used has much in common with the material flow and environmental space and justice based approach in paper 6 for developing a sustainable lifestyle material footprint benchmark. Spangenberg et al. (2010) call for a multidimensional life-cycle analysis including also social and institutional aspects to be used whenever suitable in the framework of Design for Sustainability (DfS). However, life-cycle assessment has been called a complex and expensive procedure for designers that requires both time and data that often are not available (Bhamra et al. 1999, Cooper 2000, Knight and Jenkins 2009). Although no products can be considered sustainable as such and the aim must be to determine priorities (Cooper 2000, Spangenberg and Lorek 2002), indicators are useful for following and understanding developments and concepts, especially in relation to the physical, planetary boundaries of human activities (see section 2.3). Manzini (2015a) suggests that broad and long-term views feed and orient the social conversation on how to make living sustainable and resilient, thus triggering and enhancing small, local, connected actions in a multiplicity of projects in a social learning process. "Long horizons of time and visions of a sustainable future should become the normal cultural background of future mainstream design." This thesis is about providing this kind of broad and long-term vision of a sustainable future (paper 6) while showing how this kind of vision can enhance local, connected action with households (paper 7) and discussing the possible integration of the vision in design (paper 8).

For this thesis, design provides a reasonable part of the theoretical framework because of its central role for promoting or hindering sustainability (e.g. Papanek 1984 and other references above in this section) and its central position at the interface of production and consumption (e.g. Cooper 2000, Thorpe 2010, Spangenberg et al. 2010, Edelholt 2012). Recent research shows that design is developing from technical product-orientation to systemic transition approaches (Ceschin and Gaziulusoy 2016) and its role in paving the way towards a culture of resource-smart ecological and social sustainability could be even stronger (Liedtke et al. 2015, Manzini 2015a,b). As there has been little explicit discussion on the role design could play in achieving one-planet lifestyles, the thesis seeks to sketch ways into that direction.

3. Materials and methods used

3.1 MIPS and the Material Footprint

The MIPS concept is based on the notion that inputs into the human production and consumption system (or the technosphere, as a sub-system of bio-geosphere) are finally converted into outputs back into the environment, resulting in impacts like climate change, eutrophication, acidification, etc. Consequently, material inputs (incl. the materials for providing energy) taken from nature lead to an increase of outputs and potential impacts. MIPS considers all primary material moved from their original place in nature, and connected with known and yet unknown impact to the ecological system. (paper 1)

MIPS quantifies the resource use of technologies, products, processes, services, and systems (households, companies, regions, etc.). The formula

$$MIPS = \frac{MI}{S}$$

describes the amount of primary material (MI) required for providing a specific benefit that is called service (S). The term material input (MI) comprises any natural resources required in terms of matter. The material input is calculated in mass units like kilogrammes or tonnes. (paper 1) Therefore, in the MIPS concept the term resources means natural resources in terms of matter and excludes both land or water areas and the ability of nature to provide ecosystem services to humans in different ways, which some authors also call natural resources (e.g. Kosmol et al. 2012, Müller et al. 2017). The MIPS concept considers basically five different categories of material inputs (abiotic and biotic resources, top soil erosion in agri- and silviculture, water, and air, see section 2.2 for details).

The service unit (S) in MIPS has no predetermined dimension. The unit of S has to be defined in accordance to the service delivered in the specific case, e.g. person kilometres or tonne kilometres for transportation, a piece of wearable, clean clothes or one meal, the daily nutrition of a person or a certain amount of kilocalories provided in the case of food (paper 1). Also the life of a person over one year can be taken as the service of a MIPS calculation (Kotakorpi et al. 2008).

MIPS calculation can be performed using primary data for a specific case, which requires complex and labour-intensive calculations. Therefore, it is often considered more feasible to use material intensity (MIT) factors. These are pre-calculated coefficients representing the average material intensity of e.g. basic materials, chemicals, agricultural products, electricity, transportation, or human activities. The average material intensities give the average amount of natural resources in the five resource categories used to produce a certain amount of material (e.g. 1 kg aluminium or polypropylene), energy (e.g. 1 kWh of wind power), activitiy (e.g. 1 hour of piano lesson), etc. The most comprehensive list of MIT factors is published by the Wuppertal Institute (2014). This list consists of a wide range of MIT factors for around 400 materials, energy carriers, products or services. Most of these factors represent average values for the world market, Europe or Germany, some factors are also based on case-studies. Therefore, the factors are not totally consistent to each other, which can affect the results of calculations with these factors. While the origin of many materials traded on global markets are hard to determine, the specification of the origin and the extraction and processing conditions of a specific material may cause variations in material intensity that are only partly covered by the list of MIT coefficients.

As a life cycle wide approach, MIPS has linkages with the LCA framework regarding the definition of system boundaries and service unit of a product system. The service unit of the MIPS concept equates in many cases to the functional unit in LCA. However, it refers to the provided service and therefore encourages a wider and more holistic approach. MIPS is not developed to quantify specific outputs (e.g. emissions of specific toxic substances) and assess their impacts (e.g. acidification or climate change) but supports an optimized resource input management (paper 1). Recently, the database of MIPS calculation has been enlarged by utilizing life-cycle databases and software in producing additional MIT factors (Wiesen et al. 2014).

In principle, the five MIPS resource categories are calculated separately because adding them up would mix up very different kinds of material resources and would, in practice, overemphasize water consumption and earth movements in agriculture and forestry over abiotic and biotic raw materials, erosion and air consumption. The material footprint adds up abiotic raw materials, biotic raw materials and erosion in agri- and silviculture. It thus includes the same resource categories as the macroeconomic indicators TMC and TMR (see also section 2.2). Even though macro- and micro-level calculations are based on the same three categories of natural resources, the results of macro-level calculations can differ from micro-level calculations (e.g. Lähteenoja et al. 2007) because of different allocation procedures, for example in relation to infrastructure. Macro level calculations are usually based on macroeconomic data such as monetary or physical input-output tables, whereas the micro-level material footprint as used here is based on life-cycle material flow calculations of products and activities.

Lutter et al. (2016) provide an overview on the advantages and disadvantages of input-output approaches, coefficient approaches and hybrid approaches in macro-level material footprint calculation. According to this study, the disadvantages of coefficient-based footprint calculations are, for instance, the fact that case-based coefficients can reflect specificities of the time and place of their calculation, their limited capacity for differentiation regarding countries of origin, varying quality and limited transparency in terms of coefficients, as well as the complexity of data compilation especially in the case of products and services with especially long value-chains. As advantages of a coefficient-based approach Lutter et al. (2016) respect the simplicity and transparency of the method, the high level of product detail, the independence of statistical classification and aggregation, and the direct linkage to physical material flows instead of average monetary of physical flows for whole sectors[4]. The features mentioned can also be stated for the micro-level coefficient approach as used for this thesis. In addition, coefficient-based micro-level material footprint data can help provide insight in the resource use of specific households and the strongly varying factors behind their resource use (Teubler et al. 2018). Coefficients already calculated do not directly reflect variations in technology over time (Lutter et al. 2016), coefficient-based accounting also opens the possibility of modelling future developments without the need of making too complex adjustments to the whole calculation model. This has been utilized in papers 5, 6 and 7 of this thesis.

Macroeconomic material flow calculations are usually related to one year of time whereas the MIPS approach relates the resource use to the benefit (or service) provided to the end user. In the material footprint, as used here, the material inputs for the building and infrastructure stock are allocated to the user of the infrastructure by dividing the life-cycle-wide material input by the expected useful lifetime of the infrastructure. In macroeconomic material flow accounting (MFA), inputs for constructing the infrastructure are allocated to the year the infrastructure is built. In addition, in macroeconomic calculations transport route infrastructure is usually allocated to public consumption so that its material inputs are not allocated to the households (paper 6). Thus, macroeconomic material flow calculations for consumption may provide significantly lower mobility-related values than results from micro level calculations, especially in countries with most of their transport infrastructure already built (e.g. Lähteenoja et al. 2007, Buhl et al. 2017).

Lettenmeier et al. (2009) proposed using the material footprint as a synonym for micro-level TMR (see also Ritthoff et al. 2002) in order to extend the footprint metaphor to the use of material resources (paper 6). With the ecological footprint at the start, the term footprint meant originally a surface area (Wackernagel and Rees 1998). With increasing popularity, a whole "footprint family" emerged, not only focusing on land use (carbon footprint, water footprint, etc., see Giljum et al. 2011, Galli et al. 2012, Hoekstra and Wiedmann

[4] For example, buying a double-price, higher quality T-shirt would on a monetary input-output-table basis mean a double amount of material footprint although in reality the material consumption for both T-shirts may differ only little. In a similar way, consumers usually pay much less than businesses for a flight from A to B. The material intensity of that flight is similar or even equal for both but its material input is similar or equal only in the case of coefficient-based calculation, not in the case of monetary-based input-output calculation.

2014). The Material Footprint aims at completing this “family” as an indicator focusing on material resources (Lettenmeier et al. 2009, papers 1 and 6).

The micro-level material footprint as used here includes the same resources as the macro-level indicators TMC and TMR. On the macro-level, however, Wiedmann et al. (2015) started using the term material footprint as a synonym for RMC (raw material consumption), and this has since become common practice in macro-level calculations (e.g. Giljum et al. 2016). The RMC includes the use of materials throughout the life-cycle but excludes unused extraction as the data here are not yet available or systemised sufficiently. Therefore, while methodologies for assessing the RMC of nations have developed faster and further than TMC accounting, the problem with leaving unused extraction out of the calculations has been recognised and should be tackled further (e.g. Dittrich et al. 2012, Lettenmeier and Heikkilä 2015).

Instead of MIPS and the LMF, an LCA-based approach could potentially have been used for the underlying work of this thesis. LCA has put forward the reduction of global environmental pressures on the level of everyday life. On product level the application of LCA is state of the art. However, addressing consumers directly on the basis of complex LCA results in an easy-to-understand manner remains a challenge. For instance, Nissinen et al. (2007) developed an LCA-based benchmark for relating the environmental impacts of products to the total impact and consumption. An application of this concept to planet boundary targets has not been published but could in principle be done. Jungbluth et al. (2012) propose an LCA-based measuring system for household consumption based on eco-points according to ecological scarcity. The evaluation is done on the basis of “ecological time”, which means that one year means the ecological boundary available and single products and activities are expressed as time in relation to one year. Both examples show the complexity of applying LCA on the whole lifestyle level.

The mostly and often also solely used single indicator out of the LCA impact categories is probably the carbon footprint (CF). Carbon footprinting has been widely adopted on product level and has in a relevant way promoted the growth and mainstreaming of life-cycle approaches (Finkbeiner 2009). Research on the CF impacts of lifestyles is recently emerging (see e.g. Wynes and Nicholas 2017) but such research is still rare for other types of environmental sustainability indicators. For households’ lifestyles CF and LMF show similar results in general but there are a few relevant exceptions, especially oil heating, flight trips and electric cars (Lettenmeier 2018b). Oil heating and air travel greatly affect the CF but do not play a special role in the LMF because burning oil and kerosene releases large amounts of CO_2 but their production is not especially material-intensive and air traffic requires relatively little infrastructure. In a project in Joensuu in Eastern Finland, 77% of the CF but only 29% of the LMF of one household was due to oil heating (Vähähiilinen 2016). In two other families of that project, 11% and 7.4% of the CF were due to flight trips but only 0.4% of the LMF in both cases. Vice versa, the use of electric cars decreases the CF of car-driving whereas it increases material footprints because electric cars require the same amount of infrastructure and the motive system of electric cars is more material-intensive than that of conventional cars (e.g. Frieske et al. 2015). Additionally, even electric power itself can be material-intensive. Although climate change is a highly relevant and topical challenge, it remains questionable if environmental impacts should be indicated on the basis of only one specific, though important, environmental impact category (e.g. Jungbluth et al. 2012, Schmidt-Bleek 2009). Suggestions have been made to include the CF into a set of e.g. four relevant indicators of resource use (e.g. Giljum et al. 2011, Tukker et al. 2015, Lukas et al. 2016). On a systemic level, this would not be totally consistent because the CF measures emissions, i.e. output flows, while the material footprint, the green and blue water footprints and the land footprints are input flows. This means that the carbon in carbon dioxide or methane as well as some other substances would be double-counted in both material and carbon footprints. To this respect, air consumption according to the MIPS concept would provide a more consistent part of the indicator set than the CF (see Schmidt-Bleek et al. 1998, Ritthoff et al. 2002). However, in terms of popularity and current data availability making the CF part of an indicator set for resource use can be a useful solution as the CF has been used much more widely than the strictly input-orientated yet CO2-related air consumption in the MIPS concept.

In this thesis, I use the MIPS and the related micro-level material footprint as an indicator for quantifying the natural resource use of products, services and activities (papers 3, 4, 5, 6, 7 and 8) and household consumption as a system (papers 4, 6 and 7). Paper 1 sums up the development and justification of MIPS and the Material Footprint and paper 2 compares MIPS to other life-cycle assessment approaches. Paper 3 presents the MIPS calculations of food products and extends the calculations to diets in different European countries. Papers 4 and 7 present material footprint calculations of households, the methodology of which is explained further in the following section. Papers 5 and 6 utilize material footprint calculation for determining resource cap benchmarks for nutrition as one consumption component (paper 5) and households as a whole (paper 6). The methodology is presented further in section 3.3. Paper 7 utilizes lifestyle material footprint calculation throughout a transition process designed to make households' resource use more sustainable. Paper 8 develops an orientation framework for designers on the basis of earlier material footprint calculations (especially paper 6) and utilizes material footprint calculation in testing the framework in relation to design projects from a competition for students. This calculation was based on the material intensity data used in previous Finnish LMF studies (Kotakorpi et al. 2008, paper 4, paper 7). It was estimated as the expected reduction in the LMF of an average Finn (Lähteenoja et al. 2007, paper 6) if the solution designed were to completely replace the previous solution to the same consumer need.

I chose the Material Footprint according to the MIPS concept as an indicator for this thesis and the underlying studies because

(1) it covers material flows as a whole and thus provides a comprehensive picture of human pressure on the environment and can therefore be seen as a central indicator for ecological sustainability (papers 1 and 4),
(2) it expresses results in mass units (kilogrammes or tonnes of material resources) which are understandable and comprehensible unit also for the non-experts in environmental issues participating in and addressed by the studies, and
(3) we have developed an operable micro-level database for studying the different aspects of the complex system of private households in Finland and for keeping the data manageable throughout the research process (paper 7).

3.2 Lifestyle material footprint – Micro level application of MFA on households

The material resource use by households includes, in principle, any natural material resources required for, first, producing and using materials, products, and services that private households consume, for, second, any other activities performed by or covering the needs of households, and for, third, disposing of the related materials and products. When taking a life-cycle perspective, nearly any human activity can be defined as serving private households at a certain point of time. Thus, most of the production and consumption system of an economy can be attributed to private households (paper 6). In the papers of this thesis, we attributed to households only consumption components that households are able to influence and excluded mainly public activities. For example, the resource use caused by public administration, like ministries and authorities, or the defense budget, cannot be directly influenced by household consumption despite its contribution to fulfilling the human needs of security and participation in society (paper 6). We also excluded public services, such as health care and education, of which the resource intensity is known only to a small extent and which are also mainly part of public consumption and out of households' direct influence in Finland, which is the main focus of the papers on households' material footprints (paper 4, 6 and 7).

The household system as studied in this thesis is divided into the following consumption components pragmatically, defined on the basis of people's everyday life and on the basis of the author's earlier work (starting from Kotakorpi[5]

[5] Since the report Household MIPS of Kotakorpi, Lähteenoja and Lettenmeier (Kotakorpi et al. 2008) is mentioned several times throughout the methodological part of this thesis, the author considers worth mentioning the role of that study as the first household-related MIPS study in Finland, and thus as a basis of the later projects and studies this thesis and its papers present. The author was the initiator and coordinator of the project FIN-MIPS Household, most profoundly reported in Kotakorpi et al. 2008. For establishing a sufficiently broad database for the MIPS calculation of households, we calculated MIPS values for numerous household-related goods and activities in the first stage of the research. On the basis of this we calculated the Lifestyle Material Footprints (called ecological backpacks at that time) of 27 Finnish households in the second stage. This means that the Household MIPS research served as both a starting point and a basis for primary data of Lifestyle Material Footprint calculation in Finland. Without that

et al. 2008 and basing also on other authors' earlier publications, e.g. Lorek and Spangenberg 2001):

(1) Nutrition, including all the foodstuffs and drinks consumed at home and outside the home;
(2) Housing, including the housing infrastructure, as well as the use of energy (electricity and heating) for household purposes. Cold water supply and waste-water treatment are excluded because households influence their material footprint only to a limited extent;
(3) Household goods, including the 12 product groups used by Kotakorpi et al. (2008): clothes, home textiles, furniture, electric appliances, electronic appliances, paper products, jewellery, dishes, tools, toys and leisure equipment, daily consumer goods, other goods;
(4) Mobility, including the production and use of cars, bikes and public transport for both everyday mobility and tourism, as well as the infrastructure they require;
(5) Leisure activities including sport and cultural activities either actively or as a spectator;
(6) Other purposes, including goods or services consumed, e.g., accommodation during holiday trips, but excluding public services like health care and education.

Resting on Kotakorpi et al. (2008), the consumption components of packaging and waste management were left out because of their low relevance in comparison to the total material footprint of the households.

Even within the rules of material flow accounting, different results can occur depending on the detailed methodological approach (Eisenmenger et al. 2016). This thesis is built on a widely consistent database on the material footprints of household-related products, services and activities. Most of the data were calculated for Finnish average or typical products, services or infrastructures while utilizing material intensity factors from the Wuppertal Institute's database. The data were mainly produced during the projects FIN-MIPS Transport (summarized by Lähteenoja et al. 2006) and FIN-MIPS Household (summarized by Kotakorpi et al. 2008). Table 2 summarizes the data and their sources and quality used for the calculations related to the different consumption components.

The papers chosen for this thesis represent the development and application of the MIPS-based Lifestyle Material Footprint. Paper 1 provides the theoretical basis of the MIPS concept and paper 2 compares its application on product-level to other methodologies. Paper 3 gives examples of product material footprint calculations for Italian foodstuffs and shows how results can be used for calculating and comparing diets of different countries. Paper 5 uses the material footprints of different diets for setting a resource cap benchmark for nutrition. Paper 4 shows the results of compiling the material footprints of numerous products and activities to the material footprint of the complex system of household. Paper 6 proposes a resource cap benchmark for households by utilizing Lifestyle

research project, the application of the MIPS concept in this thesis and especially its papers 4, 5, 6, 7 and 8 would hardly have been possible.

Material Footprint calculations from both average and specific households as well as numerous results of Material Footprint calculations on the level of products and services for assessing and weighing up their potential role in reducing Lifestyle Material Footprints. Similar calculations and considerations are performed for the assessment of the Material Footprints and their reduction potential of the participating households in paper 7.

The material footprint of the low-income households in paper 4 was calculated on the basis of two interviews of each person (only single households) and a consumption and lifestyle questionnaire the participants filled in during approximately two weeks between the interviews (paper 4). In the household transition study (paper 7) the initial material footprint was calculated on the basis of one interview and a three-week period of consumption survey with the monitoring or assessment of two or three consumption components per week. The effects of the households' roadmaps on their footprints were estimated on the basis of reasonable assumptions from the interventions planned by the households, and the effects of the four-week experiment period were calculated partly from interview results and partly from refilled questionnaires.

In paper 8 which developed a framework of design solutions to promote sustainable lifestyles, a range of design solutions from a students' project was evaluated (see section 3.4). In order to provide a rough estimation of the quantitative effects of the solutions designed, a rough quantification of the potential effects of the solutions on the LMF of an average Finn was calculated on the basis of Kotakorpi et al. (2008). The expected effects roughly quantified are divided into three classes of very little effect, some effect and considerable effect to be expected, meaning <20, 20-200, and >200 kg/(cap*a), respectively, which represents 0.005, 0.05, and 0.5 % of the average Finn's LMF. Potential effects of communication measures could not be quantified because they depend on the nature and efficacy of the implementation of the measures

Table 2. Material footprint data used in the papers of this thesis and the underlying studies

Consumption component	Data used	System boundaries	References	Data quality
Nutrition		Transportation and preparation by consumer part of mobility and housing components		
	Studies on the material intensity of foodstuffs in - Finland, - Italy and - Germany, based on LCA cases (IT), statistics (DE) or both (FI)	Production (FI, DE, IT) or up to shop (FI)	Kauppinen et al. 2008 (FI), (paper 3) and Mancini 2011 (IT), Lettenmeier et al. 2009 (DE)	High (FI, IT, DE)
	Sporadically data from macro-level calculations for Germany	Only biotic and erosion	Bringezu 2000	Lower level of detail
Housing	Buildings: One average building type for Finland	Most essential factors for the most common building types in Finland	Tamminen 2009, Kotakorpi et al. 2008	Acceptable though generic
	Electricity: National average for average power, wind power for green electricity	National average fuels and efficiencies, power stations excluded (but included for wind power)	Nieminen et al. 2005 and later adaptions for average power and district heat Wuppertal Institute's database for wind power	High
	Heating: National average for Finland (district heating), Wuppertal database or Finnish studies for specific fuels	Specific fuels: life-cycle until production (Wuppertal) or end user (FI)	Wuppertal list of MIT factors (different versions) Salo et al. 2008	High
Household goods		Energy consumption is part of housing		
	Finnish study on household goods	Case-specific Most essential factors included (cradle to shop)	Moisio et al. 2008	Case-specific, no average data available
	Miscellanous references for single products	Varying boundaries	Various single references	Sufficient or tole-rable
	Quick estimations of some products	Mainly material content	Kotakorpi et al. 2008	

Mobility	Studies on the material intensity of the Finnish transport system Infrastructure generalized from typical Finnish cases Vehicles from life-cycle and material inventories	Production and use of infrastructure and vehicles	Overview and summary: Lähteenoja et al. 2006 Detailed studies (in Finnish) on road (Pusenius et al. 2005), rail (Vihermaa et al. 2005), air (Nieminen et al. 2005), sea (Lindqvist et al. 2005), bicycle (Hakkarainen et al. 2005) and local (Talja et al. 2005) transport	High
	Finnish electricity Wuppertal Institute's database for fuels	Production of energy and fuels		
Leisure	Case-based studies on typical Finnish leisure activities based on Finnish data and partly Wuppertal MIT factors	Whole life-cycle	Overview and summary: Kotakorpi et al. 2008. Detailed studies in Finnish: Luoto et al. 2008 (sport) and Veuro et al. 2008 (other)	High but case-specific
	Some leisure activities from quick estimations or other studies	Varying focus, main issues covered	Kotakorpi et al. 2008	Varying
Other purposes	Partly case-based studies on domestic tourism (2 cottages, 3 hotels)	Whole life-cycle	Overview and summary: Kotakorpi et al. 2008. Detailed study in Finnish: Salo et al. 2008	High
	Bunch of activities or products from quick estimations or other studies	Varying focus, main issues covered	Kotakorpi et al. 2008, Laakso 2011	Varying

3.3 Lifestyle material footprint resource cap benchmark as a tool for household transition

Footprints have a close relation to the concept of planetary boundaries. For reaching environmental sustainability footprints must stay below their maximum sustainable levels (Hoekstra and Wiedmann 2014). Although the general need for dematerialisation in order to decrease global pressure on the environment had been stated several decades ago (Ayres and Knees 1969, Baccini and Brunner 1991, Schmidt-Bleek 1993a,c), there was no clear quantitative suggestion for planetary boundaries in terms of material flows when we introduced the Material Footprint (Lettenmeier 2009) because publications on planetary boundaries were published only during the same year (Rockström et al. 2009, Bringezu 2009). While the ecological footprint sets sustainability boundaries on the basis of the productive land area of the planet, the determination of a sustainable Material Footprint level is more complex.

By suggesting that global resource consumption should be roughly halved by the middle of the 21st century and an equal per capita use should be achieved, Schmidt-Bleek (1993c) claimed a factor of 10 as a general resource use reduction target for industrialized countries and presented some evidence from environmental research for the plausibility of that target. Bringezu (2009) applied this to the global extraction of abiotic resources, which amounted to about 100–110 billion tonnes in 2000 (16 to 18 tonnes per capita). If that amount is reduced by half and then shared equally by nine billion people in 2050, the acceptable level of abiotic resource use would be approximately 5.6–6.1 tonnes per capita. With the EU per capita consumption of 33.4 tonnes this requires a reduction by at least 80% or a factor of 5. Ekins et al. (2009) also suggested a target of six tonnes of abiotic resources per person in a year. These targets include the aspect of a fair share of resource use within the environmental space provided by the planet (e.g. Spangenberg 2002). Bringezu (2009) suggested for Europe four tonnes per capita per year as a sustainable level of biotic material use and 0.2–0.3 tonnes, respectively, for top soil erosion in agriculture and forestry. Including abiotic resources this means a sustainable TMC of approximately 10 tonnes per capita in a year. In a more recent paper, Bringezu (2015) ends up with a proposal of 6 to 12 tonnes per person in a year of abiotic resource use and 2 tonnes for biotic resource use, respectively, in order to avoid overconsumption of biotic resources. As a policy target he suggests 10 tonnes of abiotic and 2 tonnes of biotic resource use. For an overall TMC target, these proposals are still quite similar to his suggestion in 2009 although biotic resource use would be half and abiotic resource use between equal and double of Bringezu's original proposal.

The sustainable level of biotic resource use and erosion can, in principle, be determined on the basis of the surface area that is or can be used by humans. However, for the use of abiotic resources, the determination of a sustainable level is much more complex. Bringezu's (2009) calculations were based on Schmidt-Bleek's (1993b,c) factor 10, which was a relatively rough estimation on the basis of literature and observations on ecosystems' carrying capacity (e.g. Weterings and Opschoor 1992). Also more recently, Bringezu (2015) has pointed out that the impacts of abiotic resource use are so multifaceted that approaches based on single environmental impacts, like Rockström's et al. (2009) planetary boundaries or the concepts of depletion of abiotic resources used in LCA, are too straightforward to cover the whole bunches of impacts related to human-caused mass flows of abiotic resources on a global level. Therefore, Bringezu (2015) still uses Schmidt-Bleek's (1993b,c) factor 10 as a central basis for determining a sustainable level of abiotic resource use. Thus, despite different attempts to make such a determination (see also Stricks et al. 2014), there is still no major new breakthrough in determining in detail a sustainable level of abiotic resource use.

Macroeconomic calculations divide the TMC into private consumption, public consumption, and capital formation. From the micro level perspective capital formation is part of the life cycle of products and services because infrastructure, for instance, has to be taken into account in MIPS calculations (see section 3.2). Therefore, the TMC needs to be distributed only between public and private consumption. On the basis of their relation in available TMC results (Mäenpää 2000, Mäenpää and Juutinen 2001, Bringezu et al. 2009, Watson et al. 2013), we suggested to allocate 80 percent, i.e. 8 tonnes, of the sustainable TMC level to household consumption and 20 percent to public consumption (paper 6).

A sustainable TMC level of 10 tonnes and a Lifestyle Material Footprint level of 8 tonnes roughly means an 80 percent, of factor 5, reduction in resource use in the case of Finland as a contribution to roughly halving the global level of resource use. This can be compared to the order of magnitude of reduction suggestions in other concepts of resource caps or planetary boundaries, although all of these have not yet been applied on household level. In 2012, the global ecological footprint exceeded the globally available biocapacity by 60 percent (WWF 2016) and the ecological footprint of an average Finn was 365 percent (factor 3.65) in comparison to global biocapacity per person (GFN 2018). In a detailed study for Vancouver, Moore (2013) calculated an ecological footprint of 4.2 global hectares per person, which is 240 percent (factor 2.4) of the sustainable target level. Hoekstra and Wiedmann (2014) provide a summary of global footprints in comparison to their suggested maximum sustainable level. According to this summary, the global material footprint (measured as RMC, see section 2.2) exceeded the level estimated sustainable by 31%, the global ecological footprint exceeded the maximum sustainable footprint by 50% in 2009, blue water footprint's global level estimates varied from 1000 to 1700 billion m3/a while sustainable level estimates range from 1100 to 4500 billion m3/a, and the carbon footprint in 2010 exceeded the level considered necessary for keeping global warming within 2°C –which nowadays is not even considered sufficient (e.g. Akenji et al. 2016)– by more than factor 2. Other resource cap and maximum footprint estimations on the global level are thus in a similar relation to existing global footprints as Bringezu's (2009) suggestions used for this thesis. Country-level consumption-based calculations in terms of the planetary boundaries defined by Rockström et al. (2009) show that e.g. Swiss climate emissions exceed planetary boundaries 22.7 times, i.e. by factor 22.7, for ocean acidification by factor 14.5, for nitrogen losses by factor 2, and for biodiversity loss by factor 1.9 (Dao et al. 2015).

Above, I have described a way for determining a sustainable material footprint level for household consumption. In order to make that sustainable level operationable for households, designers and other actors involved, we have to think about how it could be distributed or allocated to different consumption components. For individual households, this distribution can vary and thus allow trade-offs according to their needs and preferences. Yet, we provided a general suggestion for this distribution in paper 6. This suggestion was elaborated in relation to the following five aspects (paper 6):

(1) Basic needs (in the order nutrition, housing, household equipment) were considered before other activities (mobility, leisure activities, other purposes).

(2) We used results, experiences and conclusions from earlier household studies (Kotakorpi et al. 2008, paper 3, paper 4, paper 5) to define a potential future level of material footprint in each consumption component.

(3) We used results from resource efficiency potential analyses and other examples of promising practices (see appendix of paper 6) for exploring future possibilities of sustainable consumption patterns.

(4) It has not been possible to cover the entire range of literature on potentials for household-related resource use reduction. Therefore, the examples used are mainly based on projects, contexts and publications we had been involved in. Even with this relatively restrictive approach, plenty of examples became available showing the huge opportunities for developing future sustainable lifestyles and technologies.

(5) We made the assumption that future resource intensities of materials, products and activities will be lower than today. For details, see tables 2-7 in paper 6.

For calculating sustainable future footprint levels in each consumption component we used an inverse application of the Resource Efficiency Potential Analysis (REPA) on the system and sub-system level. REPA originally analyses the resource efficiency potential of specific technologies, products and strategies in comparison to previous or average ones (Rohn et al. 2014). Footprints per capita are determined by the amount of consumption and the resource intensity of the product or service consumed (Hoekstra and Wiedmann 2014). Starting from a rough initial future Material Footprint level for a certain consumption component, we developed a proposal for plausible levels of consumption amount and material intensities that would fit into a future footprint level. Through an iterative process for the different consumption components we ended up in a proposal for future consumption levels and material intensities.

We started this for the field of nutrition, i.e. people's most basic need, by using diets from Finland, India and a sustainability projection for the UK as a basis for suggesting a future average Finnish diet. The future average Finnish diet finally grounded on the following assumptions based on experiences from households' material footprint studies: reduction of both amount and material-intensity of food by 10 % and dropping meat consumption from 79 to 14 kg per person in a year mainly by exchanging it with legume products (paper 5). In a similar way the potential future consumption levels and material intensities were determined for the other consumption components. For housing, the dwelling space in square meters per person and the origin and consumption of energy were the most relevant factors, while assumptions for future mobility were based on the amount and the material intensity of the kilometers traveled during a year (paper 6).

3.4 Developing tools for designing one-planet lifestyles and supporting solutions

Apart from rare examples (e.g. Liedtke et al. 2013, Vezzoli et al. 2015, Pettersen 2016, Garduño García 2017) it is hard to find design-related literature that explicitly mentions planetary boundaries. Although design approaches have evolved from technical and insular to people-oriented and systemic (Ceschin and Gaziulusoy 2016), an awareness of the relevance and urgency of keeping within planetary boundaries does not seem to be widespread. Nevertheless, the potential role of design in the transition to sustainability has been reckognized even without explicitely mentioning planetary boundaries (e.g. Edelholt 2012, Manzini 2015b).

Design operates at the interface of production and consumption (Thorpe 2010, Edelholt 2012) and the role of design in facilitating sustainability has been acknowledged widely (see section 2.4). As also footprint indicators take into account both production and consumption (Hoekstra and Wiedmann 2014), they could be useful for designers when "combining an understanding of how things are and probably will become under present conditions and exploring alternative futures based on (…) how it ought to be" (Edelholt 2012). This thesis is intended to provide this kind of combination. Papers 3, 4, 5, 6 and 7 contribute to showing how things are, from the viewpoint of overconsumption of natural resources on the level of society (papers 4 and 6), one sector (food, papers 3 and 5) and households (papers 4, 6 and 7). Papers 5, 6, 7 and 8 present solutions for how the world ought to be, either in terms of a footprint benchmark (papers 5 and 6) or in terms of solutions for specific households (paper 7) or lifestyles in general (paper 8).

Paper 7 of this thesis especially represents the combination of scientific facts and designerly mindsets called for by Edelholt (2012). In the future household project the paper is based on, we provided scientific facts by calculating the Lifestyle Material Footprints (LMFs) of the participating households according to the procedure explained in section 3.2. On this basis, we determined household-specific target levels for the LMF in 2030. These target levels were suggested at halfway between the households' initial LMFs and the general 8 tonnes target for 2050. The year 2030 served as a reference year in a backcasting workshop in order to keep changes more imaginable, as research (e.g. Lähteenoja et al. 2013) has identified the imagination of future lifestyles as a challenge. In the workshop, the participating households co-created and explored measures for approaching one-planet lifestyles. The workshop combined future study methods (backcasting, roadmapping) with design methods (co-creation). This kind of combination is gaining increasing importance in recent design research (e.g. Edelholt 2012, Mazé 2016, Gaziulusoy and Ryan 2017a,b). On the basis of these ideas, each household created a roadmap detailing measures and pathways towards a one-planet LMF. Out of these roadmaps, the households chose measures to be further explored and tested during the experimental part of the project. During roadmapping and testing, the households were in regular contact to the project team and to each other in order to ensure support from experts and peers. On the basis of the households' experiments and experiences, options for mainstreaming sustainable solutions were co-created and discussed in a "future workshop" with households and "gatekeepers" from administration and business (paper 7).

As argued previously, pursuing one-planet footprints could help design, in Edelholt's (2012) words, "go beyond the current mindsets of the contemporary design profession" but "utilize similar measures to promote less, and more sustainable, consumption". Therefore, I choose to start sketching something that could later develop into a Design for One Planet (Df1P) by establishing an orientation framework of one-planet solutions that could be promoted by designers. The framework aims to inspire designers by offering exemplary solutions that promote one-planet lifestyles, which means lifestyles within the 8 tonnes boundary for a sustainable Lifestyle Material Footprint. The framework is pragmatic and solutions-oriented ('which kind of solutions do we need?') rather than process-oriented ('how to design solutions?'). This does not imply that process-related questions are less relevant when developing design and its mindsets and processes towards actively facilitating one-planet lifestyles. However, taking up process-related questions would have extended the framework and resources of this thesis even further, so those questions have been left for future research.

The framework was established in the following way. The structure of the framework is based on the following criteria (paper 8):

(1) The framework concentrates on these three central components of household consumption according to numerous studies. Housing, mobility and nutrition cover the vast majority of resource use and environmental impacts (papers 4 and 6, Lorek and Spangenberg 2001, Kotakorpi et al. 2008, Tukker et al. 2008, 2010, Nissinen et al. 2015). Household goods are included in the component of housing because they are often closely related to housing. Nutrition, housing including household goods, and mobility (including leisure mobility) make up 92 % of the present Finnish LMF and 89 % of the sustainable benchmark target of 8 tonnes (paper 6).

(2) The priority action areas required under each consumption component in order to achieve a LMF of 8 tonnes are based on "core statements" summarizing the most relevant measures for reducing the material footprint of nutrition, housing and mobility (tables 2-7 in paper 6). The

priority action areas of the framework follow these core statements. Having priority action areas helps to focus on the most relevant sustainability issues and thus can help to achieve the highest impact rather than expending efforts on individual products (Heiskanen and Pantzar 1997). Following Bilharz' and Schmitt's (2011) call for addressing "key points" instead of "peanuts" (see also Nissinen et al. 2007), priority action areas provide a guideline for designers to see the wood for the trees in the peanuts jungle, where eco-design or sustainable design often has meant any improvement to the present performance of any solution independently of its relevance (see e.g. Fuad-Luke 2002, Vezzoli and Manzini 2008, Proctor 2009, Proctor 2015). In addition, forming priority action areas can reduce the need for quantifying the actual footprint reduction of solutions, which has not been so popular among designers (e.g. Knight and Jenkins 2008).

(3) Four domains of design that are sufficient to cover the preconditions for sustainable household consumption according to Spangenberg et al. (2010). These domains are product design, service design, infrastructure planning, and communication design. They are able to integrate all three preconditions for sustainable households from Spangenberg et al. (2010) into the portfolio of necessary solutions: (a) motivation and information, (b) social acceptance and desirability, and (c) availability of sustainable alternatives. While communication design links the framework especially to preconditions (a) and (b), the other three domains relate mainly to the availability of sustainable alternatives (c). In addition to product and service design, the role of infrastructure planning cannot be neglected because the infrastructure people use in their daily lives heavily influences the available choices and possible changes in consumption and lifestyles (Hertwich 2005). Furthermore, infrastructure can increase demand and thus consumption (e.g. Tapio 2002). Unlike many other indicators, the material footprint largely takes infrastructure into account (see section 3.2).

With ten priority action areas against four domains of design the basic framework forms a matrix of 40 fields. Each of these fields was filled with one to three quick examples of solutions that need to be designed, drawing on preliminary work by Lettenmeier (2015). Each solution presented in the framework is given a code in order to facilitate working with the framework.

The framework was tested by evaluating design solutions. It was applied on solutions and concepts developed by students of design in a project context (Zwanzig52 2016). The solutions were created before the framework was developed, but they were created in a context where students were educated in the need for designing solutions for resource-smart lifestyles of the future. The purpose of the test was to find out if the framework can demonstrate the relevance of solutions developed by designers. (paper 8)

4. Results

4.1 Refining and further developing an understandable methodology for complex sustainability assessments

Sustainability is a complex issue with a wide range of different aspects to be considered (e.g. Ceschin and Gaziulusoy 2015, Hoekstra and Wiedmann 2014). For instance, the United Nations have set 17 sustainable development goals with a total of 169 associated targets and indicators (UN 2015). Despite its complexity, sustainability has to be communicated in understandable terms if it to be taken seriously by, e.g., politicians and households (e.g. Sanderson et al. 2002). Due to the increased complexity and globalization of production processes and value chains, decision making on the micro level needs a holistic view on system-wide criteria that enable responsibility for economic, social and ecological challenges (e.g. Bleischwitz 2010, European Commission 2011).

The concept of Material Input per Unit of Service (MIPS) was developed 25 years ago as a measure for the overall natural resource use of products and services. Material intensity analysis (MAIA, Schmidt-Bleek et al. 1998) can be used to calculate the Material Footprint on different levels in production and consumption (value chain, life cycle, product, company, household, economic sector, regional or national economy). It focuses on the movement of natural resources from nature into the technosphere. Thus, it complements the output orientation that has traditionally been dominant in the environmental field to the aspect of resource extraction and resource management.

One central motivation behind paper 1 was that, despite its potential usefulness for policy makers and designers and its development within 20 years after its presentation, the MIPS concept was not too well known on an international level. Paper 1 aimed at presenting the concepts' key features, state of the art, and merits as an indicator of environmental sustainability. In addition, the paper demonstrates the broad applicability and application of the concept, including the application of the concept so far, as well as its potential future application from different viewpoints, including production, consumption and business management. Further, the paper identifies topical developments and challenges, e.g. in terms of integration of life-cycle databases, as well as future needs for research, development and application of the methodology.

Paper 1 was also motivated by the concern about an only weak awareness of the fact that the MIPS-concept strongly supports the assessment of also other sustainability strategies than efficiency. Therefore, paper 1 offers a profound demonstration of how the MIPS concept helps to approach and integrate the assessment of the sustainability strategies of efficiency, consistency and sufficiency (e.g. Schmidt-Bleek 1993c, Huber 2000, Schaltegger and Burritt 2014, Schäpke and Rauschmayer 2014). Efficiency aims at producing better, consistency at producing differently, and sufficiency at producing and consuming less. Efficiency means resource and energy savings per service unit either within production processes or over the life cycle. For example, on the basis of the material intensity of different modes of electric power provision transition paths towards increased resource efficiency can be established. Consistency describes the strategy of closing ecological loops within processes (parts of process chains), at production sites (e.g. by returning waste or discards into processes) or over the entire life cycle (e.g. by designing completely recyclable or degradable materials and products). For example, the MIPS concept can be used for comparing primary and secondary production of basic materials and for showing the high potential of recycled or secondary material for a lower resource input per product or service. In addition, by considering also unused extraction that does not end up in products at all and thus counteracts the concept of circular economy, the MIPS concept strengthens the concepts of consistency and circular economy. Sufficiency describes the orientation of performing social and individual acceptable activities within a limited environmental space and addresses both production (business strategies) and consumption patterns. The MIPS indicator can show the differences in resource use from different solutions and lifestyles and thus open ways for reducing overall natural resource consumption. The MIPS indicator can be used to pursue and tackle all three strategies by reducing the material input (MI), by increasing service or benefit (S) on different levels, and by reducing resource use reduction per capita in absolute terms. (paper 1)

Indicators of environmental sustainability need to enable decision makers, for example designers, to quickly identify priorities. Paper 2 focuses on the Hot Spot Analysis (HSA) developed by the Wuppertal Institute and compares it to MIPS and LCA. The paper points out that the HSA is a qualitative method evaluating the life-cycle of products and demonstrates how the HSA ends up in a semi-quantitative evaluation of life-cycle stages in relation to different aspects of resource use and environmental impacts. As the HSA is based on available literature, results of quantitative life-cycle-wide assessments like MIPS and LCA can be part of a HSA. The HSA can help companies in using existing life cycle studies without the need for performing or ordering time-, cost- and expertise-intensive conventional LCAs or primary-data-based MIPS analyses by themselves. A MIPS analysis covers the whole life-cycle of a product but is still less labour-intensive than a complete LCA. When MIPS is calculated for not too complex products on the basis of well-known materials and using already existing average values, it is less laborious and provides relevant while understandable results (paper 2). Ongoing work at Wuppertal Institute also has shown that Hot Spot Analyses may become extremely complex in cases where huge amounts of studies are available. For the comparison of products or even an application on complex system level, like in the case of households, a Hot Spot

Analysis would become too complex and hardly provide comparable quantitative results. This could turn confusing in terms of conclusions and recommendations for action.

Paper 3 demonstrates some examples of problems that product-level MIPS calculation can address. Product-level MIPS calculations allow the comparison of products when calculation methodology, allocation procedures and system boundaries are sufficiently consistent. Paper 3 analyzed the use of natural resources along the supply chains of three Italian foodstuffs: wheat, rice and orange-based products. The results show the influence of agricultural practices, degrees of processing and the life-cycle phases on the natural resource use. For example, the Material Footprints obtained for rice are 8.91 kg/kg in the case of milled rice, 9.43 kg/kg for parboiled and 9.04 kg/kg for organic rice. For the three kinds of rice, more than 70% of the material footprint is due to farming. In conventional rice (milled and parboiled) the impact of fertilizers is relevant for the category of abiotic resources (40% and 34%, respectively). The Material Footprint of organic rice is close to that of conventional rice. In opposite to a smaller consumption of abiotic resources, for example because of not using industrial fertilizers, biotic resources and erosion contribute to the higher Material Footprint because of the lower yields per hectare of organic production. A MIPS analysis on a production system allows a comparison of different farm management strategies and an evaluation of efficiency terms of input/output rates. For example, the results on rice in paper 3 indicate that a higher yield does not imply a higher productivity when this gain is obtained with more than proportional inputs. The better performance of organic rice in the category of abiotic materials (that encompasses all the external and purchasable inputs like agrochemicals, electricity, fuels, etc. as well as the material flows behind these) suggests that the farm profitability can be improved through the strategy of minimizing the inputs instead of the most common productivist scheme of yield maximization. Although toxicity is not specifically evaluated in the MIPS concept, the impact of pesticides and other chemicals on the results is visible (paper 3).

Paper 3 also shows how product MIPS values or Material Footprints can be aggregated to a systems level (e.g. the level of average country diets) when the calculation procedures have been sufficiently consistent. For example, paper 3 used a combination of material intensities of foodstuffs from Italy, Germany and Finland for analysing the influence of diets' compositions on the basis of the foodstuffs without considering inputs for cooking or shopping. Differences between different countries became visible. Germany, Austria and Italy had the highest material intensity values with 11.4, 11.3 and 10.7 kg, respectively, of Material Footprint for producing 1 kg of food. Poland, with 8.4 kg/kg had the lowest value. Within the diets, the biggest share in the Material Footprints is due to meat, fish and eggs consumption (36%), milk and dairy products follow with 19%. Differences between different countries were rather due to the amounts consumed than to the composition of the diets. Meat and animal based products demonstrate the requirement for a high amount of material resources, confirming the evidence from other studies using different assessment methods (e.g., greenhouse gas emissions in Kramer et al. 1999). When comparing these results of country diets results from household diets in Kotakorpi et al. (2008), we observed a higher variability of results in the case of households. The paper thus shows that detailed micro level lifestyle studies can provide more detailed insight into the impact of different lifestyles and consumption patterns than national statistics. On the other hand, statistics can show differences in the impact of average diets of different countries even without the need for studying specific households in depth (paper 3).

The results of papers 4 and 7 indicate that with a sufficient database on the Material Footprints of products and activities (see section 3.2) and with the consumption profile of a household the footprints can be aggregated to the Lifestyle Material Footprint (LMF) of the complex system of a private household. Different households can be compared (e.g. papers 4 and 7) and clustered according to their consumption patterns (Kotakorpi et al. 2008, paper 4, Kuittinen et al. 2013, Greiff et al. 2017). LMF results for households or individuals can be used for comparison to standards, targets or benchmarks (papers 4 and 7), and to develop measures and interventions for reducing footprints on the level of both households and actors influencing households' activities and supply (Kotakorpi 2008, papers 4 and 7, Vähähiilinen 2016).

Paper 4 presents results of a study on the LMF of 18 single households belonging to the lowest income decile in Finland. Ranging from 7.4 to 35.4 tonnes per year, the LMF of the participants was lower than the LMF of the Finnish average consumer. 13 of the 18 households studied had a LMF between 10 and 20 tonnes. Housing has the greatest share of the total, ranging from 1.3 to 13 tonnes. Housing is followed by nutrition (2.1 – 5.7 tonnes), everyday mobility and tourism. Twelve households had a smaller material footprint than the LFMs calculated from the "decent minimum" reference budgets defined by a consumer panel (paper 4).

The methodology provides insight into household behaviour and its implications. For example, the lowest LMF in (paper 4) belonged to a person who was homeless, which explains the low material use. All three persons with obviously higher LMFs than the rest of the participants and the socially sustainable reference budget level used additional resources for travelling and engaging in other special activities because they were financially supported by relatives or other persons. Hence, without additional financial support from outside, the LMFs of the households studied in paper 4 barely exceeded half of the Finnish average (paper 4). This supports the results of previous studies on the connection between income level and natural resource use (e.g. Kleinhückelkotten 2005, Kotakorpi et al. 2008, Tukker et al. 2010).

In addition to paper 4, the LMFs of specific households were also studied in paper 7. In this paper we studied more affluent households than the low-income households in paper 4. In the study of paper 7, the differences in LMFs show even more clearly the influence of different consumption patterns. The LMFs ranged from 20 to 69 tonnes per person per year (see Figure 7 in section 4.3). The consumption components with most variation were everyday mobility, tourism, and housing. The use of two cars in two households resulted in a high share of resource use for mobility. A car-free household had a clearly smaller material footprint of daily mobility, which affected also the household's smaller overall LMF. The size of the house or apartment was the largest contributor to the material footprint of housing. One household had the highest share in LMF from tourism, which was mostly due to weekend trips for meeting families and friends in other Finnish cities. The material footprints of nutrition were close to the average in all but one household with a material footprint for nutrition below half of average because of low-meat diet. The highest material footprint for nutrition among the households studied was due to higher than average consumption of meat and dairy products (paper 7).

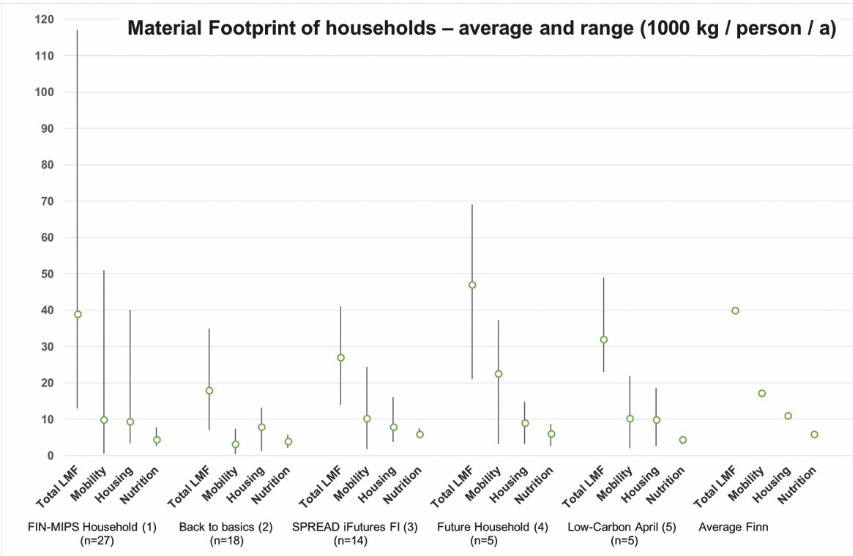

Figure 5. Overview of LMF results. (Source: Lettenmeier 2018b. Sources of footprint results: Kotakorpi et al. 2008, paper 4, Verbree et al. 2013, paper 7, Vähähiilinen 2016)

Figure 5 shows the average and range of the overall LMFs and the shares of the three most relevant consumption components in five Finnish studies out of which Back to basics (2) and Future Household (4) are represented in the papers 4 and 7 of this thesis. Material footprints for mobility, housing and nutrition of the participants in projects 1, 3, 4 and 5 of Figure 5 show similar patterns while the low-income participants in project 2 show smaller footprints in nearly every aspect. Nutrition and housing had a higher material footprint than mobility for most participants in project 2 because most participants do not commute neither travel much. Project 1 (FIN-MIPS Household) assessed the natural resource consumption of 27 households from three regions in Southern Finland. This was the first LMF calculation in Finland and is widely referenced to also in this thesis (mainly as Kotakorpi et al. 2008). The households in this project had a total of 78 members, with the household size varying from one to nine persons. The average LMF of the participating households of 39 tonnes per person in a year was close to the Finnish average. However, differences between the individual households ranged from 13 to 118 tonnes, respectively, which means a factor of nine between the households with the lowest and highest levels of consumption. In most cases, mobility, housing, nutrition and tourism were the most relevant consumption components of the participating households (Kotakorpi et al. 2008). (Lettenmeier 2018b.)

The examples show that the application of the LMF on households is possible. There is sufficiently data to cover the complex system household – at least at a sufficiently robust level. The general high relevance of nutrition, housing and mobility can be confirmed throughout most of the studies using the LMF, and exceptions are explainable (see Figure 5 and paper 4). However, the data used still can influence results. For instance, household goods have a more prominent role in the results of a German study by Greiff et al. (2017) than in the Finnish studies (Kotakorpi et al. 2008, papers 4, 6 and 7), which could be explained by a more comprehensive database for household goods in the German case (Greiff et al. 2017).

The LMF method makes visible the most important hot spots of household resource use, which allows conclusions on measures to be taken by households, companies, infrastructure providers, or politics in order to make consumption more sustainable. For example, decent housing in Finland requires at least four tonnes of natural resources per person in a year. Therefore, in terms of implications for politics and sustainability, much attention turns to infrastructural factors (paper 4). As private households have only limited possibilities to reduce the natural resource use for infrastructure for example in the case of buildings and transport routes (Lorek and Spangenberg 2001, Kotakorpi et al. 2008, Bringezu 2009, Tukker et al. 2010), governments and companies must improve the conditions and technologies that enable households to consume in a more sustainable way (paper 4). This shows again that the LMF incorporates both a production and a consumption view. The material intensity of products and services is heavily based on their production chain but their use by consumers determines the final level of resource use, as similarly stated by Hoekstra and Wiedmann (2014). Thus, the LMF combines both sides of the medal and a reduction in LMF requires measures in both production and consumption as well as in the structures and politics influencing them. Hence, one strength of the methodology is that it facilitates working on different scales and from the perspective of different parts of the economic system, e.g. material, product, service, company, household, while still preserving the connection to the macroeconomic level, so that overconsumption of resources can be tackled throughout society.

Footprint indicators have been criticized as unfeasible to be turned into sufficiently specific action towards sustainability (Voet et al. 2004, Erb et al. 2009a). For the LMF, this critique cannot be reinforced: Papers 5 and 6 show how targets and general guidelines for improving sustainability on the basis can be determined, as for papers 4, 7 and 8 show how relatively detailed recommendations for decision-making in policy, business and households can be drawn on the basis of LMF results. For example, the LMF results of papers 4, 6 and 7 show the environmental benefits of decreasing living space. So far however, policy and market actors in Finland mostly lack awareness of the environmental benefits of downsizing dwellings (Sandberg 2017).

Papers 1 and 3 show the wide application potential of the material footprint in different contexts of value chains as well as different sustainability strategies. With regards to Lutter's et al. (2016) reflections on coefficient-based material flow accounting, paper 3 shows the strength of the MIPS concept regarding product details but also weaknesses in terms of data availability for different countries. The household LMF calculations for papers 4 and 7 show the strengths of the LMF calculation in terms of both independence from statistical classification and having physical instead of monetary flows as a basis because these features enable the calculation of detailed, household-specific LMFs and their utilization in designing future lifestyles and measures supporting these lifetyles. The same calculations also show weaknesses of LMF calculation, for example the complexity of data compilation for services and limitations in terms of data consistency.

