SOCIAL METABOLISM IN FINLAND FROM THE PERSPECTIVE OF NATIONAL MATERIAL FLOWS

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ABSTRACT

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Social metabolism in Finland from the perspective of national material flows

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In this master's thesis the social metabolism in Finland was concerned from the perspective of the national material flows of biomass, fossil energy materials/carriers, metal ores and non-metallic minerals and their domestic material consumption. The source of data was Official Statistics of Finland free databases and the selected reference point of time year 2019. The hotspots of material categories were defined based their high contribution to the total domestic material consumption of the material category. To illustrate the relationship between social metabolism and domestic material consumption, the domestic material consumption of these hotspots was halved and the potential implications of the reduction on different sectors and the metabolic rate were discussed.

The identified hotspots were subcategories of wood within biomass, liquid and gaseous energy materials/carriers within the fossil energy materials/carriers, non-ferrous metals within the metal ores and sand and gravel within the non-metallic minerals. Halving the domestic material consumption of these hotspots reduced the total domestic material consumption from approximately 250 000 thousand tonnes to 140 000 thousand tonnes. Consequently, the socioeconomic metabolism, in a form of metabolic rate, decreased from 45 tonnes to 25 tonnes. The implications of reduced domestic material consumption were considered from the perspective of economic activities and provided with examples considering various sectors. Operationalising reductions would however require significant changes in urban structures, national economy, and contemporary lifestyle to an arguably unrealistic extent. The results of this master's thesis should only be view as directional due to limitations and uncertainties related to the study.

The domestic material consumption can be reduced through the reduction of consumption of materials in absolute terms. The current production and consumption patterns in Finland cannot be considered sustainable from the perspective of planetary boundaries. One of the requirements for sustainability is limiting the social metabolism within the capacity of natural environment, which enables the transition towards more sustainable society.

TIIVISTELMÄ

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Ohjaaja: Fatemeh Jouzi

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Tässä diplomityössä tarkasteltiin sosiaalista metabolismia Suomessa kotimaisen materiaalien kulutuksen näkökulmasta. Tarkasteltavat materiaalivirrat olivat biomassa, fossiiliset energiamateriaalit, metallimalmit ja ei-metalliset mineraalit. Työssä tarkasteltiin vuoden 2019 materiaalivirtoja ja jokaisesta materiaalikategoriasta määritettiin niin kutsuttu hotspot, eli materiaalialakategoria, jonka kotimainen materiaalin kulutus oli korkein kyseisen kategorian sisällä. Työssä käytettiin Suomen Tilastokeskuksen dataa, joka noudatti kansainvälistä kansatalouden materiaalivirtatilinpitoa. Sosiaalisen metabolismin ja kotimaisen materiaalien kulutuksen välisen yhteyden kuvaamiseksi, määritettyjen materiaalikategoria kohtaisten hotspottien kulutus puolitettiin. Työssä kuvattiin tämän puolittamisen teoreettisia vaikutuksia eri sektoreihin, sekä Suomen sosiaalisen metabolian tasoon.

Määritetyt hotspotit materiaalialakategorioittain olivat puu (biomassa), nestemäiset ja kaasumaiset energiamateriaalit (fossiiliset energiamateriaalit), ei-rautaiset metallit (metallimalmit) sekä hiekka ja sora (ei-metalliset mineraalit). Näiden hotspottien materiaalikulutuksen puolittaminen vähensi kotimaisten materiaalien kokonaiskulutusta noin 250 000 tuhannesta tonnista 140 000 tuhanteen tonniin. Vastaavasti sosiaalisen metabolismin taso laski 45 tonnista per henkilö 25 tonniin per henkilö. Materiaalikulutuksen puolittaminen vaikutuksia tarkasteltiin eri sektoreilla ja materiaalikulutuksen vähentämisen vaatisi merkittäviä yhteiskunnallisia muutoksia, jotka eivät nykytilassa näyttäydy realistisilta. Tämän työn tuloksia voidaan pitää vain suuntaa antavia rajoitusten ja epävarmuuksien takia.