4.2 Determining a resource cap benchmark for making planetary boundaries operationable

The determination of a sustainable LMF benchmark started from nutrition, the most basic need of humans. Paper 5 shows the relevance and role of nutrition in the overall material footprint of households on the basis of existing studies on the overall resource consumption caused by household consumption. Quantified meal and diet examples are given. It developed requirements nutrition has to meet in 2050 in order to achieve a sustainable level of natural resource use.

According to Hoekstra and Wiedmann (2014), footprint calculation requires information on the resource intensities and the amount of consumption of the object in question. Hence, for the consideration of a sustainable material footprint level for nutrition, both the amount and the material intensity of the food consumed are relevant. Paper 3 shows that there are notable differences in the amounts as well as in the material intensity of the foodstuffs consumed in 13 European countries and the EU. The amounts vary from 460 (Germany) to 730 (Greece) kg/cap./a. One explanation for this might be differences in the consumption amount of different foodstuffs because the study considered only foodstuffs with consumption and material intensity data available for all countries. Interestingly, Germany and Austria had the lowest amounts of direct food consumption (both below 500 kg/cap./a) but the highest average material intensities of their diets (more than 11 kg/kg). However, this kind of reverse relation between amount and material intensity of the foodstuffs consumed could not be found for other countries (paper 3). Also differences in national accounting systems could be a reason for the strongly varying consumption amounts (see e.g. Lutter et al. 2016). The average material intensities vary from 8.4 (Poland) to 11.4 (Germany) kg/kg. This results in material footprints of 4.3 (Poland) to 7.0 (Greece) tonnes per capita (paper 3).

The material intensities of different protein sources show differences up to a factor of 10 (Kauppinen et al. 2008). Beef and cheese are especially resource-intensive whereas soya requires relatively few resources when utilized directly as food. The material intensities of different meals in Kotakorpi et al. (2008) show that meals containing relatively high amounts of meat (e.g. mutton casserole, chilli con carne, double burger) tend to have high material footprints. While there are differences up to a factor of 8 between comparable meals (e.g. chicken casserole and mutton casserole), other ingredients can reduce this difference (e.g. lasagne and vegetarian lasagne both contain pasta, tomato and cheese).

For diets of specific households, Kotakorpi et al. (2008) report a range from 2.6 to 7.7 tonnes per capita per year with an average of 4.4 tonnes for the 27 different Finnish households studied. Five out of these 27 households had a vegetarian diet, with two of them ranging at the lower end of (3 tn.), two at average level (4.5 tn.) and one above average (5.6 tn.) of the participants. Hence, a vegetarian lifestyle does not necessarily mean an especially low material footprint but the amounts of dairy products as well as fruits and vegetables consumed are also relevant. (Kotakorpi et al. 2008) For 18 low-income single households a level of 2.1 to 5.7 tonnes per capita per year with an average of 3.9 tonnes was observed. The only of these participants who didn't eat meat and was vegan had a smaller material footprint for nutrition (2.1 tn.) than all other households (paper 4).

Figure 6 shows the material footprint of four different diets: the average Finn (Kotakorpi et al. 2008), the average Indian (calculated using FAO data for 2007), "Livewell UK 2020" (using Macdiarmid et al. 2011), and the diet "Improved FIN 2005" as a proposal to meet a sustainable material footprint level (paper 5):

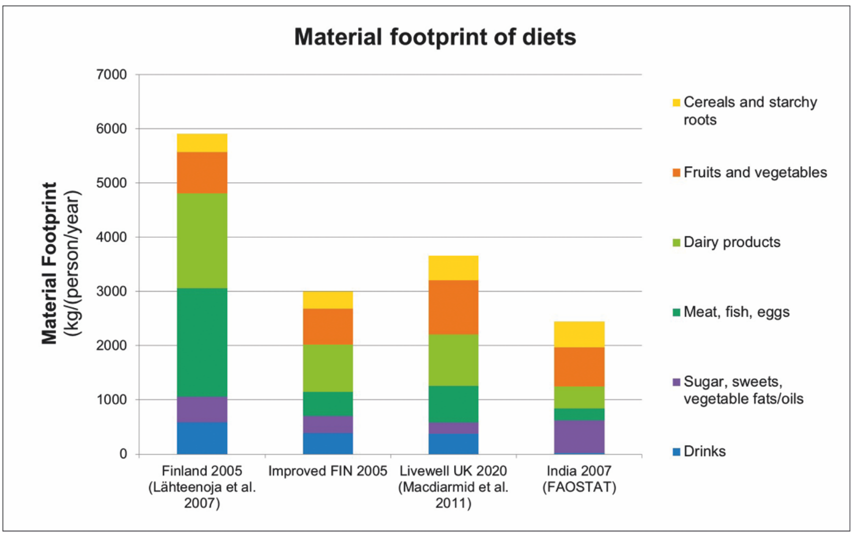

Figure 6. Material Footprints of four different diets. (Source: paper 5)

The Material Footprint level of the diet "Improved FIN 2005", 3 tonnes per person in a year, was chosen as a sustainable level of resource use for nutrition. It is higher than the footprint of the Indian diet because the Indian footprint might be in need of increase due to malnutrition (see e.g. Radhakrishna and Ravi 2004).

A sustainable material footprint for nutrition of 3 tonnes/cap./a could be achieved by consuming 500 kg of foodstuffs of an average material intensity of 6 kg/kg. This means a factor 2 reduction in the average resource use for nutrition. 500 kg of food consumption is at the lower end of European countries' consumption but still already achieved on average by some countries, for example Germany and Austria (paper 3, see above for details). An average material intensity of 6 kg/kg is relatively low, but for example cereals, bread, milk, eggs, domestic fruits, outdoor vegetables, soya and wild fish can be below 6 kg/kg already today and can further improve with improved farming, processing and logistics (Kauppinen et al. 2008, Mancini 2011, Lettenmeier et al. 2009). In addition, a waste prevention survey presented in the paper shows that there is still notable potential for decreasing resource use in the entire value chain (paper 5).

While paper 5 focused on a resource cap for nutrition, paper 6 considered also the other consumption components. Bringezu (2009) suggested a sustainable TMC level of approximately 10 tonnes on the basis of Schmidt-Bleek's (1993b,c) earlier factor 10 and other considerations (for details, see section 3.3 and paper 6). On the basis of the relation of household consumption and public consumption in macroeconomic TMC studies (Bringezu et al. 2009, Watson et al. 2013, Mäenpää and Juutinen 2001, Mäenpää 2000), paper 6 proposes a share of eight tons per person in a year for households and two tons for public consumption, respectively. Eight tonnes mean an 80% (factor 5) reduction from present Finnish average.

Table 3 gives a summary on the material footprint of an average Finnish household, the suggestion for a future material footprint, and the reduction required in the different consumption components. The order of the different consumption components proceeds from most basic needs to less basic needs. In order to make this LMF reduction operationable for policy and practice, also the LMF has to be allocated to the different consumption components. In the case of real households the allocation of the sustainable LMF to its components in Table 3 is only indicative since actual allocation can vary greatly both now and in the future (e.g. Kuittinen et al. 2013), depending on the specific needs, wants, lifestyles, situation, location, etc. of a household.

Table 3. Summary of status quo material footprints and proposal for sustainable material footprint requirements in the different consumption components. (Source: paper 6)

Consumption component	Status quo material footprint		Sustainable material footprint		Change required	
	kg/(person·a)	Share	kg/(person·a)	Share	%	Factor
Nutrition	5,900	15%	3,000	38%	–49%	2.0
Housing	10,800	27%	1,600	20%	–85%	6.8
Household goods	3,000	7%	500	6%	–83%	6.0
Mobility	17,300	43%	2,000	25%	–88%	8.7
Leisure activities	2,000	5%	500	6%	–75%	4.0
Other purposes	1,400	3%	400	5%	–71%	3.5
Total	**40,400**	**100%**	**8,000**	**100%**	**–80%**	**5.1**

Table 4. Sustainable material footprint proposal for housing. (Source: paper 6)

<table>
<tr><th colspan="5">Housing—from 10.8 to 1.6 tons/(person·a)</th></tr>
<tr><td rowspan="2">Reduction required by</td><td rowspan="2">Factor 6.8</td><td rowspan="2">Direct consumption</td><td>Present</td><td>38 m²/capita (house) [45]
11500 kWh (heat and electricity) [45]</td></tr>
<tr><td>Future</td><td>20 m²/capita (zero energy house)
1000 kWh (electricity)</td></tr>
<tr><td rowspan="2">Share in household's material footprint</td><td>Present 27 %</td><td rowspan="2">Material intensity</td><td>Present</td><td>65 kg/ m²/a
(house, unheated/uncooled) [39]
0.6 kg/kWh
(Finnish heat and electricity) [39]</td></tr>
<tr><td>Future 20 %</td><td>Future</td><td>65 kg/ m²/a (house, heated/cooled)
0.3 kg/kWh (European electricity)</td></tr>
<tr><td>Core statement</td><td colspan="4">The material footprint for housing can be reduced from 10.8 to 1.6 tons/(person·a):
- by developing zero-energy houses not exceeding present houses' material intensity (i.e., strongly combining energy and resource efficiency);
- by drastically shifting electricity production from fossils to renewables, especially wind and solar energy; and
- by decreasing individual living space. The impacts of the latter on the individual wellbeing can be reduced by increasing shared living space and improving public space more liveable and attractive.</td></tr>
</table>

Paper 6 provides central facts, assumptions and features on the material footprint level for each consumption component in a structured table and in text. The footprint reduction required is given in absolute (tonnes[6]) and relative

6 In order to avoid confusion, the author regardes noteworthy to mention the following. With exception of the acknowledgements, paper 6 uses the term tons instead of tonnes. A tonne is a metric ton of 1,000 kilogrammes while ton could also mean, e.g., a short ton (907 kg) or a long ton (1,016 kg). The term ton in paper 6 means metric tons. Originally, the author used "tonne" throughout the paper. However, during the very last edition round just before publication, the editor suggested the use of "ton", which was accepted by the co-authors while the author was on a parental leave of several weeks and did not imagine that this kind of change in the paper could still appear. Therefore, in the other parts of the thesis I strictly use the unit "tonne".

(factor X) terms, the amount of direct consumption, the material intensity and the share in the total LMF of an average Finn and the proposed future average. Multiplying the present direct consumption amount with the present or future material intensity factor results in the present or future footprint level for each consumption component, similarly as stated by Hoekstra and Wiedmann (2014) for footprints in general. This is followed by a core statement on ways and strategies for achieving the future material footprint. More detailed examples, arguments and promising practices for the different consumption component are given in the appendix tables of paper 6, from both consumption and production perspective. Table 4 shows the example of housing.

As paper 6 shows, a sustainable level of natural resource use by households is achievable and it can be roughly allocated to different consumption components in order to illustrate the need for a change in lifestyles. While the absolute material footprint of all the consumption components will have to decrease, the relative share of nutrition, the most basic human need, in the total material footprint is expected to rise, whereas much smaller shares than at present are proposed for housing and especially mobility (see Table 3). For reducing material resource use to the sustainable level suggested, both social innovations, and technological developments are required (paper 6).

Table 5. One-planet lifestyle specifications on the basis of paper 6 and Moore (2013). (Source: refined from Lettenmeier and Wackernagel 2017)

Consumption component	One-planet lifestyle for Finnish households 2050 (paper 6)	One-planet lifestyle for Vancouver 2050 Moore (2013)
Total footprint available	**8 tonnes Lifestyle Material Footprint (LMF)** = 80% reduction of current LMF (factor 5.1)	**1.75 global hectares Ecological Footprint (EF)** = 60% reduction of current EF (factor 2.4)
Nutrition	49% reduction of current MF - 29% smaller amount - mostly vegetarian (14 kg meat) - food waste mostly eliminated	48% reduction of current EF - 26% smaller amount - 50% substitution of red meat and dairy - halving food waste
Housing	85% reduction of current MF - $20m^2$ - 1000 kWh - zero heating energy within present resource intensity (in kg/m^2) of building	82% reduction of current EF - Energy efficiency improved 40% - all buildings zero emission - life span increase by 50%
Mobility	88% reduction of current MF - 10,000 km - resource-efficient public transportation - car-ownership shifting to shared use of different vehicles	80% reduction of current EF - 86% of trips by walking, cycling and public transportation - private vehicle ownership –50% - private vehicles 100% zero emission - flying –50%
Other issues	78% of current MF - less consumption - less resource-intensive consumption and production - sharing solutions, longevity, etc.	33% of current EF - 50% of current paper c onsumption - 50% of current landfilled waste - better landfill gas capture etc.

Table 5 compares the results of paper 6 to a similar study on the ecological footprint (EF) of Vancouver (Moore 2013). Moore's study calls for a slightly smaller reduction of Vancouver's ecological footprint that paper 6 for the average Finn's LMF. This is especially visible in the consumption component "other issues" for which Moore (2013) suggests a 33% reduction in EF compared to a 78% LMF reduction in paper 6 while in the components of mobility, housing and especially nutrition with the relative reduction suggestions of paper 6 are only eight, three and one percentile(s) higher, respectively. Both studies show that one-planet lifestyles require notable changes in both production and consumption. As paper 6 estimates that roughly half of the required Lifestyle Material Footprint reduction could be achieved by production-related and half by consumption-related measures, one-planet lifestyles can also open huge potentials for innovation and business, and the more rapid or disruptive technological innovations are, the smaller the need for lifestyle changes will be. Yet, it looks obvious that both approaches are required for achieving a sufficiently rapid transition and addressing technologies and lifestyles simultaneously can help direct interventions in an optimal way.

Out of the results of the Finnish studies on LMFs (see Fig. 4), only one household was found with a LMF within the long-term planetary boundaries. This was a person without a home at the moment of study. Even the low-income households with LMFs below the one calculated for the Finnish reference budget for socially acceptable decent lifestyles hat around twice the LMF of the ecologically sustainable level. From a global sustainability perspective thus, even low-income households in Finland are using relatively high amounts of resources, despite of the fact that they are far below the average households. Low-income households hardly can reduce their consumption much more. Hence, a sustainable level of resource use cannot be achieved solely by choices, decisions and activities of private households but states and companies must improve the conditions and technologies enabling households to consume in a more sustainable way (paper 4).

The sustainable LMF benchmark of 8 tonnes has also relevance outside industrialized countries like Finland. The World Business Council for Sustainable Development (WBCSD) has considered options and pathways for achieving sustainable lifestyles in the huge emerging markets of India, Brazil and China. With average LMFs of 8.4, 11.4 and 15.2 tonnes per person, respectively, these countries are currently much closer to the sustainable LMF level than Western countries although projections show that on a business as usual basis their average LMFs are likely to increase (WBCSD 2016a,b,c). The present average LMF values of these countries show that currently large groups of people must have considerably lower footprints than the sustainable level. Thus, if dematerialized goods and services are developed systematically and soon, the living standard of many people could be improved immensely without a need for exceeding the sustainable LMF level. This also means that there is a huge demand for sustainable design solutions in both production and consumption around the world in order to meet sustainable footprint targets.

4.3 Tools for designing one-planet lifestyles and supporting solutions

The sustainable LMF benchmark developed in papers 5 and 6 was utilized in the Household-level Sustainability Transition (HST) method for co-creating and testing one-planet lifestyles (paper 7) and in the orientation framework for Design for One Planet (Df1P) in paper 8.

By utilizing the 8 tonnes benchmark we were able to extend the LMF methodology from just measuring households' LMFs to developing visions, conducting experiments, as well as the aspect of learning and up-scaling, all of which contribute to the Transition-Enabling Cycle of Schneidewind and Scheck (2012). The HST method goes beyond previous studies that focused on measuring footprints and identifying potentials for the absolute reduction of resource use. With the HST method households established their own roadmaps towards sustainable resource use. During the one-month experiment period, the households tested relevant options for an absolute reduction of their material footprints towards their personal target levels (paper 7).

Figure 7 shows results in terms of LMF from the first application of the HST method: It is possible to achieve a significantly more sustainable level of consumption by relatively few changes in everyday living. Households developed roadmaps for reducing their LMF until 2030 by 37-61%, which is about half way towards the eight tonnes target for 2050. During the experiment phase, households were able to reduce their LMFs by 26-54%. Although a part of the experiment was based on simulated services not yet existing on a regular basis in the region (e.g. car-sharing, or public transport on demand), the results showed that relevant reductions in LMF can be achieved even in the short term. In addition, households reported an increase in quality of life during the experiments because of, e.g., better mobility planning, home delivery of groceries or decreased excess living space. In an interview round several months later the project households conveyed that several options tested or developed in the project were still going on, e.g., ride-sharing, giving up the second car, planning co-housing in the city centre and increasing vegetable-based food, while some changes in life situations had also increased resource use, such as measures that required a new car. This implies the need for changes in supply structures that go beyond individual behaviour changes and temporary experiments in order to facilitate sustainable resource use. Hence, achieving a one-planet use of material resources also requires systemic changes (Lettenmeier 2018b).

With a small number of households and a surrounding already interested in solutions for the absolute reduction of resource use, the first application of the HST methodology succeeded well. Households mostly felt they had managed to change their everyday routines to be more sustainable, and re-routinization (Spaargaren 1997) happened where permanent behaviour changes were possible (paper 7). The households noticed and appreciated an increase in comfort and quality of life they would not have expected. For example, home delivery of food provided extra leisure time, and so did organizing the family's leisure activities with less car use. Living in a smaller apartment instead of a big house offered a new kind of intimacy to an elder couple. Car-sharing was considered easy to use. The participants shared their experiences with colleagues, friends, and relatives, and felt they were a positive example. The households found that their experiences made it easier for others to understand the importance of consumption behaviour and the need for new and more sustainable solutions (Lettenmeier et al. 2017). The interviews conducted for the study showed that the application of the LMF was appreciated by the households because the LMF is concrete and understandable, makes overconsumption visible, and brings the big sustainability challenges down to a human-sized and operationable level (paper 7). The application of the 8 tonnes benchmark on household transition provided meaningful interim targets on the basis of which households were able to co-create and test solutions and interventions towards considerably smaller resource use.

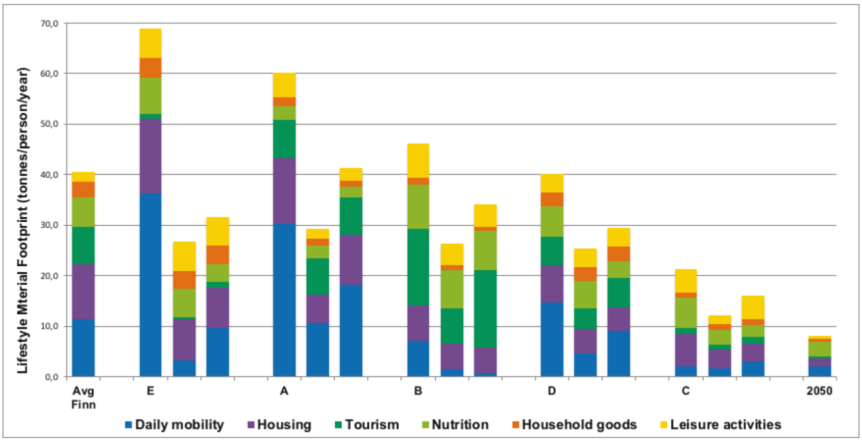

Figure 7. Material footprints of the households (A-E) at the starting point (left bar), the roadmap target levels for 2030 (middle bar), and the results of the experiment period (right bar). (Source: Lettenmeier et al. 2017.)

Manzini (2015a) calls for a design in transition that feeds co-design processes with long-term visions, ideas and proposals and thus can help everyone to find a convergence between their own and the planet's well-being. Although the Future Household project (paper 7) was far from addressing everyone, the HST method can be seen as a part of developing that design for transition as the household appreciated the long-term visions for their life on the basis of the 8 tonnes benchmark's general vision. The method thus facilitates people's move from passive users to active co-designers (Manzini 2006) of their lifestyles. One remaining challenge how to achieve a broad-based sustainable design culture that helps people in constantly co-designing lifestyles supported both by collaborating in the creation of underlying images and stories and by triggering and enhancing small, local, connected actions in a multiplicity of projects in a social learning process, as Manzini (2015a) sketches. However, several elements of the HST method could play a relevant role here if they were developed for broader use, for example the 8 tonnes benchmark, the co-creation of households' roadmaps and the experiments.

The previously described work set the foundation for a design application of the concept of sustainable lifestyles based on the eight tonnes. The HST method (paper 7) could contribute to a transition design in the sense of Mancini (2015a) where long-term sustainability visions enable people to design their own sustainable lifestyles. Although Mancini (2015a,b) proposes a radically new design culture, also more traditional approaches to design will exist in the future because there will still be a need for designing products, services, infrastructures and communication and this design also will play a crucial role in the transition to sustainable, one-planet lifestyles, as several authors have pointed out (see section 2.4). Thus, there will be a need for also integrating the pursuit of redirecting human activities within a "safe operating space" (Rockström et al. 2009), in other words the pursuit of one-planet lifestyles, in design.

Paper 8 of this thesis deals with the question what the broad pursuit of one-planet lifestyles could mean for design and if something like a Design for One Planet could emerge. The paper intends to set a cornerstone on the way to a broader application and conceptualization of a Design for One Planet (Df1P) that could facilitate the transition towards sustainable lifestyles on the basis of a LMF of eight tonnes per person in a year. The paper sketches basic principles for a Df1P on the basis of literature, proposes an orientation framework of Df1P and evaluates a set of solutions and concepts designed in a students' project context in relation to the Df1P framework.

On the basis of literature, paper 8 determines the following principles for a Df1P (paper 8):

(1) Recognition of planetary boundaries (e.g. Schmidt-Bleek 1993c, Rockström et al. 2009, paper 6);
(2) Integration of the reduction of resource use into design solutions (e.g. Luttrop and Lagerstedt 2006, Spangenberg et al. 2010, Liedtke et al. 2013, Vezzoli et al. 2015, Liedtke et al. 2015, Pettersen 2016);
(3) Assessment or quantification of the use of natural resources (e.g. Schmidt-Bleek and Tischner 1995, Lettenmeier et al. 2009, Knight and Jenkins 2009);
(4) Setting reduction targets for natural resource use in design, which are able to achieve a five percent reduction per year (based on Bringezu 2015 and paper 6);
(5) Search for new solutions on a broad basis, in order to enable the identification of solutions for one-planet resource use (e.g. Haemmerle et al. 2012, Thorpe 2010, Vezzoli et al. 2015, Manzini 2015a);
(6) Development of and experimentation with new business and action models in close cooperation with consumers (e.g. Thorpe 2010, Vezzoli and Manzini 2008, Vezzoli et al. 2015, Liedtke et al. 2015, Manzini 2015b, Laakso et al. 2017, Lettenmeier 2018a).

The paper proposes an Orientation Framework for Df1P suggesting measures that could be promoted by means of design. The framework is structured according to the priority action areas displayed in Table 6 and based on the "core statements" given in paper 6.

The measures in the framework are structured in a matrix incorporating the priority action areas and four domains of design, i.e. product design, service design, infrastructure planning and communication design. As an example, Table 7 shows an excerpt of the framework for the priority action area "Reduction in living space" (H2). Paper 8 shows the entire framework.

Table 6. Consumption components and priority action areas of the Orientation Framework for Df1P. (Source: paper 8)

Consumption component	Priority action areas
Nutrition	Mostly plant-based food (N1)
	Reduction of food intake (N2)
	Minimizing food waste (N3)
Housing	Resource-efficient zero energy houses (H1)
	Reduction in living space (H2)
	Resource-smart electricity production and consumption (H3)
	Resource-smart household goods (H4)
Mobility	Kilometre cap (M1)
	Resource-efficient public transport (M2)
	Minimizing private car traffic (M3)

Table 7. Excerpt of the Orientation Framework for Design for One Planet. (Source: paper 8)

Priority action area / Design domain	**H2** Reduction in living space
P Product design	1 Multifunctional products with compact storage 2 Replacing quantity by quality in design and provision of household goods
S Service design	1 Service concepts for replacing ownership without increasing car use 2 Services and mobile apps enabling neighbours using each other's' products and space 3 Services making space use more efficient
I Infrastructure planning	1 Buildings and apartments with efficient and low use of space 2 Buildings and blocks providing shareable space and rooms (washrooms, guest rooms, workshops, storage, etc.) 3 Houses and apartments that can easily be arranged for short- and long-term renting
C Communication design	1 Communicating the benefits and attractiveness of small living space 2 Means of communication facilitating shared use of goods and space

In a first application of the framework, a number of concepts designed by students and related to sustainable lifestyles were classified according to the framework in order to see which role the framework could play. On the basis of a rough quantification of the design concepts evaluated with the framework, the framework appears to address relevant issues, although some of the design solutions in line with the framework were not quantitatively relevant in terms of LMF reduction. The framework can thus show which fields of action are covered or not covered by a set of solutions and which solutions out of the set are relevant in terms of one-planet lifestyles. On this basis, one can draw conclusions in terms of gaps and their reasons in relation to the framework. The evaluation on the basis of the framework thus could provide an idea of the potential of the designed solutions and concepts to result in relevant reductions of lifestyle material footprints (LMF).

The framework presents a portfolio of possible solutions that are particularly relevant for reducing lifestyle material footprints (LMF), thus referring to calls for a "portfolio of diverse lifestyle changes to meet the challenges of sustainability" (Thorpe 2010), a "vision of a better life in tomorrow's society" (Spangenberg et al. 2010), and broad and long-term views that feed and orient the social conversation on how to make living sustainable and resilient, thus triggering and enhancing small, local, connected actions in a multiplicity of projects (Manzini 2015a). It can be applied, for example, during the creative process in order to inspire designers and give them the opportunity to understand which kind of solutions are priorities for the sustainability transition of lifestyles. Both applications of the framework could also be used for planning, implementing and/or evaluating design education.

5. Discussion

5.1 Summary

The intention of this thesis is to make sustainable consumption tangible and operational – to provide a way that can make sustainable lifestyles happen. The thesis starts from the development of the MIPS concepts towards the Lifestyle Material Footprint (LMF), which means both an advanced application of the concept and its opening to new purposes and users. LMF calculation aggregates results from Material Footprint calculation of products and activities to the complex system of household consumption which helps understand the relevance of different components and sub-components of consumption and thus provides a basis for decisions to reduce the environmental impacts of consumption (see research questions 1 and 2 in section 1.2).

Environmental footprints are closely related to planetary boundaries which mean the level of human resource use and/or environmental impacts the Earth has a capacity to carry (Hoekstra and Wiedmann 2014). For the LMF to serve as a sensible benchmark, planetary boundaries had to be determined, which is a central part of the thesis. The sustainable LMF, the resource cap benchmark for household consumption, of 8 tonnes per person in a year is one fifth of the present Finnish average LMF. The benchmark and its calculation are presented both on an overall level and in an example allocation to the different consumption components (see research question 3). This makes concrete the scale of the challenge we face in terms of transition to sustainability of both production and consumption.

The 8 tonnes benchmark opens the possibility for a target-oriented, planned reduction of LMFs. The Household-level Sustainability Transition (HST) method thus drives the LMF application forward from the mere assessment and analysis of LMFs to target-setting, experimenting and up-scaling of sustainable solutions (see research question 4). The HST methodology enabled the participating households to design their lifestyles towards one-planet consumption by making their own roadmaps towards the 8 tonnes target and by performing significant LMF reductions (26-54%) during the one-month experiment phase. The application of the HST method thus showed that notable LMF reductions are possible in the short term, which is an important message to both other households and other actors in society. Households acknowledged the LMF and its 8 tonnes benchmark for their understandability, substance and action-orientation (see research questions 1 and 2).

Design works at the interface of production and consumption (e.g. Cooper 2000, Thorpe 2010) and is thus in a relevant position. Therefore, another application of the 8 tonnes benchmark was the development of an Orientation Framework for Design for One Planet (Df1P). The framework structures 90 urgent solutions for reducing LMFs towards a sustainable level in ten priority action areas out of the most relevant consumption components (nutrition, housing and mobility) and relates them to four domains of design (product design, service design, infrastructure planning, and communication design) in a matrix. The framework shows that solutions to a large range of relevant challenges can be developed in the different domains of design. The framework can help to highlight crucial aspects for achieving relevant design outcomes in terms of one-planet lifestyles and could provide a cornerstone for developing a wider Df1P approach (see research question 5).

5.2 Limitations

Hoekstra and Wiedmann (2014) call the definition of sustainable levels of different footprints still "in its infancy" because of uncertainties, ambiguity and subjectivity in proposing these levels. This applies also to the 8 tonnes benchmark. While the 8 tonnes material footprint can work as a rough benchmark for making consumption more sustainable, the level proposed should be consolidated in order to make it better operational for decision-making in companies and politics. In present Western countries the 8 tonnes are far enough from average and from most people's individual LMFs that it can function as an orientation. However, especially when the gap between present consumption and the sustainable level is decreasing in the future, as I hope and expect also on the basis of this work, and in cases with already (or still) smaller footprints, like the Indian average of 8.5 tonnes (WBCSD 2016c), a more accurate determination of the sustainable footprint level will become crucial. This applies especially to the sustainable level of abiotic resource use.

While my co-authors and I have experienced the database sufficient for calculating and communicating the micro-level LMF of Finnish households and for developing the 8 tonnes benchmark, there remain uncertainties with respect to the database. For example, household goods have featured higher levels of and shares in Material Footprints in German studies (Greiff et al. 2017, Teubler et al. 2018), which might be related to the lower level of scrutiny in the database we used for the Finnish calculations. Also the database for the Material Footprint calculation of buildings does probably not sufficiently reflect the huge variety of buildings. For example, households have questioned the sufficient consideration of old wooden buildings (and their supposedly low Material Footprint) in the calculations. MIT factors differ in their quality and actuality due to complex data generation (also stated by Lutter et al. 2016), which sometimes allows only a rough estimation. MIPS is intended to be an indicator that works with data uncertainties but is reliable in roughly estimating the use of natural resources. The difficulties are not connected to one specific method such as MIPS but are a complex topic within the whole LCA community (paper 1). On a more general level, Lutter et al. (2016) have criticised coefficient-based footprint calculations –contrary to regularly updated monetary-based input-output calculations– for their linkage to specific cases, and thus specific moments and places, as well as for the complexity of data compilation in terms of products and services with especially long value-chains. The increasing utilization of life-cycle databases and software packages as a basis of MIPS calculation could be a first step to improve this situation, in terms of more regular update of coefficients as well as in terms of the amount of data available (e.g. Wiesen et al. 2014).

Limitations also pertain to the generalizability of the household experiment included in this thesis. In the context of the Future Household project (paper 7), with a small number of households already interested in solutions for designing their lifestyles towards one-planet resource use, the first application of the HST method succeeded. However, five households in one city will not change the world. Moreover, despite of the promising elements it includes, like personal creation of visions and solutions, the HST method in its present form is not yet sufficient for mainstreaming sustainable ways of living in the way envisaged by Manzini (2015b). Citizens who are less aware of the challenges of sustainability than the participants so far might face different barriers in terms of sustainability transition. Therefore, up-scaling or developing a HST approach to a vitally broader context and public will be crucial. This could, on the one hand, include IT-based approaches for consumption monitoring, material footprint calculation, and even roadmapping, testing and up-scaling. In addition, the intentional conventions emerging from a broad social learning process and that people could adopt for their lifestyle-related choices, as called for by Manzini (2015b), cannot even just be designed as such by designers. A huge field is left here for a new design culture that helps everyone to find a convergence between well-being and sustainability by "collaborating in the creation of shared images and stories that underlie a new idea of well-being" (Manzini 2015b).

Also the design application of the 8 tonnes LMF benchmark in paper 8 has not yet reached its final state. As it has not yet been tested in real-life conditions, the Orientation Framework for Df1P as presented in paper 8 must still be seen as preliminary. The framework is not necessarily exhaustive and there can still be other solutions for considerably reducing households' material footprints. On the other hand, the test of the framework showed that the framework might work better without the priority area of household goods. Although the cradle of contemporary design could be seen in the area of household goods (e.g. Bürdek 2005), this area is not an especially influencing one in terms of LMF and could thus be removed from the framework. This would not affect the relevance of household goods influencing other consumptions components, like multi-functional products reducing space requirement at home, washing machines and detergents working on cold tap water, or refrigerators sensoring foodstuffs outdating soon. This kind of products is still mentioned in the Df1P framework with product design under the different priority action areas (e.g. examples N1P2, N2P2, N3P1, H2P1, H3P2 in tables 2 and 3 of paper 8).

The Df1P orientation framework also should be reflected in the context of Lifestyle Material Footprints of other countries because its present basis is in Finnish lifestyles. The framework could further be developed by adding quantified examples to each of the 90 solutions proposed in the framework in a second layer of the matrix. This could improve the usefulness of the framework but would result in a more complex matrix. Looking at the development of different approaches and concepts of Design for Sustainability (Ceschin and Gaziulusoy 2015), the framework presented here is just a very first step into the direction of a Df1P.

One basic delimitation of this thesis is that it takes measuring resource use as a central basis for pursuing sustainable lifestyles. On the one hand, this is due to the general concept of planetary boundaries. Without measuring and using indicators, we would not be able to say so much about the state of our planet and our performance in relation to sustainability. On the other hand, there is a general saying that one cannot manage what one cannot measure – which of course is quite directly related to the common utilitarian and economy-focusing worldview we are facing everywhere in our modern world. I am fully aware that measuring performance and using numbers is not sufficient for saving our planet. Nevertheless, measuring resource use (and other indicators) can help us direct our activities to relevant ones. It also can help us understand the global nature of current environmental problems and choose effective solutions to them, let alone avoid blaming the wrong people for the situation. For instance, without knowing the real magnitude of natural resource consumption of Western people and countries, we still might tend to blame the growing population in the global South for the problems we have created at this end of the world. Also with the focus on design in the application of the 8 tonnes benchmark for one-planet lifestyles I didn't choose the most traditional field in terms of measuring footprints (see also Bhamra et al. 1999, Knight and Jenkins 2009, Edelholt 2012). Also this be a proof of the awareness of the author about the limitation of calculations and measurements while trying to offer a measuring concept as understandable as possible and make the best possible use out of it.

As this section shows, this thesis has not been able to solve all problems related to sustainable lifestyles and how design could support them. For example, the general gap between awareness of, for example, high footprints and the need for their reduction and the possibilities and barriers of actually implementing that reduction has not been part of the thesis but is fortunately covered by other research (e.g. Heiskanen et al. 2015, Laakso 2017, Jalas et al. 2017). Also the role of and implications on design could have been elaborated and discussed in more detail, for example from Ceschin's and Gaziulusoy's (2016), Manzini's (2015a,b), Hyysalo's (2009) and Hyysalo's et al. (2017, 2018), Popplow's and Dobler's (2015), as well as Tonkinwise's (2014) points of view. Nevertheless, the thesis has tried to provide input to the development of lifestyles and design towards the recognition of planetary boundaries by developing ways for measuring households' resource use and for utilizing its results in designing one-planet lifestyles and supporting solutions. The implications and contributions of the thesis' results are discussed in the following sections.

5.3 Conceptual implications and contribution of the thesis

During the recent decades, sustainability-related design approaches have developed from technical and product-orientation to system-oriented transition approaches (Ceschin and Gaziulusoy 2016). This thesis intends to contribute to this framework development,

(1) by developing the application of the MIPS concept for measuring total resource use towards its utilization for sustainable household consumption and supporting design activities in the shape of the Lifestyle Material Footprint (LMF),

(2) by connecting this approach to the concept of planetary boundaries, and

(3) by concretization and validation on the context of everyday consumption in order to make that one-planet resource cap benchmark usable in the context of facilitating sustainable household consumption by design and other means.

The thesis contributed to the development of the micro-level Material Footprint that encompasses both all direct and indirect and all used and unused material flows. Hence, it creates, in Rushforth's et al. (2013) words, equivalence between the global resource stocks of all primary materials used by humans and thus can, similar to the Water Footprint in Rushforth et al. (2013), help transform the conceptual paradigm of resource management toward a more global and interconnected one. This can help guide the worldview of the users of natural resources (i.e. consumers, designers, or basically anyone) to the global implications of material use, and participating households have acknowledged the relation of global impacts and household action they gained by using the LMF (paper 7). By increasing this kind of awareness, the Material Footprint as an indicator gains a broader influence than just monitoring and benchmarking resource use, because it can empower actors (e.g. households) to transformational change and shape worldviews towards sustainability, which Lehtonen at al. (2015) call an important feature of indicators.

The aggregation of Material Footprints of products and activities (as shown in papers 2 and 3) to a Lifestyle Material Footprint (LMF) on the household level (paper 4) facilitates a systemic view on household consumption. The thesis thus contributes to developing the MIPS-indicator from a product-orientated technical indicator (see e.g. Schmidt-Bleek 1993a, Tischner and Schmidt-Bleek 1993) to a systemic one that provides insights and allows conclusions on people's everyday life and the constellations behind it, as well as uncovers options for change (see papers 4 and 7). This is a similar development as Ceschin and Gaziulusoy (2015) have illustrated for the development of Design for Sustainability approaches from technical and product-orientation in the beginning to covering more complex and system-related issues and people-orientation, including aspects like poverty alleviation or integration of marginalized people. These have also been addressed on the basis of the LMF calculation of low-income households (paper 4, Hirvilammi et al. 2013). This is again in line with Lehtonen's et al. (2015) understanding that indicators can contribute beyond their original purpose, e.g. to setting new agendas and influencing worldviews.

Haberl et al. (2011) state that the whole humanity cannot become industrialized societies because already with one third of the population being industrialized, physical boundaries in terms of energy, material and land use and the related environmental impacts are materializing. The transition to a new age of human societies is thus inevitable. They state that the post-industrial society does not provide a sufficient model for that because it has not been able to decrease material and energy flows, and therefore it is at present hard to say what the next transition would look like although it has to happen. This thesis tries to describe a landing point or, in Brinegzu's (2015) words, a target corridor for that new sociometabolic regime from the perspective of consumption-based material flows. By opening one possible scenario of sustainable resource use on household-level and the factors behind it, the thesis contributes to the description of the goal the transition should reach. Although future society may look totally different from now, the presentation of the goal can help understand and make concrete the direction and magnitude of the transition we have to undergo.

By developing and applying the 8 tonnes material footprint benchmark for lifestyles (papers 5 and 6) the thesis made the LMF a footprint indicator in the sense of Hoekstra and Wiedmann (2014) who stress the relation between footprint indicators and planetary boundaries. Although the roughness of the 8 tonnes benchmark may show the "infancy" in defining sustainable levels (Hoekstra and Wiedmann 2014), this can foster the debate about globally acceptable economy-wide resource use levels and household consumption, thus forming an important link between political discussion and the public debate about common sustainability strategies (paper 1).

According to Hoekstra and Wiedmann (2014) footprint indicators reflect both a production and a consumption aspect because their calculation is based on multiplying resource (or other impact) intensities by the amount of consumption. This applies also to the LMF, and a reduction in LMF requires measures in both production and consumption as well as in the structures and politics influencing them. Therefore, although household consumption is in the focus of the LMF, the application of the LMF and the calculation of households' footprints does not imply that households are the only ones responsible for the overconsumption of natural resources. On the contrary, calculating households' LMF makes visible the structures behind households' consumption and the need for changes not only in consumption but also in the supply of products, services and infrastructure (papers 4, 6 and 7). For instance, when even consumers on the lowest level of consumption in Western countries cannot achieve a sustainable level of LMF besides in case of homelessness, the surrounding infrastructure and other social structures are the actual instrumental factors for high lifestyle material footprints, and not the consumers' behaviour. For example, downsizing the amount of housing space for environmental reasons, as proposed in paper 6 and others, has not yet been part of the awareness of political or commercial actors in Finland (Sandberg 2017). This situation is one reason for the thesis to address design.

With paper 8 of the thesis intending to lay a cornerstone for developing a Design for One Planet (Df1P), the thesis addresses design which is strongly related to both production and consumption (e.g. Thorpe 2010), and can thus help make lifestyles more sustainable. Looking at consumption from a sustainable LMF benchmark's point of view could help direct design activities towards structural change and thus (re)develop production towards serving consumers', or citizens', needs rather than its own ones, as called for numerous times, for instance already by Papanek (1984).

The LMF in combination with the eight tonnes resource cap encompasses all aspects included in the consumption efficiency disaggregation related to the Design for Sustainability (DfS) approach of Spangenberg et al. (2010). It is based on the provision and production efficiency of products (ecological backpack and eco-efficiency in Spangenberg et al. 2010), the MIPS concepts relates it directly to the services generated and consumed (product-service systems and consumption patterns), and the eight tonnes resource cap implies that the best possible consumer satisfaction should be achieved within the planetary boundaries given. Thus, the eight tonnes material footprint approach goes even further than the DfS approach by providing a measurable target for ensuring the sustainability of lifestyles in terms of planetary boundaries. This is in line with Lorek's and Spangenberg's (2014) call for "a 'strong sustainable consumption' perspective, focussing not on technology (without neglecting it), but on affluence, the level and patterns of resource consumption or the physical size of the economy".

5.4 Implications for design

Already the previous section pointed out that the planetary boundaries of the resource use of households do not only have implications for consumers but also for other actors because for example design and production as well as policy influence the Lifestyle Material Footprint (LMF) and, more generally, the way people consume. This section focuses on the implications of this thesis in terms of design.

For designers, the transition to low-resource lifestyles offers a huge range of tasks and opportunities. The focus of DfS has gradually developed from single product approaches to a level of complex socio-technical systems and from product- to people-orientation (Ceschin and Gaziulusoy 2015). Households are complex socio-technical systems in themselves. With regard to the ecological challenges we have, and their urgency, one-planet living should become a strong aspect in design. This thesis intends to justify and communicate the idea that the transition to one-planet lifestyles is required and design can and should play a role in this transition. Design for One Planet (Df1P) should be a new aspect integrated into designers' practice, education and research. Probably it is too early to say if Df1P can, or even needs to, develop into an own design approach or if, like Manzini (2015a) suggests for transition design, what we need is no new special kind of design but a design culture and posture capable of incorporating long time horizons and visions of a sustainable future.

Design can play an important role in making sustainable lifestyles more attractive. Marchant and Walker (2008) stress the importance of improvements in people's own quality of life: A responsible consumer is more than "an individual that sacrifices him/herself exclusively for the sake of nature of for the welfare of future generations". Manzini (2015b) argues even for a new design culture that helps people in constantly co-designing lifestyles supporting both their own and the planet's well-being. The better and easier life households experienced during the experiment period described in paper 7 can be an important argument and driver in mainstreaming sustainable solutions (Lettenmeier et al. 2017). Individual and social learning processes are essential for new routines to become a part of mainstream (Shove and Walker 2007, Manzini 2015b). Thus, design can help making sustainable lifestyles mainstream with additional efforts in product, service, infrastructure and communication design (as envisaged in paper 8) as well as in supporting individual and social learning processes in the sense of but going also beyond paper 7. The 8 tonnes LMF benchmark can support both of these roles.

An encouraging result of the household transition study in paper 7 is that we do not have to wait decades or even years for achieving considerable reductions in LMFs towards 8 tonnes. Achieving a significant absolute reduction in LMFs is possible by making relatively few changes in the consumption practices of households, and the change start immediately. However, achieving these remarkable absolute reductions requires co-operation between consumers, designers and product and service suppliers, as services like on-demand buses or car-sharing are not yet mainstream. The sustainable LMF target makes this cooperation especially vital and can help direct efforts as effective as possible.

My analysis indicates that design can support more sustainable choices in the both short and long run. Households can make even immediate decisions decreasing the material footprint. In the fields of nutrition, electricity procurement and tourism, for instance, sustainable decisions can be made any time so that even fast changes could be envisaged in these areas. Although households are, in principle, free to make decisions on their consumption, some decisions are highly complex and can be locked into existing infrastructures. For instance, housing-related decisions are made rarely compared to e.g. nutrition choices and the location of housing affects many further decisions, e.g. the mobility options available. Therefore, incentives should be set and society's rules should be developed to facilitate change in public planning and market actors' decisions, for example on infrastructure. Infrastructure affects resource use in the long run and determines lifestyles in many respects. Therefore, including the aspect of facilitating sustainable, low-resource lifestyles in public decision-making provides an opportunity for avoiding misinvestments and creating synergies from options simultaneously decreasing the resource use of several consumption components. As paper 6 points out, for example promoting car-free lifestyles in city planning can reduce car use and the need for public and private infrastructure like streets and parking space. Thus, it can decrease the material intensity of both mobility and housing. Attractive car-free quarters can reduce the highly relevant need for leisure time trips and could possibly also reduce the need for private living space. Without a car, closely situated shops and other facilities are more attractive than distant ones. In addition, the health effects of decreasing car use are evident. Increasing walking and cycling could, thus, also decrease the resource use required for leisure activities and for health care (paper 6). Design can play a role in making these interrelationships visible and tangible, in addition to developing products that facilitate change, for example electric bicycles or foldable bicycles.

As stated above, design needs to extend to public services and infrastructures if we are to reduce the consumption of material resources to sustainable levels. Most of the 18 households studied in paper 4 are still using at least factor 2 more resources than the long-term sustainable level, the ecological maximum, would require. However, from a global sustainability perspective this means that even low-income households in Finland are using relatively high amounts of resources, despite the fact that they consume far less than the average households. As low-income households hardly can reduce their consumption much more, the findings mean that a sustainable level of resource use cannot be achieved solely by choices, decisions and activities of private households but states and companies must improve the conditions and technologies enabling households to consume in a more sustainable way (paper 4). The more technology and infrastructure can be integrated into this change, the more space will be left for individual diversity in achieving sustainable household consumption (see Tables 3 and 4). Design can support this both by developing less resource-consuming products, services and infrastructures and by promoting a social transition process away from present unsustainable planning, production and consumption patterns.

The recognition of the planetary boundaries in the design process might be interpreted as a restriction of creativity. However, it might be worth remembering that without recognizing planetary boundaries, the freedom of choice in terms of both design solutions and lifestyles will probably become even more restricted in the future. In addition, designers are facing economic restrictions in their everyday work and overcoming them is one way of using and utilizing creativity. The Orientation Framework for Df1P suggested in this thesis is intended to inspire designers to integrate the recognition of the planetary boundaries into their work and thus ensure a wealthy life for all inhabitants of our planet. Although the framework is of pragmatic nature with directly addressing solutions required for the transition to one-planet lifestyles, the basic matrix of the framework with the ten priority action areas and the four domains of design can help to structure designers' work and to draw their "attention away from peanuts, towards big points and key points of sustainable consumption" (Bilharz and Schmitt 2011). The individual measures listed in the Df1P Orientation Framework could serve as a source of inspiration in the sense of an evidence- and urgency-based "portfolio of diverse lifestyle changes to meet the challenges of sustainability" (Thorpe 2010).

In addition, life-cycle-based assessments have been called complex procedures for designers requiring both time and data that often are not available (Bhamra et al. 1999, Cooper 2000, Knight and Jenkins 2009). The priority areas and solutions provided by the Df1P framework are of the kind that their quantitative relevance has already been confirmed. Therefore, with its pre-selection of priority areas and solutions that are of quantitative relevance for sustainable lifestyles, the framework could provide designers a way for taking into consideration one-planet lifestyles without the direct need for quantifying solutions. However, this does not imply that sustainability nor one-planet resource use should be out of focus when designing solutions not related to the priority areas of the framework.

In a similar way, household LMF assessments can help designers understand the scientific backgrounds when facilitating co-creation processes. In the Future Household project (paper 7) the LMF results of the households provided a useful basis for designing sustainable lifestyles because they introduced a scientific yet still personal quantitative basis into the design process (see Edelholt 2012). This helped co-create relevant measures towards one-planet lifestyles and thus was one way of answering Manzini's (2015a) call for a network of relevant local actions basing on a vision of a sustainable future.

Thorpe (2010) questions the existing design methods and if designers are adequately educated for new, sustainable-consumption-oriented approaches. Manzini (2015a) reflects on the skills and culture of design to play a major role in the transition to sustainable living and sees the new design culture built up by the interaction with bottom-up social innovation. In any case, designers' education will play a prominent role in enabling designers to understand and position themselves as active change agents in the first row (Liedtke et al. 2015). Thus, in a further step the framework should be tested in design education.

5.5 New research avenues

This thesis has developed a benchmark for sustainable lifestyles on the basis of a scientifically justified yet understandable indicator. It has applied the benchmark to designing sustainable lifestyles and by providing an orientation framework for design. The thesis has contributed to the evolution of the MIPS concept from product-orientation to covering households' entire lifestyles and allowing conclusions on the requirements in consumption, production and politics in order to reduce resource consumption to a sustainable level. By developing and applying the 8 tonnes LMF benchmark the thesis made the material footprint a footprint indicator in the sense of Hoekstra and Wiedmann (2014), who stress the relation of footprint indicators and planetary boundaries. The application of the planetary boundaries concept on the household level facilitated the development and suggestion of new approaches for household sustainability transition and design. In order to further operationalize the concept of planetary boundaries, its application on the level of products and services should be developed or at least researched. Hoekstra and Wiedmann (2014) expect this kind of development, and this would also help to better establish the idea and practice of Df1P. A preliminary study (Lettenmeier et al. 2014) showed, however, that it is not unambiguous and therefore a challenge to break down the sustainable Material Footprint level of consumption components –which is already hard to determine in a general, normative way– to the product level. In the nutrition sector there is a common approach of relating the content of specific nutrients (e.g. fat, sugar, etc.) in foodstuffs to the Guideline Daily Amount (GDA) of intake for each nutrient. A similar approach could be used for the relation of product Material Footprints to the sustainable benchmark of the related consumption component. For example, the Material Footprint of 100 grammes of cheese amounts to 4.3 kg (Kauppinen et al. 2008). This is equivalent to 52% of 8.2 kg which is the sustainable "Guideline Daily Amount" of LMF for nutrition on the basis of the LMF yearly benchmark of 3,000 kg for nutrition. However, even this approach is not unambiguous, for example when it comes to products relevant for several consumption components, like power-consuming household goods (Lettenmeier et al. 2014).

In any case, for a larger or global application of the LMF and its benchmark, also basic MIPS calculation of products and services should be extended far from today, to many additional products and services in order to achieve a broader data basis for the evaluation of natural resource consumption in different countries and contexts. There is a need for an international resource intensity data centre and for tools that support designers and other actors in companies to provide relevant information on the resource use of their value chains and management processes (see Giljum et al. 2009). A first step could be the extension of current LCA databases towards a more complete inclusion of resource-relevant aspects. Databases like Ecoinvent (about 4000 processes) or ELCD (300 - 400 processes) only consider economically used resources. To achieve a compatibility with MIPS, a first step would be to integrate unused extraction like mining overburden or unused biomass. One core issue for a successful implementation is the introduction of elementary flows for unused extraction and the international trade of resources (Wiesen et al. 2014, Saurat and Ritthoff 2013).

The application of the planetary boundary concept on lifestyles in this thesis culminated in the direction of design. However, although the field and coverage of design in the sustainability concept has steadily been emerging (Ceschin and Gaziulusoy 2016), also other approaches than design will be required. Designers are strong in developing constructive and debatable visions while science is strong in understanding how things are and probably will become (Edelholt 2012). Edelholt advocates that design can have a relevant role in facilitating scienitific and public discourses on our options for avoiding a disastrous future. However, also other disciplines should incorporate and apply the planetary boundary idea. Therefore, there is an urgent need for developing concepts for adopting the idea of planetary boundaries in, for example, technology, business, management, administration and education.

The thesis shows that considerable reductions in LMF are possible even in the short term. For achieving further reductions, changes in supply and on system level are required increasingly. Therefore, it would be highly relevant to study how to use both public and private financial resources in the best way for decreasing material footprints while maintaining a high quality of life. To which extent affluent households could facilitate reductions in resource use by using or allocating their financial resources in an optimal way and how can public earning (e.g. taxes) and spending (e.g. research and development funding) best facilitate reductions instead of increases in resource use? For example, investments in energy- and resource-efficient buildings are urgent in order to achieve the targets proposed for sustainable housing.

With the material footprint covering both household consumption and potential environmental impacts of human activities and its 8 tonnes resource cap target, the thesis provides an input to Manzini's (2015a) call for "a theory of change in which broad and long-term views are needed to feed and orient the social conversation on what to do and how". The household experiments showed that the indicator and its benchmark can be utillized "to trigger and enhance small, local, and connected actions" towards "a multiplicity of projects in a social learning process" (Manzini 2015a). The thesis thus provides an impetus to the potential development of a Design for One Planet (Df1P). In this context, the acceptance, usability and actual ways of using the Df1P orientation framework and the whole idea of a one-planet LMF benchmark should be studied. Going further, to establish Df1P as a strong aspect, or even a new field, of design, the steps of the evolution of Design for social innovation as reported by Ceschin and Gaziulusoy (2015) could provide an example to follow: With the orientation framework as a cornerstone, a broader collection and analysis of examples suitable for Df1P (similar to Meroni 2007 in the case of Design for social innovation) could be a next step, followed by a closer exploration of the role of designers (correspondent to Jégou and Manzini 2008), the development of Df1P toolkits (correspondent to Murray et al. 2010), and considerations on the role of designers in facilitating replication and up-scaling (similar to Hillgren et al. 2011), while keeping in mind the importance of creating systemic solutions instead of "techno-fixes" (Ceschin and Gaziulusoy 2015). The role of design in promoting peer innovation (see Hyysalo et al. 2017, 2018) for scaling up sustainable lifestyles should also be considered. In addition, questions related to the nature of design, including its postures, mindsets and processes (see e.g. Tonkinwise 2014 and Irwin 2015) should be strongly considered.