Kotimaisten materiaalien kokonaiskulutusta on mahdollista vähentää vähentämällä absoluuttista kulutusta. Nykyinen kulutustaso Suomessa ei ole kestävää planetaaristen rajojen tai kestävän kehityksen kannalta tarkasteltuna.

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SYMBOLS AND ABBREVIATIONS

Abbreviations

DE	Domestic extraction
DMC	Domestic material consumption
EW-MFA	Economy-wide material flow accounting
EX	Exports
IM	Imports
km	Kilometre
kWh	Kilowatt hour
MF	Material footprint
TJ	Terajoule
tpa	tonnes per annum
RME_{IM}	Raw material equivalent of imports
RME_{EX}	Raw material equivalent of exports

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1 Introduction

The pressure human activities place on Earth system today is unprecedented. In the inspection of 2023 six of the total nine planetary boundaries were transgressed and a further transgression had occurred in the boundaries that were in the previous inspections identified as exceeded. The increasing anthropogenic disturbances confront constantly weakening stability and resiliency of Earth system thus challenging the biophysical preconditions of human societies. (Richardson et al., 2023.) The increased use of natural resources of industrialised societies is responsible for the anthropogenic perpetuation of critical Earth system processes. The socio-economic flows of material and energy have thus altered global biogeochemical cycles engendering a new geological era of Anthropocene. (Krausmann et al., 2017; Steffen at al., 2015.) To approach the biophysical basis of human societies and its capacity to provide for human activities, the concept of social metabolism is applied in this master's thesis to the national material flows. The aim of this master's thesis is to describe how national social metabolism, as a conceptual approach to sustainability, can be reduced through the reduction of domestic material consumption and to discuss the potential implications of the reduction on different sectors, such as transportation sector. Also, possible sustainable consumption corridors are discussed in general.

1.1 Theoretical framework

The concept of social metabolism, the societal form of establishing and maintaining material inputs and outputs between society and nature and organizing the exchange of matter and energy in natural environment, describes the material-based relations between society and nature. In the centre of the concept is the analysis of the flows of material, energy, and information. The studies on social metabolism have increased since the late twentieth century when the concept received further interest in the field of socioecological studies. The socioeconomic transition of social metabolism has been considered in several studies of Fisher-Kowalski et al. and Krausmann at al. to mention a few (Fischer-Kowalski et al., 2007 & 2014, Krausmann et al., 2008 & 2016). Traditionally, national-scale analyses of material and energy flows has focused on the economic parameters, such as gross domestic product.

The concept of social metabolism however, enabled the assessment of human activity impacts on natural resources using ecological indicators, such as ecological footprint. (González de Molina & Toledo, 2014; Krausmann et al., 2017.)

The connection between material exchanges and exclusively social factors are recognised in the concept of social metabolism, widening the sociological perspective to the biophysical analysis of society and nature exchanges. Social metabolism provides a conceptual framework for socioecological change towards sustainable society. In this master's thesis the issue of social metabolism is approach through the material dimension of social change. The material flows of organic and mineral resources that constitute the material basis of society are studied from the perspective of reducing national social metabolism. The focus is on the material exchange between nature and society. The sociological dimension, the flows of information, of social metabolism is not further discussed in this master's thesis. This leaves the analysis of social metabolism incomplete thus constituting only a partial view of the issue, regardless of the immaterial dimension of information flows providing the framework for these material processes concerned. (González de Molina & Toledo, 2014.)

1.2 Methodological framework

To operationalize the concept of social metabolism, a method derived from socio-economic metabolism framework, an economy-wide material flow accounting, is applied to the used data of Official Statistics of Finland. The system boundary is defined according to the economy-wide material flow accounting framework. The national material flows are thus studied as flows from environment to an economy, domestic extractions, and as flows from an economy to environment, domestic processed outputs. Solid, gaseous, and liquid materials are studied within the physical interaction between a national economy, other economies, and natural environment. Material flows within an economy are not included into accounting. These physical structures of society, defined as material stocks, compromise humans, livestock, and in-use artifacts. The framework does not include bulk flows of water and air. (Krausmann et al., 2017; Eurostat, 2018.)