This thesis has provided some concepts and methods for achieving sustainable household consumption by 2050. In general, a sustainable household consumption in 2050 seems achievable on the basis of the mostly Finland-related proposals for reducing LMFs. However, the targets proposed (see Tables 3, 4 and 5) show that there is a long way to go and a lot of efforts required. The findings of this thesis can help to show the way towards sustainable household consumption and are intended to contribute to a positive vision for the enormous transformation task we are facing. Since doing good is more motivating than preventing bad, one increasingly studied approach is to develop a mindshift from decreasing footprints to catching the potential for positive action in terms of change, i.e. the concept of handprints (e.g. Behm et al. 2016). This includes also designing solutions that actively (help) reduce footprints. This thesis has not taken the concept of handprints into use but this could be a further activity to activate consumers and producers, including designers, on the basis of how much they can contribute to make the world a better place. However, even without explicitely addressing the term handprint this thesis includes many issues that can be seen as a contribution to handprint thinking, e.g. the resource-efficiency potential calculations, the method for an active transition of households and the framework of sustainable design solutions. One possible outcome could be an illustrated and quantified compendium of solutions for low-resource lifestyles in the style of Hawken (2017). This could also be a next step for developing Df1P because visualising new solutions (e.g. Meroni 2007, Fuad-Luk 2002) has been an important part of developing new design approaches, as Ceschin and Gadiulusoy (2016) show with the example of Design for social innovation.

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Paper 1

Liedtke, C., Bienge, K., Wiesen, K., Teubler, J., Greiff, K., Lettenmeier, M., Rohn, H. 2014. Resource Use in the Production and Consumption System—The MIPS Approach. Resources, 3(3), 544-574.

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Resource Use in the Production and Consumption System—The MIPS Approach

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Abstract: The concept Material Input per Service Unit (MIPS) was developed 20 years ago as a measure for the overall natural resource use of products and services. The material intensity analysis is used to calculate the material footprint of any economic activities in production and consumption. Environmental assessment has developed extensive databases for life cycle inventories, which can additionally be adopted for material intensity analysis. Based on practical experience in measuring material footprints on the micro level, this paper presents the current state of research and methodology development: it shows the international discussions on the importance of accounting methodologies to measure progress in resource efficiency. The MIPS approach is presented and its micro level application for assessing value chains, supporting business management, and operationalizing sustainability strategies is discussed. Linkages to output-oriented Life Cycle Assessment as well as to Material Flow Analysis (MFA) at the macro level are pointed out. Finally we come to the conclusion that the MIPS approach provides relevant knowledge on resource and energy input at the micro level for fact-based decision-making in science, policy, business, and consumption.

Keywords: MIPS (Material Input per Service Unit); resource consumption; natural resources; Material Intensity Analysis; dematerialization; Material Footprint, micro economy; value chain; sustainable production and consumption (SCP)

1. Introduction

In 2013, the concept of sustainability celebrated its 300th anniversary [1]. In the last decades sustainability has become an international acknowledged principle and many governments and (inter)national institutions have implemented related programs and initiatives worldwide [2,3]. During the last 20 years resource intensity of production and consumption patterns gained specific political and scientific attention in discussing increased resource productivity as a key element of sustainable development and especially for reducing environmental impact, e.g., [4–10]. In particular, Dematerialisation is seen as a strategy to decouple natural resource use from economic growth [6,11–17]. The term natural resources refers to extraction and harvest of biotic and abiotic raw materials as well as the use of water, air and soil. The latest reviews of the global resource use show that the global economy not only needs a relative decoupling (increased economic wealth with less resources) but also an absolute decoupling (reduced resource use in absolute terms) and impact decoupling (reducing environmental impact of economic including consumption activities) [18–20].

Implemented resource efficiency indicators refer to resource productivity of countries and sectors (macro level) and rely on the availability of established methods and available datasets [21,22]. In general, material productivity (GDP/DMI) measures economic performance (GDP) and the direct Material Input (DMI) of a country. It allows us to monitor the created economic wealth (including exports) out of certain amounts of utilized materials (per time), but does not integrate knowledge on indirect material flows of unused extraction, reflected by the resource productivity (GDP/TMR) and the Total Material Requirement (TMR), see [18,23–26]. The indicators Domestic Material Consumption (DMC) and Total Material Consumption (TMC) on the other hand, quantify the consumption site of used and hidden material flows within countries (without exports) [25].

There are huge differences between countries when comparing their direct material use per capita and their overall resource use. If one compares the direct resource use for production and consumption (DMI) of, e.g., Germany (20.5 t/cap in 2008) [25], USA (24.4 t/cap in 1994) [27], and China (16.6 t/cap in 2008) [27] with their total material requirement (TMR) the resource use is much higher: Germany 73.3 t/cap (in 2008) [25] or, USA 71.4 t/cap (in 1994) [27], and China 42.9 t/cap (in 2008) [27] (see further data [28,29]). In addition, there is also a major gap between countries in terms of their extraction of natural resources. For example, current calculations of the direct domestic resource extraction (DME) of countries show a difference between about 1 t/cap (e.g., Haiti) and 139 t/cap (Qatar) [30]. The global annual economically used raw material extraction was between 47 and 59 billion metric tonnes in 2005. It has been increased by factor eight during the last century (between 1900 and 2005) while the global population only increased by factor four [20]. Krausmann *et al.* [31]

and Wiedmann *et al.* [30] showed a further increase of global material extraction until 2008 up to 67 to 70 Gt. The concept of "Factor 10", which was first presented by Friedrich Schmidt-Bleek in the early nineties [6], sets the goal of a tenfold decrease of natural resource consumption in Western countries by 2050 to reach a sustainable level of global resource consumption [4,25,32–37].

Also, international initiatives such as UNEP launched a specific program and framework on resource use and sustainable consumption and production (SCP) [38]. Ever since, reducing material and energy intensity have been key principles of international actions towards SCP [2,3]. Especially European policy processes aim at increasing resource productivity [39–43] addressing raw materials, energy, water, air, land and soil. The EU discuss—beyond measuring DMC—an extended resource use indicator such as total material consumption (TMC) [44] and has suggested a complementary indicator set ("dashboard") in the categories land, water and carbon [45]. Towards resource efficient production the milestone has been defined, that by 2020 "*Economic growth and wellbeing is decoupled from resource inputs and come primarily from increases in the value of products and associated services*" [43] (p. 6).

Although a clear vision and overall goals are given, the accounting methodologies to measure a decoupling of resource inputs from well-being and economic growth in the production and consumption system are still under development. The related assessment requires adequate indicators for monitoring and reporting on all levels of economic activity [42,46–48] (pp. 5–6). There is also a need for a reliable indicator (set) and database providing aggregated data on resource intensity at micro and meso level. In this paper the concept of MIPS (Material Input Per Service unit) is illustrated as such a method to measure the resource intensity of production and consumption patterns and can be applied for decision-making in companies and households towards a low resource society and economy [9,36].

The MIPS concept has been developed to provide a proxy for ecological measures [6] (p. 101). It takes into account the multi level effects between the micro, meso and macro level of economy [6,7,49] and can be applied to management processes on the micro level as it is a reliable measure for their impacts. The methodology to calculate MIPS is the Material Intensity Analysis (MAIA) [50].

This paper reflects the current state of research and methodology of MAIA at micro and meso level. The term meso level refers in this paper to the level of companies, but to the level of branches. For the application of MAIA or related methods at macro level see, e.g., [49,51]. The paper aims at presenting an overview of the assessment method at micro and meso level as basis for:

- Discussion of several application fields of calculating material intensity mainly developed in German/European research projects;
- Discussion of current challenges and open questions of MAIA method;
- Discussion of future research needs;
- Finally, provide an updated basis for further discussion of the MIPS concept and MAIA method with an international scientific community of environmental assessment.

Embedded in a brief introduction of the MIPS concept the authors present its basic principles of input and service orientation as well as its main calculation steps as a summary of MIPS research to enhance the understanding of application discussion for the reader including examples of MIPS results (Section 2). After that, the authors present the generic micro and meso level application of MIPS for assessing value chains, supporting business management, and operationalization of sustainability strategies, which have been developed and tested in research projects or represent future application fields (Section 3). Finally, we come to the conclusion that the MIPS approach provides relevant knowledge on resource and energy input at the micro level for informed decisions of science, policy, business, and consumers (Section 4).

The paper does not thoroughly discuss the existing MIPS database itself. However, the given examples in the paper emphasise the presented research results or discussion questions. The authors invite the reader to comment on the MIPS concept and MAIA method.

2. MIPS Concept and Methodology

The MIPS concept was established around 20 years ago. It was introduced by Friedrich Schmidt-Bleek in 1992 in order to operationalize the concept of dematerialisation and its management on economic micro, meso and macro level (first published in 1993 in [6,52]). It is based on the idea of the "ecological backpack", which is a metaphor for the burden of natural resources every object "carries" in addition to the materials it contains directly. MIPS results can be used to downscale the Factor 10 concept into a metric and tangible unit for technologies, products, processes, services, and systems (e.g., companies [12,53–55] and households [36,56]). Macro level assessment of economies and sectors are not further discussed in this paper (see specific publications, e.g., [28–30,57,58].

The basic principles of the MIPS approach include input (Section 2.1) and service orientation (Section 2.4). In the following, we discuss these two principles and present the MIPS calculation based on MAIA. Additionally, the authors discuss major interlinkages of the MIPS calculation and the sustainability strategies efficiency, consistency, and sufficiency.

2.1. Principle of Input Orientation: Prevention Indicator

The MIPS concept is based on the fact that inputs in the human production and consumption system (technosphere) are finally converted into outputs with environmental impacts, e.g., climate change, eutrophication and acidification. Consequently, resources (material inputs incl. those for energy) taken from nature (ecosphere) lead to an increase of outputs (e.g., emissions, waste) and potential impacts. MIPS considers all moved primary material in nature connected with known and yet unknown impact to the ecological system.

The input focus of MIPS follows the idea of the matter-energy conservation law assuming quantitative equivalent inputs and outputs. Accounting input material flows allows preliminary estimation of the environmental impact potential of products and services [6,9,33,49]. Thus, MIPS is a practical solution to reduce the complexity of the assessment as well as the uncertainties that go along with output-oriented assessments such as the ISO 14040/44 LCA [59,60]. Many emissions last for decades or even centuries in the ecosphere, impeding the assessment of future impacts. In addition, it can be assumed that still only a small amount of all potential environmental toxins, their interactions and the resulting impact on humans and nature are known. And even if effects are known, it can take many decades until their elimination. Lead, for instance, (since 1978 lead pipes are banned in new buildings in Germany due to harmful effects of bio accumulation/lead poisoning) and the insecticide DDT (20 years after first hints of harmful effects in the 1950s it was banned in the 1970s in the USA, Canada, and Europe, resulting in the international Stockholm Convention in 2004: however, it is still in use for disease vector control) [61,62]. This example shows that there can be a very long period from the identification of impacts to the realisation of measures to avoid them. Processes to analyse such impacts are necessary but not sufficient for precautionary protection of the environment. For this, reducing the material flows on the input side will help to avoid and minimize outputs and thus known and unknown negative impacts. In addition, known toxic substances can be directly avoided or minimized at the input side respecting the legally defined limits and following a more holistic resource management understanding [7,33–35]. MIPS is not developed to quantify specific outputs (e.g., emissions of specific toxic substances) and assess their impacts (e.g., acidification, GHG), but supports an optimized resource input management [63,64]. Besides, the input-oriented MIPS concept is mostly compatible to an output-oriented LCA. If a MIPS analysis or other material and substance information indicate the need for deeper analysis of different indicators or impact categories, they can be assessed simultaneously or afterwards [32].

2.2. MIPS Calculation

The MIPS calculation has been described in [6,34,50,52]. This chapter summarizes the basic calculation convention. MIPS implements the demand for quantifying the resource use of technologies, products, processes, services, and systems (e.g., companies, households, regions, *etc.*).

$$MIPS = \frac{MI}{S} = \frac{Material\ Input}{Service\ unit} \tag{1}$$

The formula describes how much primary material—or actually "nature"—is being removed for the production of a product or the provision of a service (S). The term material comprises all required natural resources. Resources themselves are defined as raw materials including such for energy carriers and transports. The reciprocal of MIPS (S/MI) describes the resource productivity, which means the amount of service provided by a certain amount of natural resources [34,50].

The unit for the material input is kg or tonnes. When related to material, energy or distance, it is also called material intensity, e.g., kg/kg steel, t/MWh electricity; t/km transport, encompassing infrastructure (e.g., streets, buildings, harbours, *etc.*) as well as transport carriers (e.g., trucks, trains, *etc.*) and their energy consumption (e.g., fuels, electricity, *etc.*) [50,63,65]. The service unit has no fixed dimension. It has to be defined in accordance to the specified delivered service, e.g., for transport (transportation from A to B with different vehicles calculated as person kilometres or tonne kilometres), clean clothes (e.g., wearable T-Shirt for one year) or nutrition and meals (e.g., kcal per portion) [36,50,63,66,67].

The MIPS concept measures natural resource use throughout the entire life cycle (resource extraction, manufacturing, transport, packaging, operating, re-use, re-cycling, and re-manufacturing, final waste disposal) of technologies, products, processes, and services. This can be done on a product and company level. MIPS takes into account direct and indirect material use as well as used and unused extraction [6,7,33,34,49,63]. The latter is particularly important, *i.e.*, that the material input includes both resources used in human economy and unused extraction [23,26,68]. Thus, all material flows caused by humans are calculated irrespective of their economic benefits.

MIPS measures removed resources in up to five natural resource categories: abiotic raw material, biotic raw material, water, air, and earth movements in agriculture and forestry (erosion, mechanical earth movement) [50]. Raw materials include metallic and non-metallic minerals (ores, rocks, sand, *etc.*), fossil energy carriers (such as coal, mineral oil, natural gas). Energy and transport is calculated by the sum of all raw materials necessary for its production, including the required infrastructure [50] (p. 98). The different categories can be disaggregated in different materials and its life cycle use, if necessary, so that the amount of each material or substance is transparent and therefore useful for decision-making processes in environmental and sustainable management processes (e.g., [13,69]).

A MIPS calculation can be performed using primary data for a specific case. However, it becomes more feasible by using pre-calculated coefficients representing the average material intensity of, e.g., basic materials, chemicals or agricultural products. This helps to avoid the calculation out of primary data each time, which would require complex and labour-intensive calculations. These average material intensities give the average amount of natural resources in the above-described five categories used to produce a certain amount of material (e.g., 1 kg copper or polyester). The most comprehensive list of MIT factors is published by the Wuppertal Institute [70]. The list is continuously updated.

$$\mathrm{MIPS}(x) = \frac{\sum_{i=0}^{\mathrm{n}} \mathrm{m}_i \times \mathrm{MI}_i}{\mathrm{Use}(x)} \quad (2)$$

The formula shows the principle calculation: MIPS is calculated by multiplying the inputs (e.g., masses, energy carriers) by their material intensity (MIT factors) and summing up all results per MIPS category. Where x is the product/service, MIPS (x) the MIPS result of x, m_i amount of input i, n number of inputs, MI_i material intensity of input i, Use (x) service of product x [6,50,71,72]. Dividing these sums by the defined service unit (S) gives the MIPS result (see Table 1).

MIPS analyses using MIT factors can be easily done using common spread sheet programs or even pen and paper. However it has the disadvantage that modeling complex systems is very time consuming. Also the graphical analysis or complex sensitivity analysis (e.g., using Monte Carlo models) can get very extensive. In [73], the authors describe how to calculate MIPS using LCA software and matrix inversion, which opens up possibilities for enhancing MIPS-models. Another advantage of this approach is that data from LCA databases can be used. However, there are currently many challenges left which are described in [74].

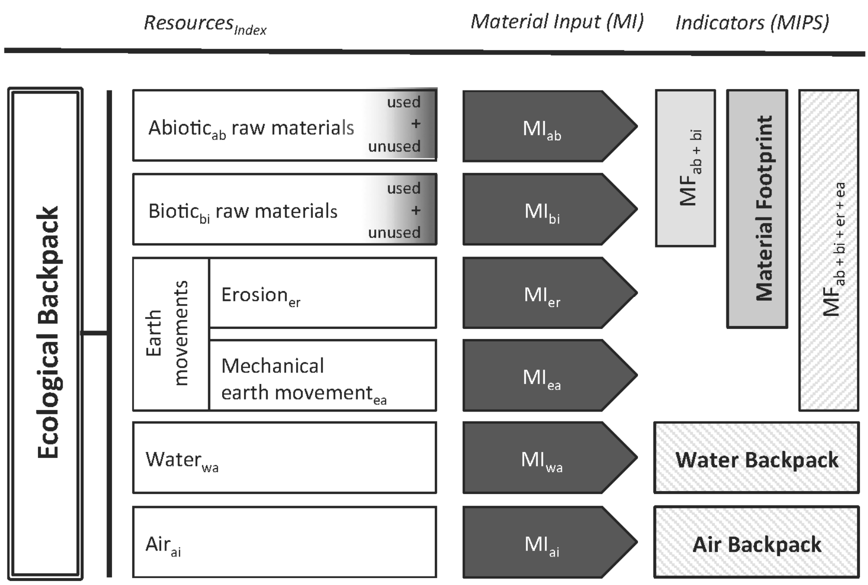
2.3. MIPS, Material Footprint and Ecological Backpack

In principal the five MIPS resource categories are calculated separately. In total they are known as the Ecological Backpack. The resource categories can be used for a subset of indicators. They are illustrated in Figure 1, which shows the five resource categories: abiotic, biotic, erosion/earth movement, water, and air. First there is the *Material Footprint*, which was established in 2009 by Lettenmeier *et al.* [63] as a parallel term for the ecological backpack created by Schmidt-Bleek [6]. The Material Footprint (MF) has been applied in projects such as [56,75]. Although the term footprint is originally closer related to land use aspects (the ecological footprint that was launched first [76,77]), the acceptance of the "footprint family" not only focusing on land use (e.g., carbon footprint, water footprint) is broad, e.g., [78,79]. The Material Footprint aims at completing this "family" as an indicator focusing on material resources ($MF_{ab+bi+er}$). It can alternatively focus on abiotic and biotic resources, in case data on earth movements are not available (MF_{ab+bi}). Further indicators are the Water Backpack and the Air Backpack, which reflect the resource categories water and air.

Table 1. Material Intensity Analysis (MAIA) calculation sheet with exemplary calculation principle for abiotic raw materials.

partial process 1 up to partial process n			**Abiotic (ab)**		**Biotic (bi)**		**Earth movement (ea)/erosion (er)**		**Water (wa)**		**Air (ai)**	
substance /pre-product	amount	unit	MIT factor	kg/unit	MIT factor	kg/unit	MIT factor	kg/unit	MIT factor	kg/unit	MIT factor	kg/unit
			kg/unit	main product	kg/unit	main product	kg/unit	main product	kg/unit	main product	kg/unit	main product
[name] 1	m_1		MI_1	$m_1 \times MI_1$	...	...	...	...	...	...	...	...
[name] 2	m_2		MI_2	$m_2 \times MI_2$	...	...	...	...	...	...	...	...
[name] 3	m_3		MI_3	$m_3 \times MI_3$	...	...	...	...	...	...	...	...
...	...		...	...	...	...	...	...	...	...	...	...
[name n]	m_n		MI_n	$m_n \times MI_n$	...	...	...	...	...	...	...	...
∑ partial process 1				$\sum m_i \times MI_i$		$\sum m_i \times MI_i$	...	$\sum m_i \times MI_i$		$\sum m_i \times MI_i$		$\sum m_i \times MI_i$
(...) calculation of further partial processes (e.g., life cycle stages)			...	...	...	...	...	...	...	...	...	...
∑ MI (sum of all partial processes)				MI ab		MI bi		MI er MI ea		MI wa		MI ai
Total amount of service units												
MIPS (MI per one service)				MIPS ab		MIPS bi		MIPS er MIPS ea		MIPS wa		MIPS ai

Figure 1. Resource categories, Material Input (MI), and Material Footprint (MF).



Regarding its resource categories, the Material Footprint equals the macro indicator Total Material Requirement (TMR), which can be used to measure the physical metabolism of national economies (including used and unused extraction as well as indirect flows, see [23]) [22,68]. As the TMR considers exports of an economy, the Total Material Consumption (TMC), which excludes exports and the related indirect flows, is a suitable measure for comparison, when results from a MIPS analysis related with consumption, e.g., of households, are scaled up to macro level.

In general one can say that MIPS supports analysing and finding the best possible way of reducing and preventing resource extraction from nature, *i.e.*, reducing the material input and thus environmental impact, while increasing the service at the same time. Although the MIPS concept allows weighting of resource categories usually each resource category is calculated separately (unweighted). The results of a MIPS analysis can be used for resource management addressing the environmental media soil, water, and air [32]. Finding the best alternative the weighing of results and categories might be useful and have to be discussed with stakeholders: depending, e.g., on regional water situation it can be reasonable to weigh MF_{wa} higher than MF_{ab+bi} [63,72].

2.4. Principle: Service Approach

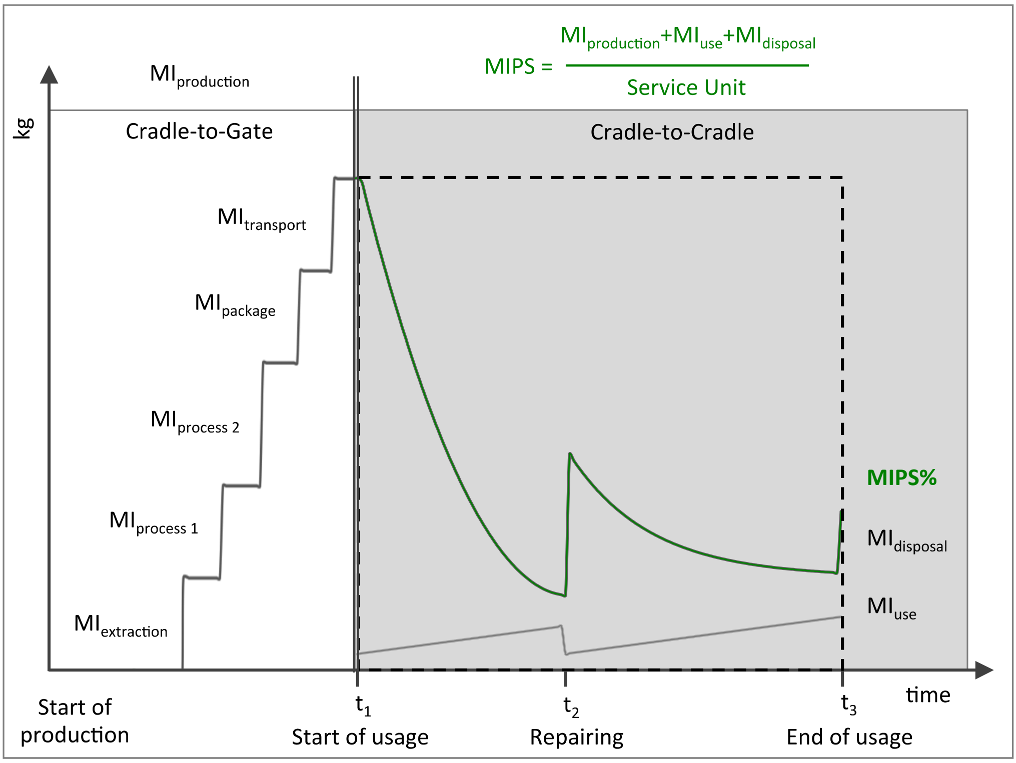
The concept of service (S) in MIPS (MI/S) is based on the notion that any product provides a specific service or fulfils a specific need [6,50]. In this sense MIPS compares not only products, *etc.*, but also services or needs that can usually be fulfilled in different ways. Depending on the product analysed, one service unit can be expressed in utilization (comfortable transfer from A to B, hygienic and clean, on my skin pleasantly portable and fashionable, my lifestyle underlining and expressing clothing, *etc.*) related to a period of utilization (e.g., 1 year, 1 day reflecting longevity, reusability, repairability). For the specific assessment the service bundle will be described respecting the individual and social needs (e.g., identity, relatedness, competence, security, self-determination [15,80] and for calculating a quantified measure related to a service unit (e.g., good life in my home environment: which amount of resources per chosen product mix and m^2 and year or an average life time per flat is consumed?) [14,50]. In the broader sense MIPS is asking the question about quality of life or personal meaning [15,80,81], because quality of life is not determined only by the consumption of goods [15,82]. Hence, in addition to optimizing just a specific product or service, the MIPS concept directly leads to the consideration of how the desired service can be fulfilled in the most resource efficient way [14,83].

As a life cycle wide approach, MIPS has linkages with the LCA framework [59,60] regarding the definition of system borders and service unit of a product system. The service unit of the MIPS concept equates in many cases to the functional unit of the LCA. However, it refers to the provided product service and therefore allows a wider and more holistic approach [14,15].

Figure 2 schematically shows this general assumption displaying time on the x-axis against mass unit (e.g., kg) on the y-axis. On the left, the cradle-to-gate assessment accumulates the material input of production phase (including resource extraction, several processes, package, and transport). The MI is growing until start of usage (t_1). On the right, the cradle-to-cradle assessment illustrates MIPS, which equals the sum of $MI_{production}$ + MI_{use} + $MI_{disposal}$ per Service Unit at a specific assumed life time.

The green graph shows that with a growing amount of services and a given MI, the MI/S (MIPS) diminishes. At point of repairing (t_2) MIPS increases due to necessary input but decreases due to prolonged life time (t_3). The grey graph illustrates MI_{use}. The longer the use phase the more MI is consumed (e.g., energy use). Repairing not only prolongs the life time but also reduces MI. MIPS calculation also includes the MI of disposal. It is obvious that a product's second life (e.g., re-use, upcycling, sharing, cascading) is only reasonable if the MI for recycling or similar processes is not higher than for primary production, which would not be reasonable in terms of a limited environmental space [6,7,14,36].

Figure 2. Schematic Material Input per Service Unit (MIPS) calculation (adapted from [6]).



3. MIPS Application Fields at Micro and Meso Level

Due to the increased complexity and globalization of production processes in value chains, the demand for management and controlling strategies is changing. Actors who deal with product chains, such as entrepreneurs, politicians and retailers, need to manage an increased complexity in order to monitor all on-going processes with the objective of optimizing value chains in terms of resource use [84–86]. Beside this they have to reflect a complex socioeconomic indicator set and standards (e.g., SA 6000, ISO 9000, ISO 26000, Reporting systems, *etc.*) to manage their companies and value chains from resource extraction to recycling processes. Decision making on the micro level needs a more holistic view on different system wide management criteria to improve and optimize the processes with a high responsibility for economic, social and ecological challenges [19,45,48]. For instance, resource efficiency is an increasingly integrated aspect in the production system: Companies define their goals and strategies including resource use indicators. Some already use MIPS as an indicator for their resource management. Others focus on selected resource use aspects (e.g., direct energy use, waste, CO_2 emissions) [54]. In the following chapter we present generic micro and meso level application of MIPS, which have been developed and tested in research projects or represent future application fields. The MAIA can be applied on several levels (value chain, life cycle, product, company, household, economic sector, regional or national economy) and is able to provide results for different levels of application.

3.1. MIPS Application along the Value Chain

Table 2 gives an overview of current examples of MIPS application along the value chain including business management. The applications have been or are being developed and tested in various research projects. Future options are also given to show extended application fields. Production aspects that have been analysed in research projects are reflecting the MI of single processes and life cycle phases or segments of value chains, e.g., cradle-to-gate or gate-to-cradle assessments. Gate-to-Gate assessments have been focusing on the production site. Also products and services, business models, the construction and maintenance of infrastructures, energy and transport have been assessed. Business perspectives (company, processes, products) are relevant focusing on the relationship between MAIA and monetary units used in business management (e.g., costs). The aim is expressing the use of natural resources at company level to inform economic actors on environmentally relevant information based on their existing business, eco accounting processes and indicators [54]. Another MIPS application has been developed for household level to record and assess resource use of private households reflecting an important level of the consumption patterns assessable by MIPS [36,87].

3.2. MIPS Application towards Integration of Sustainability Strategies

The MIPS concept helps to approach the assessment of the sustainability strategies of efficiency [6,88,89], consistency [6,90], and sufficiency [6,91,92]. Whereas efficiency describes the idea of producing *better* (less resource and energy input per service), the consistency strategy aims at producing *differently* (closing loops, change composition or quality of resource and energy input). Finally sufficiency is about producing and consuming *less* (enhance welfare with decreasing resource demand). Those sustainability strategies complete each other [14]. Together they contribute to reducing the MI and increasing the S. The integrated consideration of these sustainability strategies along with further strategies (e.g., deceleration of consuming goods [93]) aims at resource use reduction per capita in absolute terms [6,11,14,36,50,83,94].

Efficiency is defined as resource and energy savings per service unit either within production processes or throughout the entire life cycle. Table 3 shows resource efficiency examples of different energy supply systems. Offshore wind energy is the most efficient system when compared to biogas plants and lignite-fired power plants. On the basis of this kind of comparison, the development of transition paths towards increased resource efficiency is possible.

Table 2. Examples of MIPS application along the value chain.

	MIPS application: Current examples (selection) and ***future application (own suggestion)***	References of current examples (selection)
Production	**MI Processes and life cycle phases**: Single processes up to life cycle phase (e.g., extraction, production, use, recycling), *R&D of processes*	[66,69,94–101]
	MI Value chain: Cradle to Gate, Cradle to Grave/Cradle, Gate to Grave/Cradle, comparison of value chains and life cycle phases, material selection/design, *R&D of technologies/products (including development, prototyping, testing, roll out), R&D of services*	[66,69,95–97,100,102]
	MI Production site: Gate to Gate, multinational companies, small and medium sized enterprises, *cluster, industrial symbiosis*	[12,13,53,103,104]
	MI Products & services: Single products, product bunch for services, *comparison of product & service bundles*	[13–15,69,94,96,102,103,105]
	MI Business models: Service concepts, *concepts for logistics/distribution/diffusion*	[12,13,15,53,54,99, 101,102,106,107]
	MI Infrastructure: Construction & maintenance of infrastructure	[69,96,100,108–110]
	MI Energy: Power stations, energy source/storage, electricity/heat supply	[69,71,100,110]
	MI Transport: Mode of transport, mobility, *logistics, fleet management*	[50,69,111]
	MI Closed loops: at the production site, *between process chains, closed loops in whole value chains, between sectors, micro and meso level*	[12,54,66,67,100–102,112]
	MI Critical resources: Share of critical resources in total MI, *integration of material input into assessment of critical resources*	[113,114]
Consumption	**MI Consumption**: Households, individuals, groups (e.g., singles, families, age, profession), *social milieus,* companies, *public institutions, city district, region*	[66,111,115–117]
	MI Needs: Housing, mobility, nutrition, tourism, clothing, leisure time, health, *education, participation*	[66,67,75,111,112,118,119]
	MI Social practices: *Routines, action patterns (of production, consumption, production/consumption)*	[105,120,121]
	MI Rebound effects: *Shifting between areas of need, products, services, direct and indirect rebound effects*	[14,15,114]
	MI Use (including management): Operate, maintain, repair, re-use, re-manufacture; *leasing, contracting, sharing, cooperative use concepts, Do it Yourself*	[15,67,75,94,106,116,117]
Balance	**Material flow balances**: MAIA is applicable on several levels (product, small company or, e.g., the material footprint of multinationals, economic sector, local, regional or national economy)	[12,56,101,116,117,122–126]
	MI Input per Output: Resource productivity of households, companies and sites	[12,101,114,121–126]
Business management	**MI company in relation to their added value**: time series, comparison between branches	[12,54,101,122,127,128]
	Sales per working place or MI per working place: e.g., sales and resource use in large-scale enterprises per region and business unit; comparison between branches	[54,114,126]
	MI of process costs or production costs: at process level: identification of high ecological and economic "cost drivers"; comparison of similar processes within branch; at product level: time series, knowledge base for product portfolio management	[54,55,114,127]
	MI resource accounting: Resource cost accounting, direct material (costs), costs for processing/disposal burden/overhead materials	[54,55,114,127]
	MI Price: Method and indicator base for calculation of "ecological appropriate prices"	[54,114,127,129]

Consistency describes the strategy of closing ecological loops within processes (parts of process chains), at production sites (e.g., by returning waste or discards into processes) or throughout the entire life cycle (e.g., by designing completely recyclable or degradable materials and products) provided that the material input for closing loops is not higher than for primary production. Thus, consistency and efficiency support sufficient consumption patterns with consistently and efficiently designed products and services [15,83,94]. Table 4 shows an example for considering consistency on the basis of the MIPS concept. Comparing both primary and secondary production of basic materials often shows the high potential of recycled or secondary material for a lower resource input per product or service.

Table 3. Resource intensity (material, water, air) of different energy supply systems [50,130].

Material Input (kg/MWh)	MF_{ab}	MF_{bi}	MF_{er}	Water Backpack	Air Backpack	$MF_{ab+bi+er}$
Offshore wind energy	177	0	0	795	9	177
Biogas plant	595	2,973	346	1,747	954	3,914
Lignite-fired power plant	11,271	0	0	56,824	875	11,271

Table 4. Resource intensity (material, water, air) of primary and secondary aluminium [70].

Material Input (kg/kg)	MF_{ab}	MF_{bi}	MF_{er}	Water Backpack	Air Backpack	$MF_{ab+bi+er}$
Aluminium primary	37	0	0	1,074	10.87	37
Aluminium secondary	0.85	0	0	30.74	0.95	0.85

An additional aspect to be considered is that unused extraction—that does not end up in products at all—equals about one third of all material flows and presently is not transferred into a loop economy. Due to that and the resources embodied in the infrastructures of transport and communications systems only 3% of material flows are recycled at all [7] (p. 13). Thus, by accounting also unused extraction and hidden material flows, the MIPS concept also reflects the notion of consistency [14,50].

Sufficiency describes the orientation of performing social and individual acceptable activities within a limited environmental space [87,131]. From a Western perspective, sufficiency is probably the most challenging sustainability strategy asking "why and how needs can be met while minimising environmental damage without too much losses in quality of life" [14] (p. 7). It aims at production and consumption patterns implementing, e.g., management structures, which lead to products and services appropriate to the abovementioned orientation principle [53–55]. Thus, sufficiency is an applicable management strategy within the entire value chain [132] and addresses both production (business strategies) and consumption patterns. Studies concerning the material footprint of households show us a factor 9 difference between different households (13 to 120 tones per capita and year [133]) or a 113% difference from average energy use for heating per m^2 capita and heating period in the same multifamily house [134]. Material footprints of selected consumption areas, e.g., 10 km bike-riding (1.3 kg) and 10 km car driving (11.3 kg) or eating a vegetarian burger (6.45 kg/kg meal) and eating a double burger (28.80 kg/kg meal) show their material efficiency potential of different choices (own database [133]).

Table 5 gives examples of MIPS application aspects that either support single sustainability strategies or provide an integrated perspective of all three strategies efficiency, sufficiency, and consistency.

Table 5. MIPS application towards integration of sustainability strategies and resource use targets.

MIPS application aspect		**Application examples (selection)**	**References of current examples (selection)**
Efficiency	Used/unused resources	Value chain perspective: proportion of used and unused resources over life cycle	[12–15,49,51,54,55,66,69, 71,101,113,116,117,130]
	Unused resources/profit Used resources/profit	Company level: proportion of unused resources and profit	
Consistency	Unused/product weight MI/product weight	Assessment of recycling strategies at different levels: location, process chains, value chain, between sectors, micro and meso level	[14,15,69]
	Unused resources/ production costs	Assessment of recycling strategies, closed loops, costs of unused resources processed during the life cycle or per production site	[14,15,69]
Sufficiency	MI individual resource use/resource target	Assessment of current resource use against resource targets or of earlier resource use against reduced resource use	[36,135]
	Well-being/MI	Experienced well being per household inventory, time, activities	[14,15,75,135]
	MI/time	Deceleration/slowdown in different areas of need/activity fields	[12,14,15,135]
	MI/S	Resource input per service aiming at high service and low material input	[14,15,75,91,92,101,132]
	MI/land use of activities	Land use of activities, e.g., living, working; specific inventories of products, materials, raw materials, clearing out	[9,24,25,37,136]
Targets	MI targets MI present resource use/MI target	Political targets and sustainable limits at city/regional, company or household level	[36,124,125,131,137,138]

The MIPS concept is useful for developing production and consumption patterns that are in line with the environmental space we have [36,87]. Resource targets have been suggested, e.g., by Lettenmeier *et al.* [36,75] for the household level. While this is a beginning debate about globally acceptable economy-wide resource use levels and household inventories, it is an important link between political discussion and the public debate about common sustainability strategies.

4. Discussions and Conclusions

This paper provides a concept and method for an indicator, which is able to measure resource input into the production and consumption system life-cycle-wide and for different subsystems (e.g., life cycle phases, processes, production sites, transports, energy use, *etc.*). It focuses on the movement of natural resources from nature into the technosphere. Thus, it complements the previously dominant output orientation to the aspect of resource extraction and resource management through the economic system.

4.1. Political Key Strategy: Resource Efficiency

Production and consumption patterns of industrialised countries are linked to an extensive resource use. This leads to substantial damage to the environment and climate [6,7,9,35,131]. A comprehensive resource efficiency and dematerialisation policy is necessary to address the drivers and barriers for transformation pathways towards a low resource economy and society. Thus, intelligent mixed policy instruments can empower actors located in a multi-governance system to decide commonly towards resource efficiency and conservation, to accept a resource saving cultural orientation and to implement more system-oriented resource management options [42,43,139–142]. Meyer shows using his Panta Rhei Model that there are high potentials for state budget, employment development, innovation activity and resource efficiency, if an adapted policy mix will be implemented [143]. Further organizations surrounding material efficiency, e.g., in Germany the Effizienz-Agentur NRW (EFA) (translated: North Rhine Westphalia Efficiency Agency, founded 1998), the German Material Efficiency Agency—demea (founded 2005) or VDI Centre for Resource Efficiency (founded 2009) show such impacts aiming at knowledge transfer, awareness raising, developing and providing tools, and supporting enterprises and households by identifying and exploiting their resource and material efficiency potentials (see list of German initiatives in [48]). In Germany, e.g., demea consults companies on possible improvement of their resource efficiency. Evaluations of their consulting work (550 cases) shows that in average 210,000 Euro respective 2% of annual turnover has been saved due to resource efficiency policies [144,145]. Such institutional structures will help to foster transition processes towards a resource efficient society and are a key element for successful diffusion strategies [146,147]. Successful actors and change agents want to show their resource effiency performance—this could be done with an indicator and harmonized calculation method such as MIPS.

4.2. Data Base Challenges

Today the MIPS database comprises numerous MIT Factors, which have been calculated by the Wuppertal Institute. The database is publically available and lists resource intensities of metals, basic materials, plastics, chemicals, energy and fuels, transport, construction materials, and agricultural products (relevant for different regions) [70]. The database has been constantly enhanced and revised within different research projects. Further data has been published, for instance, in Finland in the context of household consumption [133] and in Austria in different business contexts (e.g., [148]). Currently e.g., the energy data of the Wuppertal Institute database is updated [69,71,130].

Nevertheless the MIT factors differ in their quality and actuality due to complex data generation, which sometimes allow only a rough estimation. MIPS is intended to be an indicator that works with data uncertainties but is reliable in roughly estimating the current use of natural resources. The topic of data generation and quality including aspects such as transparency, documentation, actuality, allocation, and system boundaries is highly relevant in the whole field of life cycle assessment. The difficulties are not connected to one specific method such as MIPS; it is a complex topic within the whole LCA community, e.g., [149].

One reason for this is that the problems concerning a general structured process of data generation and evaluation with public availability are not yet solved. There is a need for further improvement towards an international resource intensity data centre [150–152] and tools that support enterprises and households to provide relevant information on resource intensity in their value chains and management processes (e.g., towards informed decision making, product design, portfolio management and for households also the management of the usage phase and their product-service mix). As LCA databases are the basis of LCA software, a first step should be the extension of current LCA databases towards a more complete inclusion of resource-relevant aspects. Databases like Ecoinvent (about 4000 processes) or ELCD (300–400 processes) only consider economically used resources. To achieve a compatibility with MIPS, a first step would be to integrate unused extraction (e.g., mining overburden, unused biomass) and biomass flows (economically used cultivated biomass). The core issues for a successful implementation include the introduction of elementary flows for unused extraction and the international trade of resources, see, [73,74].

Data for unused extraction have been gathered within the research project INDI-Link [153] and are being updated within the EU project CREEA [154]. However, to assure extended and regularly updated resource data, the data collection should be conducted by an external or statistical agency. Ideally an international institution, which provides technical and financial assistance, would host it, helps to coordinate and implement guidelines and standards for data provision, and insures data quality and transparency [55,147].

The management experience of all related actors involved could be an excellent starting point for a concerted action supporting a more systemic development of reliable data for estimating the environmental impacts in change processes of the SCP system.

4.3. MIPS: Methodology

In the field of material flow accounting and environmental assessment the MIPS concept is a complementing approach, especially regarding meso- and micro-level resource input assessment [155,156]. MIPS can be used in line with the EW-MFA [12,138,157]; thus, both perspectives support bridging the gap between micro- und macro-level assessments.

In addition, MIPS can complement environmental assessment by identifying rebounds effects. They are not a paradox side effect of efficiency gains but created by an increased consumption of real active consumers (and producers): on average there is a direct compensation of efficiency gains in production of up to 50% by consumption [14,158].

There is great need to assure that the measures leading to a decrease of green house gas emissions do not result in higher overall resource consumption. Examples are electric vehicles, which can contribute to a reduction of GHG emissions when using electricity from renewable energies, but might lead to an increasing of resource consumption [159].

Efforts to implement resource efficiency at company level can be seen by the development of guidelines on resource efficiency by the German Association of Engineers VDI started in 2011. The guidelines provide a framework defining resource efficiency and considerations for the producing industry. They include a special guideline for SMEs as well as guidelines on methodologies to evaluate resource use indicators such as the cumulative raw material demand of products and production systems [160]. MIPS can be used as a method to implement resource efficiency within these guidelines at the micro level.

4.4. MIPS: Application

There is an increasing demand for simple, reliable and robust accounting instruments that are based on aggregated information to show total resource efficiency potentials without being too cost or time intensive [8,34]. The MIPS concept allows a measurement to focus specific resource aspects at the production and consumption side. Within business management, MIPS can be used to achieve a resource efficiency perspective.

MIPS has been applied and further developed in multiple research projects regarding different target groups and application fields within the last 20 years. On a company level, MIPS was initially used to improve resource management of small companies [53] as well as corporations with complex value and supply chains ([69,148], see further application examples at company level [25] (pp. 23–25, 39–43). However, the implementation of resource use indicators along the value chain still needs harmonization for measuring the absolute savings and monitoring of progress, problem shift from one sector to another or one medium to another or caused unexpected rebound effects [96]. In addition harmonization is important for target definition in the economic and societies subsystems, e.g., economy-wide, in sectors or branches, in value chains, processes, for technology development, *etc.* The debate over appropriate target definitions is already performed intensively to receive guardrails for the further economic and societal development [9,25,35,36].

First experiences on the field of computer-based resource accounting could be made in the CARE project [54] while in the on-going EU funded project myEcoCost [55] a software system will be developed to inform all economic actors on environmentally relevant information (of which MIPS has been proposed as an indicator for). This perspective is valuable for companies because it is connectable to current cost accounting systems and thinking. Further, existing resource efficiency potentials are not achieved in many companies [69,141,142].

Regarding the consumption side, MIPS has been applied for the analysis of the resource use of lifestyles and households in Finland [75,133]. For Germany, first research projects focus the data collection of consumption activities within households [161,162], but extended analysis with comparable results are missing.

4.5. Future Challenges for Research

To improve measuring resource consumption on the level of companies, consumers and households (Table 2), the links of statistical classification and monitoring with companies' reporting systems and lifestyles of consumer have to be developed. Currently, statistics use an aggregated framework with limited data on socio-demographics and material inventories, which do not consider a sufficient classification of products and their use on the consumption side. Also, statistical information from companies should be improved to better serve natural resource use assessment and management.

Nowadays, the most relevant needs of households as well as the most relevant business sectors in terms of resource use are known relatively well (e.g., [36,44,133]). In order to initiate and accelerate the transition to a low resource society, further research and future assessments should have their first focus on processes, products, sectors, activities and lifestyles of high relevance and dematerialisation potential (such as living and housing, food and nutrition, mobility), also in order to better address them by environmental and economic politics. Other fields should then follow.

Even though there have been done many MIPS analyses, they are not always updated frequently or they aim at specific regions (e.g., the Finnish MIPS studies [56,133]). In addition some of the studies behind the present MIPS database, although having reached high standards, have not been sufficiently verified by external reviewers.

Short-term goals for research include therefore new holistic assessments and updates of existing studies in the following areas:

- Mobility and logistics (infrastructure, individual mobility and transportation of goods). Studies like Lähteenoja *et al.* [56] should be done for different countries and for Europe as a whole;
- Construction and housing including infrastructure as well as individual preferences and habits [36];
- Mobility and communication (e.g., focusing products for information and communication technology (ICT) and physical mobility to explore low resource shifts between both);
- Energy production (further update) and electrical grids (macro and micro models);
- Nutritional turn via lifestyle changes supported by common defined strategies developed by public and private catering establishments, producers, retailer, politicians and households.

Central topics for developing methods and methodologies are:

- Extended resource efficiency analysis to screen processes, products, sectors, activities and lifestyles of high relevance and dematerialisation potential;
- R&D on sociotechnical innovation fostering behaviour change towards low resource production and consumption patterns—transformation of social practices [36,161,163];
- Sustainable service design and new business models;
- Integration of other sustainability and resource management/value chain management approaches;
- Scenario development (e.g., [135]) and modeling—Integration with agent based modeling;
- Breakdown of resource targets on a per day and per year per person level for illustrating and giving input for development of products, services, infrastructures, *etc.*

The results of a MIPS analysis can deliver data for future-oriented scenarios and modeling, as well as vision development, roadmaps and foresight processes. Together with the macro application of TMC, MIPS delivers the potentials for a more system-oriented resource management. However, integrated and future oriented applications and approaches remain to be developed and proofed.

Author Contributions

The authors have contributed to the paper in several ways. Liedtke, Lettenmeier and Rohn especially have contributed in (further) developing the MIPS approach in collaboration with Friedrich Schmidt-Bleek. All authors have conducted MIPS studies and contributed to the paper through their expert knowledge in data gathering, calculating, and interpreting MIPS results. Liedtke developed the concept and structure of the paper and did extensive work in internal reviews of paper drafts. Bienge coordinated the writing and review process and contributed especially in mainly writing the chapters Introduction together with Greiff and MIPS Concept and Methodology as well as adapting and editing the Figures. The chapter MIPS application Fields at Micro and Meso Level has mainly been written by

Wiesen and Teubler whereas Bienge developed Tables 2 and 5 in close collaboration with Liedtke. The chapter Discussion and Conclusion has been collaborative work led by Liedtke.

Conflicts of Interest

The authors declare no conflict of interest.

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Paper 2

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Resource intensity in global food chains: the Hot Spot Analysis

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Abstract

Purpose – The Hot Spot Analysis developed by the Wuppertal Institute is a screening tool focussing on the demand of reliable sustainability-oriented decision-making processes in complex value chains identifying high priority areas ("hot spots") for effective measures in companies. This paper aims to focus on this tool.

Design/methodology/approach – The Hot Spot Analysis is a qualitative method following a cradle-to-cradle approach. With the examples of coffee and cream cheese hot spots of sustainability indicators throughout the entire life cycle are identified and evaluated with data from literature reviews and expert consultations or stakeholder statements. This paper focuses on the indicator resource efficiency as an example of how the methodology works.

Findings – The identified hot spots for coffee are the raw material procurement phase in terms of abiotic material, water and energy consumption, the production phase concerning biotic material and the energy consumption in the use phase. For cream cheese relevant hot spots appear in the raw material procurement phase in terms of biotic materials and water as well as biotic materials and energy consumption during the production phase.

Research limitations/implications – Life cycle analyses connected to indicators like resource efficiency need to be applied as consequent steps of a Hot Spot Analysis if a deeper level of analysis is eventually aimed at which is more cost and time intensive in the short term. The Hot Spot Analysis can be combined with other sustainability management instruments.

Practical implications – Research and management can be directed to hot spots of sustainability potential quickly which pays off in the long term.

Originality/value – The paper shows that companies can address sustainability potentials relatively cost moderately.

Keywords Value chain, Resource management, Consumption, Resource efficiency, Food products

Paper type Research paper

1. Food industry and resource-efficiency

The whole food sector is consuming huge amounts of resources. The food and drink sector accounts for about 15-30 per cent of all environmental pressures (ETC SCP – European Topic Centre on Sustainable Consumption and Production, 2009). The production of food appears often to be less resource intensive compared to other industrial products, but especially in this industry increased complexity in production and transport structures goes together with higher resource intensity (Huff and Türk, 2006). But even though the agricultural industry and food as a field of needs have one of the highest environmental impacts, only a very limited number of detailed studies on single products or entire process chains are existing already. To name an exception a material input per service unit (MIPS) study on natural resource consumption of Finnish households and its reduction has been conducted (Kotakorpi *et al.*, 2008).

The following facts and numbers demonstrate the need for an increase in resource productivity in the food industry. By 2050, the world population might increase up to

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9.2 billion people (Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, 2007). Due to this expansion, the demand for resources, especially for food products, will increase. The increase in food production and consumption as well as changes in nutrition patterns have significant influence on the environment and cause an urgent need for the establishment of more sustainable business strategies. The requirements for complex structural supply chains in the range of social (Mikkola, 2008), as well as ecological (Hahlbrock, 2009) interaction are of growing importance in sustainable development.

For instance, loss of soil is a consequence of environmental degradation, constituting a major factor for the agricultural industry and food production. The annual losses of fertile soil reach up to 25 billion tons (Schmidt-Bleek, 2009). In the past 20 years a surface of approximately one million square kilometres – equal to the size of Germany, the Benelux Countries, Austria and Switzerland – of productive land got lost due to desertification, the overuse of fertile soil, deforestation for firewood, over-fertilization, animal breeding, droughts, operation of vehicles, wind and water erosions, the (expected) rise of the sea level and floods which are in turn due to rising temperatures, soil sealing and clear-cutting which lead to a reduced capacity for the soil to absorb water (Schmidt-Bleek, 2009). The production of meat and dairy products signifies another growing factor accelerating environmental degradation. The consumption of meat has increased fivefold since 1950 (World Watch Institute, 2006), which explains why animal breeding has a huge effect on the loss of productive land. This has led to an increasing environmental impact since the 20 billion farm animals produce a significant amount of emissions and – at the same time – demand a high amount of productive land for fodder production. Besides that, the demand of agricultural surfaces for the production of one kg of meat is three to ten times higher than for the production of one kg of wheat (Hahlbrock, 2009).

Besides the problem of decrease of productive land, which is accelerated by land use competitions especially due to the production of bio fuels, meat and the extension of infrastructures, the resource use along the various food-product-chains is extremely intensive. The following section provides an example of virtual water content of products in order to illustrate how intensive water use can be along the food-product chain.

"Human beings require approximately 4L of drinking water per day to live. However, 500 times that amount of water is used to produce the food that each one of us needs per day" (Schmidt-Bleek, 2009, p. 119). The production of 1 kg cereals (wheat, corn, rice) consumes up to 1,000L of water. However, about 40 per cent of the cereals are used as fodder. Food and fodder production only has a share of 70 per cent concerning water withdrawal (Hahlbrock, 2009). To produce a hamburger, 3,500 to 7,000L of green water are needed according to (Mauser, 2009) who refers to green water as water that is evaporated through vegetation. Hoekstra and Chapagain (2006) claim that the virtual water content of one hamburger is 2,400L. The virtual water content of a product means the sum of the water used in the various steps of the life cycle.

The trends we are facing concerning food production and consumption outlined in the previous paragraphs can be summarised as follows:

- The demand on productive land increases as the consumption of meat and dairy products per capita is rising and an increasing amount of land is used for other purposes than food production.

- A growing population of up to 9.2 billion people on earth will need to be supplied sufficiently with food and water.
- The degradation of land will accelerate even more if sustainable concepts for food production and consumption will not be applied in the future.

The topic of resource productivity will be of increasing interest for business and politics already in the near future. "Resource-efficiency and resource productivity can be defined as efficiency, with which energy and material is used within the business sector, meaning the added value per unit resource input" (Commission of the European Communities (CEC), 2003).

Beyond political objectives on the national and international level (Bundesregierung, 2002; and European Council, 2006), the topic resource-efficiency has already reached commerce and industry. The fundamental change of business that has taken place since the 1990s has caused outsourcing processes of cost-intensive units into low-wage regions, especially developing countries and countries in transition. That implies an increasing number of people involved as well as a geographical extension of value chains (Schätzl, 2000). The definition of value chain here follows the suggestion of Porter (1996) saying that it includes the whole production process of a good, from resource extraction to consumption, comprising even all-additional services, the further use and the recycling of a product as well as its waste treatment.

Owing to the increased complexity and globalisation of production processes, the demand for management and controlling strategies is changing (Folkerts and Koehorst, 1998). Actors who deal with product chains, such as entrepreneurs, politicians, and retailers need to reply to an increased complexity in order to monitor all on-going processes with the objective of optimising value chains, e.g. in terms of resource use (Seuring and Westhaus, 2002). The paper at hand will therefore focus on complex global value chains and their designers such as producers, consumers and politicians influencing the resource use of the world supporting their possibilities to implement more sustainable production and consumption systems. To avoid risks for the different actors including companies and consumers, it is not sufficient anymore to organise corporate processes internally but the interorganisational relations within the value chain need to be considered too (Christopher, 1998). All relevant stakeholders have to be integrated in such a design process of global value chains. They need a status quo analysis that addresses the most important issues of such subsystems like coffee or cream cheese value chains and their implications on the eco- and social system along the production and consumption stages.

Thus, there is an increasing demand for simple, indicatory management and controlling instruments, that are based on aggregated information in order to show resource-efficiency potentials without being cost or time intensive (Schary and Skjoett-Larsen, 2001). Established methodologies like life cycle assessment (LCA) are far too time, and cost intensive for applying them in a company for all production and consumption processes (ISO 14041). In fact, there are a few LCA existing for products of the food industry[1]. Also for material-intensity analyses based on the MIPS-concept, there are only some examples applied in entire food-product chains (Kaiser *et al.*, 2008; Kauppinen *et al.*, 2008a, b). In order to estimate the input-oriented impact on the environment caused by a product or service, MIPS indicates the quantity of resources[2] required for this product or service. A MIPS analysis covers the entire life cycle of a product or service but is still less labour-intensive than a complete LCA (Ritthoff *et al.*, 2002; Lähteenoja *et al.*, 2006; Kuhndt *et al.*, 2002).