Together with domestic material consumption, material footprint addresses the issues of production and consumption of an economy. Domestic material consumption describes the actual amount of material, when material footprint is the virtual amount of material required throughout the supply chain to meet the final demand of an economy. As the metabolic rate of a nation is described as domestic material consumption per capita of population, the reduction of social metabolism in Finland is approached trough the reduction of domestic material consumption of material flows of biomass, fossil energy materials/carriers, metal ores and non-metallic minerals. (UN, 2022ab.) The implications of reduced domestic material consumption are considered from the perspective of economic activities and provided with examples considering the sectors of housing, industry, transportation, and construction.

The research question of this master's thesis is how the relationship between national material flows and social metabolism can be described using a methodology of an economy-wide material flow accounting to understand the consumption patterns of natural resources and their sustainability implications within a national economy. The case study of this master's thesis demonstrates how the methodology of economy-wide material flow accounting framework can be utilised in a context of social metabolism through a national material flow analysis.

In this master's thesis the issue of production and consumption is firstly concerned from the perspective of planetary boundaries and the biophysical basis of human societies. The inspection is then broadened to the concept of social metabolism that is shortly introduced and provided with discussion on decoupling material use from environmental degradation. Also, the concept of sustainable consumption corridor is introduced. The methodology of economy-wide material flow accounting and indicators of material footprint and domestic material consumption are concerned within an overview on the development of the global material footprint and domestic material consumption. In the empirical part following the theoretical part of this master's thesis the national material flows of biomass, fossil energy materials/carriers, metal ores and non-metallic minerals are considered, and the hotspots of these material flows identified. The domestic material consumption of the hotspots is reduced by 50 % to illustrate the relationship between the social metabolism and domestic material consumption and its impacts on national metabolic rate. Lastly, the process of conducting this master's thesis is discussed and the findings of the master's thesis concluded.

2 Issue of production and consumption

This chapter concerns the main concepts of this master's thesis. The issue of production and consumption is approached through the introduction of planetary boundaries and social metabolism provided with discussions on decoupling of material use from environmental degradation.

2.1 Planetary boundaries

For the past 10 000 years the environmental state of the planet Earth has been stable. The regulatory capacity of Earth has maintained natural conditions within narrow range and changes in the environment have occurred for natural reasons during this period of stability, the Holocene. The Industrial Revolution and the era of Anthropocene has challenged this environmentally desirable state that enabled the development human civilisations. The human activities of industrialised societies have now become the main drives of environmental change. (Rockström et al., 2009.)

To prevent environmental change caused by human activities Rockström et al. proposed a framework of planetary boundaries in 2009. The aim of these planetary boundaries was to define the safe operating space for human activities within the Earth system and its biophysical subsystems and processes. The recognition of system complexity emphasised the sensitivity of thresholds levels of key variables. The cross of these the thresholds would cause subsystem changes that would have negative impacts on humans. (Rockström et al., 2009.)

The nine planetary boundaries were defined based on the associated thresholds of Earth-system processes generating irreversible environmental change when crossed. Boundaries of interrelated processes of biophysical Earth system are values for control variables that indicate the distance from thresholds. Quantifying of planetary boundaries comprehend uncertainties on thresholds positions thus safe operating space being processes with evidenced threshold behaviour and dangerous operating space being processes with no evidenced threshold behaviour. (Rockström et al., 2009; Stockholm Resilience Centre, 2023.)