The few MIPS analysis and LCA studies covering the entire food-product chains aim at giving an overview about the relative material intensities of different areas within the food chain as well as demonstrating interdependencies between certain parameters.

Although the demand for specific analyses obviously exists, it seems in any case reasonable to identify hot spots along the whole value chain before applying a MIPS analysis or even a deeper LCA which are cost and time intensive and require expertise. To bring sustainability and resource management into corporate practice, a step-by-step approach has proven appropriate for a corporate context. As a first step, a Hot Spot Analysis should be applied (Kuhndt *et al.*, 2002; Wallbaum and Kummer, 2006). This can be followed later on by a MIPS analysis, possibly including also other core indicators. A whole or segmental LCA approach can be applied at last, in case a more exact differentiation will be necessary, e.g. if detailed scenarios including also emissions and similar aspects are required. Every step needs to be concluded by "indicators for action" in order to create direct use for the respective company. A step-by-step approach will increase the database and thus the ability to implement and improve sustainability management data and information systems. Focus can be various indicator sets, such as, for instance, resource efficiency as is in the paper at hand, but also social or economic ones. Table I compares the main characteristics of the Hot Spot Analysis, MIPS and LCA approaches. The Hot Spot Analysis explores the most relevant factors or phases influencing, e.g. the indicator resource use in the life cycle or product chain with regard to sustainability according to available literature, expert consultations or stakeholder statements while MIPS looks at the physical material flows, i.e. the input side of production and consumption systems, aggregated flows of abiotics, biotics, top soil, water and air (oxygen), which are regarded as central background of environmental impacts, during the life cycle of a product or service. The LCA approach focuses on mainly emission- and energy-based environmental impacts during the life cycle such as global warming, acidification or eutrophication. The Hot Spot Analysis provides companies and perhaps their stakeholders with a rough overview over relevant aspects in a short period of time and is based on scientific publications. This requires knowledge of scientific literature. The Hot Spot Analysis does not offer quantitative productivity potentials. MIPS are often calculated on the basis of already existing average figures but a process specific calculation is also possible. In order to apply MIPS its concept needs to be understood. The calculation is relatively easy and allows a comparison between the options available and the investigation of consumption patterns. MIPS can be used as a basis for labelling and indices. Efficiency potentials of resources and costs can be calculated. But MIPS itself is costly. MIPS, as well as LCA need more time than the Hot Spot Analysis. LCA are based on existing data and process specific data, which require a special software and knowledge of the product concerned. A detailed analysis of development options can be conducted which might lead to less environmental impact through the calculation of potentials but which is very expensive and complex.

The authors of this paper argue that the Hot Spot Analysis is very suitable for companies and relevant actors in order to detect potential hot spots of resource

Table I. Main features of the approaches of Hot Spot Analysis, MIPS analysis and LCA for the identification of resource use and environmental impacts during the life cycle of products or services

	Methodology Hot Spot Analusis	MIPS (Material Input per Service unit) analysis	Life Cycle Assessment
Main sources	Kuhndt *et al.*, 2002; Wallbaum and Kummer, 2006	Schmidt-Bleek, 2009; Ritthoff *et al.*, 2002	LCA/ISO 14041
Short description	Elaboration of the most relevant factors or phases influencing sustainability indicators such as resource use in the life cycle/product chain	Analysis of the physical material flow inputs during the life cycle of a product or service. Material flows are understood as the central background of environmental impacts	Analysis of mainly emission- and energy-based environmental impacts during the life cycle
Aspects covered	Sustainability aspects of different life cycle phases, according to available literature, expert consultations or stakeholder statements	Input side of production and consumption systems, aggregated flows of abiotics, biotics, top soil, water and air (oxygen)	Different environmental impacts like energy use, global warming, acidification, eutrophication, etc.
Level of depth	Rough overview over relevant sustainability aspects	Often calculated on the basis of existing average figures but process-specific calculation possible	Calculated on the basis of existing databases and/or process-specific data
Origin of data used	Scientific publications	Published LCA and other studies average material intensity coefficients or process-specific information	Published LCA and other studies database and/or process-specific emission data
Suitability to companies	Requires knowledge of scientific literature. Provides an overview of relevant aspects of the product chain. Does not offer quantitative productivity potentials	Requires understanding of MIPS concept. Relatively easy calculation possible using, e.g. Excel sheets. Provides a useful comparison between different options and phases of the value chain. Resource and cost efficiency potentials can be calculated (Beucker *et al.*, 2004)	Requires special software and detailed background information on the product studied. Can provide a detailed analysis of specific development options in processes and product chains. Potentials for less environmental impacts can be calculated
Suitability to SMEs	Relatively easy. Requires time and knowledge of scientific literature	Relatively easy but may require more time in case of complex products or less known materials (depending on the level of detail), and relatively less basic calculation knowledge and information from inside and outside	Relatively complex and time intensive, requires special software and detailed background information from inside and outside
Suitability for consumer information	Can be used to separate big and small issues from each other but not for comparing products	Understandable concept. Very suitable for comparison of product groups or consumption patterns to each other. In principle applicable for product-specific information but costly. Can be used as a basis for labelling or indices	Direct use would be too complex. Can be used as a basis for labelling or indices but remains cost intensive

intensity along the value chain. Compared to MIPS and LCA it is a feasible approach with regard to costs and time. Companies often do not have the financial and time resources to apply MIPS and LCA and can easily start with the Hot Spot Analysis. In case a deeper level of analysis is pursued MIPS and LCA should be applied as consequent steps. In the following a detailed explanation on the methodology of the Hot Spot Analysis is given in the next section elaborating on the advantages and disadvantages of the Hot Spot Analysis.

2. The methodology of the Hot Spot Analysis

The introduction of the Hot Spot Analysis by the Wuppertal Institute (Kuhndt *et al.*, 2002;Wallbaum and Kummer, 2006) intends to be a qualitative assessment instrument that estimates the resource-intensity or other indicator areas of a product along its value chain. Other indicators could be applied gradually, such as economic or social ones. The main objective of a Hot Spot Analysis is to identify central peaks of resource use or sustainability issues along the whole value chain quickly, reliably and life-cycle-phase-specifically. The use of abiotic material[3], biotic material[4], water and energy is analysed for the life cycle phases' raw material procurement, production, use and waste treatment. Thus, the relative resource use of the respective life cycle phase becomes obvious as well as the extent of specific resources consumed along the value chain. Those "peaks" in consumption identified are defined as hot spots. It needs to be considered though that high resource consumption is not equivalent to a high saving potential. For a more specific analysis of resource-saving potentials an additional instrument should be introduced after the Hot Spot Analysis that is MIPS, LCA or other instruments.

A Hot Spot Analysis is performed in three steps:

(1) Estimation of sustainability topics within a life-cycle phase (e.g. absolute resource-intensity within each phase)

(2) Evaluation of these topics between the life-cycle phases (relative resource intensity of resource categories along the life cycle)

(3) Identification of hot spots by an integrated analysis of step 1 and 2

Scientific publications that provide facts about the resource-intensity in the whole value chain or parts of it are the basis for the analysis in step one and two. LCA studies – if existing – are of special interest. But these studies do not reflect the specific situation of the regarded value chain but use the information of existing, not in all areas relevant studies and LCAs so that puzzle parts are used of the whole picture to get a first estimation about relevant topics, summarize the information, structure and evaluate it concerning the investigated product chain. One of the limitations of the Hot Spot Analysis is that it is based on existing studies or parts of it. In the food sector, for instance, it might be difficult to find LCA studies. A multitude of data of various institutions is not consistent and clearly accessible. Nevertheless there is a huge amount of available literature or expert and stakeholder knowledge, which can be made use of and therefore the Hot Spot Analysis is still a very useful tool to explore hot spots of resource intensity along the whole life cycle of a product. The assessment of the resource-intensity is done according to a scale from "high" (three points) to "low" (one point). The Hot Spot Analysis considers the resource consumption directly connected to the product or service, its raw materials and intermediate goods.

Materials not directly connected to the product (e.g. packaging material or the maintenance of production or transportation machines) are not part of the analysis in the first step. If results exist that indicate that parts of them are important they could be flexibly included. But the first objective for analysis is the area where the actors can act and influence the sustainability directly. Therefore the decision makers get information to improve their hot spots gradually – first for the relevant need for action in the own value chain, and second if relevant in the process environment (e.g. relevant logistic problems of coffee products – transporting by airplane instead of ships). Table II and Figure 1 show the three steps of the assessment of an imaginary product to introduce the methodology of the Hot Spot Analysis, which can be used for orientation for further Hot Spot Analyses. The two case studies on coffee and cream cheese are supposed to substantiate the methodology in concrete examples taken from the food sector. The choice of coffee and cream cheese will be explained more in detail.

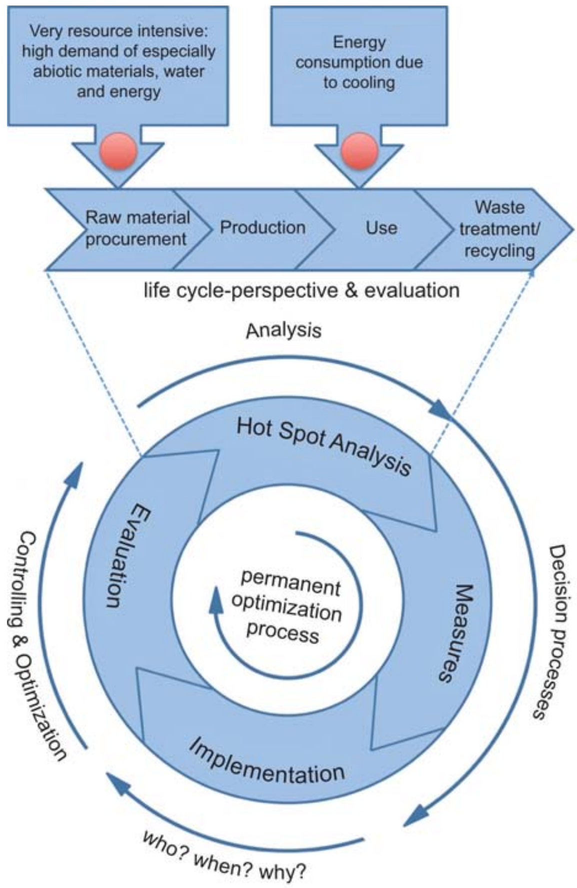
In step one, the raw material procurement phase of an imaginary product is defined by a high extent of abiotic[3] materials and energy, while in the production phase a high amount of water consumption is obvious and the consumption phase is characterised by high water and energy consumption. Although the energy consumption is considered to be high in two phases, this does not mean that their absolute value is comparable, because only an estimation of the relative evaluation within the respective life-cycle phase is done.

In order to compare the amount of resource consumption of one phase to another one, step two is performed. As there are only limited data for most products and services, the resource categories abiotic materials, biotic materials, water and energy cannot be applied like in step one. Thus, the aggregation of two categories "non-energetic"[5] resources and "energy" is necessary. Table II shows how the

	Hot Spot Analysis of an imaginary product			
Life cycle phase	Raw material procurement	Production	Use	Waste treatment
Step 1: Assessing the resource-intensity within each life cycle phase				
Resource category				
Abiotic material[a]	3	1	2	2
Biotic material[b]	1	2	1	2
Water	2	3	3	1
Energy	3	1	3	1
Step 2: Assessing the resource-intensity between the different life cycle phases				
Non-energetic	3	1	1	2
Energy	2	2	3	1
Step 3: Identification of hot spots on the basis of steps 1 and 2				
Abiotic materials[a]	9	1	2	4
Biotic materials[b]	3	2	1	4
Water	6	3	3	2
Energy	6	2	9	1

Notes: [a]Non-renewable resources like mineral raw materials and fossil fuel; [b]Renewable resources like vegetable biomass from cultivation, plants and animals. In step 3, the results of steps 1 and 2 are multiplied by each other so that the hot spots can be defined (scores of six and nine points)
Sources: Adapted from Kuhndt *et al.* (2002); Wallbaum and Kummer (2006)

Table II.
Allocation of assessment points based on the extent of resource and energy consumption in the respective life-cycle phase (step 1) and by analysing the relevance of the phases to each other (step 2)



Notes: Exemplarily for a typical food chain, based on the imaginary product Identification of hot spots along the whole life cycle chain as part of a permanent optimization process consisting of the Hot Spot Analysis, measures, implementation and evaluation of instruments for food product chains based on the imaginary product

Figure 1.
Hot spots

assessment is supposed to look like. This example shows a high relevance of raw materials for the non-energetic resources and of the use phase for the energy consumption.

The hot spots are identified in the concluding step three. For a better visibility of the hot spots, the scores of steps one and two are multiplied by each other. The resource categories abiotic materials, biotic materials and water from step one are multiplied with the evaluation factor "non-energetic", the category energy with the factor energy. For example, in the column raw material procurement the scores from step one, i.e. abiotic material (3), biotic material (1), water (2) and energy (3) are multiplied by the respective life-cycle evaluation factor from step two, i.e. (3) for non-energetic resources and (2) for the category energy. The result of the multiplication (still on the column raw material procurement) appears as:

- abiotic materials $3 \times 3 = 9$;
- biotic materials $1 \times 3 = 3$;
- water $2 \times 3 = 6$; and
- energy $3 \times 2 = 6$.

Hot spots are the fields with a result of six to nine points. In that way an overview of the most important life cycle phases regarding resource intensity can be generated for any value chain. As mentioned earlier, with this method, no productivity potentials are identified. Figure 1 visualises the approach of the Hot Spot Analysis exemplarily for a food product chain based on the imaginary product. Hot spots along the whole life cycle chain are identified as part of a permanent optimization process consisting of the Hot Spot Analysis, measures, implementation and evaluation of sustainability instruments. Hot spots are the red circles, which are explained more in detail in the blue arrows in which these circles are integrated. The arrows point to the specific life cycle phase where the hot spots occur. The raw material procurement phase is very resource intensive since a high demand of abiotic-materials, water and energy have been identified as part of the Hot Spot Analysis. The use phase is very energy intensive due to cooling and storage of the imaginary product. The Hot Spot Analysis is only part of a permanent optimization process as visualised in the bigger circle. In the next phase measures have to be implemented in the decision processes in turn resulting in the actual implementation phase which deals with the stakeholders involved, time frames and reasons for implementation. The evaluation phase follows after the other three phases dealing with controlling and optimization of the measures of the decision processes and the implementation phases. For reaching successful and sustainable improvements it is important to keep in mind permanent optimization processes in a cradle-to-cradle approach expressed in the choice of a circle for this figure. Further explanations can be found in the previous caption.

The following sections introduce the hot spot analysis applied in the case studies on coffee and cream cheese. These products have been chosen since they represent a German and a non-European product (cream cheese and coffee) from the food sector, which contributes essentially to environmental degradation as outlined in the introduction. Coffee has been chosen because it is a popular product for a broad public and therefore promising to communicate the results. Coffee has one of the biggest shares in fair traded food, which accounts for an increased alertness of consumers regarding this product. The consumption of coffee is bound to lifestyles and trends, which is why it enables a tight link to the discussion of sustainable consumption. Coffee is an agricultural product with only a marginal upgrading process but must be imported from overseas and it is a growing product area concerning lifestyle behaviour and feeling (different sorts of drinking preparation). As explained previously meat and dairy products are extremely resource intensive which is why a case study of cream cheese is a valuable example for a Hot Spot Analysis. Cream cheese is an upgraded milk product which is more resource intensive in the upgraded stages compared to the first stage of raw milk, but is coming from livestock and therefore a highly resource inefficient product like meat. Household studies have shown that coffee and dairy products are relevant products that show specific consumption behaviour of different households in different social milieus (highly income/education households use a variety of highly upgraded coffee products with sophisticated and luxurious coffee machines and diary products instead of meat, lower income/education households consume less sophisticated coffee and eat more meat (Kotakorpi *et al.*, 2008) The overall result is that the eco-oriented household consumes more resources having more eco-efficient strategies and the eco-afar households consume eco-inefficiently, but altogether more resource-efficiently. Therefore both products are highly relevant and core indicators for developing sustainable household behaviour strategies and patterns. Social responsibility in the interaction of each individual stakeholder involved plays an essential role in sustainable development (Rimmington *et al.*, 2006).

3. The case studies on coffee and cream cheese

3.1 The Hot Spot Analysis of coffee

For the Hot Spot Analysis along the life cycle of coffee, the resources needed to produce packaging or marketing material as well as such for production plants, transport vehicles and machines are not considered since their environmental impact is minimal compared to others (Kuhndt *et al.*, 2002; Wallbaum and Kummer, 2006; Kaiser *et al.* 2008). Transportation and logistic processes are not presented as single phases but the resources connected to transportation will be accounted in the respectively following life-cycle phase. For example, the transport of coffee beans to the processing plant is allocated to the production phase and the transport of the completed product to the retailer or consumer is allocated to the use phase.

The following paragraph explains the resource consumption in the life cycle phases of coffee more in detail. Existing scientific studies (structured in life-cycle phases) have been investigated in order to constitute which of the resource categories distinguished between abiotic (A), biotic (B), water (W) and energy (E) are most relevant per life-cycle phase. Table III summarises the results.

The energy consumption caused by using agrochemicals and the drying process of the beans is the one most relevant within the phase of raw material procurement, followed by the consumption of abiotic materials and water. The agrochemicals have to be considered here as pre-products of coffee and are therefore within the boundaries of the system. In the past decades, intensive mono-cultivation has expanded which implies an increase of agrochemicals (fertiliser, pesticides) that lead to higher harvests (WRI, UNDP, 1998; Rice and McLean, 1999). Especially for the production of artificial fertilisers a lot of energy and raw materials are needed. According to a study from Costa Rica, the percentage of energy spent to produce fertilisers, reaches up to 69 per cent of the overall energy needed in the coffee production process. Depending on the procedure, additional energy consumption can result from the drying process. The coffee trees face more often vermin or diseases in tropical or subtropical than in moderate climate conditions (Deutscher Kaffeeverband, 2005). Therefore intensive protection is required. Coffee-monocultures depend on water systems to some extent. In case the method of the so-called "wet treatment" is chosen, a massive amount of preferably pure spring water is consumed. The estimation of this amount differs from 40,000 to 70,000 l/t (EDE (Consulting for Coffee, International Coffee Organization), 2001) and 130,000 to 150,000 l/t for raw coffee (Deutscher Kaffeeverband, 2005). Compared to systems cultivating in the shadow, the degradation of soil is much higher

Table III.
Central results of scientific studies on life cycle aspects of coffee, by life cycle phases and with indication of relevance for the resource categories abiotic (A), biotic (B), water (W) and energy (E)

	Relevance
Raw material procurement [a]	
The use of agrochemicals (fertiliser, pesticides)	A
The production of artificial fertilisers and the drying process consume huge amounts of energy and raw materials	A, E
Protection against vermin or diseases	A, E
Water systems	W
If the "wet treatment" is chosen a massive amount of (preferably) pure spring water is consumed	W
Especially in monocultures a degradation of soil is constituted	A
Production [b]	
Mainly coffee beans	B
The transportation consumes relatively low energy	E
The roasting process spends a relatively low amount of energy and water	W, E
Instant coffee spends significantly more energy than coffee powder	E
Use [c]	
Energy consumption during transport and storage most relevant	E
Transportation mostly for purchasing food	E
Energy needed to prepare coffee has the biggest influence transportation by car	E
Waste treatment [d]	
Resource consumption is rather low and therefore irrelevant	–

Notes: A = abiotic material; E = energy; W = water; B = biotic material. [a]Assigned resource intensity in points for the raw material procurement phase: A: 2 (medium), B: 1 (low), W: 2 (medium), E: 3 (high). [b]Assigned resource intensity in points for the production phase: A: 1 (low), B: 3 (high), W: 1 (low), E: 2 (medium). [c]Assigned resource intensity in points for the use phase: A: 1 (low), B: 1 (low), W: 2 (medium), E: 3 (high). [d]Assigned resource intensity in points for the waste treatment phase: A: 1 (low), B: 1 (low), W: 1 (low), E: 1 (low)
Sources: Adapted from Kuhndt *et al.* (2002); Wallbaum and Kummer (2006)

in monocultures. According to studies undertaken in Central America, the degradation is increasing while switching to monocultures (EDE (Consulting for Coffee, International Coffee Organization), 2001).

The production phase comprises the transport of the beans to the roaster as well as the roasting process. From the perspective of resource use, the coffee beans themselves are the most relevant, followed by the energy consumption. The coffee beans are the most important raw material in that phase, since the final product consists mainly of milled coffee beans. The transportation itself is connected to relatively low energy consumption, because it happens to be a mass product and it gets therefore mainly shipped (Wolters *et al.*, 2001). The roasting process is connected to water and energy consumption, which is not, estimated that high though (Diers *et al.*, 1999). The amount of energy utilized increases significantly if instead of coffee powder instant coffee is analysed. Comparing the demand on energy for different food products, instant coffee reaches up to first position with 18,948kcal/kg (Pagan and Lake, 1999).

The use phase starts with the transportation of coffee from the processing plant via the retailer to the consumer. Most relevant in that phase is the energy consumption during transport and storage within the households according to a product life-cycle analysis of vacuum packaged coffee (Diers *et al.*, 1999). Other scholars argue that the energy demand to prepare coffee has the biggest influence in the use phase (Wolters *et al.*, 2001). The consumption of water is negligible.

For the waste treatment phase the LCA mentioned previously concludes that filter and coffee grounds are more relevant than the packaging (Diers *et al.*, 1999). Packaging and filter are not part of the analysis because of their lower relevance per kg coffee or service unit (drinking a cup of coffee). The resource consumption connected to the coffee ground is considered to be rather low and is therefore not considered in the following anymore (Diers *et al.*, 1999; Kotakorpi *et al.*, 2008).

For the Hot Spot Analysis of coffee, a summarising assessment of the resource consumption as described previously and summarised in Table III will be done, first within each life-cycle phase (see Table IV, step one). In order to get the full picture, the relevance of the phases towards each other has to be considered (step two).

Step two in Table IV visualizes qualitatively the relevance for resource intensity in the whole life cycle. For the assessment of the relevance of singular life cycle phases to each other in step two (see Table IV), results from LCA and similar studies, which consider the whole life cycle are used. The conclusion drawn from the studies of Wolters *et al.* (2001) and Diers *et al.* (1999) is that the raw material procurement phase is the most intensive one both for the energetic (energy) as well as for the non-energetic resources (abiotic materials, biotic materials, water). For both resource categories non-energetic and energetic three points are assigned for the raw material procurement phase, which expresses a high relevance compared to the other life cycle phases. After that the production phase is following. Two points are assigned for both energetic and non-energetic resource categories indicating a medium relevance compared to other life cycle phases. The use phase, has a low resource intensity, for the non-energetic resource category (one point) and a medium resource intensity for energetic resources in comparison to the other life cycle phases (two points). The phase of waste treatment is assigned a low resource intensity, for both the energetic and non-energetic resource categories (one point) relative to the other life cycle phases.

Resource category	Raw material procurement	Life cycle phase Production	Use	Waste treatment
Step 1: Assessing the resource-intensity within each life cycle phase				
Abiotic materials	2	1	1	1
Biotic materials	1	3	1	1
Water	2	1	2	1
Energy	3	2	3	1
Step 2: Assessing the resource-intensity between the different life cycle phases				
Non-energetic	3	2	1	1
Energy	3	2	2	1
Step 3: Identification of hot spots on the basis of steps 1 and 2				
Abiotic materials	6	2	1	1
Biotic materials	3	6	1	1
Water	6	2	2	1
Energy	9	4	6	1

Sources: Based on Kuhndt *et al.* (2002); Wallbaum and Kummer (2006

Table IV. Hot Spot Analysis of coffee

To get the picture complete, both parameters of step one and two are multiplied for a better visibility (step three in Table IV). The resource categories abiotic materials, biotic materials and water from step one are multiplied with the evaluation factor "non-energetic", the category energy with the factor energy. As a result hot spots are identified. Hot spots are defined as fields with a result of six to nine points. These mark the range where direct action is needed. The identified hot spots for coffee are: the raw material procurement phase in terms of abiotic material (6), water (6) and energy (9) consumption; the production phase concerning biotic material (6) and the energy (6) consumption in the use phase.

3.2 The Hot Spot Analysis of cream cheese

An analysis of the "cream cheese-chain" starts necessarily with the cow-husbandry including fodder production. It extends further to the "extraction" of milk, the distribution of cream cheese products, finishing with the consumption and waste treatment of the products. Cream cheese production uses milk as "raw material" to 99 per cent (Fraunhofer Institute for Process Engineering and Packaging, 2004; Kaiser *et al.*, 2008; Kauppinen *et al.*, 2008b). The transportation processes are not analysed singularly but they are integrated in the respectively following life-cycle phase. Further aspects like agricultural machines or packaging material are considered to be irrelevant compared to the whole life cycle. This applies also for the pre-value chains regarding production of fodder. That means for example that the fodder itself is included in the calculation, the fertiliser to produce the fodder instead is not though the highest energy consumption in the life-cycle of milk derives from the production of fertilisers and fodder (Swedish Dairy Association, n.d.; Høgaas Eide, 2002). Furthermore this analysis only refers to milk deriving from cows not to such from sheep or goats. Analogue to the example of coffee, results taken from scientific studies will be listed (sub structured in life-cycle phases) and underlined according to their relevance for the resource categories abiotic (A), biotic (B), water (W) and energy (E).

As mentioned earlier, the most important raw material for the production of cream cheese is milk. There are further ingredients like lactic acid bacteria (rennet) as well as salt, herbs, fruits or similar ingredients. Due to their lower relevance at this point compared to milk they will not be considered furthermore (Kuhndt *et al.*, 2002; Wallbaum and Kummer, 2006). The highest resource consumption exists concerning biotic material and water. The material intensity values are: 1, 1 kg/kg abiotic material; 3 kg/kg biotic resources; 31 kg/kg water and 0,31 kg/kg erosion (Kauppinen *et al.*, 2008b). Energy is used for milking and storage (cooling) of milk products in this life cycle phase.

The phase of production includes the transport of milk, the filtration and the pasteurisation in the processing plant as well as the addition of further ingredients (fruits, herbs, etc.) to the product. The analysis of relevant studies led to a high relevance of the category biotic materials. That is because milk is the most important material in the process. Average relevance was identified for water and energy. In comparison to other activities of the food industry, the production phase of milk products is not very energy-intensive (Confederation of the Food and Drink Industry of the EU, 2002; Kauppinen *et al.*, 2008b). Typical energy consumption levels of milk processing are estimated with 0,5 to 1,2MJ/kg used milk. A study undertaken by Kraft Jacobs Suchard (KJS) on Philadelphia cream cheese concluded that the major part of fossil primarily energy demand for production is needed outside KJS (Fraunhofer Institute for Process Engineering and Packaging ISI/ DIW/ GfK/ IEU/ TUM (publisher), 2004). According to an environmental declaration of the private cheese factory in Waging am See, energy consumption is one of the most important aspects within this phase (Bergader Privatkäserei, 2004). Regarding water consumption, the production of milk products is comparatively water intensive, because a lot of water is used for cleaning purposes in order to fulfil high hygienic standards. Processes that work relatively efficiently consume 1,3 to 2,3 l water per kg milk. It is even possible to lower the value to 0.8 to 1.0 l water per kg though. During the process phase side products and waste is produced. According to a study of the Fraunhofer Institute, the average losses of raw material in the production process of cream cheese are less than 2 per cent (Fraunhofer Institute for Process Engineering and Packaging, 2004). Due to that reason waste will not be considered as a relevant fact, because it could even be used as a side product (e.g. fodder). The resource use for packaging that was identified from the Federal Environmental Agency for the use phase is rather relevant for the production phase. This is again relevant for the consumption of abiotic materials though but because preliminary phases of the value chain are not considered, this aspect is not relevant for the whole phase (Federal Environmental Agency, 2002).

During the use phase, the transportation of cream cheese from the retailers to the consumer is analysed. The very use phase itself – meaning the consumption of cream cheese by the final consumer – is not connected to any significant environmental impact. The most relevant resource category of that phase derives from the energy consumption but on the whole it is only of average relevance because cooling energy is partially due to the existence of other products in the cooling shelves or fridges. The cooling energy is continuously needed and can vary considerably (Dutilh and Kramer, 2000). Different LCA (Bernhard and Moos, 1998; Svenskmjölk (Swedish Dairy Association) (n.d.) conclude, that energy consumption is important in that phase mostly due to transportation but negligible compared to other phases. Nevertheless the Federal Environmental Agency considers the emissions caused by the transportation and the packaging in that phase as relevant aspects (Federal Environmental Agency, 2002). The emissions point to the relevance of the category energy; packaging is not connected to additional resource consumption and is therefore not analysed furthermore. Regarding the route of transportation of products by consumers a Hungarian study concludes that per household and year about a total distance of 300 to 500 km is covered for purchasing food (Massari, 2002). Another LCA concludes that the transportation of a product by car plays a rather important role (Diers *et al.*, 1999). The consumption of water is instead less relevant.

The packaging deriving from cream cheese packages are most relevant in the waste treatment phase. The relevance is rather low because the recycling systems mainly offer a treatment for such packages. But the raw material consumption connected to recycling is not considered here (energy, wastewater, emissions) because the resource intensity is low related to the whole life cycle and per service delivered (200 g boxes or a relevant service unit enjoying a slice of bread with cream cheese). Furthermore the waste treatment of product waste that might not be consumed is not considered although the prevention of such product waste would have a noticeable influence on the whole life cycle. The idea behind is that a reduced resource input will lead to several reductions of waste and therefore costs in purchasing, processing and disposal along the whole life cycle chain. Table V summarises the results.

Table V.
Central results of scientific studies on life cycle aspects of cream cheese, by life cycle phases and with indication of relevance for the resource categories abiotic (A), biotic (B), water (W) and energy (E)

	Relevance
Raw material procurement[a]	
Most important raw material: milk All resource categories relevant but highest resource consumption: biotic material and water	A, B, W, E
Energy is used for milking and storage (cooling) of milk products	E
Production [b]	
Not very energy-intensive	E
High relevance of the category biotic materials: milk most important material Average relevance was identified for water and energy	B
Major part of fossil primarily energy demand for production is needed outside KJS	E
Energy consumption: one of the most important aspects	E
Production of milk products is comparatively water intensive (for cleaning purposes: high hygienic standards)	W
Average losses of raw material in the production process: less than 2 per cent: irrelevant, could be used as side product (e.g. fodder)	B
The resource use for packaging that was identified for the use phase is rather relevant for the production phase	
Relevant for the consumption of abiotic materials though but because preliminary phases of the value chain are not considered, this aspect is not relevant for the whole phase	A
Use [c]	
Cooling energy	E
Energy consumption important: transportation but negligible compared to other phases	E
Emissions caused by transportation and packaging relevant aspects: relevance of the category energy	
Packaging irrelevant	E
Route of transportation for purchasing food	E
Transportation of a product by car rather important Consumption of water irrelevant	E
Waste treatment [d]	
Packaging deriving from cream cheese packages most relevant	
Relevance for Germany rather low: recycling systems offer treatment for such packages	(In Germany)

Notes: A = abiotic material; E = energy; W = water; B = biotic material. [a]Assigned resource intensity in points for the raw material procurement phase: A: 1, B: 3, W: 3, E: 2. [b]Assigned resource intensity in points for the production phase: A: 1, B: 3, W: 2, E: 2. [c]Assigned resource intensity in points for the use phase: A: 1, B: 1, W: 1, E: 2. [d]Assigned resource intensity in points for the waste treatment phase: A: 1, B: 1, W: 1, E: 1
Source: Adapted from Kuhndt *et al.* (2002); Wallbaum and Kummer (20060

The studies mentioned previously (Høgaas Eide, 2002; Svenskmjölk, n.d.; Kauppinen *et al.*, 2008b; Kaiser *et al.*, 2008) conclude that the agricultural production phase is the most resource-intensive one regarding the whole life cycle of cream cheese. Of subordinated relevance is the production as well the use phase – the order of those two can alter though, depending on the point of view. Milk and cream cheese as easily perishable goods need to be cooled during their whole value chain, which makes energy a relevant category. The life-cycle wide relevance of the single phases regarding the resource consumption is assessed in step two of Table VI. The phase of raw material procurement and production proved to be strongly relevant here. In step three, these values are multiplied by the results of step one.

The most important life cycle phases regarding resource intensity are identified. Referring to step three in Table VI based on the scientific results mentioned previously, relevant hot spots appear in the raw material procurement phase in terms of biotic materials (9) and water (9) as well as biotic materials (6) and energy consumption (6) during the production phase. The high-energy consumption derives mostly from the constant need of cooling which is relevant for all life-cycle phases. For the fodder consumption biotic material is most relevant which is accounted in the raw material procurement phase.

4. Conclusions

The Hot Spot Analysis seems to be a good opportunity for companies to address resource efficiency potentials that are at the same time relatively cost moderate. Several companies have adopted this methodology in their management system in order to define their needs of action. The specific results are confidential because of high importance for competitiveness in their market. Therefore it could be established that the methodology is accepted and used for a first screening step in complex value chains with several stakeholder requirements. The different companies have implemented lots of arrangements that affected the sustainability level positively approved by external experts and stakeholders (Kuhndt *et al.*, 2009). Secondly they often got results that were surprising – for example great difference of resource efficiency rates between similar product chains and same products. Some compared value chains showed differences of a factor four of resource efficiency producing the same product (Kuhndt *et al.*, 2002). Some companies used a sustainability indicator set for estimating the hot spot including social and economic criteria. The methodology gave them the possibility to this and resulted in reliable decisions for example other

Resource category	Raw material procurement	Life cycle phase Production	Use	Waste treatment
Step 1: Assessing the resource-intensity within each life cycle phase				
Abiotic materials	1	1	1	1
Biotic materials	3	3	1	1
Water	3	2	1	1
Energy	2	2	2	1
Step 2: Assessing the resource-intensity between the different life cycle phases				
Non-energetic	3	2	1	1
Energy	2	3	2	1
Step 3: Identification of hot spots on the basis of steps 1 and 2				
Abiotic materials	3	2	1	1
Biotic materials	9	6	1	1
Water	9	4	1	1
Energy	4	6	4	1

Sources: Adapted from Kuhndt *et al.* (2002); Wallbaum and Kummer (20060

Table VI. Hot Spot Analysis of cream cheese agricultural methods, social acceptable contracts with land workers, hygienic standards, working conditions etc. The companies used it for strategic management decision concerning designing value chains, electing of suppliers, asking for and helping for more sustainable management in the different process stages. Another important practice was using the systematic view on value chains for marketing and communication tools that will position them at the POS. In conclusion: Due to this methodology, companies are able to identify hot spots of resource consumption and other sustainability topics in their product chains in order to take countermeasures. Although the Hot Spot Analysis appears as an instrument applicable for companies of all sizes and budgets, there is still the requirement for understanding and collecting scientific information before performing the analysis. On the other hand, this does not necessarily need to be done by each company itself but could be done, e.g. by branch organisations.

The Hot Spot Analysis is also applicable to the macroeconomic level. This could be relevant for political decision makers, for instance in the context of land use competitions or when developing instruments for promoting sustainable consumption and production.

The Hot Spot Analysis will not substitute the necessity of material intensity analysis or LCA because it only provides indicatory information. The Hot Spot Analysis is even dependent on certain MIPS or LCA studies already done. However, Hot Spot Analysis can help companies in using existing life cycle studies without the continuous need for creating or ordering time- and cost-intensive conventional life-cycle analyses by themselves with their need of a high amount of data or information. For the Hot Spot Analysis presented here the problems of time- and cost-intensity do not apply but it clearly does not substitute a material flow analysis (e.g. MIPS analysis) or – as a next step – a detailed LCA. However, the Hot Spot Analysis can provide a foundation for more detailed analyses because it points out relevant needs for action where at first detailed data analyses must follow. Adapted indicator sets for measuring sustainability will help to clarify the situation and result in action points with high potential for sustainability effects.

The examples examined in this paper show that compared to other life cycle phases the extraction is of high importance, which is confirmed by several studies in the food sector. Talve (2001) concludes that in a LCA for beer, Høgaas Eide (2002) and Sevenskmjölk (n.d.) for milk and Moller *et al.* (1996); and Carlsson-Kanyama *et al.* (2001) for meat. Also the use phase can have a high relevance, especially when storage and preparation of food is connected to high-energy consumption (cooking, cooling or deep-freezing).

Numerous studies (Baudisch *et al.*, 2004; Hirschfeld *et al.*, 2008; Kaiser *et al.*, 2008; Kauppinen *et al.*, 2008a, b) show that foodstuffs based on animal products are connected to higher resource consumption than those based on vegetable origins. Food that underwent a complex processing (cooling, cooking, baking, heating up, pulverise) is characterised by high-energy consumption in the production, as well as use phase. In case of easily perishable goods, the cooling process needs to be guaranteed for the whole value chain, which leads to an additional energy demand. Waste treatment does not usually play a significant role but the prevention of waste is reflecting on the whole life cycle. While the relevant processes in the production and use phases seem to be represented well in Hot Spot Analyses of foodstuffs, the relevance of fodder production and the relevance of food waste prevention are aspects that might be underestimated within the system boundaries applied in the case studies of this paper.

Notes

1. Compare LCA food database.
2. Named "materials" in the MIPS concept.
3. Non-renewable resources like mineral raw materials and fossil fuel.
4. Renewable resources like biomass from cultivation, plants and animals.
5. Biotic and abiotic materials and water.

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Paper 3

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Application of the MIPS method for assessing the sustainability of production–consumption systems of food

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ABSTRACT

The article estimates the natural resource consumption due to nutrition from the supply and demand sides. Using the MIPS (Material Input per Service Unit) methodology, we analyzed the use of natural resources along the supply chains of three Italian foodstuffs: wheat, rice and orange-based products. These figures were then applied for evaluating the sustainability of diets in 13 European countries. The results outline which phases in food production are more natural resource demanding than others. We also observed different levels of sustainability in the European diets and the effect of different foodstuffs in the materials, water and air consumption.

1. Introduction

"Nutrition" is one of the most material demanding areas of need, accounting for approximately 20 percent of the total natural resource consumption of the German economy (Ritthoff et al., 2009). The ongoing increase of the world population entails huge challenges for all countries' agro-food systems. Agriculture has to satisfy growing food requirements both in quantitative and qualitative terms, but the on hand natural resource stock is quickly depleting. Moreover, food production and energy production from biomass are competing for land (Pimentel and Pimentel, 2008; Hahlbrock, 2009). Therefore, the topics of nutrition and sustainability have been gaining more and more attention in the political agenda of many governments and international institutions. FAO (2010) recently declared that the need for alternative protein is urgent, due to the growing world population. Thus, it is promoting edible insect consumption as a sustainable food strategy. Giving this emerging awareness, we can state that the evaluation of the consumption of natural resources embodied in foodstuffs and agricultural products has many policy implications, and the topic of food–farming systems sustainability has a crucial importance in the world economy.

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Different assessment tools for evaluating the impact of food in the ecosystems can be used, e.g. Life Cycle Assessment (LCA), energy requirements indicators, virtual water and carbon footprint of food (Kramer et al., 1999; De Fraiture et al., 2001). Nevertheless, a comprehensive ecological indicator should cover main environmental categories, consider the broad life cycle of a product or service and be understandable and easy to communicate to a non-expert audience (Burger et al., 2009).

In this context, we propose a material input based methodology (MIPS, the Material Input per Service Unit) for assessing the environmental sustainability of food production and consumption. According to this approach, the volume of primary materials that are extracted from nature for the economic activities indicates a generic pressure on environment. Targeted to a product or a service, MIPS gives a preliminary estimation of the potential environmental impact of those products or services and allows comparing alternatives that provide the same service.

The analysis regards both the supply and demand side of the food sector. In the first part, we calculated MIPS for Italian foodstuffs (wheat, rice and orange-based products) along their supply chains. LCA surveys and information from the literature were the main sources of data. Finally, we outlined which factors and phases are more relevant in the supply chains for a reduction of the material input. In the second part, we used MIPS results on Italian productions and other figures from the literature for accounting the natural resource consumption due to nutrition in thirteen European countries and at EU level. A set of MIPS-based indicators was calculated for outlining the intensity in the use of three resources: materials, water and air. The interpretation of results allowed highlighting the sustainability of different diets. We also detected which foods in diets are affecting more sustainability and commented these outcomes with the ones from another application of MIPS in food consumption.

2. Methodology

2.1. MIPS concept

MIPS stands for material input per service unit and estimates the overall environmental pressure caused by products or services by indicating the life-cycle-wide consumption of natural resources in relation to the benefit provided. The equation

$$\mathrm{MIPS} = \frac{\mathrm{MI}}{\mathrm{S}} \quad (1)$$

also shows that MIPS is the reciprocal of resource productivity. Thus, this indicator tells us how much "nature" we are using for producing or consuming something. Material input (MI) encompasses all matter and energy flows from natural systems to techno-sphere, in mass units. Energy is included through the energy carriers quantification in terms of mass. They also include the "ecological rucksacks", i.e. "the total mass of material flows that are not physically included in the economic output under consideration but have been necessary for production, use, recycling and disposal" (Spangenberg et al., 1999). Backward chains of a specific product must also be taken into account for a proper estimation of ecological rucksacks.

Five or six different categories of material inputs are considered: abiotic (non-renewable resources like mineral row materials, fossil energy carriers, soil excavations), biotic (renewable resources from agriculture and silviculture) earth movement in agriculture and silviculture (mechanical earth movement), water (surface, ground and deep ground water) and air (all parts of the air that are changed chemically, i.e. mainly the quantity of oxygen combusted that reflect the amount of carbon dioxide formed); also erosion can be calculated separately.

The "Service Unit" component (S in Eq. (1)) refers to the benefit provided by using material or immaterial goods. The dimension unit of this part depends on the object under consideration and the specific performance it provides (e.g. person–kilometers for a means of transport, floor area for buildings). Products that are used just once (for instance, food) have $S = 1$ and

$$\mathrm{MI} = \mathrm{ER} + \mathrm{PW} \quad (2)$$

where ER is the ecological rucksack and PW is the weight of the product we are considering.

Relating the material input with the service unit allows comparing different ways for fulfilling a need, or alternative production techniques for producing something, on the base of their intensity in resource use. Thus, MIPS can also be defined as the "ecological price of a utility" (Schmidt-Bleek, 2008) and be easily integrated in the economic analysis.

In order to avoid the calculation out of primary data each time, MIPS calculation is often done using average MI factors for materials and other inputs. They are the ratio between the quantity (in mass units) of resources used and the quantity (mass) of product obtained. Many MI factors of materials and "modules" (electricity, transport, etc.) have been calculated and are published by the Wuppertal Institute (available online: http://www.wupperinst.org/uploads/tx_wibeitrag/MIT_v2.pdf). The use of already calculated MI factors makes MIPS calculation easier, because not every pre-process-chain needs to be recalculated by each user.

The theoretical basis of MIPS lays in Material Flow Analysis (MFA). The common consideration is that production processes are extracting resources from nature and transforming them into something suitable (the product) and something unsuitable (emissions, waste, etc.). The quantification of the throughput of process chains and the minimization of these physical exchanges between human society and environment is the aim of MFA (Bringezu et al., 2002).

MIPS has an input-oriented approach. Consistent with the matter-energy conservation law, it assumes that, as the input and the output side are equivalent in quantitative terms, accounting the input side is enough to have a preliminary estimation of the environmental impact of products and services (Ritthoff et al., 2002; Schmidt-Bleek, 1993).

The input-orientated approach of MIPS also implies that MIPS is not a sufficient indicator when measuring specific outputs (e.g. emissions of specific substances) or specific environmental impacts (like acidification or toxicity). Thus, MIPS allows conclusions on the overall pressure on the environment (as any input into the human production–consumption system will become an output at some point in time) but not on specific environmental impacts. As MIPS contains all physical input flows, it is rarely used in index-type combination with output indicators, because this would affect double-counting of certain material flows.

On a microeconomic level, MIPS can be applied to a variety of products and services for evaluating eco-innovations and indentifying eco-efficiency improvements along the supply chains (Burger et al., 2009). It is also applicable at a macroeconomic level for an evaluation of the sustainability of the economic growth in national and regional economies. It has also been used for an evaluation of policies from the environmental point of view (Lettenmeier and Salo, 2008). The most controversially discussed aspect of the MIPS concept is probably the link between the mass flow of resources and the environmental impacts caused by it. The traditional approach of environmental policy focused rather on the impact of hazardous substances in the output flows than on the material flow input, considering also the possibility of material recycling and the treatment of waste and emissions. Nevertheless, the importance of input mass flows and the necessity of a reduction of these amounts are evident. The both economic and ecological costs as well as the incompleteness of output treatments and the impossibility of a complete recycling of materials are some common reasons for this approach (Lettenmeier and Maijala, 2006). Moreover, the specific environmental impact of most substances humans release into nature is only partly known for just for a very limited amount of substances. Thus, the amount of materials moved from their original location can be considered a proxy measure for the human use of natural capital potential environmental impact (Hinterberger and Seifert, 1997).

2.2. MI-based indicators for sustainability strategies

A drastic reduction in material resources use is necessary for approaching sustainability.

Accounting for the material input of products and economies is essential to enforce a dematerialization strategy both at micro and macro levels. Depending on the objects of evaluation, different indicators based on the material requirements can be used. For the interpretation of MIPS results, the different resource categories have to be examined separately. So far, the “earth movement in agriculture and silviculture” category is often left out from the interpretation as the available documentation is still inadequate and just “erosion”, which is encompassed in this category, is considered. In this study, we neglected the interpretation of soil movements but considered erosion inside TMR (Total Material Requirement):

$$\mathrm{MI[TMR]} = \mathrm{MI[abiotic]} + \mathrm{MI[biotic]} + \mathrm{MI[erosion]} \tag{3}$$

This indicator gives instantaneous information about the use of materials of different alternatives (Ritthoff et al., 2002).

In order to implement dematerialization strategies, resource productivity has to be stressed. At the same time requirements of resources should decrease also in absolute terms. Technologies and innovations can be evaluated measuring MIPS along the various steps of the value chain and in the different category of resources (Lettenmeier et al., 2009). At least three equations should be minimized:

$$\mathrm{MinTMR}_{tot} = \mathrm{TMR}_a \times x_a + \mathrm{TMR}_b \times x_b + \ldots + \mathrm{TMR}_n \times x_n \tag{4}$$

$$\mathrm{MinMIw}_{tot} = \mathrm{MIw}_a \times x_a + \mathrm{MIw}_b \times x_b + \ldots + \mathrm{MIw}_n \times x_n \tag{5}$$

$$\mathrm{MinMIa}_{tot} = \mathrm{MIa}_a \times x_a + \mathrm{MIa}_b \times x_b + \ldots + \mathrm{MIa}_n \times x_n \tag{6}$$

where TMR, MIw and MIa are the requirements of material resources, water and air in all the phases of the value chain; a, b, c, n represent the various steps of the value chain, from the extraction of raw materials up to the consumption phase; x_n is the amount of goods that is produced or consumed in each phase.

TMR is also used in resource accounting of national economies (United Nations et al., 2003; Bringezu et al., 2001). In this case it refers to the total mass of natural material resources used in the economy and it is calculated as:

$$\mathrm{TMR} = \mathrm{DMI} + \mathrm{DHF} + \mathrm{iDMI} + \mathrm{iHF} \tag{7}$$

where: DMI is the domestic direct material input, i.e. the flows of domestic natural resource commodities entering the economy; DHF is the domestic hidden flows, i.e. the unused extractions linked to DMI (e.g. excavated and disturbed materials and biomass that is removed but not used for production); iDMI is the imported direct material input, that is all the flows of resources coming from abroad; iHF is the hidden flows associated with imports (in the literature DMI often stands for direct material input, which is the sum of domestic and imported flows used in the national economies). TMR of the European Union has been calculated by the European Environment Agency (EEA, 2001) and many MFA of national economies are already available in the literature. Information on material flows can be used for adjusting GDP with the depreciation of natural capital due to economic activity and evaluate the sustainability of economic growth (Hinterberger and Seifert, 1997).

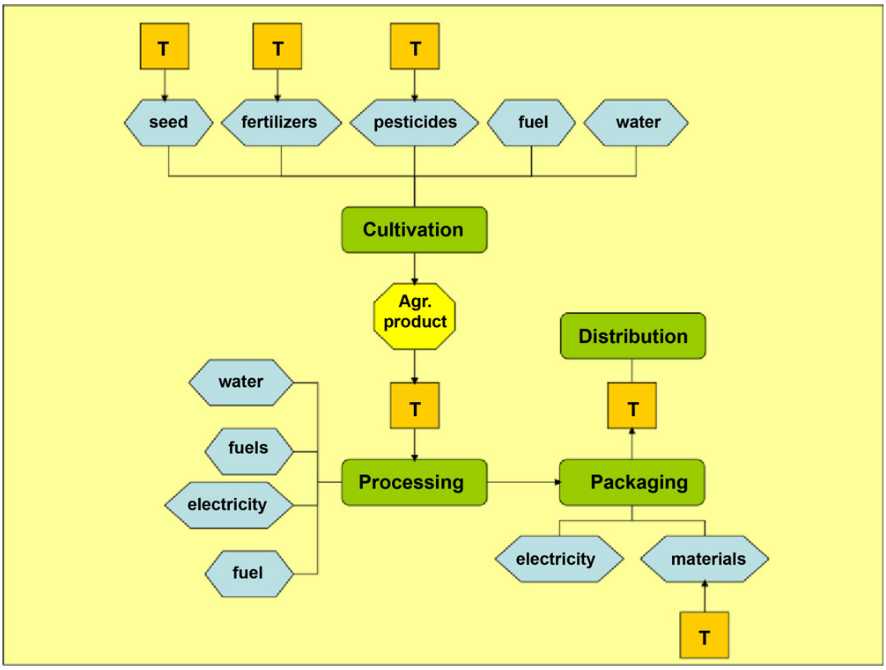

Fig. 1. System boundaries for MIPS calculation of foodstuffs. "T" represents the transport process.

Pursuing the eco-efficiency of consumption behaviors and production processes has a positive feedback also in economic terms because it allows gaining a better resource allocation. On the production side, eco-efficiency entails a cost reduction, since the resources are managed in a more rational way. Moreover, acting upstream through a minimization of resource use, the downstream costs for waste management, pollution treatment and purification are also reduced. Nevertheless, the ecological and economic efficiency can diverge when market prices underestimate the biophysical scarcity of natural resources and overestimate the capacity of the ecosystems as a sink, thus encouraging a wasteful management. Therefore, an integrated evaluation of economic and ecological efficiency of processes can be useful for providing information on the overall performance of processes. Using DEA (Data Envelopment Analysis) models Kauppinen et al. (2008) studied the sustainability of food consumptions, scoring a set of foodstuffs on the basis of the overall (economic and ecological) efficiency. In this study, the material intensity of foodstuffs and their prices are considered as inputs in the DEA model, while the food's nutritional values are used as output. The results show the efficiency of each foodstuff in providing individuals with a proper amount of nutrients while minimizing the material input and the household expenditure. A similar investigation can be applied on the supply hand for evaluating the overall efficiency of productive processes.

2.3. *Material intensity analysis of food value chains*

In the first part of the study we used the MIPS approach for investigating the ecological rucksacks of three Italian foodstuffs along their supply chains: wheat, rice (milled and parboiled rice from conventional farming and milled rice from organic farming), and citrus-based products (oranges, natural and concentrated orange juice). The scope of the study was twofold. From the supply side, we wanted to test the MIPS methodology as a tool for sustainable food production; from the demand side, we wanted to use these estimations for the assessment of natural resource consumption due to nutrition in different European areas.

The first step of the supply chain analysis was to assess the material intensity of some Italian foodstuffs and agricultural products. The choice of products was based on their representativeness of the Italian agro-food sector and their importance in diet. We also considered the availability of data and life cycle assessment surveys, which are the main sources of information for material intensity accounting. Statistics and other surveys from the literature have also been used for completing the data basis.

Soil erosion statistics are not available for different crops in Italy. We applied to the three crops (wheat, rice and orange groves) the estimation of 10 t/ha year of erosion in Italian agriculture use published by the National Statistical Agency in 2003 (ISTAT, 2003). The system boundaries were defined from the production and transportation of the chemicals and other inputs for agriculture (Fig. 1) up to the distribution to the selling points. The transport of the packaging materials and the means of transports are also included, while the impact of infrastructures and the capital goods is neglected.

We choose the service unit of 1 kg of food, without considering the content of different nutrients provided by the foodstuff. Thus, the results are expressed as kg of materials per kg of food. The MIPS indicator can focus both on micro-economic level (taking data from a single enterprise) and on macro-economic level, using average data from different sources or national statistics (Baedeker et al., 2008). Depending on the availability of data, we used the first or the second approach with a focus on micro level data in production and on macro level in consumption. The MIPS-based indicator, TMR (for details, see above), includes the abiotic, biotic and erosion categories and was used for an interpretation of the results. Material intensities of fertilizers, pesticides, fuels, means of transport and all the materials and energy carriers used in agriculture and food industry are from the available literature (www.mips-online.info). They are not specific for Italy but most of them have been calculated for Germany or Europe. The material intensity of electricity is available for European and OECD countries and has been applied in the calculation.

For the MIPS calculation of wheat we used average data from three different LCA surveys (Bevilacqua et al., 2001, 2007; Della Corte et al., 2003) that investigate the production of two different brands of pasta. We considered only conventional durum wheat cultivation, with nitrogenous and phosphorous fertilization and pest treatments. Irrigation is usually not necessary for durum wheat cultivation, except in case of extraordinary drought. Therefore, we excluded it from the MIPS calculation. The average yield from the literature is 5678 kg/ha; for the accounting of earth movements in agriculture we assumed a maximum depth of ploughing of 30 cm and an average soil density of 1300 kg/m3.

The system includes the transports of raw materials and inputs and the trip to the milling point. Information about rice from conventional agriculture (milled and parboiled) is from Blengini and Busto (2008). These average data are representative of a typical farm in the Vercelli district in the North-West of Italy (this area provides 33 percent of national rice production). We considered an average yield of 7040 kg/ha of paddy rice, with the resort of nitrogenous, phosphorous and potassic fertilization and pest treatments. Earth movements include tilling, ploughing and the maintenance of water canals; irrigation is based on the network of canals where water flows without the use of any pumping systems. The annual water consumption for irrigation is 19,800 m^3/ha. Fuel consumption for field operation is from ENAMA (National Agency for Agriculture Mechanization) and Ministry for Agriculture statistics.

All the transports are included in the system. We assumed a local distribution to the retailers with an average distance of 200 km. Parboiled rice needs a special treatment after the drying of paddy rice. It consists of boiling, soaking, steaming and drying again. The packaging of milled and parboiled rice is made of a polyethylene bag and an external carton box.

Data on organic rice (Mandelli et al., 2005) refer to a specific farm, in the area of Milan. The breeding activity of the same farm provides manure and slurry for the fertilization; mustard seeds are sowed before rice for improving the chemical characteristics of the soil. The yield of paddy rice is 5000 kg/ha and the water for irrigation is 2500 m^3/ha, according to Mandelli. The organic rice is packed in a cotton bag and an internal polyethylene film.

We applied the MIPS methodology to the production of oranges, natural (NJ) and concentrated (CJ) orange juice, based on Beccali et al. (2009) LCA information. The area of cultivation is Sicily and the manufacturing process of citrus-derived products regards a Sicilian factory with regional representative size.

In the conventional farming of citrus groves nitrogenous, phosphorous and potassic nutrients are applied and water consumption for irrigation is about 4200 t/ha. We assumed the deepest ploughing being 80 cm before the planting, one time in 25 years (the life span of the grove) and a soil density of 1350 kg/m^3. We neglected the nursery production.

The average yield is 25 t/ha of oranges. The manufacturing process of NJ is composed of selection and washing, primary extraction, refining, pasteurization and cooling, refrigeration and packaging. CJ needs an additional treatment for reducing the amount of water. One kilogram of oranges provides 0.142 kg of NJ and 0.028 kg of CJ.

We assumed average transport distances of 150 km from the field to processing and 500 km from processing to retailers. The products are packed into LDPE bags.

2.4. Material intensity of European diets

MIPS results on foodstuffs were applied for assessing the natural resource consumption due to nutrition in European countries. We took into account the consumption of 18 foodstuffs in 13 European countries and in the European Union as a whole. The main source of data was the Eurostat report "From Farm to Fork" (EUROSTAT, 2008). It provided figures on gross human apparent consumption of foodstuffs per capita of the twenty-seven European Union's countries. We excluded from the analysis all the countries lacking data for food consumption in 2007 and took only the foodstuffs for which material intensities[1] were available in the literature (we excluded from 27-EU: Malta, Denmark, Estonia, Lithuania, Latvia, Bulgaria, Czech Republic, Hungary, Romania, Slovakia, Slovenia, Belgium and Luxemburg).

Previous results on material intensities of wheat, rice and oranges were used for this application. The other figures are from German (Ritthoff et al., 2009) and Finnish (Kauppinen et al., 2008) studies on agriculture and nutrition. Some values have been estimated by the authors on the basis of similar food categories already existent. The material intensity of pears, for instance, was assumed to be like that of apples; we used fresh tomatoes figures also for processed tomatoes and the cattle figures also for sheep and goats. In Table 1 is a list of material intensities and the information sources. The same material intensities were used for every country, as no specific data was available. This means that the wide variability

[1] In the case of food, MIPS values are also called we Material Intensity because the service has the same unit measurement then the MI (kg/kg).

Table 1
Material intensities of foodstuffs.

Foodstuffs	Abiotic	Biotic	Water	Air	Soil	Erosion
Wheat[c]	0.34	2.13	30.84	0.29	731.9	1.87
Rice[c]	2.53	3.84	4804	0.94	2589	2.40
Potatoes[a]	0.10	1.06	0.4	0.01	113	0.22
Vegetable oils and fats[a]	4.50	3.72	70.5	0.98	5490	11.49
Sugar[a]	8.58	12.6	53.7	4.70	542	1.15
Apples[b]	1.00	1.00	7.0	0.01	93	0.32
Oranges[c]	0.20	1.00	181	0.11	17	0.40
Pears[b]	1.00	1.00	7.00	0.01	93	0.32
Tomatoes[b]	8.00	1.00	793	4.00	36	0.01
Cattle[a]	10.9	26.4	451	2.81	3329	11.1
Poultry[a]	6.44	5.93	234.9	1.63	3405	5.90
Pigs[a]	2.57	6.89	62.3	1.01	2968	6.51
Sheeps and goats[a]	10.86	26.39	450.8	2.81	3329	11.12
Fish and seafood[a]	2.80	4.70	271.0	0.83	148	0.17
Drinking milk[a]	0.15	2.75	4.7	0.03	259	0.89
Butter[a]	3.42	56.87	105.8	0.79	5366	18.43
Cheese[a]	0.84	14.24	25.5	0.20	1344	4.62
Eggs[a]	1.15	1.98	28.56	0.25	605.9	0.93

[a] Ritthoff et al. (2009).
[b] Kauppinen et al. (2008).
[c] Our MIPS results for Italian productions.

of environmental and climatic conditions as well as specific agronomic techniques and processes could not be taken into account. Moreover, neither the cooking, preparation of the food at home, nor the question of whether they are domestically produced or imported were included in the analysis. However, the same methodology proposed here can be used with specific data once they are available in order to have a more accurate assessment.

Using this set of data, we calculated the following indicators:

$$\mathrm{RIT}_{i,j,k} = \mathrm{MI}_{i,j,k} \times \mathrm{X}_{i,j} \tag{8}$$

$$\mathrm{TMR}_{i,j} = \mathrm{MIT(ab)}_{i,j} + \mathrm{MIT(b)}_{i,j} + \mathrm{MIT(er)}_{i,j} \tag{9}$$

$$\mathrm{WR}_{i,j} \tag{10}$$

$$\mathrm{AR}_{i,j} \tag{11}$$

$$\mathrm{TMR}_j = \sum_{i=1}^{18} \mathrm{TMR}_{i,j} \tag{12}$$

$$\mathrm{TWR}_j = \sum_{i=1}^{18} \mathrm{WR}_{i,j} \tag{13}$$

$$\mathrm{TAR}_j = \sum_{i=1}^{18} \mathrm{AR}_{i,j} \tag{14}$$

$$\mathrm{AMI}_j = \frac{\mathrm{TMR}_j}{X_j} \tag{15}$$

$$\mathrm{AWI}_j = \frac{\mathrm{MIT(w)}_j}{X_j} \tag{16}$$

$$\mathrm{AAI}_j = \frac{\mathrm{MIT(a)}_j}{X_j} \tag{17}$$

where i = [1...18] is the foodstuff; j = [1...14] is the country (EU included); k = [1...6] is the resource category; $X_{i,j}$ is the amounts of the foodstuff i consumed in the country j; $\mathrm{RIT}_{i,j,k}$ (resource intensity) represents the amount of the resource k that is on average necessary for the consumption of foodstuff i by a inhabitant of the country j; $\mathrm{TMR}_{i,j}$ is the total material requirement for the consumption of foodstuff i in the country j; $\mathrm{WR}_{i,j}$ and $\mathrm{AR}_{i,j}$ are the requirements of water and air for the consumption of foodstuff i in the country j; TMR_j is the total material requirement for food (that is the set of 18 foodstuffs) of the country j; TWR_j and TAR_j are the total requirements for water and air for food (that is the set of 18 foodstuffs) of the country j; AMI_j, AWI_j, AAI_j are the average resource intensity (for materials, water and air), i.e. the average amount of resources that is used for consuming one unit of food in a given country.

The comparison of the resource intensities (materials, water and air) of diets facilitates a rough assessment of their sustainability. In addition, we can outline how different groups of food are contributing to the natural resource consumption of nutrition.Countries were graded on the base of total annual consumption and TMR of the selected foodstuffs per capita, and the average intensity of materials, of water and of air.

3. Presentation and description of results

3.1. MAIA analysis of the supply chains

3.1.1. Results for wheat

Table 2 presents the material intensity results of durum wheat; Fig. 2 shows the contribution of different phases of the supply chain. The TMR for one kilogram of durum wheat is 4.35 kg. Fig. 2 shows the contribution of different input factors in the total resource use due to wheat cultivation. 84 percent of water consumption is due to pesticides production, while two-thirds of total abiotic materials are used for producing chemical products for agriculture (these include fertilizers and pesticides). Fuel for field operation weighs 40 percent of the total air consumption, while transport operations from storage to milling place consume 13 percent of air and 12 percent of abiotic materials.

3.1.2. Results for rice

TMRs of rice are 8.91 kg/kg milled, 9.43 kg/kg parboiled and 9.04 kg/kg organic (Table 3). For the three kinds of rice, more than 70 percent of TMR is due to farming (Figs. 3–5). In conventional rice (milled and parboiled) the impact of fertilizers is relevant for the category of abiotic resources (40 percent and 34 percent) and irrigation is responsible for almost the total consumption of water. Transports are also quite important for the consumption of air (28 percent and 21 percent of the total). Electricity affects parboiled rice more, which has higher material intensities also in absolute terms (in the categories of abiotic, air and water). Concerning the organic rice, the TMR is not lower than the conventional ones (8.93 kg/kg). In opposite to a minor consumption of abiotic resources, in which packaging materials and electricity are contributing more, biotic resources and erosion contribute to a higher TMR. Air and water consumption are lower in organic rice and affected more by packaging materials than transport and electricity.

Table 2
Material intensity of conventional durum wheat.

	Abiotic	Biotic	Erosion	Soil	Water	Air	TMR
Material intensity (kg/kg)	0.34	2.13	1.87	731.9	30.84	0.29	4.34

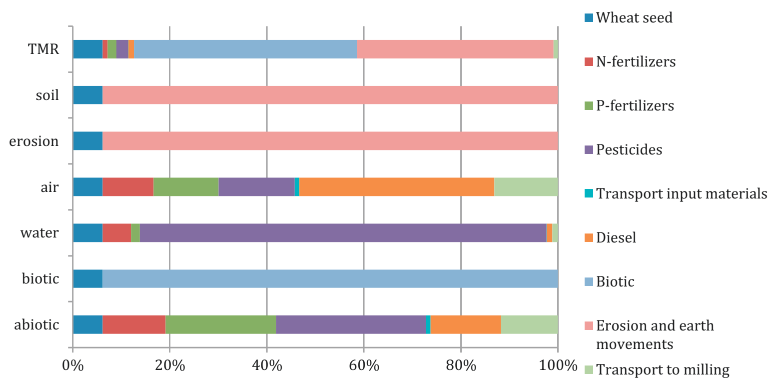

Fig. 2. Composition of the material intensity of durum wheat.

Table 3
Material intensity of rice.

Material intensity (kg/kg)	Abiotic	Biotic	Erosion	Soil	Water	Air	TMR
Milled conventional rice	2.53	3.84	2.40	2589	4804	0.94	8.77
Parboiled conventional rice	3.20	3.84	2.40	2589	4828	1.37	9.43
Organic milled	1.14	4.16	3.57	3866	1457	0.43	8.89

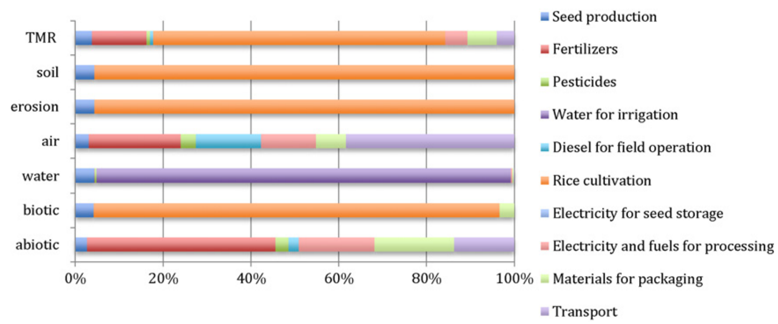

Fig. 3. Material intensity composition of milled conventional rice TMR.

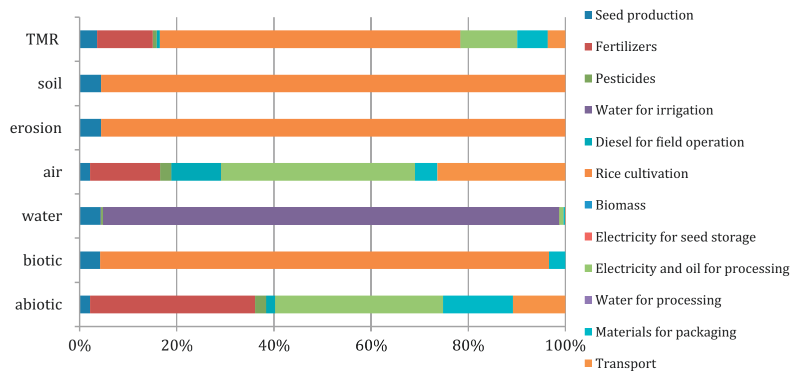

Fig. 4. Material intensity composition of parboiled conventional rice TMR.

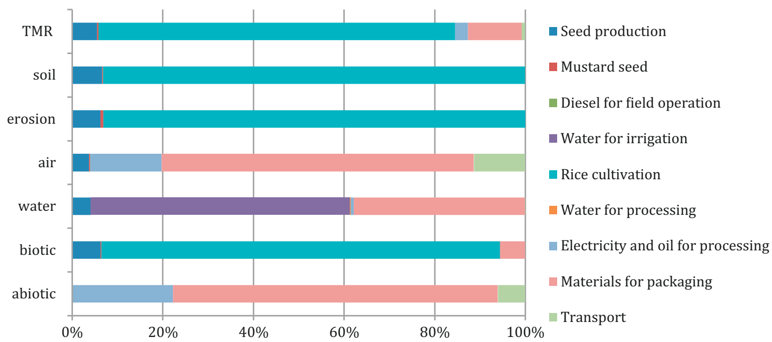

Fig. 5. Material intensity composition of organic milled rice.

3.1.3. Results for oranges and citrus-based products

Material intensity results are much higher for CJ, due to the minor yield of juice of a factor of five (35 kg of oranges for 1 kg of CJ, 7 kg of oranges for 1 kg of NJ) (Table 4). If we would consider products at the moment of consumption we should include the dilution of the concentrated juice, and these values will be more similar. Abiotic resource consumption is especially higher in CJ, due to the electricity and fuels for industrial processing (82 percent) while fertilizers are responsible for about 50 percent of the abiotic resource consumption in NJ (Figs. 7 and 8). Materials for packaging contribute overall to the air category (82 percent in NJ and 40 percent in CJ), while water consumption depends most on irrigation. Considering oranges production, fertilizers have a relevant influence on abiotic materials, accounting for 77 percent of the total (Fig. 6). The impact of pesticides on the material input is negligible. Fertilizers, diesel for field operations and transport combine with almost equal parts to the total consumption of air.

Table 4
Material intensity of citrus-based products.

Material intensity (kg/kg)	Abiotic	Biotic	Erosion	Soil	Water	Air	TMR
Oranges	0.20	1.00	0.40	17	181	0.11	1.60
Natural orange juice	2.17	7.06	121.9	2.82	1302	6.73	12.05
Concentrated orange juice	35.56	35.27	609.5	14.1	6901	13.92	84.94

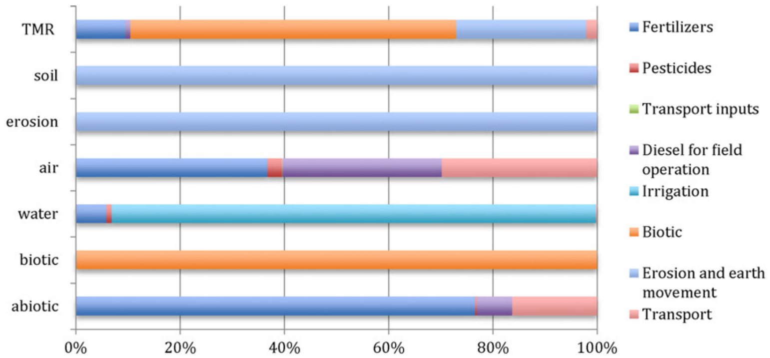

Fig. 6. Material intensity composition of oranges.

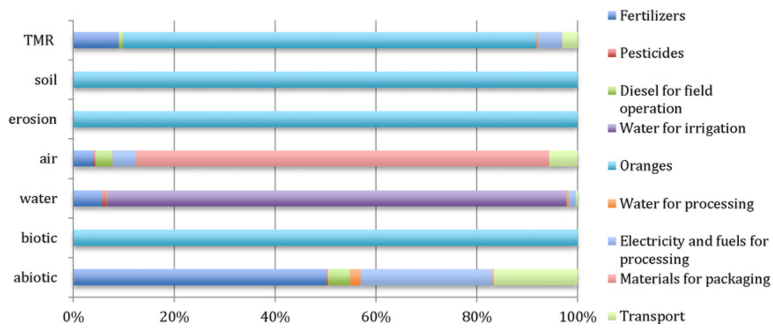

Fig. 7. Material intensity composition of natural orange juice.

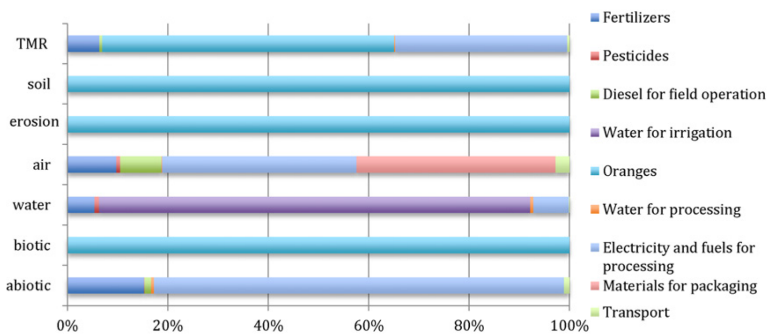

Fig. 8. Material intensity composition of concentrated orange juice.

3.2. Resource intensity of European diets

Figs. 9 and 10 show total annual consumption and TMR of the selected foodstuffs in the European countries. Results on the use of the three resources (materials, water and air) follow. We observe in Fig. 11 Germany, Austria and Italy having the highest value of AMI (see chapter 2.4 for indicators' equations), with 11.4, 11.3, 10.7 kg of material resources for producing 1 kg of food. Poland, with 8.4 kg/kg has the lowest. Table 5 illustrates the share of different groups of foodstuffs (cereals

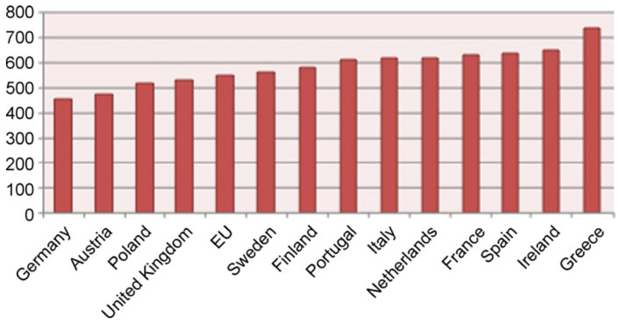

Fig. 9. Total consumption of the selected foodstuffs in the 13 European countries and in the EU (kg/capita/year).

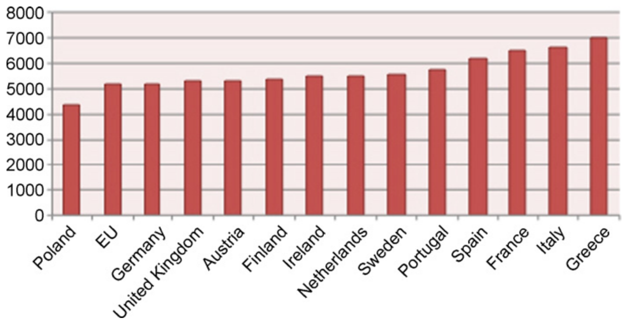

Fig. 10. Total material requirement for the selected foodstuffs' consumption in 13 European countries and in the EU (kg/capita/year).

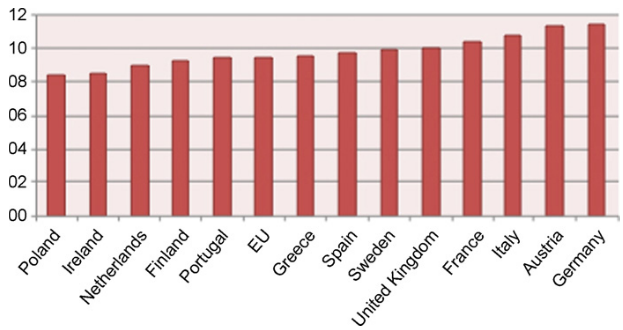

Fig. 11. Average material intensity of food in 13 European countries and the EU (kg/kg).

Table 5
Composition TMR of European diets among six groups of food (percent).

AMI (percent)	Cereals and potatoes	Fruits and vegetables	Meat, fish eggs	Milk and dairy products	Sugar	Vegetable oils and fats
Poland	18.8	4.6	36.3	20.4	17.4	2.4
Ireland	13.6	5.8	44.9	17.3	13.0	5.4
Netherlands	11.1	9.0	40.9	21.0	11.2	6.8
Finland	9.2	6.6	37.8	28.2	16.3	1.8
Portugal	16.0	5.2	48.0	11.8	11.8	7.3
EU	15.5	7.8	36.1	18.8	15.1	6.7
Greece	18.8	12.5	34.0	11.8	9.1	13.7
Sweden	10.2	6.6	41.3	21.4	19.5	1.0
Spain	12.1	7.5	48.2	10.9	10.6	10.7
UK	14.6	3.5	45.9	17.0	10.0	9.1
France	11.7	8.2	42.4	20.5	12.6	4.7
Italy	15.6	11.7	36.7	12.9	14.8	8.3
Austria	10.5	5.8	43.9	19.2	16.1	4.5
Germany	11.4	5.0	38.2	22.3	16.2	6.9

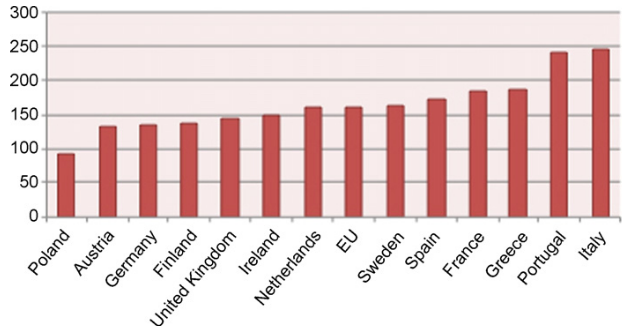

Fig. 12. Average water intensity of food in 13 European countries and the EU (kg/kg).

Table 6
Composition of water requirements of European diets among six groups of food (percent).

AWI (percent)	Cereals and potatoes	Fruits and vegetables	Meat, fish eggs	Milk and dairy products	Sugar	Vegetable oils and fats
Poland	29.7	34.6	28.7	2.4	3.8	0.8
Austria	28.9	32.1	32.2	2.1	3.3	1.4
Germany	33.0	31.1	28.0	2.5	3.3	2.1
Finland	30.2	35.3	29.0	2.5	2.6	0.4
UK	41.1	18.0	35.4	1.5	1.7	2.3
Ireland	42.6	27.3	26.0	1.3	1.8	1.1
Netherlands	25.6	46.6	23.4	1.5	1.5	1.4
EU	36.0	36.5	22.6	1.4	2.1	1.4
Sweden	38.1	30.5	26.7	1.7	2.8	0.2
Spain	31.1	33.9	30.6	0.8	1.4	2.2
France	30.8	39.3	25.7	1.5	1.7	0.9
Greece	22.7	54.3	18.6	0.8	1.1	2.5
Portugal	60.7	13.0	23.6	0.6	1.1	1.0
Italy	37.5	42.3	16.7	0.7	1.6	1.3

and potatoes, fruits and vegetables, meat, fish and eggs, milk and dairy products, sugar, vegetable oils and fats) in the TMR for food. Countries in the table are graded according to the AMI values, from the less intensive up to the more intensive. Considering the EU diet, the biggest share of material requirement is due to meat, fish and eggs consumption (36 percent); milk and dairy products follow with 19 percent. No remarkable differences emerge between low and high-AMI countries in the composition of diets from this analysis. Considering the resource "water", Fig. 12 and Table 6 present results of intensity in water use (AWI) and composition of water requirements among the groups of food. Values for Italy and Portugal are considerably higher then the other countries (almost 250 kg/kg vs. 92 kg/kg of Poland). Looking at the table we can observe that water requirements are mostly due to cereals and potatoes in Portugal (61 percent) and fruits and vegetables in Italy (42 percent). The same categories also have the biggest weight also in the EU diet. Fig. 13 and Table 7 illustrate the intensity of air (AAI) and the contribution of the different groups of food in the total air requirement (TAR), in each country. Italy is again the most intensive country, consuming 1.2 kg of air for each kg of food. Compared to the values of the EU, Italy presents a higher share of fruit and vegetables (38 percent). Sugar has a considerable impact in this category of resource in all of the countries (32 percent in the EU).

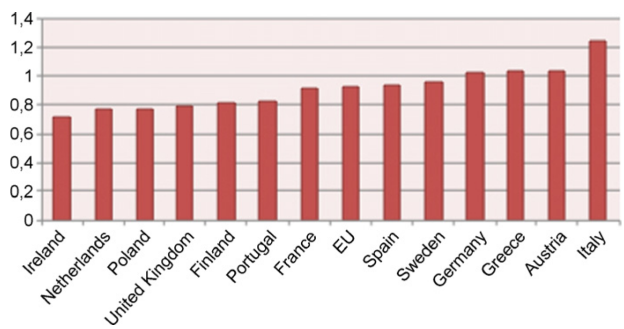

Fig. 13. Average air intensity of food in 13 European countries and the EU (kg/kg13).

Table 7
Composition of air requirements of European diets among six groups of food (percent).

AAI (percent)	Cereals and potatoes	Fruits and vegetables	Meat, fish eggs	Milk and dairy products	Sugar	Vegetable oils and fats
Ireland	9.1	17.0	36.7	1.8	32.2	3.2
Netherlands	7.4	26.6	32.5	2.3	27.2	3.9
Poland	11.3	18.1	27.6	2.0	39.7	1.3
UK	10.8	15.3	39.9	1.9	26.5	5.6
Finland	5.8	21.5	29.9	3.0	38.8	1.0
Portugal	11.9	15.1	39.7	1.2	28.1	4.1
France	8.5	23.8	32.8	2.3	30.0	2.6
EU	9.7	26.5	26.3	1.8	32.3	3.4
Spain	7.6	27.1	35.9	1.0	23.0	5.5
Sweden	6.2	20.7	28.6	2.0	42.0	0.5
Germany	7.5	19.6	28.7	2.4	38.0	3.8
Greece	10.8	43.1	21.1	1.0	17.7	6.3
Austria	6.9	19.8	32.0	2.0	36.9	2.5
Italy	9.1	38.0	21.3	1.1	27.0	3.6

A second step of analysis takes into account the whole basket of foods, in order to evaluate the weight of each foodstuff in the total natural resource consumption for nutrition. For each foodstuff, we observed how much it weights in the food consumption (i.e. in the total amount of consumed food) and in the resources requirements.

The factor of difference between these two components is presented in Table 8. The figures are the average values of all the countries. Factors are higher than 1 when the incidence on diet is smaller than the incidence in the total resource consumption for that foodstuff. The higher is the factor, the more resource intensive is the corresponding foodstuff. Butter, with 8.1, has the highest factor for TMR. This means that the share of TMR due to butter is 8 times higher than its share in total food consumption.

Cattle and sheep and goats are also highly resource intensive, with a factor of 5 and are then followed by sugar and vegetable oils and fats. Above we observed that "cereals" is the most impacting group for water. Factor's analysis indicates that rice is strongly affecting this value, with an average factor of 33.5. Tomatoes and meat (especially cattle and sheep) are also important groups contributing to water consumption, with a factor of 5.5 and 3.1.

Regarding the air category sugar is confirmed to have a severe impact. Its incidence in resource use is 5.3 times the incidence in food consumption. Tomatoes and meat (beef and sheep and goat) are also quite intensive, with factors of 4.5 and 3.2, respectively.

4. Interpretation of results

The analysis of three food chains showed how different elements and phases in the production are having an environmental impact. We observed the organic rice farming impact being almost similar to the conventional one, due to the use of a larger area of land for gaining the same unit of food. A major use of the soil consequently implies a higher value of erosion. The consumption of biotic resources, larger than in conventional rice, is also due to the use of mustard seed, the cotton bag for packaging and the major amount of seeds for hectare that is required (200 kg/ha vs. 120 kg/ha of conventional one).

The saving of abiotic raw materials is instead relevant once chemical products for agriculture are avoided and transport distances are reduced, like in the organic farm.

Table 8
Average factor of difference between food consumption share and resource use share.

	TMR	Water	Air
Wheat	0.6	0.3	0.4
Rice	0.9	33.5	1.1
Potatoes	0.1	0.0	0.0
Vegetable oils and fats	2.0	0.5	1.1
Sugar	2.3	0.4	5.3
Apples	0.2	0.0	0.0
Oranges	0.2	1.3	0.1
Pears	0.2	0.0	0.0
Fresh tomatoes	0.9	5.5	4.5
Cattle	5.0	3.1	3.2
Poultry	1.9	1.6	1.8
Pigs	1.6	0.4	1.1
Sheep and goats	5.0	3.1	3.2
Fish and seafood	0.8	1.9	0.9
Drinking milk	0.4	0.0	0.0
Butter	8.1	0.7	0.9
Cheese	2.0	0.2	0.2
Eggs	0.4	0.2	0.3

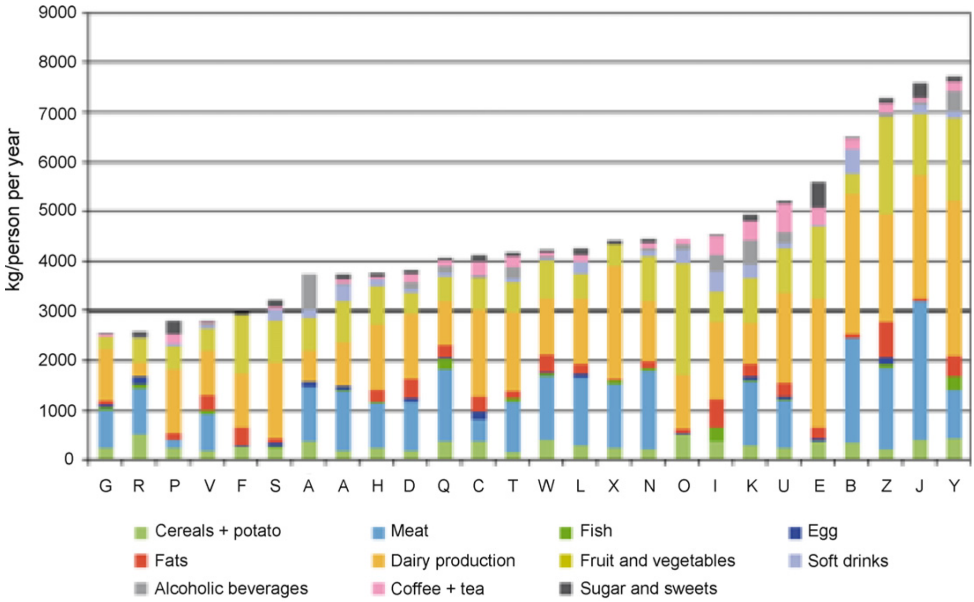

Fig. 14. Contribution of the sub-components to the TMR of foodstuffs for 27 Finnish households.
From Kauppinen et al. (2008).

In general, a minimization of external inputs employment contributes to reducing production costs and can improve the farm profitability. A specific MIPS analysis on a production system allows the comparison of different strategies of farm management and the evaluation of the most efficient in terms of input/output rates. Instead, the results on rice disclose that a major yield does not imply a higher productivity when this gain is obtained with more than proportional inputs. The better performance of organic rice in the category of abiotic materials (that encompasses all the external and purchasable inputs like agro-chemicals, electricity, fuels, etc. as well as the hidden material flows behind these) suggests that the farm profitability can be improved through the strategy of minimizing the inputs instead of the most common "productivist" scheme of yield maximization.

Although toxicity is not especially evaluated in the MIPS concept, the impact of pesticides and other chemicals on the results is visible. However, with the resources of this study it was not possible to perform a detailed material intensity assessment of the use of pesticides that are applied in smaller and smaller doses thanks to technological progress.

The calculation of natural resource consumption due to nutrition in European countries used the same material intensities of foodstuffs, which came from three different areas of production: Italy, Germany and Finland. Thus, the only variable was the amount of different foodstuffs that are consumed in each country. For this reason an analysis of diets' compositions allow gleaning which elements in food habits are more responsible for a high intensity in resources use.

Meat and animal based products demonstrated requirement for a large amount of material resources, confirming the evidence from other studies using different assessment methods (e.g., greenhouse gas emissions in Kramer et al., 1999).

The high water consumption of rice has also been also proven. High values for fruits and vegetable are probably affected by using MIPS values from Finnish productions. Calculation could be repeated once data from a more suitable area of production is available.

MIPS was also applied in a research on food consumption in Finnish households in Kotakorpi et al. (2008). In this project data on consumption are from direct interviews with the households. Using the Finnish data basis on material intensity of foodstuffs the TMR of each household was calculated (Fig. 14).

In this case, we observe a higher variability of results than when comparing the countries' diets. Statistics do not provide the same insight into the impact of different lifestyles and consumption patterns as detailed as micro level studies. Nevertheless, statistics can show differences in the impact of average diets of different countries even without the need for in-depth study of the specific households.

Concerning the components of TMR in Finnish households, the biggest share comes from dairy products and meat consumption.

5. Conclusions

The actual trend of growing population and economic development in some countries represents new challenges for the agricultural sector in terms of food supply capacity and natural resource management. Food systems are asked be productive, but at the same time to preserve the available natural resources. Sustainability is becoming an urgent need and governments, international institutions and local administrations are approaching new initiatives to promote sustainability in food production and consumption.

Concerning the food supply, MIPS results suggest that policy should foster the eco-efficiency of agricultural processes and turn them towards a lower use of external inputs. It would provide a double benefit. On the one hand, the environmental protection is improved; while on the other hand, it contributes to reducing the dependence on supplier inputs and cutting the production costs. At the same time, results showed that food transportation contributes substantially to the air and abiotic materials' consumption. Sustaining and propelling local food systems, can produce considerable advantages for the producers, the consumers, and a sustainable regional development.

From the analysis of European countries' diets emerged that cattle, sugar and butter are the most resource intensive foodstuffs (fruits and vegetables are very demanding in water and air, but the data used refers to the Finnish production, and it stands to reason that these would change significantly considering crops on a more favorable climatic condition). These outcomes hint that a reciprocal relation could exist between the environmental performance of food production and its healthiness. Many studies have pointed to the negative effects of high meat, sugar and fat consumption and our results confirmed that these products embody huge amount of natural resources. Thus, acting on eco-efficiency and natural resource saving could enable the achievement of positive effects on the environment and on health at the same time. Obesity, diabetes and many other diseases caused by a bad nutrition have enormous costs in terms of public expenditure. The chemicals used in agriculture are also dangerous for the health as well as more processed and treated foodstuffs containing higher amounts of additives, preservatives and other harmful substances. An agricultural policy focused on the reduction of inputs and on the production of natural and healthy food would contribute to reducing the expenditures for the public health, and preserving the ecosystems. Contemporaneously, spreading a basic knowledge on sustainability and raising public awareness of the benefit of a healthy nutrition would contribute to creating and reinforcing a demand for an organic and low-impact agriculture.

Sustainability requires a reduction of material throughputs in the economies and the optimization of resources productivity (Risku-Norja and Mäenpää, 2007). For this purpose physical inputs have to be evaluated in an unambiguous way and for the whole food chain.

At the same time, the promotion of sustainability needs suitable and readily communicable indicators for guiding consumers and producers' choices, as well as appropriate tools for supporting decision-making.

MIPS has been used for an assessment of the natural resource consumption in agro-food systems. The methodology allowed encompassing different aspects of nutrition's environmental burden, providing a raw estimation of the use of nature due to this activity, both from the supply and demand side.

Concerning the production of food, we observed that the most important phases affecting the sustainability of the supply chain are the agricultural phase in rice and wheat and the processing phase one in orange juices. In the latter case, an eco-efficiency strategy should basically focus on the energy provisions. Fuels and electricity efficiency should be improved and the use of low input energy sources (see e.g. Rohn et al., 2010) could be evaluated in order to reduce the impact. Improving sustainability in agriculture can be obtained through a decreasing of pesticide use in the case of wheat and improving the efficiency in water use in rice cultivation.

Sustainability in food consumption has been evaluated through the calculation of a set of indicators based on material, water and air intensities. The Italian diet was shown to be the least sustainable for the three categories of resources. On the contrary, the Polish diet is the most sustainable.

Results confirmed the high impact of animal products, especially for the material resources. Between them, cattle provide the most resource-intensive meat. Sheep and goats present the same results because we assumed MIPS figures to be equal to the ones of cattle. Butter has also an important impact on material resources while rice is heavily affecting water requirements. Fruits and vegetables have high water and air requirements and tomatoes are the most resource-intensive crop in this group. Crop irrigation and greenhouse infrastructures can explain this result.

Further research could outline how much results would vary when applying more country-specific data, e.g. when considering open field tomato crops in Mediterranean areas instead of greenhouse cultivation in Finland. Moreover the material intensity evaluation should be extended to many other products in order to achieve a broader data basis for the evaluation of natural resource consumption.

On the basis of this first attempt of evaluating sustainability of food production and consumption many developments are possible. Land use could be integrated in the analysis, including the occupation of soil in the natural resource consumption due to nutrition.

In a macroeconomic perspective, the use of resources in agriculture could also be related with economic indicators, in order to trace the trend of the sector in terms of sustainability over time. From a microeconomic point of view, the assessment of material intensity along the supply chain can help implementing eco-efficiency strategies. Further research at this level could investigate the relation between a low application of external inputs in agriculture (using a material intensity approach) and the profitability of these farms, in comparison with others adopting more intensive farming techniques.

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Paper 4

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Resource use of low-income households — Approach for defining a decent lifestyle?

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HIGHLIGHTS

- We studied the material footprints of 18 low-income single households in Finland.
- The natural resource use of the participating households was lower than average.
- 2/3 had a smaller footprint than the "decent minimum" defined by a consumer panel.
- The footprint of all households is higher than ecological sustainability requires.
- We conclude that the material footprint is useful for defining a decent lifestyle.

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ABSTRACT

A decent, or sufficient, lifestyle is largely considered an important objective in terms of a sustainable future. However, there can be strongly varying definitions of what a decent lifestyle means. From a social sustainability point of view, a decent lifestyle can be defined as the minimum level of consumption ensuring an acceptable quality of life. From an ecological sustainability point of view, a decent lifestyle can be defined as a lifestyle that does not exceed the carrying capacity of nature in terms of natural resource use.

The paper presents results of a study on the natural resource use of 18 single households belonging to the lowest income decile in Finland. The yearly "material footprint" of each household was calculated on the basis of the data gathered in a questionnaire and two interviews. The results show that the natural resource use of the participating households was lower than the one of the average consumer. Furthermore, 12 of 18 households had a smaller material footprint than the "decent minimum" reference budget defined by a consumer panel. However, the resource use of all the households and lifestyles studied is still higher than long-term ecological sustainability would require. The paper concludes that the material footprint is a suitable approach for defining and measuring a decent lifestyle and provides valuable information on how to dematerialize societies towards sustainability.

1. Introduction

In social science a decent lifestyle necessary for preventing poverty is often defined in relation to the average consumption level without paying attention to the fact that the present average consumption in western welfare states is ecologically unsustainable (see e.g. Halleröd et al., 2006). On the other side, when environmental scientists argue that the level of natural resource use or CO_2 emissions should be reduced, their message often omits a profound understanding about the implications in people's lifestyles the changes would bring (see also Druckman and Jackson, 2010). Therefore, in this study, we will apply a methodology where both aspects of decent life style are concerned.

Environmental research about a sustainable future evidently proves that the present level of consumption in Western countries is ecologically unsustainable (e.g. Schmidt-Bleek, 2009; Bringezu, 2009; Ewing et al., 2010). An ecologically sustainable lifestyle would require natural resources without exceeding the long-term carrying capacity of nature. In this paper, we call this sustainable level of natural resource use as an "ecological maximum".

From a social sustainability perspective, this "ecological maximum" level of resource use still needs to be sufficient for ensuring that people have possibilities to achieve a decent lifestyle. In this paper, "decent minimum" refers to the sufficient level of resources to fulfil needs, participate in society and ensure human dignity. Decent minimum is

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"a standard that social policy should aspire for everyone to meet" (Bradshaw et al., 2008).

When considering both the ecological and socio-economical aspects of decent lifestyle, it is obvious that the environmental policies aiming to cut the use of natural resources should not lead to an increasing deprivation or a diminishing quality of life: an ecological maximum and socially decent minimum have to meet each others' requirements. Hence, we need to clarify what are the products and services included into a decent minimum and how they meet the limitations of an ecological maximum in the present society.

The purpose of this paper is to evaluate the use of the material footprint approach for defining what a decent lifestyle can mean and to provide some ideas on how to achieve it. Therefore, the paper presents results of a study on the natural resource use of 18 single households in Southern Finland. Data was gathered in a questionnaire and two interviews. All households were living on disability pension or the minimum level of unemployment allowance and thus they belonged to the lowest income decile in Finland.

Low-income households are an especially interesting group to study when trying to achieve a more comprehensive understanding about the decent minimum and the ecological maximum. Previous studies show that there is a strong connection between the income level and the use of natural resources: the level of natural resource use can be expected to rise along with the income (e.g. Tukker et al., 2010; Kotakorpi et al., 2008; Kleinhückelkotten, 2005). It can be assumed that low-income households use relatively low amount of natural resources, whereas wealthy consumers require more natural resources. This, however, challenges the common assumption that only wealthy people can afford to "be green" and protect the environment, for instance by buying organic products or purchasing new, energy-efficient cars (see e.g. Haberl et al., 2011).

In the light of the aforementioned studies, low-income households might be more "environment-friendly". However, people living on the minimum level of social security often lack the basic necessities or consumption habits that are regarded as a part of the socially acceptable lifestyle in the present society (Moisio et al., 2011). Thus, both aspects of sustainability have to be considered.

2. The two dimensions of decent lifestyles

2.1. Socio-economical approach

In the Finnish welfare state everyone has a right for a minimum income in case of a social risk like old age, sickness, unemployment or disability. The minimum level of social benefit should guarantee a decent and dignified lifestyle. People living on minimum income ought to have not only sufficient means for fulfilling basic needs (such as having a shelter or adequate nutrition) but also means for participation (such as having a phone, recreational activities and other forms of social participation) (Forma et al., 1999).

A decent lifestyle in socio-economical terms is specified on the basis of the quality, quantity, and price of the goods and services required for a decent life. According to Borgeraas (1987), the decent life should be sufficient to meet one's physiological, psychological and social needs and enable full participation in society. It comprises goods and services needed in everyday life so that people can 'get by' and their life goes smoothly while feeling oneself as part of the surrounding society. A decent minimum describes a consumption level regarded necessary for all members of society in order to live a decent life but excludes commodities that are regarded aspirational, not necessary (Bradshaw et al., 2008).

In previous studies, the socio-economical decent minimum has been studied, for instance, by inquiring what consumption goods and social opportunities are regarded necessary for all members of a society. One approach for this is a reference budget (or budget standard). In Finland, the reference budgets were compiled by using consumer panel ($n = 53$) to define which products and services are regarded necessary and parts of a decent lifestyle. The budget contains the following products and activity groups: food, clothing and footwear, household appliances, entertainment electronics, ICT (information and communication technology), health and personal care, leisure, participation, transport, and housing (Lehtinen et al., 2011). These same categories were taken into consideration in the questionnaires of this study.

2.2. Ecological approach

If sustainability is to become a reality, a huge increase in absolute resource efficiency is required. Dematerialisation needs to take place, as proposed in the discussion on factor 10 as the magnitude required for decreasing resource use in Western industrialised countries (Schmidt-Bleek, 1993; World Resources Forum, 2009; Lettenmeier et al., 2009). According to Bringezu (2009) an acceptable level of total material consumption (TMC, which means the consumption-based use of material resources in an economy, i.e. the total material requirement of an economy minus the export-based resource use) would be approximately 6 t of abiotic materials per capita in a year. In addition, the present use of approximately 4 t of biotic resources in Europe could probably be maintained, whereas erosion should be reduced by a factor of 10 to 15 from the present 3 t per capita (Bringezu, 2009).

Thus, a sustainable level of TMC would amount to a maximum of 10 t per capita in a year, including household consumption as well as public consumption and capital formation. This means a reduction by a factor of 3 to 8.5 from the present TMC level of western industrialised countries according to Bringezu et al. (2009). In Finland, the present average resource use is at least 40 t (Kotakorpi et al., 2008). The sustainable level would, thus, mean a reduction of natural resource use by a factor of 6 to 8 depending on the level of resource use from public consumption and capital formation that could be considered sustainable.

2.3. Methodology

In this study, we calculated the natural resource use of households, the "material footprints" by using a simplified approach on the basis of the previous Finnish study on household level, conducted by Kotakorpi et al. (2008). This is due to two reasons. First, that study used the MIPS concept, which measures the natural resource use considering the whole life cycle of products and activities and including direct resource use (used extraction) as well as indirect resource use (unused extraction). The MIPS-method has proved to function as a holistic, useful, reliable and understandable measure for natural resource use. Thus, it serves also as a central indicator for ecological sustainability (see Schmidt-Bleek, 2009; Giljum et al., 2011; Aachener Stiftung Kathy Beys, 2010; Rohn et al., 2010). Secondly, the previous study of Kotakorpi et al. (2008) provides an interesting and useful basis for comparing the resource use of the households participating in this study to the resource use of 27 different households in that study, as well as an average Finn based on statistical data. To compare the results with the "decent minimum" we calculated the material footprint of the decent minimum reference budgets, and measured the material footprint on the basis of the yearly consumption of a single household.

The resource use is given as material footprint per capita per year in mass units of TMR (total material requirement, i.e. the sum of abiotic and biotic resource use plus the top soil erosion in agriculture and forestry, see e.g. Ritthoff et al., 2002). The material footprint of the participating low-income households was calculated on the basis of two interviews of each single household and a consumption and lifestyle questionnaire the participants filled in during an approximately two-week period between the interviews.

Material footprints are calculated by multiplying the direct input with a material intensity factor specific for each input (see Lettenmeier et al., 2009). Most of the material intensity factors used for calculating the material footprints were taken from Kotakorpi et al.

(2008), Lähteenoja et al. (2006) and Lettenmeier et al. (2009). Some coefficients, e.g. for health care and hairdressing, were calculated during this study.

3. Results of the study

The material footprint of the participating single households ranges between 7.4 and 35.4 t per year. 13 of the 18 households studied have a material footprint between 10 and 20 t. According to the consumption components displayed, housing has the greatest share of the total, ranging between 1.3 and 13 t. Housing is followed by nutrition (ranging between 2.1 and 5.7 t), everyday mobility and tourism.

Fig. 1 provides a summary of the results and compares them to the average Finn according to Kotakorpi et al. (2008) as well as to the material footprint of the minimum decent reference budget of a single woman below 45 years of age according to Lehtinen et al. (2011).

4. Discussion of the results of the study

Half of the participants in this study have a material footprint of max. 16 t. The material footprint of all households studied here is definitely closer to the sustainable level of resource use than with most of the households studied by Kotakorpi et al. (2008) or than with the average Finn based on statistical data (ibid.). Kotakorpi et al. (2008) reported four households with a material footprint of more than 60 t per person per year out of the variety of 27 households studied. For these households, a sustainable resource use on the basis of Bringezu (2009) would require a reduction by a factor of 10 and more, whereas in this study most of the households are only factor 2 to 3 above the sustainable level described above.

In this study, six households exceed the material footprint based on the minimum decent reference budget (see Fig. 1). Two thirds of the participating households have material footprints below the decent minimum level of consumption defined in the reference budgets.

When looking at the different consumption components studied, differences to the households in Kotakorpi et al. (2008) are visible. Especially the relevance of everyday mobility and tourism is much smaller with the households of this study. Also for housing and nutrition less resources are used but the difference to the average of Kotakorpi et al. (2008) is smaller. Nevertheless, only the highest values for housing were in the same magnitude as the typical values in Kotakorpi et al. (2008).

These results are confirmed when having an insight into the different consumption components. In each of the consumption components of everyday mobility, tourism and leisure time activities, there are households with a material footprint of zero. This means that these households are not travelling, do not have special leisure activities and/or only walk during their daily activities. This is an understandable situation for households being outside the labour market and having a very low income.

Most of the households have a material footprint for housing of at least 4 t. Only one household has a material footprint of 1.3 t for housing, because the person was homeless and staying with friends while the investigation was done. In this case, we considered only some energy consumption and a storage space for home equipment in the material footprint calculations.

With nutrition, the lowest material footprint belonged to the participant who was vegan. The material footprints for nutrition that resulted in this study can be seen as maximum values. This is due to the time restraints of the study that did not allow quantifying the effect of eating food that might otherwise have become waste, as many participants did.

The consumption of the households with the highest material footprints was not solely based on living on the minimum level of social benefits provided by the Finnish welfare state. Instead, for these few households the higher resource use for travelling and other special activities was possible because relatives or other persons were supporting them financially. This supports the results of previous studies on the connection between income level and natural resource use (e.g. Tukker et al., 2010; Kotakorpi et al., 2008, Kleinhückelkotten, 2005).

5. Conclusions

The overall results presented above imply the following preliminary conclusions in terms of the sustainable maximum of natural resource use.

Housing is the consumption component with the greatest share in resource use with the low-income households studied. This is due to the fact that housing always needs some infrastructure and that single households tend to need more living space per capita than bigger households — leading to more sizeable environmental impacts

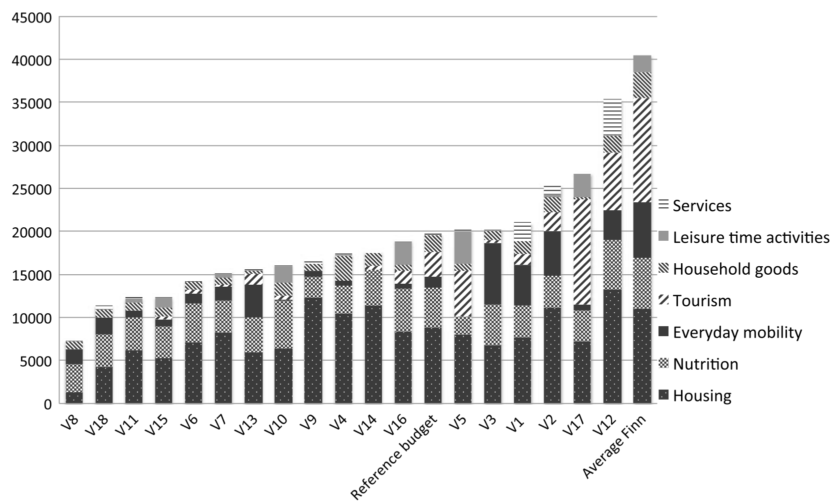

Fig. 1. Material footprint in kg/cap./a of 18 single low-income households, an average Finn and a decent minimum reference budget.

(Tukker et al., 2010). A reduction in living space per capita, more resource-efficient and longer-lasting houses and a decrease in energy consumption could reduce the material footprint of housing.

Nutrition is a basic need that cannot be ever reduced. However, the material footprints for nutrition of the participating households show that material footprints of 2 t or less for nutrition are possible already today. Thus, a sustainable level of resource use for nutrition seems well achievable on a general level when taking into consideration potential future improvements in technology and diet.

The material footprint for a decent minimum based on the decent minimum reference budget is approximately 20 t per year. The households studied show that in the present Finnish society people living on minimum income do not always reach this level. Their material footprint varies, being in most cases roughly between 15 and 20 t per person in a year. With this level they are able to have decent housing, adequate nutrition, means for participation and possibilities for recreational activities as well as some basic services. If the value was below this amount, there would possibly occur some deprivation, like being homeless or eating only leftover food.

Most of the 18 households studied are still using at least factor 2 more resources than the long-term sustainable level, the ecological maximum, would require. On the one hand, this means that from a global sustainability perspective even low-income households in Finland are using relatively high amounts of resources, despite of the fact that they are far below the average households. On the other hand, this is a promising result: by ensuring the basic needs and a decent lifestyle it is possible to reach factor 2, which is on the right direction towards a sustainable future. As low-income households hardly can reduce their consumption anymore, the findings mean that a sustainable level of resource use cannot be achieved solely by choices, decisions and activities of private households but states and companies must improve the conditions and technologies enabling households to consume in a more sustainable way.

Concerning the use of the material footprint for defining and conceptualizing a decent lifestyle we can state the following. The material footprint as used in the study described has proven to be a useful tool for assessing the sustainability of lifestyles. It is suitable for assessing the level of natural resource use as well as for illustrating the differences between the different households and for explaining the reasons and backgrounds for these differences. Hence, the material footprint can, and should, be used for further research on how to achieve sustainable lifestyles in terms of both ecological sustainability and social sustainability.

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Paper 5

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Material Footprint of a Sustainable Nutrition System in 2050 – Need for Dynamic Innovations in Production, Consumption and Politics

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Abstract

The field of nutrition is facing numerous social, ecological and economic challenges in the coming decades. The food industry belongs to the most significant economic sectors worldwide and the increasing population of 9 billion in 2050 will cause a growing demand on food. So far, changing lifestyles, especially the global rising consumption of meat and dairy products are increasing environmental damage. Moreover our health and wellbeing are the direct result of healthy or unhealthy nourishment and influence follow-up indicators like individual and public health, the expense of the health sector and work productivity.

The material footprint is a tool to measure and optimize the resource consumption of both products and their ingredients and the production processes along the whole value chain. It covers the whole life cycle of the products, from the extraction of raw materials to the processing industry, distribution, consumption, recycling, and disposal. In order to decrease resource consumption to a level in line with the planetary boundaries, the material footprint of household consumption should achieve a level of six to eight tonnes per capita in a year by 2050. This means a reduction in natural resource consumption by a factor of 5 to 10 in Western European countries. In order to ensure a decent lifestyle for all people in 2050, also the material footprint of nutrition has to be reduced significantly by 2050.

The paper shows the relevance and role of nutrition in the overall material footprint of households on the basis of existing studies on the overall resource consumption caused by household consumption. Quantified meal and diet examples are given. It also discusses the causes of food waste and raises the question how a reduction of food waste is possible and can help decreasing the resource consumption in the food sector.

On the basis of this, requirements are developed nutrition has to meet in 2050 in order to achieve a sustainable level of natural resource use. E.g. by eating 600 kg of food with an average material footprint of 5 kg/kg a food-related resource consumption level of three tonnes per capita in a year could be achieved. The paper discusses options to achieve these requirements as well as dynamics and innovations that are needed from the perspective of production, consumption and politics. It discusses practical implications of a sustainable resource use in nutrition and gives recommendations on how to proceed towards it. Resource efficiency and waste prevention potentials in food chain as well as other requirements for a sustainable level of resource use in nutrition are discussed.

Keywords: *foodstuff, nutrition, value-chain management, resource-efficiency, material footprint, natural resource use, factor 10, sustainability*

1 Introduction

1.1 The challenge of sustainable resource use

The field of nutrition and the food industry, on of the most significant economic sectors worldwide, are facing numerous social, ecological and economic challenges nowadays and in the coming decades. The increasing population of estimated 9 billion in 2050 will cause a growing demand on food although arable land is tending to decrease and land use for competing, e.g. energy crops is increasing (Foresight 2011). This affects rising prices and social problems related to these. In addition, increasing prosperity and changing lifestyles, especially the global rising consumption of meat and dairy products, are even increasing the demand for crop production, thus fostering environmental damage like erosion, soil degradation, resource depletion, biodiversity reduction, climate change, etc. (Foresight 2011). More prosperous nutrition habits in industrialised and industrialising countries can result in even unhealthy nourishment and influence follow-up indicators like individual and public health, the expense of the health sector and last but not least work productivity.

It is indisputable that there is a need for the radical dematerialisation of our Western societies in order to achieve an ecologically and socially sustainable resource use on global level (Schmidt-Bleek 1993, Schmidt-Bleek 2009). Global resource use has to be adapted to the environmental space available (Moffat 1996). This means that resource use should happen within the limit provided by one planet in the long term and resources should be shared among the world population in a way that ensures a sufficient life for all people. The food sector is responsible for a significant share of the resource consumption of a society, in Europe the food sector's (including the value chains of food and beverage) share of greenhouse gas emissions is about 17 % and its resource consumption amounts to appr. 28% (KOM(2011) 571). Due to its share, and even more due to the fact that the consumption of food cannot be stopped completely, it is necessary to consider this sector intensively. As the present resource consumption of the food sector cannot be taken for granted in terms of a sustainable future, a sustainable level of resource use for nutrition has to be defined.

Table 1.
Worldwide development of calorie consumption expected until 2030.
Source: Pricewaterhouse Coopers 2011

Region	**Annual** GDP growth rate per capita (in %)		**Growth** 1999-2030 (in %)		
	1997/1999-2015	2015-2030	population	consumption of calories per capita	total calorie consumption
world	**2,3**	**2,9**	**40,2**	**8,8**	**52,3**
developing countries	**3,7**	**4,4**	**50,2**	**11,2**	**67,0**
• sub-Saharan Africa	1,8	2,3	114,1	15,7	147,8
• Middle East and North Africa	1,8	2,4	72,7	5,5	82,1
• Latin America and the Caribbean	2,8	3,5	44,0	11,2	60,1
• South Asia	3,9	4,3	53,5	20,7	85,2
• East Asia	5,3	5,8	25,2	9,2	36,7
developed countries	**2,6**	**2,8**	**9,8**	**3,6**	**13,6**
emerging countries	**4,0**	**4,3**	**-7,7**	**9,4**	**1,0**

The worldwide demand for resources is mainly governed by world population and the level of prosperity. The latter has a great effect on manners of nutrition, housing and mobility and thus determines the consumption of resources per capita. Population as well as economic performance reside on a worldwide long-term path of growth. Tab. 1 shows the change that consumption patterns undergo alongside the acquisition of wealth. Taking into account the prognostics regarding the rising calorie consumption and the prospective change of consumption patterns, the explosiveness of the resource-controversy of nutrition becomes evident.

1.2 The material footprint of households

A variety of studies (e.g. Acosta-Fernández 2007, ETC/SCP 2011, Seppälä et al. 2011, Tukker et al. 2006) have shown that the food sector belongs, together with housing and mobility, to the three most relevant consumption components of modern societies in terms of natural resource use and other environmental impacts. Depending on the indicator used, the share of nutrition in the total resource use and environmental impacts of consumption ranges around one third to one fifth of the total impact of consumption. This evidence from mostly macro level studies has been confirmed by studies on micro level that have assessed the material footprint of the consumption of specific households.

Kotakorpi et al. (2008) report a share of appr. 15 % on average in a study on the material footprint of 27 different Finnish households. The 27 different households studied by Kotakorpi et al. (2008) consumed between 2.6 and 7.7 tonnes of material resources per person in a year for foodstuffs (see Fig. 1). The up to a factor 3 difference in the material footprints of the different households can be seen as a relatively small difference as the differences rise to a factor of 85 in the field of mobility.

Lettenmeier et al. (2011) studied 18 Finnish low-income single households. The nutrition of these households causes quite similar though slightly smaller material footprints (from 2.1 to 5.7 tonnes per person in a year) as the households studied by Kotakorpi et al. (2008). However, the relevance of nutrition in the total material footprint of the low-income households is higher as their total consumption is below average.

Mancini et al. (2011) assessed the material footprint of average diets in 13 European countries and the EU on the basis of data provided by Eurostat. These average material footprints range between 4.3 and 7.0 tonnes per person in a year. This is in the same magnitude as the material footprints of the specific households described above and shows that there are also notable differences between different countries. For countries outside Europe no comparable information on the material footprint of nutrition could be found so far.

In order to decrease resource consumption to a level in line with the planetary boundaries, the material footprint of household consumption should achieve a level of six to eight tonnes per capita in a year by 2050[1]. As the nutrition-related material footprint of

[1] A sustainable level for the material footprint of household consumption has been proposed by Lettenmeier et al. (2011) on the basis of the considerations of Bringezu (2009) on a sustainable level of Total Material Consumption for European economies. Total Material Consumption (TMC) means the total amount of life-cycle-wide abiotic and biotic resources consumption as well as soil erosion in agriculture and forestry of an economy. This means the same resources as the material footprint used in this paper (see section 2.1). TMC includes the domestic consumption and its global implications in terms of material flows but excludes export-related material flows as these are part of the TMC of the countries consuming the exported products. According to Bringezu (2009), a consumption of 6 tons of abiotic resources per each inhabitant of the world, 4 tons of biotic resources per capita for Europe and 0,2-0,3 tons of erosion could be considered a sustainable TMC. As a part of the TMC is used for public consumption (e.g. education, health care, public administration) and

households (see Fig. 1) and countries already may reach a level of 6-8 tonnes, also the material footprint of nutrition has to be reduced significantly by 2050 in order to ensure a decent lifestyle for all people in 2050 – despite of the fact that nutrition will always play a certain role in the resource use of households as it is the probably most basic need of human beings.

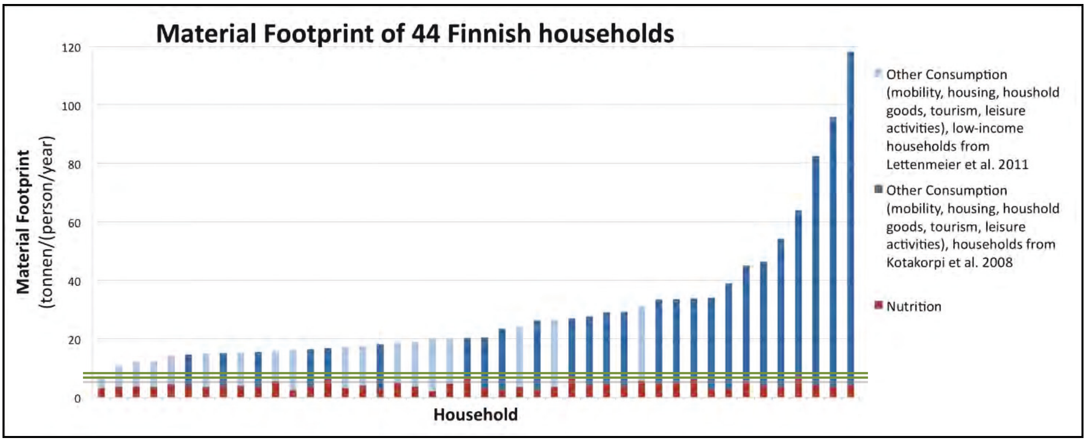

Figure 1. The share of nutrition in the material footprint of 44 different Finnish households and in relation to the sustainable material footprint of 6-8 tonnes (green lines).

1.3 The problem of food waste

The fact that 25-50% of foodstuffs are lost or discarded on their way from field to fork is increasingly critically observed by the public. The higher the economic growth of a country, the further the occurrence of food waste is pushed back within the value chain. In poorer countries, crop loss, storage and transport are the main reasons for food loss. In richer countries, the consumer is the one discarding most of the food (Gustavsson et al. 2011). Generally, it is possible to differentiate between loss of goods and destruction of goods. A loss of goods takes place, when sensitive raw ingredients have to be taken out of the manufacturing process due to technical issues, mistakes in handling or planning or spoilage. These have to be distinguished from by-products that arise during industrial food production (more definitions see European Commission 2010). Destruction of goods means the practice of destroying foodstuffs and meals that were meant to be consumed by humans, but are not called for, discarded due to oversized portions or rejected because of legal requirements. Both lost and destroyed food may partly be put to use in the feed industry or for generation of energy in biogas plants.

A closer look at the industry shows two contradictory facets that have to be considered when talking about loss and destruction of goods. On the one hand, food industry and retail constantly work on the reduction of the loss of goods. Focus is put on best-before or expiration date management, waste management and process enhancement on the individual value-added levels. On the other hand, in industry it is common practice to accept

companies' capital formation, Lettenmeier et al. (2011) estimate that households could probably consume 6-8 tons per capita per year. The role and share of public services in the context of sustainable resource use in total has not yet been addressed sufficiently. This is one reason for only defining a corridor of 6-8 tons instead of one exact value.

destruction of large amounts of foodstuffs for marketing reasons balancing between the availability of goods for an excellent product presentation with a high product range and depth and the amount of waste accompanied (Teitscheid 2012). For example, the rate of returns for bread and baked goods range from 10 (EHI 2011) to 20 % and for vegetables the number of destruction along the whole value chain is even higher.

Even though consumers consider themselves responsible for avoiding food waste, they also have a considerable part in the destruction of goods. Surveys conducted by Forsa (2011) and Cofresco (2011) confirm the trends that have also been observed in other industrial societies through long-term studies: Approximately 21 % of foodstuffs in German households are discarded, adding up to a value of nearly 25 billion Euros in expenses for food, or 80 kg of food per person in a year.

A Forsa poll initiated by the German Federal Ministry of Food Agriculture and Consumer Protection (BMELV) delivers initial findings on waste-behavior of German consumers: “About 84 % of Germans waste food because the expiration date has been reached, for many people a sign, that the goods have turned bad. 19 % also find exceedingly big packaging sizes to be their main reason. 16% of citizens throw away foodstuffs because they do not like the taste. And about one quarter states that they have bought too much in the first place. In the survey, 58 % declare that their household disposes of food on a regular basis. 69 % of the citizens have a bad conscience when discarding foodstuffs” (Lohmer 2011). The Cofresco study (2011) confirms these numbers. The research from Teitscheid et al. (2012) confirmed the causes of food waste in households finding that food is wasted because it has been forgotten, it has been stored wrong or it was not tasty.

Smil (2004) takes his examination of food waste to the next level and even takes into consideration the overnutrition, meaning the growing gap between food production and consumption. According to FAO’s food balance sheets all high-income countries now have available at retail level more than 3000 kcal of food per day per capita, with Europe leading the list. The entire continent averages nearly 3300 kcal/day and the EU mean was about 3500 kcal/day in the year 2000 (FAO 2002). The US rate is about 3600 kcal/day and the Canadian one about 3300 kcal/day. In contrast, aging population (metabolic requirements decline with age) and the increasingly sedentary way of urban life mean that the actual daily food requirements range mostly between 1500–2000 kcal/capita for adult females and 2000–2600 kcal/capita for adult males, and weighted means for entire populations are rarely above 2000 kcal/person.

This means that per capita gaps between average availability and actual consumption are now greater than 1000 kcal/day in every high-income country, with maxima approaching, or even surpassing, 1500 kcal/day. In order to account for inevitable food losses and to provide an adequate safety margin the average per capita food supply should be 30% above the needed mean of 2000 kcal/capita, averaging no more than about 2600 kcal/capita. The difference of 700 kcal/capita between this rate and the current EU mean could supply another 350 million people with the meaty and fatty diet that now prevails in affluent countries, or easily twice as many people consuming largely vegetarian but nutritionally adequate Asian diet Smil (2004).

1.4 Consumers longings

Consumers have started to search for sustainable lifestyles, even though it is not yet visible in actual consumption patterns. Surveys on the needs and desires of consumers in Germany and other European countries show the same picture: the consumption society shows its downsides. The possession of material goods is increasingly perceived as a burden, material consumption is no longer a guarantor for happiness, people feel threatened by the globalization and estranged from what they buy. Especially for foodstuffs values like homeland and naturalness move more and more into the foreground. Overall, the rich societies in Europe are on the road to a so called „Sehnsuchts-Konsumgesellschaft“ (consumer society of longing) (Lüdi/Hauser 2010).

The Gottlieb Duttweiler Institut in Zürich describes this development with the terms “reconnection” (to an idealized origin), “age of less” (less is more, restraint is no longer anti-pleasure, but relief) and “back to basics”. Applied to the food sector, this means: people yearn for regional and natural foodstuffs that they can prepare together with friends and consume in pleasant company. Unlike the politically motivated movement of restraint in the 1980’s, self-fulfilment is today’s main incentive (see Lüdi/Hauser 2010). Abstaining from material goods and moving towards enjoyment and aesthetics relieves people and helps them to do themselves something good. Today’s performance society, or meritocracy, with its high demands on daily life still forces people to compromise (see Falser/Dahlmann 2011), but desires show a different side (of society). This development is a chance for a change towards a sustainable lifestyle. It is yet unclear, in which way this development will affect consumer behaviour and supplies. During this process of transformation, consumers and producers need assistance in defining what makes a sustainable lifestyle.

For both producers and consumers, it is not easy to navigate in the prevailing jungle of different aspects and indicators of sustainability. In this paper, we use the material footprint, which means the consumption of natural resources during the whole value chain or life-cycle (see Lettenmeier et al. 2009), as the indicator for the ecological aspect of sustainability of nutrition.

2 Materials and methods used

2.1 Material footprint and resource efficiency potential analysis

The material footprint is a tool to measure and optimize the resource consumption of both products and their ingredients and the production processes along the whole value chain (Lettenmeier et al. 2009). It covers the whole life cycle of the products, from the extraction of raw materials to the processing industry, distribution, consumption, recycling, and disposal. In this paper the term material footprint is used as the sum of the consumption of abiotic and biotic resources plus the erosion in agriculture and forestry.

The material footprint is based on the MIPS concept (material input per unit of service, see Schmidt-Bleek 1993; 2009; Ritthoff et al. 2002). It provides a comprehensive and understandable tool to reduce different kind of present and future environmental challenges instead of or in addition to concentrating on specific problems. The material footprint thus serves as a tool to comprehensively direct activities to keep within “planet boundaries” as described e.g. by Rockström et al. (2009).

In this paper, the material footprint is used for comparing different foodstuffs and meals to each other on the basis of earlier studies. In addition, the material footprints of the following four different diets either existing or suggested are calculated in order to assess the resource efficiency potential and the level of sustainable resource use for nutrition:

- The average diet of a Finn in 2005 (directly from Lähteenoja et al. 2007).
- A diet developed from the average Finn 2005 based on the following assumptions: reduction of both amound and material-intensity of food by 10 % and dropping meat consumption from 79 to 14 kg per person in a year mainly by exchanging it with legumes like soya. These assumptions are based on experiences from households' material footprint studies (Kauppinen et al. 2008, Lähteenoja et al. 2008, Lettenmeier et al. 2011, Mancini et al. 2011), experiences from resource efficiency potential analyses (e.g. Rohn et al. 2010) and results of the food waste survey described in section 2.2.
- The Livewell UK 2020 diet proposed by Macdiarmid et al. (2011). The WWF UK published this report in order to provide guidance towards a more sustainable nutrition, to show how official diet recommendations should be developed to enable people to implement more sustainable diets and to discuss how to proceed to a 70 % reduction in carbon footprint of diets by 2050. It suggests a diet with a 25 % decrease in carbon footprint in 2020.
- The average Indian diet in 2007 on the basis of FAOSTAT (2011).

The material footprint values of foodstuffs, meals and diets calculated or presented here include only the natural resource consumption from raw-material extraction / production up to the point of sale, and thus do not include the material footprints consumers can influencing directly when travelling to the shop, storing and preparing meals at home and disposing off foodstuffs. This is in line with the studies of Kotakorpi et al. (2008) and Lettenmeier et al. (2011). Both studies allocate cooking and storing energy to housing, cooking and storing devices to household goods and shopping trips to mobility instead of nutrition in order to provide a comprehensive picture of the different consumption components. Cooking and storing devices cause relatively small material footprints when related to the material footprint of nutrition in general, the same is the case with disposal (Kotakorpi et al. 2008). A similar statement can be made for cooking and storing energy on the basis of the studies of Kotakorpi et al. (2008) and Lettenmeier et al. (2011). However, this cannot necessarily be generalized to any situation and any food product because both studies have been done in Finland and the material intensity of Finnish electricity is relatively low (appr. factor 3 to EU average and factor 5 to German electricity, see Kotakorpi et al. 2008, Salzer 2008 and Wiesen et al. 2010). The transport intensity of shopping can be even more relevant in terms of material footprint, expecially when cars are used for buying relatively small amounts of food (see Eberhard et al. 2010).

The resource efficiency potential assessment (REPA) compares the material footprint of a resource efficient option (e.g. product or diet) to that of the current status option (Rohn et al. 2012). Resource efficiency potentials can be identified either on micro level, regarding the value chain, or on macro level, addressing the potential to reduce resource consumption on a national level. REPA can be used for estimating the magnitude of a sustainable level of resource use for nutrition. Section 3.1 gives several examples of the resource potentials of diets. In section 4, the resource efficiency potential of nutrition is given as a suggestion for a sustainable material footprint level as a conclusion of the results given in section 3.

2.2 Identifying causes and effects of food waste

For action plans against food waste it is necessary to know the causes of loss or destruction of goods. The literature shows different reasons for food waste in the EU for specific areas: manufacturing, wholesale and retail, food service and restaurants (including hospitality industry, schools, hospitals) and households. Reasons for producing food waste are spread in the household sector and the food service sector and involve a range of issues including portion size, labelling, packaging, storage, awareness, preferences, planning and socio-economic factors. Households produce the largest fraction of EU food waste among the four sectors considered, at about 42 % of the total or an average of about 76 kg per capita. In the wholesale/retail and manufacturing sectors logistical and technical issues are most important (European Commission 2010).

For regional actions the Ministry for Environment in North Rhine-Westphalia, Germany has funded a study, which was developed in the working committee “the new valuation of food”. The study includes an extensive literature research of food waste with international comparison. The survey is collecting data for the German state of North Rhine-Westphalia through qualitative research along the value chain to identify causes of food waste, approach within households to spot discarding food and leftover foodstuffs, valuation of food and possibilities for action and identification of food waste sources and ways of recycling.

The project analyses the link between causes and effects of “food waste” along the supply chain and identifies key objectives and stakeholders in a workshop with experts focusing on the development of options for political action to decrease food waste. In a second workshop with the participants of the working committee “the new valuation of food” options for action will be emphasized and their enforceability and acceptance will be requested.

To identify the causes and effects of food waste along the value chain (Fig. 2), the Institute for Sustainable Nutrition and Food Production (iSuN) at the University of Applied Sciences Münster used a qualitative approach examining the question: “What kind of food waste is occurring on which level of the value chain and for what reason?” Therefore 44 interviews with experts have been carried out inquiring food waste for the product groups: bread and bakery, vegetables, milk and milk products and meat and sausages along the value chain from the agriculture to retail.

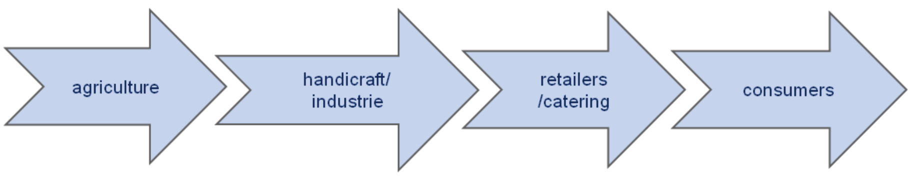

Figure 2. The supply chain of food

Qualitative content analysis is used for preparing evaluating and interpreting data within the team of researchers focusing on the development of actions to reduce food waste. This qualitative approach is looking at different products along the value chain but not studying the content of garbage bins to identify properly matching actions for the region. Thus, a vulnerability of the approach is that the statements of the interviews cannot be proved and are based on the information given by the respondents (Teitscheid et al. 2012).

3 Results

3.1 Resource efficiency potentials in diets

Material intensity data on numerous foodstuffs have been published, for instance, by Kauppinen et al. (2008), Lettenmeier et al. (2009) and Mancini et al. (2011). Foodstuffs can be compared to each other on the basis of their material intensity. Fig. 3 shows the material intensities (material footprint in kg of material resources per kg of the specific foodstuff) of different protein sources on the basis of Kauppinen et al. (2008). There are differences up to a factor of 10 depending on the source of protein. Beef and cheese are especially resource-intensive whereas soya requires relatively few resources when utilized directly as food. In general, meat tends to be resource-intensive but relatively high material footprints have been reported also e.g. for vegetables grown in greenhouses all year round (see Kauppinen et al. 2008, Eberhard et al. 2010).

Kotakorpi et al. (2008) have calculated the material footprints for a number of meals on the basis of material footprints of single foodstuffs (as shown in Fig. 3). Tab. 2 gives examples of the material intensities (material footprint in kg of material resources per kg of the specific meal) of meals. Also in these examples meals containing relatively high amounts of meat (e.g. mutton casserole, chilli con carne, double burger) tend to have high material footprints. There are still differences up to a factor of 8 between comparable meals (e.g. chicken casserole and mutton casserole) but other ingredients can reduce this difference (e.g. lasagne and vegetarian lasagne both contain pasta, tomato and cheese).

When the material footprints of single foodstuffs (like in Fig. 3) and meals (like in Tab. 2) are counted up to diets, Kotakorpi et al. (2008) report a level of 2.6 to 7.7 tonnes per capita per year with an average of 4.4 tonnes for the 27 different Finnish households studied. Five out of these 27 households had a vegetarian diet. Two of these vegetarian households are at the lower end of the range (3 tn.), two at average level (4.5 tn.) and one above average (5.6 tn.). Lettenmeier et al. (2011) report a level of 2.1 to 5.7 tonnes per capita per year with an average of 3.9 tonnes for 18 low-income single households. Only one of these households didn’t eat meat and was vegan. This household had a smaller material footprint for nutrition than all other households (2.1 tn.). Hence, a vegetarian lifestyle does not necessarily mean an especially low material footprint but the amounts of dairy products as well as fruits and vegetables consumed are also relevant.

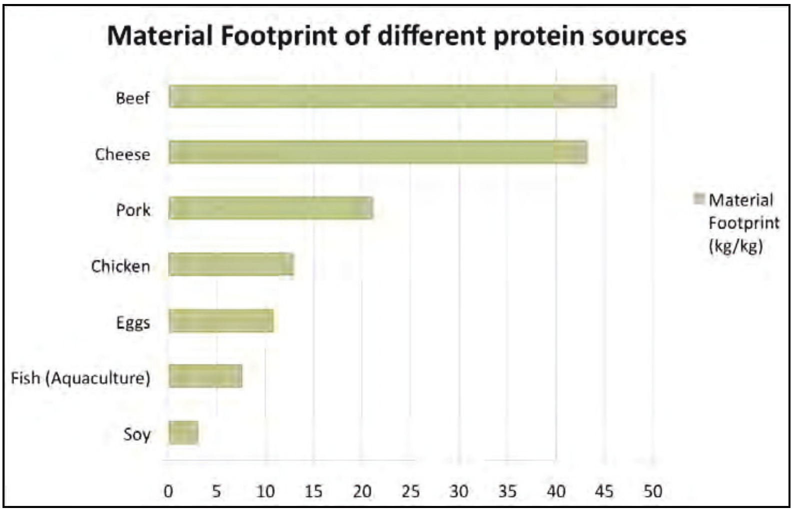

Figure 3. Material footprint of different foodstuffs used as protein source on the basis of Kauppinen et al. (2008).

Table 2.
Material footprint of different meals on the basis of Kotakorpi et al. (2008)

Meal	Material footprint (kg/kg)
Chicken casserole	7.5
Mutton casserole	59.2
Rainbow trout casserole	9.4
Chicken pasta	10.3
Chili con carne	24.8
Wild mushroom pasta	6.2
Patties of root vegetables	5.0
Meatballs	9.8
Lasagne	15.4
Vegetarian lasagne	9.6
Double burger	28.8
Veggie burger	6.5

Mancini et al. (2011) report a level of 4.3 (Poland) to 7.0 (Greece) tonnes per capita in a year for 18 foodstuffs consumed in 13 European countries and the EU. There are notable differences in the amount as well as in the material intensity of the foodstuffs consumed. The amounts vary from 460 (Germany) to 730 (Greece) kg/cap./a while the average material intensities vary from 8.4 (Poland) to 11.4 (Germany) kg/kg.

As the previous examples show, for the consideration of a sustainable material footprint level for nutrition, both the amount and the material intensity of the food consumed are relevant.

Fig 4. shows the material footprint of four different diets. The diet “Improved FIN 2005” was proposed and its material footprint calculated for this paper. Also the material footprints of “Livewell UK 2020” and “India 2007” were calculated for this paper.

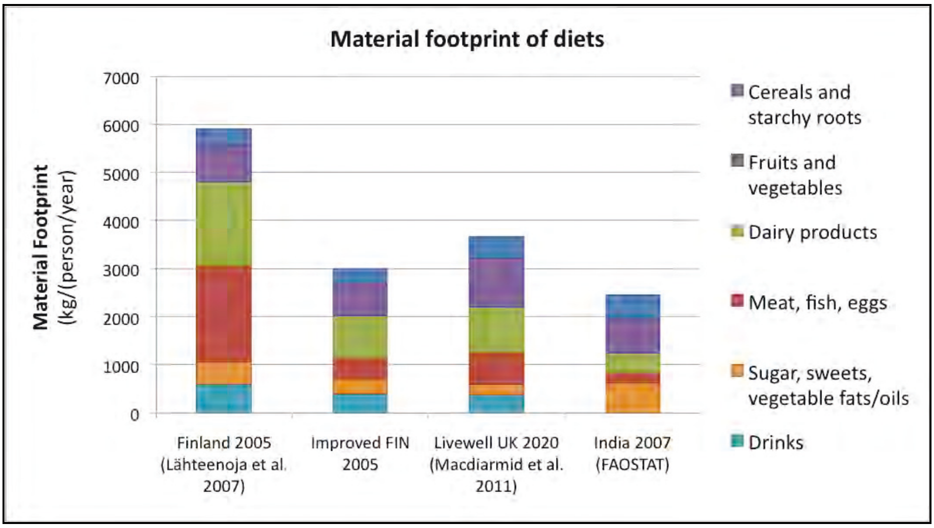

Figure 4. Material footprint of four different diets.

3.2 Resource efficiency in the food chain: potentials and limitations

Along the whole value chain for food, considerable possibilities exist for reducing the consumption of resources on different levels (see Teitscheid et al. 2012). Insufficient planning and a lack of communication often lead to food waste and losses that can be prevented through a consistent supply chain management.

However, there are boundaries that have to be considered: Food industry is the most efficient when natural raw materials used meet clearly defined standards with the lowest rate of deviations possible. To create such commodities, agriculture as the precursor to industrial food production aims to create the required standards through breeding and keeping conditions. So far, only few kinds of plants can be standardized like that and, accordingly, only few breeds of animals. In addition, this can result in a loss of biodiversity as a consequence of efficient food business.

A big challenge is to change the prevalent patterns of consumption and eating, as well as the dominant competition conditions. On the German market, for instance, a massive price competition prevails. Profit is mainly possible by concentration and by increasing business volume. Food is cheap and easily replaced, visual appearance drives consumption and waste behaviour, and consumers do not know and care much about the wastage of resources. Saturated markets create waste; foodstuffs in abundance are offered to the consumer at all times in a wide variety. Consumers orientate themselves strongly on the look of goods and only choose best products. All other goods are left over. Quality is whatever looks good, sensory quality fades into the background. All kinds of food are available at all times. Foodstuffs are cheap and replaceable with very little effort. Preparation has been handed over to the food industry. Consumers lack competences in the treatment of foodstuffs as well as in the judgment of food quality. Esteem has gotten lost – basic competencies lack.

The food production and distribution chain is governed by the rules of process optimization. Industry and retail set the standards and whatever does not fit into the machines or packaging is not harvested or used. Moreover, the volatile markets cause that agricultural commodities will not even be harvested if prices are too low, it is not profitable to pay workers to sort rotten fruit off a pallet and processes are not optimized to particularly reducing waste. At least food waste is kind of legitimized because it is an important source on so called secondary markets feed industry or biogas plants. This changed usage does not mean a direct loss of goods but a loss of value.

On the basis of the cause analysis above, two areas of action are identified for developing measures to reduce food waste and resource use. First, in order to reduce food waste and thus save resources the focus must be placed on the interface between the actors in the value chain and on actions across the whole chain. Even though the single steps of the value chain are nearly optimised, food waste is generated by a lack of coordination between these steps. Also complex relationships of cause and effect are found along the whole value chain and often occur and work on different levels. By recognising these relationships (e.g. quality standards for vegetables which are set by producers or retail) influence on the use of resources can be taken. Second, food waste is mainly systemic, which means market rules, the political framework and the behaviour of the actors cause. It is necessary to reformulate the political framework for the use of resources and to stimulate new consumption patterns by setting incentives, educating and internalizating external costs. A new esteem for Foodstuffs is indispensable (Teitscheid et al. 2012).

4 Conclusions

A sustainable material footprint for nutrition of 3 tonnes/cap./a would mean a share of 35-50% for nutrition in the total material footprint of sustainable households, which would be definitely more than at present (see Fig. 1). However, this can be justified, as nutrition is the most basic need of human beings so that the resource use for nutrition cannot be ever reduced.

On the basis of these findings a sustainable material footprint for nutrition of 3 tonnes/cap./a could be achieved by consuming 500 kg of foodstuffs of an average material intensity of 6 kg/kg. This means a factor 2 reduction in the average resource use for nutrition (Fig. 4). 500 kg of food consumption is at the lower end of European countries' consumption but still already achieved by some countries. 6 kg/kg is a relatively low average material intensity but e.g. cereals, bread, milk, eggs, domestic fruits, outdoor vegetables, soya and wild fish can be below 6 kg/kg already today (Kauppinen et al. 2008, Kaiser et al. 2012, Mancini et al. 2010). In addition, the waste prevention survey showed that there is still notable potential for decreasing resource use in the value chain.

We conclude with a short outlook on necessary steps and important research questions for a sustainable resource management in food production and consumption. A sustainable level of resource use for nutrition is achievable but requires a lot of efforts of all actors involved. Especially the following points should be taken into consideration:

- *Producers* and retailers have to increase resource efficiency by improving supply chain management and implementing technical, product and service innovations along the whole food chain.
- *Consumers* have to reinvent modern lifestyles and shift their diets towards smaller material footprints and better health.
- *Governments* have to promote sustainable nutrition habits by different interventions, e.g. by publishing less resource-intensive nutrition recommendations, setting waste

prevention targets and creating a resource-efficiency-orientated political and legal framework.

- Appreciation of foodstuffs is becoming a priority topic of *education* for sustainable development.

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Article

Eight Tons of Material Footprint—Suggestion for a Resource Cap for Household Consumption in Finland

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Abstract: The paper suggests a sustainable material footprint of eight tons, per person, in a year as a resource cap target for household consumption in Finland. This means an 80% (factor 5) reduction from the present Finnish average. The material footprint is used as a synonym to the Total Material Requirement (TMR) calculated for products and activities. The paper suggests how to allocate the sustainable material footprint to different consumption components on the basis of earlier household studies, as well as other studies, on the material intensity of products, services, and infrastructures. It analyzes requirements, opportunities, and challenges for future developments in technology and lifestyle, also taking into account that future lifestyles are supposed to show a high degree of diversity. The targets and approaches are discussed for the consumption components of nutrition, housing, household goods, mobility, leisure activities, and other purposes. The paper states that a sustainable level of natural resource use by households is achievable and it can be roughly allocated to different consumption components in order to illustrate the need for a change in lifestyles. While the absolute material footprint of all the consumption components will have to decrease, the relative share of nutrition, the most basic human need, in the total material footprint is expected to rise, whereas much smaller shares than at present are proposed for housing and especially mobility. For reducing material resource use to the sustainable level suggested, both social innovations, and technological developments are required.

Keywords: consumption; lifestyle; household; natural resources; resource cap; sustainability; transition; material footprint; MIPS; ecological backpack

1. Introduction

An increasing number of consumers, especially in Western societies, can be characterized by a medium or high resource consumption profile. Since these lifestyles are becoming more popular in growing cities worldwide, resource efficiency is an issue of increasing importance on different levels.

The use of natural resources by human activities has been constantly growing during the recent decades. From 1980 to 2008, for example, the extraction and use of many raw materials on a global scale has grown by tens or hundreds of percent. Since 2000, the global resource extraction has risen further and with a stronger growth rate than in the previous decade [1]. The Total Material Consumption (TMC) of between 40 and 50 tons per capita in a year [2] for most industrialized countries is factor four to five higher than the sustainable level suggested by Bringezu [3]. In addition, the "ecological footprint", *i.e.*, the land area required for human activites either directly or for absorbing the carbon dioxide emitted, has doubled since 1966. It has exceeded the productive land area available already during the 1970s, from 2008 on by more than 50 percent [4]. Other studies focus on the limited environmental space and the effect of exceeding limits on, e.g., biodiversity, climate change, clean water, erosion, soil degradation, migration, social conflicts due to limited acces to resources, *etc.* [5–9].

The welfare and the consumption of households are the ultimate purpose of basically any economic activities [10]. The amount of household consumption is still growing on a global level [11]. Thus, the way households are living and consuming is a major basic driver of the overconsumption of natural resources by the human technosystem [12,13]. However, this does not mean that households were the only actors that can affect sustainable resource use. In order to decrease the resource use from household consumption, both production and consumption patterns have to be changed, as well as infrastructures and politics that are provided by governments.

The purpose of this paper is to explore the general possibilities of, and the basic prerequisites for, "sustainable lifestyles" [14] in terms of natural resource use. The hypothesis of this paper is that a sustainable level of natural resource use by households is achievable and it can be roughly allocated to different consumption components in order to illustrate the need for change in our lifestyles. The paper is mostly based on data from Finland. Therefore, the assumptions, comparisons, and conclusions especially relate to Finnish households, although they might be similar when studying other Western countries.

On the basis of results from macroeconomic calculations [2,3] we propose an amount of eight tons per person in a year for household consumption and two tons per person in a year for public consumption (e.g., education, health care, public administration). The indicator for describing the resource use by household consumption is the material footprint (see Section 2.3). On the basis of existing research on Finnish households and other research results, promising practices and examples, possible future material footprint levels are reasoned (Section 4). They can, on a more holistic basis than earlier benchmarking approaches (e.g., [15]), provide a benchmarking framework to which the material footprint of products and activities can be compared. However, it is noteworthy to mention that these are only suggestions because user behavior and social practices of households greatly vary (e.g., [16–18]) and technological development in the coming decades can hardly be anticipated [19,20]. Therefore, Section 4 shows only one possible profile of sustainable household consumption. Conclusions concerning the results and the ways to achieve them are given in Section 5.

2. Methodology

This paper is based on several methodological approaches and decisions choosen for developing a reference framework to assess household consumption. It integrates an interdisciplinary and transdisciplinary, transition research oriented view for an action research approach that helps to reflect present resource use. Thus, it is intended to support the creation of new ways of low resources individual lifestyles. It, thus, refers to a variety of approaches of transition and action orientated research, such as [21–26]. The material footprint as a method for calculating the natural resource use of households is briefly described in Section 2.1. Section 2.2 describes in which way the system boundaries for households were set. Section 2.3 shows central assumptions for the study and its calculations, as well as how and which kind of existing research results, promising practice examples, and other aspects were utilized for suggesting a framework for sustainable resource use in household consumption.

2.1. Material Footprint and Resource Efficiency Potential Calculations

The term material footprint was established by Lettenmeier *et al.* [27] as a parallel term for the ecological backpack created by Schmidt-Bleek [28]. The intention was to apply the increasingly popular footprint metaphor for comprehensively illustrating and communicating resource use and material flows. The term material footprint has mostly been used to describe the life-cycle-wide resource use of products, services, activities, and households on micro level (e.g., [27,29]).

The material footprint as used in this paper is calculated by using the MIPS methodology (Material Input Per unit of Service). MIPS values are calculated by summing up the amount of natural material resources required throughout the life cycle in order to provide a specific benefit [27,28,30,31]. The material footprint, as used in this paper, sums up the MIPS categories abiotic and biotic recources, as well as the erosion out of the category soil movement in agriculture and forestry. The resource categories of water and air are not part of the material footprint and are, thus, left out of this study.

The material input contains both the resources used in human economy and the unused extraction (see [32]). This means that any material flows, regardless of their economic utility, are considered.

MIPS values are expressed in mass units per unit of the service provided, for instance in kilograms per kilometer traveled. The concept of service (S) in MIPS is based on the notion that any product is not an end in itself, but it is only produced to fulfill a specific service or need [28]. Thus, even very different products and services can be compared to each other on the basis of the service they provide (e.g., a video conference service and an aeroplane as means for meeting people located far away).

The calculation data used for this paper is mostly the same as in two Finnish research projects on the material footprint of households, "FIN-MIPS Household" [33] and "Basic income MIPS" [29].

The calculation and presentation of the results in Section 4 can be seen as a rough variation of the Resource Efficiency Potential Analysis (REPA) described by Rohn *et al.* [34]. The REPA analyses the resource efficiency potential of specific or new technologies, products and strategies in comparison to previous or average ones. In this paper, the comparison of the sustainable material footprint level to the existing level for both household consumption as a whole and the different consumption components can be interpreted as REPA on system and subsystem level.

In addition to defining the household as a system, system boundaries are also strongly influenced by the way of calculating the resource use of households. The material footprint, as a micro level approach, is calculated on the basis of the life-cycle material input of all goods and services used by the household (see [27,30]). In terms of natural resource categories, it is equivalent to the term Total Material Requirement (TMR), including abiotic and biotic material resources (including their unused extraction) and erosion in agriculture and forestry, which is the cumulative primary material requirement for the products and services consumed. However, the calculation procedures used here are different from the application of TMR (Total Material Requirement) and TMC (Total, Material Consumption, see [34]) on a macro level. Macro level calculations are usually based on data such as physical input-output tables and consumption expenditure, whereas the TMR (*i.e.*, material footprint), used here, is based on life-cycle material flow calculations of products and activities.

One major difference between applying TMR as micro level material footprint in this paper and its application on most macro level studies concerns the allocation of the material flows of infrastructure like houses, roads, railways, *etc.* In the material footprint, as used here, the material inputs for the existing infrastructure stock, newly built infrastructure and infrastructure maintenance are allocated to the user of the infrastructure by dividing the life-cycle-wide material input required by the expected useful lifetime of the infrastructure (see [31,35,36]). In macroeconomic material flow accounting (MFA), inputs for constructing the infrastructure are usually allocated to the year they are used. Only the maintenance, use, and renewal of the infrastructure are allocated to the material flows of the years the infrastructure is in use. Thus, in countries with most of their transport infrastructure already built, this leads to considerably smaller values for mobility and transportation in macroeconomic TMR and TMC calculations. In addition, in these maroeconomic calculations, transport infrastructure is often allocated to public consumption so that its material inputs are not allocated to the households. Thus, macroeconomic material flow calculations for consumption (e.g., [2,37,38]) may provide significantly lower mobility-related values than results from micro level calculations like [29,39] or this paper.

2.2. The System Boundaries of Household Consumption

The material resource use by households includes, in principle, any natural material resources required for, first, producing and using materials, products, and services private households consume, for, second, any other activities performed by or covering the needs of households, and for, third, disposing of the related materials and products.

When taking a life-cycle perspective, nearly any human activity can be defined as serving private households at a certain point of time. Thus, basically most of the production and consumption system of an economy can be attributed to private households. However, in this paper we attribute to households only consumption components that households are able to influence and exclude mainly public activities. For example, the resource use caused by public administration, like ministries and authorities or the defense budget, cannot be directly influenced by household consumption despite contributing in fulfilling the human needs of security and participation in society. We also exclude public services, such as health care and education, of which the resource intensity is known only to a small extent and which are also mainly part of public consumption and out of households' direct influence in Finland. In addition, water supply and waste-water treatment are excluded from the calculations because households influence the material footprint of these public services only to a limited extent. However, the energy required for heating the water is part of the calculations. On the basis of earlier results [39], the consumption components of packaging and waste management were left out because of their low relevance in comparison to the total material footprint of the households.

The household system as studied in this paper is divided into the following consumption components pragmatically defined on the basis of people's everyday life:

(1) Nutrition, including all the foodstuffs and drinks consumed;
(2) Housing, including the housing infrastructure, as well as the use of energy (electricity and heating) for household purposes;
(3) Household goods, including the 12 product groups used by Kotakorpi *et al.* [39]: clothes, home textiles, furniture, electric appliances, electronic appliances, paper products, jewellery, dishes, tools, toys and leisure equipment, daily consumer goods, other goods;
(4) Mobility, including the use of cars, bicycles and public transport for both everyday mobility and tourism;
(5) Leisure activities including sport and cultural activities either actively or as a spectator;
(6) Other purposes, including goods or services consumed, e.g., accommodation during holiday trips, but excluding services provided by public systems like health care and education.

2.3. Basic Methodological Procedures and Assumptions

The level of a sustainable material footprint for household consumption in 2050 is reasoned in Section 4.1 on the basis of the sustainable level for the total material consumption (TMC) for European countries proposed by Bringezu [3]. Macroeconomic calculations divide the TMC into private consumption, public consumption, and capital formation (e.g., [2,40]). From the micro level perspective that deals with the whole life cycle or value chain of products, capital formation is part of the life cycle of products and services because infrastructure, for instance, has to be taken into account in MIPS calculations [31]. Therefore, the TMC needs to be distributed only between public and private consumption. On the basis of their relation in present TMC results [2,37,40,41], we roughly break up the sustainable level of TMC into 80 percent for household consumption and 20 percent for public consumption.

While the sustainable level of material footprint for household consumption suggested is based on existing literature, the target level for the different consumption components can differ and allow trade-offs according to individual needs and preferences. For example, someone who is not travelling at all could have a higher material footprint for housing and, thus, "afford" more living space. This serves the establishment of a diversity of possible development paths, as well as strategic acceptance, awareness and responsibility for the desired change with the actors involved (see [17]).

For the basic allocation of the sustainable material footprint level to the different consumption components, the four following aspects have been considered: First, basic needs (nutrition, housing, household equipment) were considered before allocating material footprints to other activities (mobility, leisure activities, other purposes). The basic needs identified are in line with the observations of Lettenmeier *et al.* [29] on the material footprint of households living on low social standards.

Second, we used results, experiences and conclusions from household level studies [29,39,42] to define a potential future level of material footprint in each consumption component.

Third, results from resource efficiency potential analyses (e.g., [43,44]) and other examples of promising practices were utilized for exploring future possibilities of sustainable consumption patterns. This includes examples of developments or niche solutions already accepted or promoted although still far from mainstream. This part of the research contains also websites and grey literature because only a part of the examples has been described in peer-reviewed scientific literature.

Fourth, as household consumption is an extremely broad topic, it would not have been possible to cover all research done and examples available in this paper. Therefore, the examples used are mainly based on projects, contexts and publications the authors have been involved in. Even with this relatively restrictive approach, plenty of examples became available showing the huge opportunities for developing future sustainable lifestyles and technologies.

For the consideration and calculation of the material footprints of the different consumption components in 2050, the assumption was made that future resource intensities of materials, products and activities will be lower than today. For example travelling 3000 km by bike, bus, tram, metro, or ferry requires approximately 1 ton of material footprint today. For the future, we assumed that improvements in materials, production processes, and capacity use of both infrastructure and vehicles should allow 5000 km of travelling out of 1 ton of material footprint. These material intensity assumptions are basically artificial. Their plausibility was based on a range of studies on existing material intensities and resource efficiency potentials already identified (Appendix). The assumptions used are given in a structured table for each of the consumption components (Tables 2–7).

3. Literature Review on the Present and Sustainable Resource Use by Households

3.1. Present Level, Composition and Diversity of Resource Use

The total material footprint of an average Finn is 40 tons per capita in a year [45,46]. This average material footprint was calculated from a micro level approach though utilizing a mixture of statistical and survey data published by different sources from 2005 to 2007. This makes it comparable to the material footprints calculated for specific households described below. Mobility, housing, and nutrition make up 84% of the average Finn's material footprint (recalculated on the basis of [45,46]). Compared to other studies on the environmental impact of consumption [47–49], this is a similar, though even slightly bigger, share of these central consumption components.

Kotakorpi *et al.* [39] calculated the material footprints of 27 Finnish households from questionnaires and diaries of the actual consumption of these households. With an average material footprint of 39 tons per person in a year, the results show a huge diversity both in level (maximum difference of factor 9, from 13 to 118 tons) and composition of the material footprints. The diversity in both terms continues when disaggregating the different consumption components into subcomponents. Nutrition shows a factor 3 difference in the material footprint levels while the differences in the other consumption components range from factor 11 for household goods to factor 85 for mobility [39] (pp. 44–60).

Lettenmeier *et al.* [29] report the material footprints of 18 Finnish low-income single households ranging between 7 and 35 tons per person in a year with an average of 18 tons. In general terms, both the absolute levels of and the diversity among the material footprints of the participants were lower than in [39]. With a range from 7.4 to 35.4 tons per person the maximum difference in the footprint level is slightly below factor 5 and all households are below the average Finn's level. Housing has the greatest share in the material footprints and nutrition is second with most of the households. Housing, nutrition and household goods are the only consumption components with a material footprint higher than zero for each of the 18 participants.

Lettenmeier *et al.* [50] calculated the material footprint for different decent minimum reference budgets developed by the Finnish National Consumer Research Centre [51]. The material footprints for these reference budgets, *i.e.*, for the minimum living standard Finnish inhabitants should be able to achieve, ranged from 20 to 24 tons per person in a year, depending on the household type [50].

The average annual material footprint of Europeans today is estimated as being between 27 and 40 tons per capita by Groezinger *et al.* [52]. An average European's material footprint from 22 to 26 tons per person in a year was reported by Kuittinen *et al.* [16]. That study calculated the material footprint of 69 individual consumers from mostly European countries on the basis of a web questionnaire (see [16]). The material footprints of the participating individuals ranged from 8.5 to 69 tons per person in a year [16] but exclude some aspects included in the other studies described (e.g., leisure activities and water consumption). Kuittinen *et al.* [16] stress the importance of the diversity in the households' lifestyles and their material footprints now and in the future. They show the examples of seven participants in terms of material footprint level and diversity, explaining factors behind them (e.g., "compact home and the life nearby" or "big home and moving around"), as well as potential future development and preferences.

Finnish macroeconomic calculations give values from 14 to 31 tons per person in a year [45,53]. German macro-based values for household consumption are reported from 22 tons per person in a year [2] to 29 tons, respectively [38]. Macroeconomic data tend to show lower values for the resource use of household consumption because of differing system boundaries and allocation procedures, for instance by allocating the material input for building infrastructure in a different way (see Section 2.1).

3.2. Sustainable Future Level of Resource Use

The need for a general dematerialisation in order to decrease global environmental problems has been stated already for several decades [28,54–56]. However, unlike the ecological footprint the sustainable boundaries of which are set by the productive land area our planet is providing, the determination of a sustainable material footprint level is complex and not unambigous.

By suggesting, in 1993, that global resource consumption should be halved by the middle of the 21st century and an equal per capita use should be achieved, Schmidt-Bleek [28] claimed a factor of 10 as a necessary, but not sufficient, transformation goal for industrialized countries. Bringezu [3] applied this to the global extraction of abiotic resources, which amounted to about 100–110 billion tons in 2000 (16 to 18 tons per capita). If that amount is reduced by half and then shared equally by nine billion people in 2050, the acceptable level of abiotic resource use would be approximately 5.6–6.1 tons per capita. With the EU per capita consumption of 33.4 tons this requires a reduction by at least 80% or a factor of 5. This is in line with the suggestion of Ekins *et al.* [57] of six tons of abiotic resources per person in a year. It also includes the aspect of a fair share of resource use within the environmental space provided by the planet as proposed by Spangenberg [5].

For European countries, Bringezu [3] proposes a sustainable level of biotic material use and top soil erosion in agriculture and forestry of four and 0.2–0.3 tons, respectively. Including abiotic resources this means a sustainable TMC of approximately 10 tons per capita in a year.

Since 2000, global resource extraction has risen further and with a stronger growth rate than in the previous decade [1]. The used extraction increased from 2000 to 2008 by 27 percent to 68 billion tons (abiotic and biotic). Business as usual would cause a further increase globally [58,59]. Thus, from the perspective of recent development, a return to the global resource use in 2000 would be progress already [60]. Bringezu therefore revised his original proposal [3] and proposed a global abiotic TMC of 11–12 tons per capita per year in order to not exceed the resource use level of the year 2000 while, for the EU, with most of its housing and mobility infrastructure already built, he considers plausible a level of 10 tons, respectively [60]. However, the considerations behind this are rather related to political target-setting than to new scientific findings on the planetary boundaries. Therefore, we still use Bringezu's [3] original target of 10 tons of TMC in total as the starting point for this paper. The distribution of these 10 tons into household consumption and public consumption for this study is explained in Section 2.3.

4. Results and Discussion

This section first gives a suggestion on the sustainable level of material footprint for household consumption and one example on how to allocate it to the different consumption components. In Sections 4.2–4.7 the values suggested for each consumption component are explained and reasoned on the basis of already existing technologies, solutions, concepts, and other developments.

4.1. A Sustainable Lifestyle of Eight Tons Material Footprint

On the basis of Section 2.3, we propose a share of eight tons per person in a year for household consumption and two tons for public consumption, respectively. In order to make this amount of resource use operationable, it has to be allocated to the different consumption components. In the case of real households this aggregation depends on the specific needs, wants, lifestyles, situation, location, *etc.* of a household. Table 1 gives a summary on the material footprint recently reported for Finnish households (on the basis of [45] and [46] which used statistical data published from 2005 to 2007), the suggestion for a future material footprint, and the reduction required in the different consumption components. The order of the different consumption components proceeds from most basic needs to less basic needs, as explained in Section 2.3.

Table 1. Summary of status quo material footprints and proposal for sustainable material footprint requirements in the different consumption components.

Consumption	**Status quo material footprint**		**Sustainable material footprint**		**Change required**	
component	**kg/(person·a)**	**Share**	**kg/(person·a)**	**Share**	**%**	**Factor**
Nutrition	5,900	15%	3,000	38%	–49%	2.0
Housing	10,800	27%	1,600	20%	–85%	6.8
Household goods	3,000	7%	500	6%	–83%	6.0
Mobility	17,300	43%	2,000	25%	–88%	8.7
Leisure activities	2,000	5%	500	6%	–75%	4.0
Other purposes	1,400	3%	400	5%	–71%	3.5
Total	**40,400**	**100%**	**8,000**	**100%**	**–80%**	**5.1**

Sections 4.2–4.7 provide the central facts, assumptions and features on the material footprint level for each consumption component in a structured table and in text. Central assumptions and other relevant information are given in the text before each table. The tables contain the following issues. The resource use reduction required is given in absolute (tons) and relative (factor X) terms. The amount of direct consumption, the material intensity and the share in households' total material footprint is listed for the recently reported consumption of an average Finn and the proposed future average. Multiplying the present direct consumption amount with the present or future material intensity factor results in the present or future material footprint level for each consumption component. This is followed by a core statement on ways and strategies for achieving the future material footprint.

More detailed examples, arguments and promising practices for the different consumption component is given in Tables A1–A6. These are provided from both a consumption and a production point of view as results reasoning that the material intensity and the amount of service proposed can be seen plausible.

We have to emphasize that the material footprint reduction requirements presented are suggestions on an average basis. However, different households and individuals have very diverse needs, wants, locations, and other circumstances affecting their present material footprints. Therefore, their future material footprint distribution can also vary considerably [16]. As long as the average future material footprints of households do not exceed eight tons per person in a year, the individual footprints can highly differ from each other.

4.2. Nutrition

The average material footprint for nutrition requires a reduction by half from present (see Table 2). The level suggested here is based on a highly but not totally vegetarian nutrition, a slightly smaller amount of foodstuffs (600 kg/(person·a)) consumed compared to today, and efficiency gains in the food chain, e.g., by reducing waste. Table A1 shows arguments for determining a sustainable material footprint for nutrition at three tons per person in a year. This value includes both food and drinks.

A reduction by a factor of 2 is a smaller reduction than with the other consumption components. Thus, the share of nutrition in the total material footprint will considerably increase in the future while the shares of the other consumption components either decrease or just slightly increase (see Table 1). This is because nutrition can be considered the most basic need represented in the consumption components.

Table 2. Sustainable material footprint proposal for nutrition.

Nutrition—from 5.9 to 3 tons/(person·a)					
Reduction required by	**Factor 2**		Direct consumption amount	Present	**840 kg** (including drinks) [45]
				Future	**600 kg** (including drinks)
Share in household's material footprint	Present	**15%**	Material intensity	Present	**7 kg/kg** (including drinks) [45]
	Future	**38%**		Future	**5 kg/kg** (including drinks)
Core statement	The material footprint for nutrition can be reduced from 5.9 to 3 tons/(person·a): - by reducing the amount of food and drinks consumed to a healthy and still enjoyable level; - by developing acceptable and delicious diets e.g., towards notably less meat and dairy products; - and by increasing the resource efficiency in the food chain e.g., through waste prevention.				

4.3. Housing

Housing is another very basic need. The suggested 85 percent reduction in the material footprint of housing is based on a decrease in living space per person by nearly half to an average of 20 m^2 per person while the energy and resource efficiency of houses would increase drastically. In addition a decrease in electricity use to 1000 kWh per person in a year and a notable increase in the resource efficiency of the electricity produced will be necessary and can be expected.

Table 3 shows the consequences of and Table A2 arguments for suggesting a sustainable material footprint for housing at 1.6 tons per person in a year. This value includes both the building and the energy used in the building.

Table 3. Sustainable material footprint proposal for housing.

Housing—from 10.8 to 1.6 tons/(person·a)					
Reduction required by	**Factor 6.8**		Direct consumption amount	Present	**38 m^2/capital** (house) [45] **11500 kWh** (heat and electricity) [45]
				Future	**20 m^2/capital** (zero energy house) **1000 kWh** (electricity)
Share in household's material footprint	Present	**27%**	Material intensity	Present	**65 kg/ m^2/a** (house, unheated/uncooled) [39] **0.6 kg/kWh** (Finnish heat and electricity) [39]
	Future	**20%**		Future	**65 kg/ m^2/a** (house, heated/cooled) **0.3 kg/kWh** (European electricity)
Core statement	The material footprint for housing can be reduced from 10.8 to 1.6 tons/(person·a): - by developing zero-energy houses not exceeding present houses' material intensity (*i.e.*, strongly combining energy and resource efficiency); - by drastically shifting electricity production from fossils to renewables, especially wind an solar energy; and - by decreasing individual living space. The impacts of the latter on the individual wellbeing can be reduced by increasing shared living space and improving public space more liveable and attractive.				

The material footprint proposed requires a huge change in building infrastructure as most houses are far from a zero energy standard at present. Presently existing buildings that will still be in use by 2050 cannot necessarily be assumed to be zero energy houses then. This means that the additional material inputs required for heating those houses in the future have to be compensated, e.g., by increasing the benefit provided by them or decreasing their material input in a way or another. For example, longevity and renewable energy can open additional options for reducing the material intensity of existing buildings. On the other hand, increasing urbanization is still going in Finland. This provides opportunities for establishing a much more energy and resource efficient stock than previously if resource efficiency is developed and taken into account in new buildings and quarters. In addition, increasing urbanization can help to achieve the mobility proposals given in Section 4.5.

4.4. Household Goods

A part of the household goods we are using can be considered as basic need. However, as the amount of household goods used on average today certainly exceeds the most basic needs, a reduction of 83 percent is suggested for the material footprint of producing the goods households use (Table 4). This should be achieved by a decrease in ownership as well as an increase in longevity, reuse, second-hand use, sharing, and other options. Table A3 shows arguments for this proposal.

Table 4. Sustainable material footprint proposal for household goods production.

Household goods production (cradle to retail)—from 3 to 0.5 tons/(person·a)				
Reduction required by	**Factor 6**	Direct consumption amount	Present	**1943 items/household** (avg), out of which **568** second hand or similar [39]
			Future	**less** own items
Share in household's material footprint	Present **7%**	Material intensity	Present	**200 kg**/(**person·a**) as an average for the 12 product groups, with a range from 15 to 420 kg/(person·a) per one product group and with only 3 product groups below 170 kg/(person·a) [39]
	Future **6%**		Future	**42 kg**/(**person·a**) on average for each of the 12 product groups
Core statement	The material footprint for household goods can be reduced from 3 to 0.5 tons/(person·a) by increasing longevity, decreasing ownership of equipment, increasing sharing options, improving reuse and second hand schemes, *etc.*			

Recycling and reuse (e.g., second hand products or reuse of components in appliances) usually cause particularily low material footprints because in the MIPS concept the material input is allocated to the original material or product produced. For additional using times afterwards only the material input for reintegrating the material or product into the market (e.g., sorting plants, washing, transportation) is calculated [31].

This section covers the material footprint for the production of the 12 product groups used by Kotakorpi *et al.* [39] with a life cycle "from cradle to retail". The resource use during the use phase of the products is covered by Section 4.3. Because all electricity and energy used at homes is allocated to the consumption component of housing, and households usually receive only one electricity bill for all the power consumed at home (see also [59]). Furthermore, the transportation of goods from retail to home is included in the mobility figures.

4.5. Mobility

Mobility has a strong influence on the present average material footprint (Table 1). The diversity of different activity profiles concerning mobility is huge [16] (pp. 24–41), [29] (pp. 1436–1438) and [39] (pp. 48–49).

The greatest average reduction (88%, *i.e.*, close to a factor of 9) we suggest is for this consumption component. It can be achieved by reducing private car traffic to a fraction of present levels. In addition a reduction of overall mobility performance to 10,000 km per person in a year is required while simultaneously increasing the resource efficiency of public transport from present.

Table 5 shows the central consequences and Table A4 the arguments for determining a sustainable material footprint for mobility at 2 tons per person in a year. This value includes both everyday mobility (e.g., trips to work, shopping and leisure activities) and tourism-related transportation (but excludes trips that are done on behalf of the employer). This means that also the composition of a sustainable material footprint for mobility can differ according to a person's individual needs and interests. Table 5 shows a range of values for present mobility in the case of aeroplanes, trains, and other transport subsystems because the huge differences in both material intensity and function between, for instance, local and long-distance trains or domestic and intercontinental flights are too big to be covered by one single average value.

Table 5. Sustainable material footprint proposal for mobility.

<table>
<tr><th colspan="6">Mobility—from 17.3 to 2 tons/(person·a)</th></tr>
<tr><td rowspan="2">Reduction required by</td><td rowspan="2" colspan="2">Factor 8.7</td><td rowspan="2">Direct consumption amount</td><td>Present</td><td>17,500 km</td></tr>
<tr><td>Future</td><td>10,000 km</td></tr>
<tr><td rowspan="2">Share in household's material footprint</td><td>Present</td><td>43%</td><td rowspan="2">Material intensity</td><td>Present [61]</td><td>1.44 kg/person-km* (private car)
0.53–1.2 kg/person-km (train)
0.06–0.56 kg/person-km (plane)
0.26–0.38 kg/person-km (bus, coach, tram, metro, ferry, bike)</td></tr>
<tr><td>Future</td><td>25%</td><td>Future</td><td>0.2 kg/person-km</td></tr>
<tr><td>Core statement</td><td colspan="5">The material footprint for mobility can be reduced from 17.3 to 2 tons/(person·a):
- by making public transport and biking still more resource-efficient;
- by reducing the role of private cars dramatically;
- by limiting the amount of kilometres travelled to 10,000 km/(person·a);
- by changing travel requirements for work and leisure, e.g., by a higher attractiveness of the living environment as well as the change of production and communication structures that allow a reduction in mobility and transports;
- by the integrative management of mobility and ICT options.</td></tr>
</table>

Note: * kg/person-km: material input in kg per person transported one kilometre.

4.6. Leisure Activities

Leisure activities are important because they provide recreation and health to people who are often doing one-sided work. The material footprint for leisure activities is suggested to be reduced from present by 75 percent. This should be possible by reducing especially resource-intensive activities and products, by keeping the amount of activities and products on a sufficient level and by increasing the resource efficiency of the activities or products.

Table 6 shows the central consequences and Table A5 the arguments for determining a sustainable material footprint for leisure activities at 0.5 tons per person in a year. This value focuses basically on activities out of the home because activities within homes are covered by the consumption components of household goods and housing. The material footprints reported for basic leisure activities at home have been relatively low, for example 1 kg/h for watching TV or 2 kg per shelf centimeter of books [39]. However, if leisure activities at home could also be allocated to this consumption component if they require a huge amount of additional resources, e.g., for equipment.

Table 6 shows a range of values for common leisure activities. They appear to follow a rough pattern according to which they can be divided into

(1) low-infrastructure activities with low material footprints, such as jogging;
(2) group or mass activities with an apparent need for infrastructure, such as using a swimming hall or fitness club, thus requiring a higher amount of resources; and
(3) highly individual and/or infrastructure-intensive activities showing also the highest material footprints, such as golf or sailing.

Table 6. Sustainable material footprint proposal for leisure activities.

Leisure Activities—from 2 to 0.5 tons/(person·a)				
Reduction required by	**Factor 4**	Direct consumption amount	Present	**3.5 h** of physical exercise or other leisure activities outside the home [45]
			Future	**3 h** but strongly dependent on the material intensity of the activity
Share in household's material footprint	Present **5%**	Material intensity	Present [39]	**1 kg/h** for low-infrastructure outdoor activities; **5–15 kg/h** for activities requiring infra-structure like buildings, harbours, slopes; ≥**30 kg/h** for resource-intensive individu-al activities like sailing, golf, motor sport
	Future **6%**		Future	**1–6 kg/h** (e.g., 2 × 50 h/a × 1 kg/h + 1 × 50 h/a × 6 kg/h)
Core statement	The material footprint for leisure can be reduced from 2 to 0.5 tons/(person·a): - by rather decreasing than increasing leisure activities that are highly material intensive and/or require built and heated infrastructure; - by utilizing outdoor options requiring few resources (walking, jogging, canoeing, gardening, …); - by using infrastructure more efficiently (e.g., schools in the evening); and - by making leisure activities more resource efficient (e.g., longevity of venues, resource efficient use of energy).			

The latter of these will have the greatest needs for decreases in material intensity, improved resource management, and/or trade-offs with other consumption components in the future, depending on the needs and interests of individuals and households.

4.7. Resource Use for Other Purposes

As this concumption component, in principle, covers anything not covered by the previous ones no direct consumption amount nor material intensity has been specified in Table 7. In addition the reduction required in reality is probably higher than proposed because, for example, the consumption of many services is not yet included in the calculations so far (see Section 2.1 for details). Other purposes could include, e.g., services or accommodation during holiday trips (see also Table A6).

Table 7. Sustainable material footprint proposal for other purposes.

Other purposes—from 1.4 to 0.4 tons/(person·a)				
Reduction required by	**Factor 3.5**		Direct consumption amount	not specified
Share in household's material footprint	Present	**3%**	Material intensity	not specified
	Future	**5%**		
Core statement	The material footprint for other purposes should be reduced from 1.4 to 0.4 tons/(person·a) in order to keep the material footprint of household consumption within the limits of 8 tons/(person·a).			

5. Conclusions

This paper provides a basic reference framework for achieving sustainable household consumption by 2050. In general, a sustainable household consumption in 2050 seems achievable on the basis of the mostly Finland-related proposals of the paper (Section 4). However, the targets proposed (see Table 1–7) show that there is a long way to go and a lot of efforts required (see also Appendix, Tables A1–A6). The findings of this study can help to show the way towards sustainable household consumption and are intended to contribute to a positive vision for the enormous transformation task we are facing.

For the suggested average factor 5 of reduction in material footprint (see Table 1), a factor 2 to 3 improvement appears necessary in terms of both production-based and consumption-based solutions (see Appendix, Tables A1–A6 for examples). By developing four different scenarios for achieving sustainable lifestyles by 2050, Leppänen *et al.* [62] have shown that the transition to sustainable lifestyles can have very different faces. They defined some common features of the different scenarios that can be confirmed by the results in Section 4. These aspects are:

- A reduced consumption of meat and other animal-based foodstuffs;
- A radical reduction of the heating and cooling energy demand of houses;
- A strongly dematerialized, fossile-free electricity production, and a lower level of mobility including a drastically decreased use of private cars.

The more technology and infrastructure can be integrated into this change, the more space will be left for individual diversity in achieving sustainable household consumption. However, even with advanced developments in technology and infrastructure the role of basic needs, especially nutrition, and their satisfaction is likely to increase strongly in the future (see Table 1).

Households have space for even immediate decisions decreasing the material footprint. In the fields of nutrition, electricity procurement and tourism, for instance, sustainable decisions can be made any time so that even fast changes could be envisaged in these areas. Although households are, in principle, free to make decisions on their consumption, some decisions are highly complex and can be locked into existing infrastructures (see [16,39,63,64]). For instance, housing-related decisions are done rarely compared to e.g., nutrition choices and the location of housing affects many further decisions, e.g., the mobility options available. Therefore, incentives should be set to facilitate change in public planning and decisions, for example on infrastructure.

Infrastructure affects resource use in the long run and determines lifestyles in many respects. Therefore, including the aspect of facilitating sustainable, low-resource lifestyles in public decision-making provides an opportunity for avoiding misinvestments and creating synergies from options simultaneously decreasing the resource use of several consumption components. For example, promoting car-free lifestyles in city planning can reduce car use and the need for public and private infrastructure like streets and parking space. Thus, it can decrease the material intensity of both mobility and housing. Attractive car-free quarters can reduce the highly relevant (see [65,66]) need for leisure time trips and could possibly also reduce the need for private living space. Without a car, closely situated shops and other facilities are more attractive than distant ones [67]. In addition, the health effects of decreasing car use are evident [68]. Increasing walking and cycling could, thus, also decrease the resource use required for leisure activities and for health care.

The framework given by this paper could also help preventing rebound effects of changing consumption patterns. For example, information and communication technology (ICT) has a considerable potential for decreasing mobility needs. Therefore, trade-offs between mobility, household goods and housing (electric power) should be considered. ICT can, for instance, facilitate car-sharing and public transport and monitor, control and reduce the need for lighting and heating at home. However, a challenge of ICT use is the increased need for copper and other resource-intensive materials and equipment (e.g., [69]). The material footprint of digital banking, for instance, has been reported to be still 40% in comparison to traditional banking (approximately 1.1 and 2.8 kg/happening, repsectively) because also digital banking requires bank infrastructure, electric power, computers, *etc.* [70]. In addition, Rohn *et al.* [71] have pointed out the need for a careful resource management in the ICT sector in order to avoid rebound effects.

Another example that can either increase or decrease resource use is collaborative consumption. Collaborative consumption is a rising trend with dematerialisation potentials in different consumption components [72]. However, if sharing consumer goods largely increases, rebound effects should actively be avoided in terms of both the overall amount of different products in use and their potential overall energy consumption and especially the potentially increasing car use for providing and acquiring products and services. This is one area further research should focus on.

Additionally, the following suggestions for further research could help to facilitate the transition challenge we are facing.

Investments in production and infrastructures highly influence what and how people consume. Therefore, it would be highly relevant to study how to use both public and private financial resources in the best way for decreasing material footprints while maintaining a high quality of life. To which extent affluent households could facilitate dematerialisation by using or allocating their financial resources in an optimal way and how can public earning (e.g., taxes) and spending (e.g., research and development funding) best facilitate dematerialisation instead of increasing resource use? For example, investments in energy and resource efficient buildings are urgent in order to achieve the targets proposed in Section 4.3.

There is a high demand for further research in order to make concrete and to mainstream the dematerialisation options sketched in Section 4 and Appendix. For example, resource-efficient zero-energy construction and low-energy retrofitting still require lots of questions to be solved. Both urban structures and mobility systems that reduce car dependency have been developed only to a small extent, so far.

An enlargement of the database to other countries than Finland and to other continents would help to address and compare household consumption on a broader basis. We also excluded public services the resource intensity of which is known only to a small extent although their contribution to resource use is highly relevant. Examples for this kind of services are health care and education.

This paper provides a first framework for developing household consumption towards a sustainable material footprint. Hopefully it can inspire also other researchers and practitioners to make sustainable lifestyles more attractive and concrete and to develop political and business solutions facilitating sustainable lifestyles.

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Appendix

Table A1. Promising examples and practices supporting the sustainable material footprint proposal for nutrition in detail.

Nutrition—from 5.9 to 3 tons/(person·a)	
Central consumption-related arguments, examples, promising practices	- 6 out of 27 Finnish households studied already achieve 3200 kg or less [39]; - 4 out of 18 low-income single households already achieve 3200 kg or less, with one vegan participant at 2200 kg [29]; - Indian average diet (2007) at 2500 kg, "Livewell UK 2020" at 3700 kg [73]; - Present differences in the direct consumption of selected foodstuffs (including most relevant foodstuffs, excluding drinks) in European countries [42]: amount from below 500 and over 700 kg/(person·a), For Finland the present amount consumed according is 540 kg/(person·a) and the present material intensity 8.2 kg/kg (both excluding drinks) [42]; - Vegan and vegetarian lifestyles presently becoming trendy in Western countries, which opens people options for less resource-intensive diets; - Catering establisments have huge opportunities for developing and spreading low resource diets, and thus for initiating behavioral change. So far, these opportunities are used rarely. Their potentials have not been sufficiently analyzed so far but single examples show that relevant new practices can be developed on the basis of user- and actor-integrated experiments (e.g., [74] (pp. 6–9)).
Central production-related arguments, examples, promising practices	- Huge differences presently in the material intensity of selected (most relevant ones included, drinks excluded) foodstuffs in selected European countries: from 8.4 to 11.4 kg/kg, several European countries already below 9 kg/kg [42]; - Cereals and bread, milk, eggs, domestic fruits, outdoor vegetables, soya, wild fish can already today be below 6 kg/kg [27,39,42]; - Material footprints of typical lunch meals, for instance, vary between 1.7 and 6.8 kg/meal [75] and material intensities by factors of 5 and more [39]; - The reduction of the high amount of food waste in Western countries at present offers opportunities for decreasing food consumption and material intensities. German food waste amount (value chain, incl. production, distribution and consumption) estimated at 146 kg/(person·a) and its material footprint at 1185 kg/(person·a) [76]; - Also food production technologies can still be developed less resource-intensive (e.g., [44] (pp.52–53)). - Agricultural production and practices can be developed more resource efficient (e.g., [44] (pp. 30–31,109–111)). So far, factors like animal welfare, erosion, soil quality, irrigation, soil movement, etc. have usually rather been optimized in terms of cost efficiency than resource efficiency. Niche solutions and concepts like permaculture show that huge potential from different production practices exists (e.g., [77,78]). - Legal requirements and industrial standards concerning the appearance and shape of the products cause unnecessary resource use in the production chain of food [79].

Table A2. Promising examples and practices supporting the sustainable material footprint proposal for housing in detail.

Housing—from 10.8 to 1.6 tons/(person·a)	
Central consumption-related arguments, examples, promising practices	- 8 of 27 households already achieve 1500 kg or less for the building (excluding heating). 14 of 27 households already achieve 300 kg or less for electricity consumption [39]; - 20 m^2 of living space is 55% of present European average but also today reality for students and other groups; - Shared space use is an option for increasing individual living space. Co-housing is seen as a promosing practice emerging in the context of sustainable living [80]; - A study on residents' heating behavior using data loggers in different apartments of multifamily residences found out that the heating energy consumption of flats with the same floor plan differed by 110% [81]. Thus, the user behavior has a notable effect on heating energy consumption.
Central production-related arguments, examples, promising practices	- European law requires that all new buildings shall be nearly zero-energy consumption buildings by the end of 2020 [82]. To provide this energy efficiency level with present material intensities will require innovations in construction materials but some interesting solutions are on the market already; - In Austria several innovative house concepts have been developed [44] (pp. 56–57) and [83,84]. These houses reduce the life-cycle impacts of houses by up to 90% (factor 10). Innovative building materials can be used, e.g., wood, straw and clay; - An insulation material innovation with a material intensity cut by half shows that additional insulation can be done resource-efficient [43] (pp. 54–60). - The production of heavy bulk materials like gravel and cement has huge resource efficiency potentials. Innovaitons are currently developed, see e.g., [44] (pp. 38–39, 66–67). - 0.3 kg/kWh of electricity is appr. 50% of the present Finnish but only 10% of German power's material intensity [85,86]. However, power production technologies with low material intensity are already in use or under development: wind power (0.09–0.16 kg/kWh [86]), Desertec power (0.12–0.22 kg/kWh [87]) and photovoltaic (0.2 kg/kWh, [43] (pp. 84–90)). New developments in wind power, for instance, may still be even more productive than present solutions (e.g., [44] (pp. 26–27)). The resource use of wave power has not been assessed yet but this could provide another low resource technology for power production (e.g., [44] (pp. 40–41)). - The energy efficiency of many household goods has increased considerably in the recent years so that reducing power consumption by half by 2050 appears achievable. E.g., washing and lighting are expected to develop considerably towards low resource use (e.g., [43] (pp. 44–45, 58–59) and [88] (pp. 162–166). There is a potential rebound effect of using more devices more often thus jeopardizing energy efficiency gains. With a need for decreasing living space and decreasing material footprints for household goods (see Section 4.4) an actual reduction in power consumption still appears achievable.

Table A3. Promising examples and practices supporting sustainable material footprint proposal for household goods production.

Household goods production (cradle to retail)—from 3 to 0.5 tons/(person·a)	
Central consumption-related arguments, examples, promising practices	- 500 kg/(person·a) of material footprint is close to the very lowest end of the 27 Finnish households ranging between 560 and 5.900 kg/(person·a) [39]. Thus, 500 kg means a considerable decrease compared to today; - 3 out of 18 Finnish low-income single households already achieve below 750 kg [29]. Generally, the low-income households in this study tend to have smaller material footprints than the households studied by [39]. This is at least partly due to second hand purchases and an intensive use of public sharing services like libraries; - A reduced living space per person (see Section 4.3) decreases the space and the need for household goods to a certain extent (e.g., [39] (p. 68)); - Among consumers swapping and sharing schemes as well as collaborative co nsumption are rising trends (e.g., [80]) with clear advantages in terms of resource use (e.g., [89]). They thus can decrease the need for the production of new goods notably if rebound effects are avoided.
Central production-related arguments, examples, promising practices	- Longevity and modularity for repair/reuse of products can decrease the material input per year of product use notably (e.g., [88,90] for furniture, shoes and jewelry). The availablility of repair and reuse services is a central factor in order to facilitate a long life of products. Mobile repair services can help to make repair services accessible while preventing consumers from having to drive long distances (e.g., [44] (pp. 60–61)). - If a product requires energy during its use face, a long lifetime might increase total resource use. However, with low material footprints for energy (as proposed in Section 4.3), longevity remains a resource-efficient option (e.g., [88,91]). - Increasing the share of recycled materials and/or reused components in products is another option decreasing the material footprint. Especially recycled metals have considerably lower material intensities (see [88] (pp. 58–61) and [92]). This can be an increasingly important option for electronic products as the availability of several raw-materials of theses products is predicted to decrease during the coming decades (e.g., [93,94]). Also durable jewelry has a huge reuse and recycling potential [88] (pp. 58–91). - Numerous examples show that product design, standardization and other measures can decrease both the amount of products in use and their material intensity (e.g., [44] (pp. 44–45, 50–51)).

Table A4. Promising examples and practices supporting sustainable material footprint proposal for mobility.

Mobility—from 17.3 to 2 tons/(person·a)	
Central consumption-related arguments, examples, promising practices	- 2 out of 27 Finnish households achieve 2500 kg or less [39]; - 13 of 18 participants already achieve 2000 kg or less for daily mobility and 14 participants 1500 kg or less for tourism (most of which relates to mobility) [29]; - The distance of 10,000 km can mean 40 km on 250 days of the year, for instance. However, with lower daily mobility also longer trips are still possible. A holiday trip of 10,000 km one-way for example would be possible if daily mobility didn't exceed 10,000 km in 3 years. - Car-free households studied in Vienna use public transport while reference households use a car as basic means of transport. Yet, the total distances travelled and the flights made by car-free households are only slightly higher than in the reference group [95]; - Car-sharing can reduce the need of owning and using private cars by providing a possibility of car use when it's especially necessary.

Table A4. *Cont.*

Mobility—from 17.3 to 2 tons/(person·a)	
Central production-related arguments, examples, promising practices	- Bus transport in finnish cities already achieves an average material intensity of only 0.1 kg/person-km *, bike traffic in Helsinki 0.2 kg, respectively [96]; - Private cars in their present use and amount can hardly be seen as a broad solution to achieve a sustainable material footprint for mobility. Even wind-power-based electric drive decreases the material footprint only slightly when infrastructure is not even considered [43]. - Longhaul flights are presently well below, long European flights and ferry trips close to 0.2 kg/person-km in material intensity (0.06, 0.11 and 0.26 kg/person-km, respectively [61]). Thus, this kind of travelling would basically be possible in the future also but probably to a much smaller extent than flight-intensive lifestyles are presently consuming. Compared to the material footprint and other means of transport, the air consumption and carbon footprints of flights are relatively high. Thus, there may occur further future needs to restrict flights because of their climate impacts although peak oil is expected to reduce flying dramatically long before 2050 [97]; - Development of low resource services concerning the social interaction needs of individuals and social groups as well as basic procurement like shopping. These services should be developed on the basis of low resource infrastructure because presently infrastructure requires a huge share of mobility material footprints [61].

Note: * kg/person-km: material input in kg per person transported one kilometre.

Table A5. Promising examples and practices supporting sustainable material footprint proposal for leisure activities.

Leisure activities—from 2 to 0.5 tons/(person·a)	
Central consumption-related arguments, examples, promising practices	- 2 out of 27 Finnish households achieve less than 800 kg [39]; - 13 out of 18 low-income single households already achieve 500 kg or less but this is often due to financial constraints [29]; - 6 kg/h is already achieved by activites in e.g., music schools, fitness centres or sports halls, 1 kg/kg with e.g., jogging or rowing [39]; - Presently resource-intensive activities like golf or going to a theatre (see [39]) could be done only sometimes per year; - Activities at home can be excluded from here if they fit into the consumption components of housing (e.g., electricity use, see Section 4.3) and household goods (see Section 4.4).
Central production-related arguments, examples, promising practices	- Increase in resource efficiency of activities expectable by 2050 e.g., by more efficient use of infrastructure and by more resource-efficient energy use (electricity and heat, similar to the requirements and achievements in housing, see Section 4.3). Sensitivity analyses of leisure-related MIPS studies show that the longevity, the energy use and the capacity use of leisure infrastructure are important factors affecting and being able to decrease material footprints [65,66]. - The location and accessibility of venues greatly affects mobility needs. Presently often half or more of the material footprint of events or training sessions is affected by transporting participants and/or spectators to the venue [39] (pp. 65–66, 69); [88] (pp. 99–107) and [90]. Although mobility is covered by Section 4.5, this is an important aspect when planning leisure facilities. - The other parameter greatly influencing the material footprint of leasure activities is the venue [65,66] and [88] (pp. 99–107). Therefore, in order to achieve lower material footprints, the capacity of venues should be used as efficiently as possible, also for other purposes than the original one (see e.g., [66] for additional events in theatres). Also the use of schools etc. for evening or weekend events can decrease material footprints especially when it decreases the need for building additional facilities.

Table A6. Promising examples and practices supporting sustainable material footprint proposal for other purposes.

Other purposes—from 1.4 to 0.4 tons/(person·a)	
Central consumption-related arguments, examples, promising practices	- The content of this consumption component can be highly different depending on the specific household. In the calculations for the average Finn the 1400 kg used here is related to accommodation on holiday trips, e.g., in hotels or cottages. However, it could contain something totally different, like going to events, purchasing medicine, having pets, or just consuming more in other consumption components (Sections 4.2–4.6). Therefore, consumption-related ways for reducing material footprints can be based on similar strategies as before, e.g., using less, sharing goods with other consumers, using instead of owning, using infrastructure already existing, using less material-intensive materials, products or energy modes, *etc*.
Central production-related arguments, examples, promising practices	- Accommodation in hotels or cottages can be developed less resource-intensive e.g., by decreasing the amount of space required, by reducing the level of equipment, or by increasing capacity use [98]. New collaborative consumption schemes like airbnb can even reduce the need for additional hotels and second homes by making the use of existing homes and second homes more efficient; - As "other purposes" can contain any products or activities, production-related ways for reducing material footprints can be based on similar strategies as in the examples mentioned before, e.g., applying less resource-intensitve materials, products or energy modes, designing goods and infrastructures for multi-purpose use and longevity, utilizing reused components and recycled materials in production, *etc*.

Conflicts of Interest

The authors declare no conflict of interest.

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Paper 7

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Household-level transition methodology towards sustainable material footprints

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ABSTRACT

This paper presents a new household-level methodology for transition towards sustainability. The methodology includes measuring the resource use of households on a micro level, testing relevant measures towards a one-planet resource use, and developing mainstreaming options in co-operation with households and providers of services, products, and infrastructures. We use the MIPS (*Material Input Per unit of Service*) method to calculate the use of natural resources and concentrate on the material footprint as an aggregated indicator for the overall use of material resources. With HST (*Household-level Sustainability Transition*) methodology, we extend the material footprint methodology from just measuring household resource use to developing visions, conducting experiments, as well as learning and upscaling, all of which contribute to the whole *Transition-Enabling Cycle*. Results from the first application of the HST methodology on five households in Jyväskylä, Finland, show that it is possible to achieve a significantly more sustainable level of consumption by a relatively few changes in everyday living. Achieving a one-planet use of material resources, however, also requires systemic changes.

1. Introduction – reducing global resource use by local activities

Material flows from nature into the human economy and back to nature have been steadily growing for decades, even for centuries (Krausmann et al., 2009). Already in the late 1960s, Ayres and Knees (1969) identified a connection between the volume of human resource use and the extent of environmental impacts. As a result of this growing use, resource availability has declined dramatically (e.g. Erdmann and Graedel, 2011; Halada et al., 2008; Lutz et al., 2012; Global Footprint Network, 2014; WWF, 2012). In addition, under business-as-usual conditions, the extraction and harvest of natural resources between 2000 and 2030 is expected to nearly double from 52 to over 100 billion tonnes (Giljum et al., 2009). These figures include the extraction of fossil fuels, metals, minerals, and biomass (used extraction), but not the excavation for infrastructures, mining and quarrying, nor the erosion linked to agriculture (unused extraction). Unused extraction ranges from double to triple the size of the used extraction (Bringezu, 2011), and this ratio is expected to grow (Aachener Stiftung, 2011).

Schmidt-Bleek (1993) has proposed a 90% reduction in material consumption in advanced economies by 2050. This target, known as 'factor 10', derives from the assumption that global abiotic resource extraction should be halved and shared equitably by 10 billion people by 2050, and it is supported by a number of scientific observations of how humans impact processes (Schmidt-Bleek, 1993). Industrialized countries should be forerunners in reducing their resource use because they have benefited from over-exploitation of the Earth's resources, have developed presently unsustainable lifestyles, and are able to develop and provide new solutions in production and consumption (Schmidt-Bleek, 1993, 2009; United Nations, 1992).

To use natural resources sustainably, we must use fewer resources more efficiently from the household to the national level and in both the public and private sectors. The role of households in reducing resource use to a sustainable level is vital (Caeiro et al., 2012; Lorek and Spangenberg, 2001), since the way households live is an important driver of overconsumption of natural resources (Bringezu et al., 2009; Lettenmeier et al., 2014b). Attempts to

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encourage sustainable consumption have not advanced significantly and household consumption continues to grow (e.g. Hobson, 2002; Mont et al., 2014; Tukker et al., 2010). This failure is due mostly to simplistic behavioral assumptions that overlook the socio-cultural aspects of daily practices (Doyle and Davies, 2013; Heiskanen et al., 2013). To understand the opportunities for transitioning towards lower household resource use, we must 1) compare material intensities of products and services, 2) quantify and understand how household consumption forms and changes, and 3) generate and evaluate alternative configurations (e.g. Doyle and Davies, 2013; Schroeder, 2010).

Even if we can address most of the resource use in the human economy to the consumption of individual households at some point, households can directly influence their material consumption only partially (Kopsakangas-Savolainen and Juutinen, 2013; Lettenmeier et al., 2014a). Existing infrastructure and prevailing services determine a basic level of resource use that exceeds sustainability limits even among minimum income receivers in an industrialized country such as Finland (Hirvilammi et al., 2013). Systemic changes call for alterations in the overall configuration of these systems, including technology, policy, markets, infrastructure, cultural meaning and scientific knowledge, in addition to consumer practices and how they are carried out (Geels, 2011; Schneidewind and Augenstein, 2012). As Liedtke et al. (2013) and Schroeder (2010) point out, research and innovations on sustainability need dynamic links between micro-level implementations and macro-level strategies, and vice versa.

This paper aims to take into account both of these premises of household consumption: We develop a new step-by-step method that goes beyond the approaches that have been used so far in studying sustainable resource use on the household level. Earlier approaches have concentrated on assessing the resource use of household consumption (e.g. Kotakorpi et al., 2008; Lettenmeier et al., 2012) and developing general visions for sustainable resource use on household level (Lettenmeier et al., 2014b). The Household-level Sustainability Transition methodology, or HST, goes further by developing visions for sustainable resource use on the level of households. On the basis of this it continues by experimenting low-resource consumption in the households and adds a learning and upscaling process including relevant stakeholders. In other words, HST encompasses the whole framework for transition towards low-resource consumption as proposed by Schneidewind and Scheck (2012). Thus, it opens options for achieving action for an absolute reduction in natural resource use in reality and is not limited to just stating the need for absolute reduction and generating general visions.

This paper also reports on the first application of HST in practice and presents the main results from a project in Jyväskylä, Finland. We then analyze whether this kind of transition approach is useful in targeting significant reductions in resource use at the household level, what is the role scientific knowledge plays in this transition, and how we can upscale the lessons from this qualitative study to the local level.

Section 2 presents the principles of the MIPS (Material Input Per unit of Service) methodology, as well as the transition approach and its application in the absolute reduction of household resource use. We also look at previous studies on the material footprints of households. Section 3 introduces the materials and methods, and Section 4 presents the results of our research project. In conclusion, in Section 5 we evaluate the significance of this kind of methodology for studying and more generally promoting sustainable consumption and offer suggestions for further research and action.

2. From household material flows to sustainability transitions

As noted in the introduction, we need to quantify the material intensity of our consumption practices, understand how to change these practices, and overcome the barriers to more sustainable consumption. We must focus on the links between supply and demand, on micro-as well as on macro-level dimensions. In the following section, we present two approaches: the material footprint calculation and the Transition-Enabling Cycle. We use them in our study to take into account the different aspects of sustainable resource use.

2.1. MIPS method in quantifying the sustainable level of natural resource use

To measure the system-wide environmental impacts of consumption, Schmidt-Bleek (1993) introduced the MIPS (Material Input Per unit of Service) concept. MIPS sums up the amount of natural material input (MI) required throughout the life cycle of a certain product or service in order to provide a specific benefit (called service, S). Material inputs are calculated separately for five resource categories: abiotic raw material, biotic raw material, soil movement in agriculture and forestry, air, and water (Ritthoff et al., 2002; Schmidt-Bleek et al., 1998) and then expressed in mass units such as kilograms. MI contains both the resources used in the human economy and the unused extraction (see Bringezu et al., 2003; Stricks et al., 2014).

Based on the MIPS concept, the material footprint sums up abiotic and biotic resources, as well as topsoil erosion in agriculture. Thus, the material footprint includes the same resource categories as the macroeconomic indicators TMC (total material consumption, or sum of household consumption, public consumption, and capital formation) and TMR (the total material requirement of all production and consumption activities) (Bringezu et al., 2003). Lettenmeier et al. (2009) propose using material footprint as a synonym for micro-level TMR (see also Ritthoff et al., 2002) in order to extend the footprint metaphor to the use of material resources. In this paper, we use the material footprint as a basis for quantifying household consumption.

Bringezu (2009) used national material flow calculations (e.g. Mäenpää, 2005; Seppälä et al., 2011 for Finland) to concretize the sustainable level of material resources use to approximately ten tonnes of TMC per capita. Of this TMC, Lettenmeier et al. (2014b) suggested allocating 80%, or eight tonnes, to households and 20% to public consumption, as public consumption (e.g. schools, universities, and defense activities) cannot be reasonably allocated to individual households. They constituted a preliminary proposal to allocate this benchmark of eight tonnes to different consumption components of nutrition (3 tonnes per person per year), housing (1.6 tonnes), mobility (2 tonnes) and other purposes (1.4 tonnes, respectively). This proposal is based on development of both consumption practices and technology that appears plausible on the basis of existing research results. However, Lettenmeier et al. (2014b) stress that their proposition is only one possible example of allocating the eight tonnes to these consumption components and it could be distributed differently according to individual households' demands and desires.

2.2. Transition-Enabling Cycle as a framework to sustainability transitions

Transitions can be seen as non-linear processes resulting from interaction at three levels: niches, socio-technical regimes, and the socio-technical landscape (for a multi-level perspective on transitions, see, e.g., Geels, 2002, 2011; Rip and Kemp, 1998; Schneidewind and Augenstein, 2012). The socio-technical landscape is characterized by large-scale developments and trends, rising from political ideologies, societal values, and economic patterns. Representing a lower level, regime refers to the structure and culture of social groups. (Geels, 2011, 27.) Here, locked-in mechanisms and practices can change due to innovations from niches. Kemp et al. (1998) and Schot and Geels (2008) have observed that niche innovations occur when small groups of actors engage in new practices, based on expectations and visions. Individual and social learning processes are essential for new routines to become a part of regime (Shove and Walker, 2010).

The sustainability transition approach derives from the conclusion that the factor 10 target can only be realized through transitions at different scale-levels and in multiple dimensions, such as technological, material, institutional, politic, economic, and socio-cultural (Rotmans and Loorbach, 2009; Schneidewind and Scheck, 2012; Shove and Walker, 2010). Overcoming barriers to sustainability transition require not only long-term strategies, but also processes of individual and social learning, as well as experimenting with ways to achieve these targets. Engaging actors in the process and developing societal pressure enables emerging niches to create new societal regimes. (Loorbach and Rotmans, 2010.)

Schneidewind and Scheck (2012) proposed a 'Transition-Enabling Cycle' for structuring transdisciplinary research on the German energy system's sustainability transition (fostering these transitions is also known as transition management; see, e.g., Rotmans et al., 2001). The Transition-Enabling Cycle consists of four successive fields: assessing the problem, developing a vision, implementing an experiment, and learning and upscaling (see Fig. 1).

The HST methodology follows the steps for transition management proposed by Loorbach (2007) and Loorbach and Rotmans (2006, 2010): It 'stimulates niche development' at the micro level by establishing the transition arena by measuring household resource use. It develops a sustainability vision and derives pathways for actors to these visions. It then prepares transition experiments for specific pathways, as well as learning goals for these experiments. According to Rotmans and Loorbach (2009), empowering niches by providing resources, such as knowledge, competence, and space for experimenting, is one of the key elements in the transition process. Finally, it gives suggestions for upscaling these experiments. Throughout the process, we monitor and evaluate the transition management process (Rotmans and Loorbach, 2009). Before we describe the framework for the HST methodology in more detail, we present the conclusions of previous studies on household resource use. We do not intend to provide a literature overview, but instead to sum up the lessons learned from these studies and point out how we apply these lessons in our research. Hence, we focus mainly on Finnish and European studies with a focus on material footprint assessment.

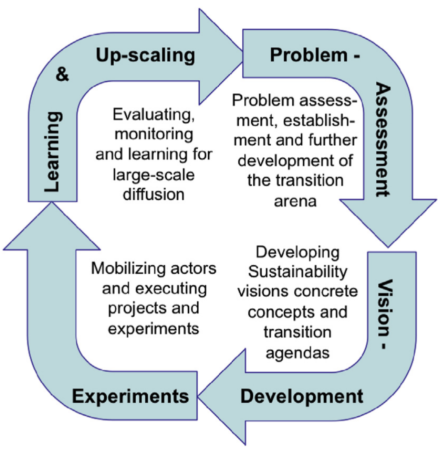

Fig. 1. Transition-enabling cycle (Schneidewind and Scheck, 2012).

2.3. From problem assessment to vision development — lessons from previous studies

Two micro-level projects have studied the material footprints of Finnish households. The 'FIN-MIPS Household' project studied the natural resource use of 27 households and a total of 78 members (Kotakorpi et al., 2008). Another study formed part of the project 'Back to basics: Consumption and basic income security' coordinated by the Social Insurance Institution of Finland. This study analyzed the material footprints of 18 single households living on basic social security (Hirvilammi et al., 2013; Laakso, 2011; Lettenmeier et al., 2012, 2014a). Of the 45 households examined in these studies, 44 exceeded the sustainable material footprint of eight tonnes by a factor of 1.5–15. The households with the smallest material footprints were minimum-income receivers who were less able to meet their basic needs, yet still exceeded the level of sustainable natural resource use (Hirvilammi et al., 2013).

In addition to the material footprint calculations, Kotakorpi et al. (2008) summed up the lowest results for each consumption category to quantify potentials for the absolute reduction of household resource use. They ended up at a 'factor 4 household' with a material footprint that was 25% of the average. They also quantified the reduction potential of one household and concluded that in the short term, this household could reduce its use of natural resources by 28%. This result, in addition to the factor 4 household, has served as a benchmark in developing the sustainable material footprint of eight tonnes (Lettenmeier et al., 2014b). These results were also the first to propose that within the prevailing system, it could be possible to reduce consumption by a factor of four. Hirvilammi et al. (2013), however, found that sustainable consumption also requires systemic changes. In other words, Kotakorpi et al. (2008) and Hirvilammi et al. (2013) contributed to our knowledge of household resource use and showed the need of transition to sustainability. Enabling this transition, however, will require guidance and governance that introduce visions and goals for the change (Smith et al., 2005; Lettenmeier et al., 2014b).

When it comes to proceeding from studying the resource use of household consumption to the whole Transition-Enabling Cycle, the 'SPREAD Sustainable Lifestyles 2050' project took some additional steps beyond the studies presented above. As part of the project, four scenarios for sustainable lifestyles in 2050 were developed based on the prerequisite of attaining a material footprint of eight tonnes per capita per year (Leppänen et al., 2012; Neuvonen et al., 2014). The backcasting method served to describe how changes in societies emerge and transform, and how experiments can serve as bottom-up drivers for transitions (Lähteenoja et al., 2013). Another part of the SPREAD project investigated how to reduce in practice the material footprints of 60 persons from four European countries (Finland, Germany, Hungary, and Spain) (Kuittinen et al., 2013; Groezinger et al., 2013). Material footprint calculations and interviews served as a basis for developing the current and future lifestyle profiles of the participants (Kuittinen et al., 2013). A large diversity of lifestyles was identified between the participants and their material footprints, ranging from 8.5 to 69 tonnes per person per year (Groezinger et al., 2013).

Indicators, such as the material footprint, that identify the key issues and rate of success can serve as 'powerful pedagogical and communicative tools' for transition towards sustainability (Lyytimäki et al., 2013, 389). Because these indicators offer no specific guidelines to decision-making, we must use them together with other tools and methods (Caeiro et al., 2012). The experiences of the SPREAD project provide valuable information on scenario use and the backcasting method in studies of sustainable consumption, and other European studies have also employed similar methods (e.g. Doyle and Davies, 2013). Kersten et al. (2014) highlight the role of participatory methods, such as workshops. As Lähteenoja et al. (2013, 1) point out, however, a 'lot of imagination is needed to understand how the shift from the current overconsumption can be turned into sustainable lifestyles for all. On the one hand, we need a deeper understanding on how to scale up current promising practices. On the other hand, we need to know how far these practices will take us towards sustainable living for all.'

In this paper, we use the whole Transition-Enabling Cycle as a framework to develop the HST methodology step by step in order to facilitate niche innovations that lead to socio-technical transitions. The following section proceeds to the HST methodology, which aims both at overcoming the shortcomings of the previous studies presented in this section and at including all phases of the Transition-Enabling Cycle for enabling households to achieve an absolute reduction in resource use according to the MIPS concept.

3. Broadening the perspective to the household-level sustainability transitions – data and methods

Section 2.3 exposed the need to combine methods from different studies of household consumption into a coherent whole that takes into account the different phases of transition. Next, we propose a methodology for broadening the view on the material consumption of households to cover the entire Transition-Enabling Cycle of Schneidewind and Scheck (2012), as presented in Fig. 1 in Section 2.2. The main steps of the methodology described here are: 1) assessing the problem by calculating material footprints for participating households, 2) developing household-specific visions in the form of roadmaps, 3) having participating households conduct experiments, and 4) learning and upscaling together with different stakeholders.

We applied the HST methodology the first time in Jyväskylä, Finland in 2014 in the 'Future Household' project coordinated by the Finnish Innovation Fund Sitra. The project began in April 2014 with a call for participating households. Five of the 40 households that applied were selected for the project. Due to the experimental and in-depth nature of the project, the number of households was limited to five. Moreover, testing this new and transdisciplinary approach first with a relatively small number of households seemed prudent.

The households included one single person (household A), one commune of two students (household B), two families with two and three children (households C and D), and one empty-nest couple (household E). Two of the households lived in the city center, one in a suburb and two in surrounding, smaller villages. In addition, the households varied greatly in terms of living space per person and car ownership. Due to the themes of the project (sustainability and resource-wisdom), we expected all households that applied to be at least somewhat interested in these issues. Kotakorpi et al. (2008), however, found no correlation between environmental consciousness and the material footprints of the households studied and this is in line with the results of other studies on the value-action-gap of consumption (e.g. Barr, 2006). When asked about their motivation to apply for the project, the households replied:

> *"I saw the announcement on Facebook. – We both thought that this sounds really interesting."*
>
> *"We thought that, well, since we are students, we cannot afford to consume that much, but we haven't thought about these issues from an ecological perspective at all, so we were thinking that it would be interesting to find out how to make ecological choices with a small budget. – But we haven't thought about any environmental issues previously; maybe this is a way to learn how to."* (Household B)

We interviewed the households for the first time in June 2014. The in-depth interviews covered the themes of everyday routines, consumption practices, and environmental attitudes. The kick-off event took place in August 2014, followed immediately by a three-week period for the consumption survey. The long interval between the interviews and the kick-off was due to the timing of the survey period: to obtain results from everyday living, we wanted measurements from the working term instead of from the holidays. The households monitored the consumption components of housing and nutrition (first week); household goods and leisure time activities (second week); and daily mobility, tourism and (where applicable) summer houses (third week). Based on feedback from the households in a previous study (Kotakorpi et al., 2008), we halved the duration of the survey period. We calculated the material footprints for the different consumption components from the data obtained during the survey period. The interview data complemented the data from the monitoring.

A central part of the vision development was a workshop in which participants co-created ideas for reducing the material footprints of the households. The households received their material footprint results from the survey period in advance. The workshop applied backcasting so as to propose for each household a material footprint target for 2030 as a halfway point from the present to a sustainable level of eight tonnes per person per year by 2050. The year 2030 served as a reference year for the workshop in order to keep changes more imaginable, as research (e.g., Lähteenoja et al., 2013) has identified the imagination of future lifestyles as a challenge. Assisted by the project team, the households developed ways to reduce their material footprints through both behavioral and systemic changes. On the basis of these ideas, each household created a roadmap detailing measures and pathways towards halving their material resource use. Previous studies (e.g., Kersten et al., 2014) have shown that such participatory methods are both valuable and empowering. The roadmaps served as the basis for the experimental part of the project. The material footprints and each household's target levels for 2030 appear in Fig. 2 in Section 4.

The households chose some of the ideas in their roadmaps to be implemented in a four-week experiment period that began in October 2014. We estimated that four weeks would be sufficient time for people to establish themselves in the new routines and forget the temporary nature of the experiments or, as Spaargaren (1997, 28–29) describes, to de- and re-routinize. The experiments included notable changes such as giving up a car or switching to a vegan diet. In addition, simulated services such as car-sharing and improved public transportation were part of the experiments. A more detailed description of the experiments appears in Table 1.

In addition, the households had ideas that were not implemented during the experiment period but were meant to be carried out in the near future. These included changing to eco-electricity, using a lendable cargo bike instead of a car, using insects as food, making renovations on the basis of the energy consultant's suggestions, replacing material-intensive hobbies with more resource-efficient ones, and cultivating own vegetables, for instance.

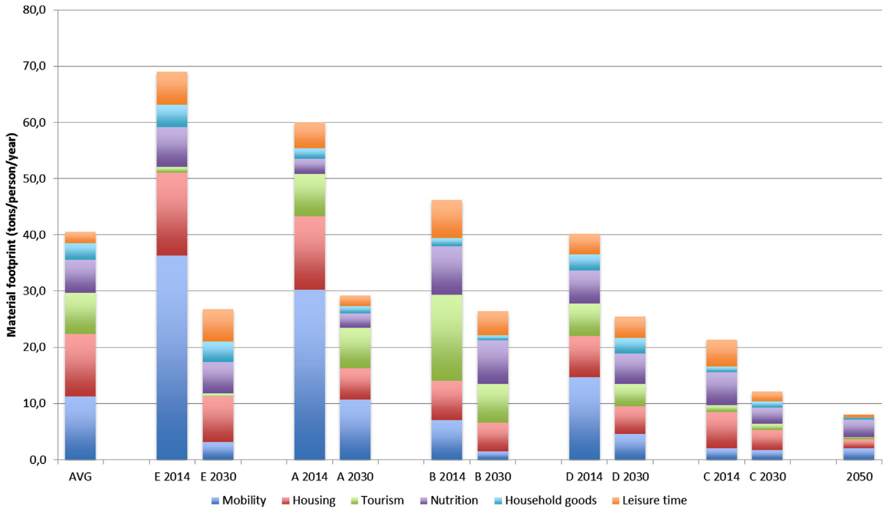

Fig. 2. Material footprints of the household at the starting point and the target levels for 2030. The material footprint of an average Finn is presented on the left and target level of eight tonnes per person per year on the right.

During the experiments, we made calculations on their effects to the material footprints, as well as observations on how the experiments affected everyday practices of households. The households shared their experiences in social media and the regional newspaper throughout the project. This facilitated the connection between the different phases of the Transition-Enabling Cycle, as households reflected the influence of the experiments to their everyday living and reduction targets.

After the one-month period of experiments, the households and the project team, together with infrastructure providers, service providers and municipal servants, discussed the experiences and results from the project. In this 'future workshop', ways of overcoming the barriers for sustainable lifestyles were brainstormed to find out possibilities for mainstreaming sustainable solutions. The roles of consumers, and public and private sectors in reducing natural resource use of household consumption were also discussed. The workshop was linked to the development of a new residential area, Kangas, next to Jyväskylä city center. The new area is designed on the basis of the 'One Planet Living' principle and the workshop aimed at supporting this principle by utilizing the results of the project.

After the workshop, we interviewed eight 'gatekeepers' of which three were public service providers (gatekeepers 1, 2, and 3), two private service providers (gatekeepers 4 and 5) and three local policy-makers (gatekeepers 6, 7, and 8), on their thoughts about the upscaling potential of the experiments. Four of these gatekeepers also participated in the workshop. In addition, we interviewed the households one last time after the final workshop. The content of these interviews was the course of the experiments and feedback on the whole project.

4. Results from the first application of household-level sustainability transition methodology

The material footprints of the households varied from 20 to 69 tonnes per person per year (see Fig. 2). The consumption components with most variation were everyday mobility, tourism, and housing. The high share of mobility in households D and E can be explained by the use of two cars in both households. Household C, on the other hand, did not own a car, which can be seen as a clearly smaller material footprint of daily mobility. When it comes to housing, the size of the house or the apartment reflects to the material footprint of housing. Household B had the highest material footprint of tourism. This was mostly due to weekend trips to meet families and friends in other Finnish cities. The material footprints of nutrition were close to the average in all but one household (A) whose material footprint for nutrition was below half of average due to low-meat diet. Household B, on the other hand, had the highest material footprint of nutrition due to higher than average consumption of meat and dairy products.

When we sent to households their material footprint results, most of them were surprised of the share of housing and mobility. On the basis of this observation, it was useful for households to receive their results in advance, as they had an opportunity to focus on the consumption components with the highest reduction potential when developing ideas for roadmaps. Kotakorpi et al. (2008) found that material footprints were an understandable way for illustrating the impacts of consumption, and this is in line with our findings.

> *"I started to like this MIPS method because it is so concrete.* I had no idea that we, our family, are so far from the sustainable level, and it was very concrete. – *We are such environmental criminals!"* (Household E)

As can be seen in Fig. 2, households aimed at halving their material footprints in their individual roadmaps. However, during the one-month experiment period all these reductions were not possible to achieve (like energy renovations on the basis of consulting). The households also faced some challenges during the experiment period: Household A had problems with finding public transportation connections due to varying working hours and household D had some atypical days, which made planning of mobility difficult. Household C moved to a new house in the beginning of the one-month period and it took time. On the other hand, they felt that the possibility to use car-sharing made going to

Table 1
List of experiments conducted during the four-week period.

House-hold		Topic fields	Actual experiments
A	Single	- Replacing 85% of own car use	- Using public transport and car-pooling, one remote working day per two-week period
		- Vegetarian diet	- Having three or more vegetarian days per week
		- Reducing the number of household goods	- Replacing goods with services
		- Resource-efficient exercising	- Reducing the need for infrastructure in exercising
B	Two students	- Giving up a car	- Using a shared car and car-pooling, home-delivery of food twice a week
		- Attention to energy use	- Conserving electricity and water
		- Resource-efficient eating habits	- Increasing the share of vegetables in daily diet
		- Reducing waste	- FiFo (first in, first out) concept simulating a smart fridge, reducing the amount of food waste and better sorting of waste
		- Reducing the number of household goods	- Replacing goods with services and using recycling services
C	Family with two children	- Using even less car than before	- Using shared car if necessary instead of borrowing one, home-delivery of food once a week
		- Attention to energy use	- Energy consultancy to the new home, reducing the need for extra space with general-purpose space design
		- Vegan diet	- Changing to whole vegan diet and using ingredients that are easily available (food of the season)
D	Family with three children	- Replacing 50% of own car use	- Simulating improved public transport, such as on-demand bus service, as well as existing public transport, car-pooling, and car- sharing. One remote working day per week for the other parent
		- Attention to energy use	- Reducing the need for extra space and making remote working possible
		- Vegetarian diet	- Replacing meat products with vegetables at every second meal.
E	Empty-nest couple	- Giving up second car	- Using public transport. One person works from home once a week
		- Smaller apartment	- Moving to a smaller apartment in the city center, also reducing the need for a car
		- Vegetarian diet	- Vegetarian meal once a day
		- Reducing the number of household goods	- Giving up extra clothes

hardware store easier and more frequent. Therefore, using the car-sharing service temporarily raised their material footprint of mobility compared to the survey period when they used mostly bicycles (see Table 2).

However, all household succeeded in dropping their material footprints considerably towards their roadmap targets during the experiment period. Significant absolute reductions in material footprints were made in different consumption components, as can be seen in Table 2. Mobility contributed most to the material footprint reduction in most cases. Tourism is not mentioned in Table 2 because during the experiment period no significant observations were made in the field of tourism.

From households' perspective the experiments succeeded well, all in all, and households mostly felt they had managed to change their everyday routines to be more sustainable. The households thought that they were going to continue some of the experiments, like using local buses, ordering home-delivery of food, and eating vegetarian meals. In other words, we can say that re-routinization happened at least in those areas of consumption where permanent behavioral changes were possible.

When it comes to learning, the households considered the support and knowledge from the experts helpful, especially in the areas of nutrition and energy solutions. Households shared their experiences with their colleagues, friends, and relatives and felt that they had acted as a positive example in their circle of acquaintances. They also told about these experiences to the participants at the final workshop. In other words, households passed on what they had learned during the project both horizontally and vertically.

> *"The focus on households was important to me in this project. It made these big things, which before this were too large to handle also for us, more human-sized."* (Household D)

The households could not predict whether the results from their experiments will have effect on a larger scale. They estimated, however, that their experiences make it easier especially for other households to understand the importance of their consumption behavior, as well as the need for new, more sustainable products and services.

The gatekeepers we interviewed had similar thoughts about the results of the project. The public service providers estimated that the project does have an upscaling potential, as there were representatives from different sectors at the final workshop who can take the results and discussions onwards. They all mentioned that the culture of experimenting is something that is needed in both supply and demand sides. The two private service providers highlighted the importance of acknowledging also the economic aspects of sustainable innovations and thought that gaining the 'critical mass' of consumers is one of the key elements in upscaling the results. All three of the local policy-makers estimated that the greatest value of the project was the concrete nature of the

Table 2
Material footprints of households at the starting point, their targets and achieved reductions during the experiments (tonnes per person per year).

Household	Starting point	Roadmap target 2030	Effect of experiments by consumption component					Experiment period result
			Everyday mobility	Nutrition	Housing	Household goods	Leisure time	
A	60100	29200	−12000	−600	−3300	−630	−2300	41300
B	46100	26400	−6300	−1000	−1900	−500	−2300	34100
C	21300	12100	+1000	−3400	−2900			16000
D	40200	25400	−5700	−2600	−2500			29400
E	69000	26800	−26700	−3500	−6700	−400		31700

experiments and examples provided by the participated households. They highlighted that it is important to take all the different actors into account in policy-making.

"If these kind of experiments are not done, how can we know whether the new practices work or not? This way we get real feedback from users and we can identify the shortcomings in time. – Experiments provide new kind of realism in developing new service models." (Gatekeeper 3)

"I believe that these examples the households have brought up, they make people to think about their own behavior. – From my opinion, these changes start from the dialogue between different actors and these results can be brought up during this dialogue." (Gatekeeper 7)

All of the gatekeepers interviewed brought up the idea that the results can be exploited, one way or another, in the development of the new residential area in Jyväskylä. Examples of this utilization include further testing of car-sharing services, common spaces in housing, and further implementation of the culture of experimentation in local decision-making.

5. Conclusions and outlook

In this paper, we have developed HST, a transdisciplinary methodology for improving Household-level Sustainability Transitions to achieve an absolute reduction in the resource use of household consumption. The HST methodology broadens the view from material footprint assessment to the whole Transition-Enabling Cycle. Households were engaged in the study not only by reporting about their consumption but also by participating in roadmapping, testing, and co-operating with local actors in order to facilitate upscaling. The new HST methodology goes beyond previous studies that focused on measuring footprints and identifying potentials for the absolute reduction of resource use. With the HST methodology households established their own roadmaps towards sustainable resource use. During the one-month experiment period, the households tested relevant options for an absolute reduction of their material footprints towards their personal target levels.

The Transition-Enabling Cycle provided a useful framework for developing the HST methodology and studying the new practices for achieving absolute reduction in material resource use. By doing experiments in households' everyday lives, the implementation of absolute reduction becomes real and measurable. Since the material footprint can be used to measure all aspects of consumption, it helps to keep the data produced understandable and manageable throughout the research process. This can be seen as strength when going through the whole transition process together with households and other actors.

The results show that achieving a significant absolute reduction in the material footprint of consumption is possible by making relatively few changes in the consumption practices of households. The results also show, however, that achieving these remarkable absolute reductions requires co-operation between end-users and product and service suppliers, as services like on-demand buses or car-sharing are not yet available on a wider scale. This co-operation becomes even more vital when the target is an absolute reduction to the sustainable level of eight tonnes of material resources per person per year. The encouraging result is that we do not have to wait until 2030 to be on the mid-point towards sustainable lifestyles but that point can be achieved even today (see household E in Table 2).

The small number of households made the in-depth nature of the study possible, and gave us new information on dynamics of everyday living and re-routinization of new practices. The observation of households gave us information on the successes and failures of more sustainable practices, and the reasons behind these successes and failures. This way, both scientific knowledge and user perspectives can be better used together to induce the sustainability transition and the absolute reduction in resource use so that the gap between macro strategies on sustainability and micro implementation in everyday life, as described by Liedtke et al. (2013) can be bridged.

It would be interesting to observe the development of the new routines in households and the upscaling of the results from the project at local level in the longer run. Due to the several projects conducted in Jyväskylä (e.g. Mattinen et al., 2014), of which the Future Household project was one, the City of Jyväskylä has pledged its support to sustainable development and 'resource wisdom' of the area. Hence, we can say that our aim to facilitate sustainability transition by experiments at the niche level may lead to developing options for mainstreaming more sustainable services, products, and infrastructure for the broader public, or in other words, socio-technical transitions at the local level. This can make absolute reduction in resource use reality on a much broader level than the specific households that participated in the project.

In the context of the Future Household project, with a small number of households and a surrounding already interested in solutions for the absolute reduction of resource use, the first application of the HST methodology succeeded well. However, five households in one city will not yet change the world. For the generalizations of the Household-level Sustainability Transition approach and the results of its first application, more projects and studies on household consumption need to be conducted. It would also be crucial to broaden the studies to include citizens that are not as aware of the challenges of sustainability as the participants in this study, as we can assume that the barriers they face might be different. Therefore, efforts should be spent on upscaling the HST approach to a much broader context and public. This could include IT-based approaches for consumption monitoring, material footprint calculation, and even roadmapping, testing and upscaling. Also service-providers like the ones participating in the experimenting period should be linked to this broader application of HST. We hope to inspire other researchers, as well as local actors, in different countries to establish similar projects in order to speed up the transition to sustainable consumption, as well as the absolute reductions in natural resource use.

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Paper 8

Lettenmeier, M. 2018. Design for One Planet – An orientation framework.

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Design for One Planet – An orientation framework

Manuscript in review

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Abstract

This paper contributes to the development of a Design for One Planet (Df1P) facilitating the transition towards sustainable lifestyles. Sustainable lifestyles are lifestyles that enable all humans on Earth to consume a decent amount of natural resources within the limits that one planet provides. This is defined as a material footprint of eight tonnes per person in a year, which current Western lifestyles exceed several times over. The paper aims at offering a practicable tool to design concepts that make sustainable lifestyles more attractive and accessible. It provides an orientation framework of Design for One Planet suggesting highly footprint-relevant measures that could be promoted by means of design. The measures are structured in a matrix incorporating priority action areas in the fields of housing, nutrition and mobility and four domains of design, i.e. product design, service design, infrastructure planning and communication design. A number of concepts designed by students were classified in order to evaluate the framework's coverage. The results show that the framework can help identifying relevant areas not covered by the processes prior to design tasks. The framework can help prioritize measures with an especially high influence on Lifestyle Material Footprints and uncover underrepresented design domains and fields of action. It thus can be used for evaluating whether design solutions focus on environmentally significant aspects of lifestyles.

Key words

One planet lifestyles, sustainable consumption, material footprint, MIPS, Design for One Planet

1 Introduction

Design basically affects anyone. Grillo (1960) calls design everyone's business and states that "whenever design loses contact with the public, it is on the losing end". Nowadays, 62 persons own as much as half of the world population (Hardoon et al., 2016), natural resources are used unequally (Dittrich et al., 2012), and human resource use threatens the earth's natural systems (Steffen et al., 2015). In order to remain everyone's business, design has to support the transition to sustainable lifestyles and respect the earth's ecological limits. As natural resource use by humans has grown for long (Krausmann et al., 2009), the transition required is considered similar to the industrial revolution (Haberl et al., 2011).

The role of design for promoting sustainability has been acknowledged for decades (e.g. Papanek, 1984; Tischner and Schmidt-Bleek, 1993). Numerous approaches have been launched to integrate sustainability aspects into design (e.g. Schmidt-Bleek and Tischner, 1995; Manzini, 1999; Knight and Jenkins, 2009; Lindsey, 2011; Liedtke et al., 2013). However, explicit research on the role of design in achieving one-planet lifestyles (i.e., lifestyles that the planet can support for the global population without ecological damage) is hard to find. Prior research shows that existing tools for eco-design fail to prioritize measures that support sustainable lifestyles because their focus is narrowly on products (e.g. Haemmerle et al., 2012; Ceschin and Gaziulusoy, 2016).

The purpose of this paper is to provide a building block for integrating the endeavour of one-planet lifestyles into design (see Fig. 1). Section 2 summarizes the discussion on the concepts and methods used for this paper and gives a summary of the empirical basis of the sustainable Lifestyle Material Footprint (see Empirical background and Challenge in Fig. 1 and section 2.2 for details). Section 3.1 gives the materials and methods used for the development of a structured framework of measures for providing inspiration and orientation to designers in terms of one-planet solutions. The results are presented and discussed in section 4 as a priority-based structured framework of measures to be designed (see Priority areas and Framework in Fig. 1). The potential application of the framework (see Application in Fig. 1) was tested on concepts students have designed in the context of sustainable lifestyles (sections 3.2 and 4.3). Section 4.4 analyses the application and section 4.5 discusses the use of the framework. Section 5 reflects on how the framework contributes to and what could be next steps for facilitating Design for One Planet (Df1P).

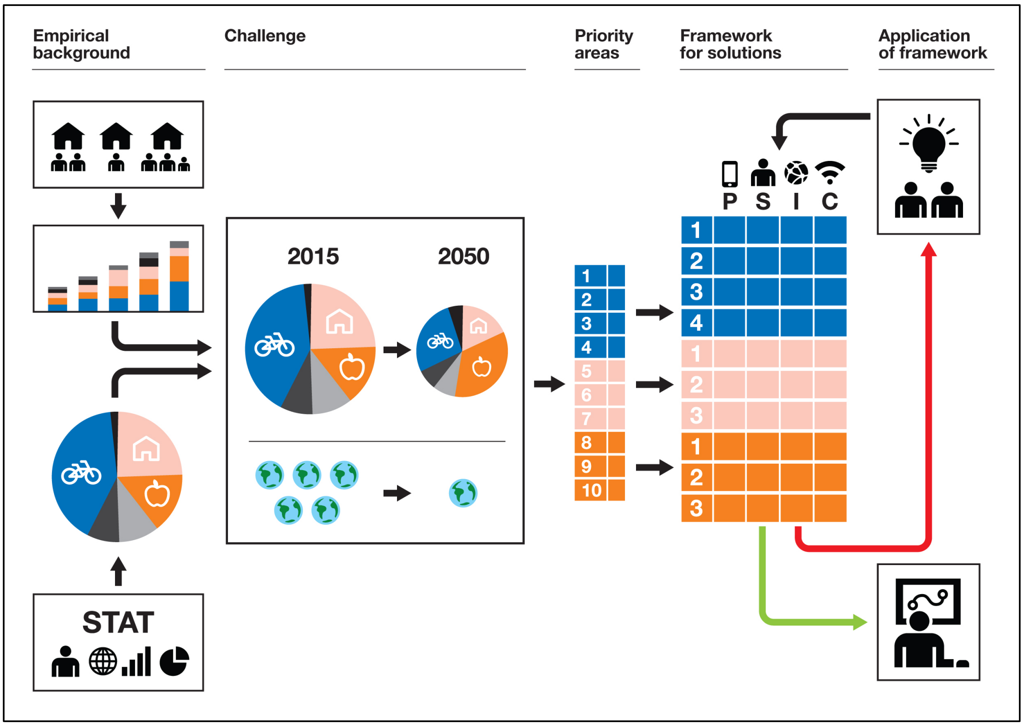

Figure 1: Background, development and potential application of the Df1P orientation framework. Source: own compilation. Graphics: Jalo Toivio.

2 Background and theory

2.1 Overconsumption of natural resources: the need for lifestyle transition

Developed civilizations have made extraordinary technical progress but "we have lost our conception of how to use our skills to put together an acceptable setting for our lives" (Pile, 1979). This is confirmed by numerous studies on human resource use. For instance, from 1970 to 2010 global raw-material use has tripled (Schandl et al., 2016). Resource use per capita per year for most industrialized countries is a factor 4-8 higher than the sustainable level suggested (Bringezu, 2009, 2015; Schandl et al., 2016). Resource use by humans exceeds planetary boundaries to various respects (e.g. Schmidt-Bleek 1993b, 2009; Dittrich et al., 2012; Wackernagel and Rees, 1998; Steffen et al., 2015; Lettenmeier et al., 2014.

Several authors have warned of the severe impacts human activities will have on natural ecosystems already decades ago (e.g. Meadows et al., 1972; Schmidt-Bleek, 1993b; Wackernagel and Rees, 1998). More recent studies have reported impacts and threats on a more detailed level. For instance, Steffen et al. (2015) state that especially in the case of biodiversity and biochemical flows, planetary boundaries are already being exceeded by far.

Already Smith (1776) called the welfare and consumption of households the ultimate purpose of economic activities. For the modern economy, e.g. Heiskanen and Pantzar (1997) state that consumption is the reason for producing anything. Household consumption makes up approximately 55 % of final use in the European Union, thus exceeding public consumption and capital formation (Watson et al., 2013). Globally, affluence and population are growing much faster than technological efficiency (Lorek and Spangenberg, 2014). To make consumption sustainable, greener goods and other individual issues are not sufficient but the resource intensity of Western lifestyles has to be reduced drastically (Heiskanen and Pantzar, 1997). Measures for reducing resource use and environmental impacts should address "key points" instead of "peanuts" (Bilharz and Schmitt, 2011). Therefore, design cannot sufficiently contribute to the sustainability transition of lifestyles by improving individual products and convincing people to buy them (Thorpe, 2010) but it has to broadly support the systemic transition to sustainable lifestyles (Ceschin and Gaziulusoy, 2016).

2.2 The Lifestyle Material Footprint: measuring the sustainability of lifestyles

Household consumption is one relevant driver of growing resource use and environmental impacts (e.g. Schandl et al., 2016; Jackson 2014; Tukker et al., 2008). For making consumption sustainable and setting the foci for efficiently reducing environmental pressure, the resource and environment implications of lifestyles have to be known.

Life cycle assessment (LCA) has facilitated the reduction of global environmental pressures on the level of products and services. However, LCA-based impact benchmarks (Nissinen et al., 2007; Jungbluth et al., 2012) still appear abstract and laborious. For designers, LCA seems to be a complex procedure requiring, in addition to time, also data that often does not exist (Bhamra et al., 1999; Knight and Jenkins, 2009).

Footprint calculations aim to render complex impacts understandable. The 'footprint' metaphor has been extended from surface area (Rees, 1992; Moore, 2015), to materials and mass units (e.g. Lettenmeier et al., 2009; Giljum et al., 2011; Wiedmann et al., 2015). The popular carbon footprint reduces LCA results to climate change. However, it is questionable if environmental impacts should be indicated on the basis of only one specific, though important, environmental problem (e.g. Jungbluth et al., 2012; Schmidt-Bleek, 2009).

The Lifestyle Material Footprint (Lettenmeier et al., 2012; Laakso and Lettenmeier, 2016) is based on the Material Input Per unit of Service (MIPS) concept (Schmidt-Bleek, 1993a, 1993b; Schmidt-Bleek et al., 1998; Liedtke et al., 2014). Some aspects of MIPS are debatable: Jungbluth et al. (2012) interpret MIPS as one specific environmental impact, i.e. material use, and Lindahl and Ekermann (2013) do not recognize that MIPS covers the whole life-cycle of products. However, the original idea of the MIPS concept is to reduce environmental problems at their source by decreasing material use throughout the life-cycle of products and services (Schmidt-Bleek, 1993a, 1993b; Spangenberg and Lorek, 2002) because environmental problems cannot be solved without an overall dematerialisation of the human economy (Ayres and Kneese, 1969; Schandl et al., 2016).

Early on, Schmidt-Bleek (1993b) introduced the basic idea of product-service systems replacing the thinking in terms of products, which has later been taken up in numerous design approaches (e.g. Manzini, 1999; Mont, 2002; Spangenberg et al., 2010; Vezzoli et al., 2015). By addressing the service products are finally providing, the MIPS concept can help to overcome the limitations of product-focused eco-design (e.g. Haemmerle et al., 2012). In addition, it could provide a comprehensible quantitative basis (e.g. Schmidt-Bleek et al., 1999; Lettenmeier et al., 2009; Liedtke et al., 2013) for developing ecologically sustainable design solutions.

The Lifestyle Material Footprint (LMF) covers the life-cycle-wide use of abiotic and biotic natural resources and the agricultural erosion caused by the lifestyle of a household or person. Lettenmeier et al. (2014) calculated the LMF available for an average person, given planetary boundaries and equal shares of resource use, and made a suggestion on how to allocate the sustainable LMF of eight tonnes per person in a year (see also Challenge in Fig. 1) to different consumption components like mobility, housing and nutrition.

The average LMF in Finland is 40 tonnes per person in a year (Lähteenoja et al, 2007; Laakso and Lettenmeier, 2016), which is manifold higher in comparison to average consumers in China, Brazil and India with 15, 11.5 and 8.5 tonnes, respectively (WBCSD, 2016b,a,c). Reasons for the high LMF in Finland are both the amount of consumption (e.g. in terms of kilometres, living space or meat) and its resource-intensity (e.g. high need for infrastructure). Households in other Western countries have similar LMF levels (see Greiff et al., 2017;

Kuittinen et al., 2012), which shows the need for reducing LMFs in Western countries. Also the *ecological footprints* of lifestyles in most countries exceed the one-planet level (Moore, 2013). Yet, huge differences in the LMF of individual households have been observed (Kotakorpi et al., 2008; Kuittinen et al., 2012; Lettenmeier et al., 2012; Laakso and Lettenmeier, 2016; Greiff et al., 2017).

Lettenmeier et al. (2014) point out that achieving a sustainable level of LMF is possible because numerous dematerialized solutions are already being developed on the production side, and the lifestyle changes required on the consumption side can already be found among existing households. Using the transition method described by Laakso and Lettenmeier (2016) households were able to reduce their material footprints considerably even in the short term while quality of life could even increase (Lettenmeier et al., 2017). However, making sustainable lifestyles mainstream still requires significant efforts. Hence, it is necessary to develop products, services and infrastructures enabling household to live within the limits of one planet.

As a basis of their Design for Sustainability DfS approach Spangenberg et al. (2010) disaggregate consumption efficiency into five factors and their background aspects. The sustainable LMF completes the DfS approach by providing a measurable target for ensuring the sustainability of lifestyles, thus responding to Lorek's and Spangenberg's (2014) call for a strong sustainable consumption perspective focussing, besides on technology, also on the resource consumption level and the physical size of the economy.

2.3 Design: creating solutions to support sustainable lifestyles

The previous sub-sections described the need and opportunities for achieving sustainable lifestyles by reducing LMFs to eight tonnes per person in a year. The change will be enormous but it can also provide enormous opportunities for better life (e.g. Lettenmeier et al., 2017) and new business (e.g. WBCSD, 2016a,b,c). Design works at the interface of lifestyle and business, or consumption and production (Thorpe, 2010; Spangenberg et al., 2010). This section deals with the relevance of design in supporting sustainable lifestyles.

Thorpe (2010) asks if design can acquire "a substantial role in supporting sustainable consumption" instead of "being a cog in the wheel of consumerism". She tends to see designers on the problem side, because the design stage fixes 90 % of a product's environmental impacts and eco-design has not sufficiently linked consumers to upstream environmental and social impacts. She opens a role for designers in facilitating "strategies that help us meet needs with fewer purchased solutions" but questions if there exist sufficiently design methods and if designers are adequately educated for new, sustainable-consumption-oriented approaches.

Design can "contribute to imagining and proposing new ways of organising daily life" and can engage people in actively making their lifestyles sustainable (Marchand and Walker, 2008; Manzini, 2015). Vezzoli et al. (2015) underline the role of design in developing product-service systems creating well-being "while operating within the limits of our planet". Haemmerle et al. (2012) stress the interdisciplinarity of design because wicked problems require radical innovation. In a design-oriented, resource-light future scenario called "Society of Creation" Liedtke et al. (2015a) give design a role in resource management, especially in relation to business models for low-resource product-service systems.

This paper contributes to the vision of better life designers require (Spangenberg et al., 2010; Manzini, 2015) by providing a "portfolio of diverse lifestyle changes to meet the challenges of sustainability" (Thorpe, 2010) in the form of a framework that helps designers prioritize solutions that are relevant for achieving one-planet lifestyles.

2.4 Principles for a Design for One Planet

On the basis of the literature analysed, the following principles for a Design for One Planet (Df1P) could be identified:

1. Recognition of the limits of natural resource use (e.g. Schmidt-Bleek, 1993b; Rockström et al., 2009; Lettenmeier et al., 2014);
2. Integration of the reduction of resource use into design solutions (e.g. Luttrop and Lagerstedt, 2006; Spangenberg et al., 2010; Liedtke et al., 2013; Vezzoli et al., 2015; Liedtke et al., 2015b; Pettersen, 2016);
3. Assessment or quantification of the use of natural resources (e.g. Schmidt-Bleek and Tischner, 1995; Lettenmeier et al., 2009; Knight and Jenkins, 2009);
4. Setting reduction targets for natural resource use in design, which are able to achieve a five percent reduction per year (based on Bringezu, 2015; Lettenmeier et al., 2014);
5. Search for new solutions on a broad basis, in order to enable the identification of solutions for one-planet resource use (e.g. Haemmerle et al., 2012; Thorpe, 2010; Vezzoli et al., 2015; Manzini, 2015);

6. Development of and experimentation with new business and action models in close cooperation with consumers (e.g. Vezzoli and Manzini, 2008; Thorpe, 2010; Liedtke et al., 2015a, 2015b; Vezzoli et al., 2015; Manzini, 2015; Laakso et al., 2017; Lettenmeier, 2018).

The framework developed in the following is intended to serve as a building block on the way to a broader application and conceptualization of a Df1P.

3 Methods

3.1 Orientation framework of Design for One Planet (Df1P)

The framework contains a structured list of solutions that are based on priority action areas for achieving a sustainable lifestyle of eight tonnes of material footprint (see Fig. 1 in section 1). The framework represents solutions required ('what solutions do we need?') rather than ways to achieve them ('how to design solutions?'). The framework aims to inspire designers by offering exemplary solutions to the long-term vision of a sustainable life in future society (Spangenberg et al., 2010; Manzini, 2015) and the "portfolio of diverse lifestyle changes to meet the challenges of sustainability" (Thorpe, 2010). At the same time, it allows an evaluation of solutions designed. The framework presents a portfolio of solutions that are particularly relevant for reducing LMFs. It was established in the following way.

The structure of the framework is based on the following criteria that are elaborated in more detail below:

1. The most relevant consumption components in terms of LMF according to numerous studies (e.g. Lähteenoja et al., 2008; Tukker et al., 2008, 2010; Lettenmeier et al., 2014).
2. The priority action areas required under each consumption component in order to achieve a LMF of eight tonnes, based on Lettenmeier et al. (2014).
3. Four domains of design that are sufficient to cover the preconditions for sustainable household consumption (Spangenberg et al., 2010).

The framework concentrates on the three central components of household consumption: Nutrition, housing and mobility make up 92 % of the present Finnish LMF and 89 % of the sustainable benchmark target of 8 tonnes according to Lettenmeier et al. (2014). This corresponds well to the results of other studies on the life-cycle impacts of consumption both in Finland (Lettenmeier et al., 2012; Lähteenoja et al., 2008; Nissinen et al., 2015) and Europe (Tukker et al., 2008, 2010; Watson et al., 2013; Greiff et al., 2017). Household goods, like home electronics, clothes and furniture, are included in the component of housing because they are often closely related to housing.

The priority action areas of the framework follow Lettenmeier's et al. (2014) "core statements" summarizing the most relevant measures for reducing the material footprint of nutrition, housing and mobility. Priority action areas help to tackle the highest impacts instead of expending efforts on individual products (Heiskanen and Pantzar, 1997). Table 1 in section 4.1 presents the priority action areas together with central arguments for naming these areas and the corresponding references.

The third criteria for structuring the framework was the division into four domains of design, i.e. product design, service design, infrastructure planning, and communication design. These design domains integrate the three preconditions for sustainable households, motivation, social acceptance and availability of alternatives (Spangenberg et al., 2010) into the portfolio of necessary solutions. In addition to product and service design, the role of infrastructure planning cannot be neglected because the infrastructure people use in their daily life heavily influences the available choices and possible changes in consumption and lifestyles (Hertwich, 2005). The material footprint largely takes infrastructure into account (Schmidt-Bleek et al., 1998; Lettenmeier et al., 2014).

With ten priority action areas against four domains of design the basic framework forms a matrix of 40 fields. Each of these fields was filled with one to three quick examples of solutions that need to be designed, drawing on preliminary work by Lettenmeier (2015). Each solution presented in the framework is given a code in order to facilitate working with the framework. The code consists of a letter (N, H, M) for the consumption component, a number (1 to 4) for the priority action area within a consumption component (see also Table 1), a letter for the design domain in questions (P, S, I, C), and another number (1 to 3) for the number of the solution in each field of the matrix.

Section 4.2 shows the framework in three matrices (Tables 2-4) for the consumption components of nutrition, housing and mobility, together with the example solutions. The following sections 3.2 explains a first application of the framework.

3.2 Application of the framework on examples of solutions designed by students

The framework can be applied in different ways. First, it can be a "portfolio of sustainable solutions" (Thorpe, 2010) during the creative process in order provide designers inspiration, orientation and the opportunity to understand which kind of solutions are priorities for the transition of lifestyles. Second, it can be used to evaluate if solutions developed in a certain context are able to address relevant areas in terms of lifestyle transition (see Application in Fig. 1). In this case, one could draw conclusions in terms of gaps and their reasons in relation to the framework. Both applications can also be used for planning, implementing and/or evaluating education.

In this paper, the framework was tested by evaluating design solutions in order to find out if the framework can demonstrate the relevance of solutions developed by designers. It was applied on solutions and concepts for the world of tomorrow developed by students from design majors at three universities. The solutions were created before the framework was developed, but they were created after an introduction to concepts like overconsumption of natural resources, footprinting and sustainable consumption. The solutions and concepts were designed in the context of Zwanzig52 (2016), a project of the Club of Rome Germany aiming at making the Club of Rome's ideas tangible for relevant actors in society to promote sustainable solutions for everyday life.

Section 4.3 categorizes the solutions and concepts designed in Zwanzig52 (2016) into the framework by naming the measures represented in the framework in relation to each solution or concept designed. The evaluation thus provides an idea on the potential of the designed solutions and concepts to result in relevant reductions of LMFs.

4 Results

4.1 Priority action areas for design solutions

The priority action areas of the Df1P orientation framework are displayed in Table 1. The framework uses three priority action areas for both nutrition and mobility while housing is complemented by a fourth priority action area that is related to household goods. The priority action areas are not exhaustive for two reasons. First, in real life, the lifestyles of consumers differ a lot and can show different foci, and, second, the nature of a priority area is to prioritize and not to encompass everything. The formation of the priority areas is described in detail in section 3.1.

Table 1: Consumption components and priority action areas of the Df1P orientation framework.

Consumption component	Priority action areas	Central argument and reference for naming the priority action area
Nutrition	Mostly plant-based food (N1)	Animal products make up 64% of the average Finn's Material Footprint for nutrition (Lähteenoja et al., 2007)
	Reduction of food intake (N2)	Up to 1,5-fold differences in direct food intake between 13 EU countries (Mancini et al., 2012)
	Minimizing food waste (N3)	Material footprint of food waste in Germany notable: 1185 kg/(cap*a) (Lettenmeier and Rohn, 2012)
Housing	Resource-efficient zero energy houses (H1)	Heating has the greatest share (35%) in the material footprint of an average Finn's housing (Lähteenoja et al., 2007)
	Reduction in living space (H2)	Living space and its heating amount to 62% of an average Finn's material footprint of housing (Kotakorpi et al., 2008)
	Resource-smart electricity production and consumption (H3)	Factor 10-30 resource-efficiency potential of wind and solar power in comparison to conventional power (Rohn et al., 2013)
	Resource-smart household goods (H4)	Household goods production contributing with 7.5% to LMF of average Finn. Factor 10 diversity between 27 different households studied. (Kotakorpi et al., 2008)
Mobility	Kilometre cap (M1)	Transport performance of appr. 16,000 km/(cap*a) of average Finn (Lähteenoja et al., 2007) and of appr. 14,000 km/(cap*a) of "Three-Plus-Planets" lifestyle archetype (Moore, 2013)
	Resource-efficient public transport (M2)	Public transportation already factor 3-6 better than private cars (Lähteenoja et al., 2006), further efficiency potential existing, especially in cities (e.g. Talja et al., 2006)
	Minimizing private car traffic (M3)	Car traffic causes 93% of mobility-related and 40% of total material footprint of an average Finn (Lähteenoja et al., 2007)

4.2 The orientation framework of Design for One Planet

This section provides the structure of the framework and gives examples of solutions for the different priority action areas and design domains. Tables 2-4 give the framework in simple matrices and examples for solutions in each field of the matrix. In total the three tables contain 90 solutions in 40 fields.

Table 2. Df1P orientation framework in the field of sustainable nutrition.

Priority action area **Design domain**	**N1** **Mostly plant-based food**	**N2** **Reduction of food intake**	**N3** **Minimizing food waste**
P **Product design**	1 Attractive food products replacing meat and dairy 2 Kitchen equipment facilitating plant-based food preparation	1 Plates, dispensing equipment and packaging supporting smaller portions	1 Plates, dispensing equipment and packaging supporting smaller portions 2 Products from foodstuffs otherwise becoming waste
S **Service design**	1 Attractive meals and menus replacing meat and dairy 2 Integration of footprint data in shops' and restaurants' sale (labels, receipts, etc.) 3 Services facilitating urban gardening	1 Integrating portion size into meal pricing 2 Replacing quantity by quality when designing and offering meals	1 Appealing meals from foodstuffs otherwise turning waste 2 Discount on foodstuffs approaching their expiration date or looking slightly affected
I Infrastructure planning	1 Improving preconditions for even small-scale urban gardening 2 Kitchen and restaurant equipment facilitating plant-based food preparation	1 Buildings and interior design facilitating varying portion sizes	1 Buildings and interior design facilitating the use of surplus foodstuffs
C **Communication design**	1 Communicating the benefits of plant-based meals and diets (advertising, advice, nudging, information, etc.) 2 Footprint information in different contexts (packaging, advertising, advice, nudging, labelling, mobile apps, info, etc.) 3 Shifting status symbols and role models from meat to attractive plant-based products	1 Communicating health and other benefits of eating less (advertising, advice, nudging, information, etc.)	1 Highlighting the benefits of waste prevention in the communication and marketing of shops and restaurants 2 Pointing out the relativity of expiring dates in the appropriate foodstuff groups

Table 3. Df1P orientation framework in the field of sustainable housing.

Priority action area / Design domain	**H1** Resource-efficient zero energy houses	**H2** Reduction in living space	**H3** Resource-smart electricity production and consumption	**H4** Resource-smart household goods
P Product design	1 Product concepts promoting energy efficiency in residential buildings 2 Durable, repairable, maintainable, etc. products for the home 3 Products promoting energy-efficiency and longevity in existing houses with indoor air still healthy	1 Multifunctional products with compact storage 2 Replacing quantity by quality in design and provision of household goods	1 Further minimization of power use of devices, e.g. standby and auto-turn-off 2 Devices communication with the grid and working while wind and solar power available 3 Options for local storage of electric power	1 Replacing quantity by quality when designing and supplying goods 2 Durable, long-lasting and multifunctional products
S Service design	1 Service packages making energy efficiency and related investments easily accessible for consumers 2 Service concepts telling building energy efficiency already during planning and selling 3 Footprint calculators for house planners, renovators, buyers, etc.	1 Service concepts for replacing ownership without increasing car use 2 Services and mobile apps enabling neighbours using each others' products and space 3 Services making space use more efficient	1 Service concepts integrating power supply fluctuation in pricing and use of power 2 Services illustrating solar power options for any building 3 Services enabling anybody to install solar energy and to efficiently use it at home	1 Service concepts providing benefits without ownership and still without additional car use 2 Services and mobile apps enabling neighbours using each others' products and space 3 Services enabling consumers to manage with fewer goods
I Infrastructure planning	1 Durable, repairable maintainable, flexible and otherwise resource-light buildings and their components 2 Increasing share of wood as main building material of houses 3 Designing garden landscapes close to their natural state and without heavy foundations	1 Buildings and apartments with efficient and low use of space 2 Buildings and blocks providing shareable space and rooms (washing rooms, guest rooms, workshops, storage, etc.) 3 Houses and apartments that can easily be arranged for short- and long-term renting	1 Public and local grid facilitating the residential utilization of power supply fluctuation 2 Integrating solar and wind energy production and storage in buildings and infrastructure 3 Preparing for future reduction in power and heat use when planning power stations	1 Buildings and blocks facilitating shared use of household goods
C Communica-tion design	1 Communication concepts highlight-ting use phase energy efficiency already during planning and selling 2 Footprint info to building planners, constructors, renovators and users 3 Shifting status symbols and role models towards smart and compact future solutions	1 Communicating the benefits and attractiveness of small living space 2 Means of communication facilitating shared use of goods and space	1 Communicating the benefits of solar and wind power 2 Communications tools displaying the applicability of any building for solar power production	1 Communication concepts facilitating sharing goods and space 2 Communication between producers /importers and consumers to foster repairing and shared use of goods 3 Communication of footprint data related to household goods (advice, advertising, labelling, apps, etc.)

Table 4. Df1P orientation framework in the field of sustainable mobility.

Priority action area **Design domain**	**M1** **Kilometre cap**	**M2** **Resource-efficient public transport**	**M3** **Minimizing private car traffic**
P **Product design**	1 Cars especially suitable for shared use	1 Easily accessable and usable means of transport	1 Cars especially suitable for shared use 2 Means of public transport attractive for different users
S **Service design**	1 Location and organization of services to be used without private cars 2 Ride-sharing services 3 Service packages for spending holidays nearby	1 Attractive, safe and easy-to-use public transport system 2 Pricing facilitating travelling outside rush-hours	1 Demand-based transport services in the middle ground between present public, taxi and car transport 2 Services for planning entire travel chains also including footprint data 3 Public transport services with easy access and attractive prices
I Infrastructure planning	1 Easily accessible, attractive car-free blocks and neighbourhoods 2 Placement of leisure venues and recreation areas close to the residents 3 Taking future smaller mobility needs into account in infrastructure planning to avoid overcapacity	1 Street and neighbourhood infrastructure facilitating public transport use	1 Location of services to be used without private cars 2 Preferring public and bike traffic in public space and street planning by weakening car traffic where necessary 3 Placing parking space to the edge of residential areas, at least as far as public transport stops
C **Communication design**	1 Mobility calculators taking into account total mileage and footprint data 2 Applications helping to find everyday leisure and holiday activities on short distance 3 Shifting status symbols and role models from long-haul to nearby holidays	1 Means of communication facilitating and rewarding public transport use 2 Communicating the convenience and sustainability aspects of public transport	1 Understandable instructions for using public transport to events and venues 2 Shifting status symbols and role models from car traffic to attractive and healthy alternatives

4.3 Example of applying the Df1P orientation framework to evaluate design concepts

The framework developed in the previous sections is tested by applying it to design solutions developed by students in a project context (Zwanzig52, 2016; see section 3.2 for details). Table 5 gives an overview on the concepts and solutions designed in the framework of Zwanzig52. The table provides the name and a short description of each design solution and categorizes the design solutions in terms of the Df1P framework by providing the code of the related measure(s) in the framework. The potential effects in terms of material footprint reduction are roughly quantified in the last column of the table. The quantification is based on the material intensity data used in previous Finnish LMF studies (Kotakorpi et al., 2008; Lettenmeier et al., 2012; Laakso and Lettenmeier, 2016). It has been estimated as the expected reduction in the LMF of an average Finn (Lähteenoja et al., 2007; Lettenmeier et al., 2014) if the solution designed were to completely replace the previous solution to the same consumer need. The potential effects are classified in very little effect (+), some effect (++) and considerable effect (+++) to be expected, meaning <20, 20-200, and >200 kg/(cap*a), respectively. For communication concepts, possible maximum effects were marked in brackets and are based on the assumption that the issue communicated were completely implemented by the average Finn and would completely replace the previous solution in use.

Table 5: Concepts designed in Zwanzig52 (2016) and their relation to the framework.

Name (and English translation)	**Description**	**Position in framework**	**Rough quantification of effects**
Indicative interface	Indicative interface to prevent youth from overusing computers	H3P1	++
Papiersparen im Büro (Saving paper in office)	Concept for saving paper in offices	–no direct relation–	+
Seeanemonen-Sessel (Arm chair)	New techniques to produce design furniture from waste textiles	H4P1, H4P2	++
Nachhaltiger Versand-karton (Sustainable cardboard packaging)	Reusable package for camera objectives that can be used as also for storing	H4P1, H4P2	+
Labor für Zucht und Ordnung (Biological laboratory)	Fablab, laboratory and design agency for sustainable biological materials and democratizing science	–no direct relation–	–not quantified–
Geschirrspülen im Single-Haushalt (Dish-washing in a single household)	Ultrasound dish-washing device than can be temporally installed in a sink	H3P1	++
Lebensmittel wegwerfen? (Food waste?)	Combination of fridge and shelf to avoid food waste by storing food too long and forgetting it	N3S1, N3I1, H3P1	++
Motivations-App	Mobile application encouraging people to implement their plans	–no direct relation–	–not quantified–
Eltingmöbel (Elting furniture)	Product design and design products from items for disposal	H4P2	++
Tütentausch statt Plastik-rausch (Bag exchange)	Collection point for re-using shopping bags	–no direct relation–	+
Yaranga – Umzugskarton und Möbel (Moving box and furniture)	Portable furniture system on the basis of a stackable box that can be used also during moving	H4P1, H4P2	+
Modulares Erbstück (Modular inheritance)	Durable, modular furniture system on the basis of wood modules with metal junctions	H4P1, H4P2	++
Der hippe Schuster (Hipster shoemaker)	Schoemaker toolbox allowing to repair also sneakers and other modern shoes in order to prevent them from disposal	H4S3, H4C2	+
Ole, Lage für Lage (Layer soap)	Simplified, resource-light soap system for showering	–no direct relation–	+
Recup	Closed material cycle system for the collection and close-loop recycling of mugs for drinks to go	–no direct relation–	+
Carly – Dein persönlicher Ressourcen-Tracker (Personal resource tracker)	Mobile tracking gadget application giving immediate information on the material footprint of activities incl. social media elements to increase motivation	M1C1	(+++)

Truegum – nachhaltiger Kaugummi (Sustainable chewing-gum)	Biodegradable chewing gum from biological materials	–no direct relation–	+
Wipp Lounge	Board game questioning conventional consumption patterns and providing sustainable alternatives	No relation to specific measures mentioned but suitable for N1C1, N1C3, N2C1, H1C3, H2C1, H3C1, M1C3, M2C2, M3C2	(+++)
Warum Früchte Heimweh haben (Homesickness of fruits)	Book for children addressing globalizing foodstuff transportation and the usefulness of seasonal nutrition	–no direct relation–	(+)
Sonntagsbraten (Sunday roast)	Movie addressing different aspects of high-impact meat production and consumption	N1C1, N1C3	(+++)
Aus dem Häuschen (From home)	Magazine opening sustainable lifestyle options for young people moving to and in Cologne	No relation mentioned but suitable for N1C1, N1C3, N3C1, H1C3, H2C1, H2C2, H4C1, M1C3, M2C2, M3C2	(+++)
Tagesblatt Kalender 2017 (Daily calendar)	Calendar giving daily hints for sustainable choices to people without internet	No direct relation mentioned but suitable for N1C1-3, N2C1, N3C1-2, H1C3, H2C1-2, H3C1, H4C1, H4C3, M1C3, M2C1-2, M3C2	(+++)
Bee-Square	Business model selling urban beekeeping modules. e.g. beehives or greening roofs	N1S3, N1I1	+
Düsseldorf Kaffee (Düsserldorf coffee)	Mobile application collecting points for each cup of responsible coffee purchased and providing hints for other responsible choices	No direct relation mentioned but suitable for e.g. N1C1-3, N2C1, N3C1-2, H2C2, H4C1, H4C3, M2C1	+
Pendelverkehr 2052 (Commuting 2052)	Combining sustainable commuting measures in 2052, e.g. community office, urban cycling, public transport, bus sharing	M1P1, M1S1-2, M1I3, M2S1, M2C1, M3P1, M3S1-3, M3I1-2	+++
Virtual Explorer powered by Deutsche Lufthansa	Simulating and replacing travelling by virtual, haptic, olfactory, acoustic and gustatory sensuous experiences supported by virtual reality glasses, special suites etc., incl. a transition model for Lufthansa	M1S3, M1I2	+++
Manna and Wachtel, die saisonale Sandwichküche (Seasonal sandwich kitchen)	Franchising concept for a moving snack kiosk selling vegetarian, vegan, seasonal and regional snacks on university campuses	N1P1, N1S1	++
Fungifarm	Holistic concept for mushroom cultivation and products that facilitate regenerating overused soils and new businesses for farmers (food, bio-based plastic, vegan leather, fruits and juices)	N1P1, N3P2	++
Bilbo	Online platform for compiling individual, adventurous, unique and low-footprint trips in a spirit of slow travelling.	M1S3, M1C1, M3S2	(++)

4.4 Interpretation of the results

This sub-section discusses the results of the previous sub-sections. It thus gives an example how the application of the Df1P orientation framework can provide conclusions on the ability of design solutions to promote one-planet lifestyles. For evaluating a range of design concepts in a setting like in sub-section 4.3, one can, first, assess how the concepts developed match with the framework's priority action areas and the measures under them, a 'match' meaning a measure in the D1fP framework that is covered by at least one of the solutions designed. On the basis of this, one can, secondly, identify and discuss 'blind spots', meaning measures in the framework not covered by any of the concepts designed. These blind spots might show areas not covered by the design brief or teaching underlying the design work. Thirdly, the distribution of the matches and blind spots within the framework can help to evaluate or make transparent the comprehensiveness of a design education curriculum.

Out of the 90 examples in the Df1P framework (see Tables 2 to 4), 19 are related to product design, 27 to service design, 21 to infrastructure planning, and 23 to communication design. When looking at the distribution of matches by design domains in the test of the framework (Table 5), product design has the strongest representation, followed by service design, with 17 and 13 matches respectively. Infrastructure planning and communication design both have only six matches each. However, communication design could have 43 matches if the communication concepts proposed but not specified by content were applied to all possible measures in the framework. The distribution of matches by consumption components is the following: The total number of matches is 10 in the field of nutrition, 14 in housing and 18 in mobility. Mobility is also the only field with matches in all three priority action areas. The priority action areas with the largest number of matches to the concepts designed were N1 (vegetable-based nutrition), H4 (resource-smart household goods) and M1 (kilometre cap).

When it comes to the identification of blind spots, roughly half of the measures in the framework were not matched by the design concepts in Table 5. Priority action areas N2 (reduction of food intake), H1 (resource-efficient zero energy houses) and H2 (reduction in living space) were without direct matches. These missing matches represent two fields especially: the interior, equipment and activities of kitchens and restaurants, and several aspects of housing.

Out of the 29 concepts studied (Table 5), eight could not be directly linked to the framework. These were mostly concepts not covered by the framework (e.g. chewing gums, disposable mugs or work-related concepts). Four communication concepts (gadget application, board game, magazine, calendar, see Table 5) did not directly mention specific measures for reducing footprints but they could be utilized for promoting multiple relevant measures in the framework. One concept has links to more than five measures in the framework because it tackles future mobility in a holistic manner. Roughly half, i.e. 14 of the concepts are focused in a way that they relate to only one or two measures in the framework.

For evaluating the functionality of the Df1P orientation framework, Table 5 also shows a rough quantification of the potential LMF effects of the concepts designed (for the quantification procedure, see section 4.3). The effects of five out of six concepts without direct relation to the framework were estimated as very low. Out of the seven communication concepts, five could potentially have considerable effect if applied and implemented extensively. Out of the 15 concepts directly related to the framework, five are of very little, eight of some, and two of considerable effect. Both concepts with considerable effects are mobility-related while nutrition-related concepts are classified to have some effect. Three of the five concepts with very little effect are related to priority action area H4 (resource-smart household goods).

4.5 Discussion

The test application of the framework as given in Table 5 shows that infrastructure planning was weakly represented in the students' design concepts, probably because infrastructure is not the central focus of design studies. However, infrastructure planning is an important factor influencing household consumption and LMFs (Hertwich, 2005; Lettenmeier et al., 2012), The framework could thus guide designers' views onto the relevance of infrastructure planning.

The majority of the concepts the students developed (Table 5) have a potential for reducing households' material footprints. However, the effects of the concepts evaluated range from very little to considerable effects. The concepts not related to the framework are of relatively low relevance in terms of one-planet lifestyles, which is a positive sign in terms of the framework's usefulness.

Out of the design solutions covered by the framework, not all were quantified particularly relevant, or represent "key points" (Bilharz and Schmitt, 2011). Especially solutions related to the priority action area of resource-smart household goods (H4 in Tables 1 and 3) are of minor quantitative relevance for reducing footprints. This corresponds to the results of LMF analyses (Kotakorpi et al., 2008; Lettenmeier et al., 2012; Laakso and Lettenmeier, 2016) where household goods are not of central importance. In the concepts studied household goods were also closely related to product design, and the narrow focus of product-related eco-design has been identified a challenge in literature (e.g. Spangenberg et al., 2010; Haemmerle et al., 2012; Ceschin and Gaziulusoy, 2016).

By developing an orientation framework for Df1P, this paper contributes to the challenges related to the narrow focus of product-related eco-design (Spangenberg et al., 2010; Haemmerle et al., 2012; Ceschin and Gaziulusoy 2016). On the basis of its first application, the framework appears useful for guiding design and communication solutions towards relevant fields, for evaluating in which way a concept helps to pursue sustainable lifestyles, and for contributing to a vision of sustainable future (Spangenberg et al., 2010; Manzini 2015) and a portfolio of diverse lifestyle changes (Thorpe, 2010).

5 Conclusions

5.1 Summary: Role of the framework in developing a Design for One Planet

This paper contributes to the challenges of eco-design in relation to sustainable lifestyles (Spangenberg et al., 2010; Thorpe, 2010; Haemmerle et al., 2012; Ceschin and Gaziulusoy, 2016) by developing and testing an orientation framework for Design for One Planet (Df1P). The framework rests on priority action areas that are based on results of empirical research on the material footprint of lifestyles (see Fig. 1 in section 1). It offers a structured approach to identifying solutions for reducing Lifestyle Material Footprints (LMF) towards a sustainable level (Lettenmeier et al., 2014). The framework contains ten priority action areas in the most important consumption components identified by literature: nutrition, housing and mobility. These consumption components are related to four domains of design (product design, service design, infrastructure planning, and communication design) in a matrix, resulting in 90 measures that require design solutions in order to support sustainable lifestyles (see Fig. 1). The framework shows that solutions to a large range of relevant challenges can be developed in the different domains of design.

The Df1P orientation framework can be used in different ways. It can be used to check if an idea developed can contribute in a relevant way to promoting sustainable lifestyles, one of the hugest challenges of our time. If the idea is related to the solutions provided by the framework, it could be developed further into a design solution (black and green arrows under Application in Fig. 1). Otherwise the idea might be refined in order to better address the one-planet lifestyle challenge (red arrow in Fig 1). The framework can also be used for the evaluation of concepts developed in an education-related context. It can show how solutions developed can contribute to relevant reductions in LMFs and where possible gaps can be found. By showing priority areas as well as underrepresented design domains in a larger sample of design exercises, the framework can help to highlight crucial aspects for achieving relevant design outcomes in terms of one-planet lifestyles.

With respect to the Df1P principles given in section 2.4, the framework helps to fulfil principles 1 and 2 as it is based on the eight tonnes material footprint benchmark of sustainable resource use (Lettenmeier et al., 2014). By focusing the view on the priority action areas identified most relevant on the basis of quantitative assessment (see section 3.1 and Fig. 1), the framework also relates to principles 3 and 4 of Df1P. By suggesting measures that are identified as urgent the framework can help to put efforts on principles 5 and 6 but it does not provide design tools or methods to this end. The framework as presented here can thus be one though not the only building block for Df1P.

5.2 Future work

The following limitations of the Df1P orientation framework presented in this paper should be known and tackled by future research and application in order to facilitate Df1P: The framework is not exhaustive and there can still be other solutions for considerably reducing households' material footprints. The framework also should be reflected in the context of LMFs of other countries because its present basis is in Finnish lifestyles (see Lettenmeier et al., 2014).

The further development of Df1P could seek to integrate quantitative assessment and target-setting into design processes. It could open up design methods to facilitate a holistic dematerialization of the service or purpose aspired. So far, the framework does not provide an immediate tool for assessing resource use and setting reduction targets. It could be developed into that direction, for instance by adding quantified examples to each of the 90 solutions proposed in the framework in a second layer of the matrix. Although this would result in a more complex matrix, it could improve the usefulness of the framework and help introduce aspects of quantitative relevance into design work, thus providing a possible approach to quantification-related principles 3 and 4 of Df1P, as identified in section 2.4.

A future version of the framework could be sharper if household goods were left out of the consumption component of housing. This would have notably increased the relevance of the solutions covered by the framework in the test application and further decrease the product design focus of the framework. In addition, this would conform with the studies on the material footprint of household consumption that separate housing and household goods from each other (e.g. Greiff et al., 2017; Laakso and Lettenmeier, 2016; Lettenmeier et al., 2012; Lähteenoja et al., 2008).

To make designers understand and position themselves as active change agents in the first row (Liedtke et al., 2015a), designers' education will play a crucial role. Therefore, in a further step the Df1P orientation framework should be tested in design education in order to see how it works when applied before solutions are designed, and integrated into educational materials and appropriate assignments. The framework could also be used to evaluate the relevance of solutions given in exhaustive handbooks for eco-design (e.g. Fuad-Luke, 2002; Vezzoli and Manzini, 2008; Proctor, 2009) or sustainable design (e.g. Proctor, 2015) in terms of transition to sustainable lifestyles.

In order to develop detailed implications for design and design education, detailed guidelines should be developed on how to apply the Df1P orientation framework and also the Df1P idea as a whole in different contexts.

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List of Abbreviations

C	Communication Design
Df1P	Design for One Planet
DfS	Design for Sustainability
H	Housing
I	Infrastruture Planning
LCA	Life Cycle Assessment
LMF	Lifestyle Material Footprint
M	Mobility
N	Nutrition
MIPS	Material Input per Unit of Service
P	Product Design
PSS	Product-Service System
S	Service Design
WBCSD	World Business Council for Sustainable Development

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How can we know which lifestyles are sustainable? How can we make our lifestyles sustainable? How can designers contribute to sustainable lifestyles?

This thesis provides answers to these questions. It develops a benchmark for sustainable lifestyles: 8 tonnes of material footprint. This is only 20% of the current Finnish average. By applying the 8 tonnes benchmark, households were able to cut their Lifestyle Material Footprint by tens of percents when redesigning their lifestyles. The thesis shows what a sustainable lifestyle could look like and how the Lifestyle Material Footprint can help detect the critical factors behind our unsustainable lifestyles.

For designers, the thesis has developed an orientation framework for Design for One Planet (Df1P). The framework provides numerous examples for sustainable solutions to be developed by product design, service design, infrastructure planning and communication design. The thesis thus hopes to inspire designers to adopt Df1P in their work.

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