The transgression of planetary boundaries has progressed during the years of 2009—2023. In 2009 the control variables of climate change, biogeochemical flows and biosphere integrity were transgressed, and the variable of land-system change in 2015. In the inspection of 2023 six of the total nine planetary boundaries were transgressed as the variables of novel entities and freshwater change acquired dangerous operating space. A further transgression has also occurred in the boundaries that were in the previous inspections identified as exceeded. The variables of stratospheric ozone depletion, atmospheric aerosol loading, and ocean acidification are still within the safe operating space. (Stockholm Resilience Centre, 2023; Richardson et al., 2023.) The Figure 1 describes the status of planetary boundaries in 2023.

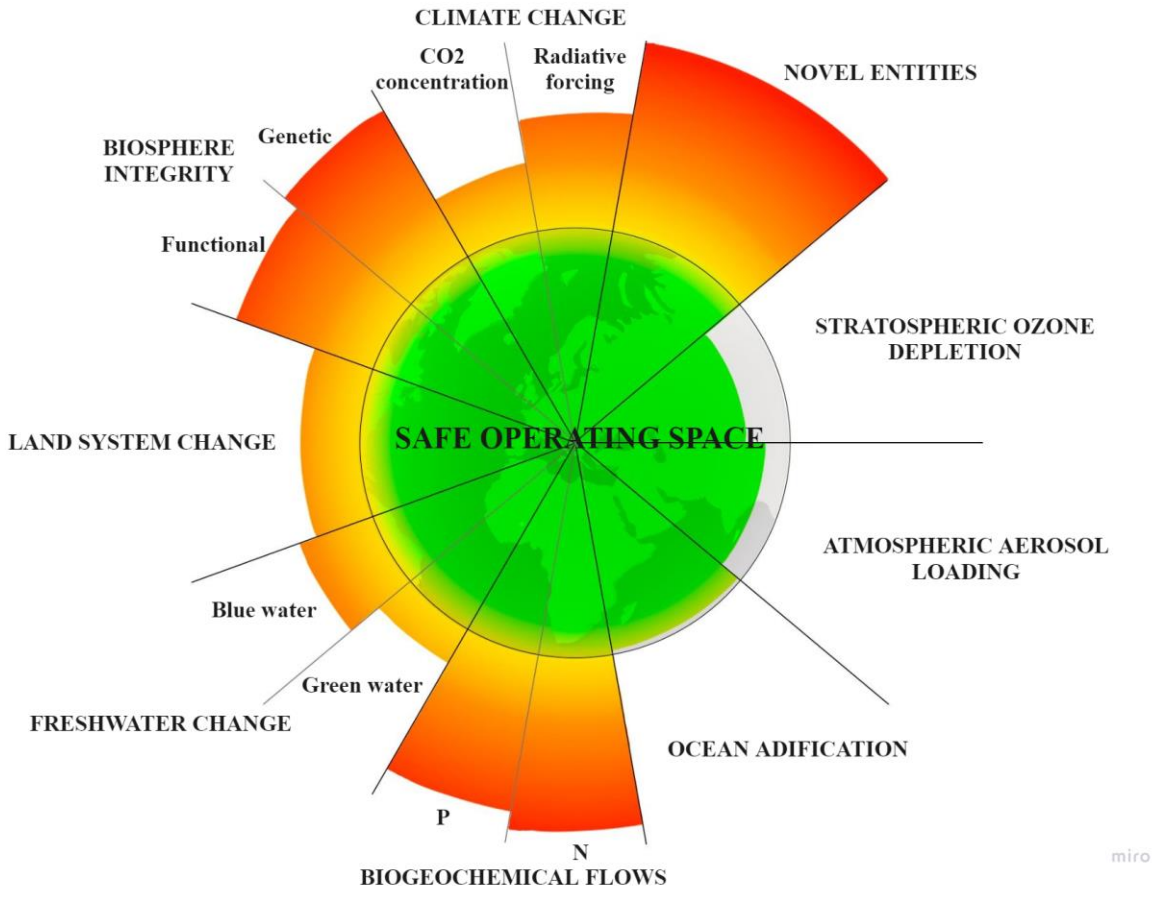

Figure 1. The planetary boundaries in 2023 (Stockholm Resilience Centre, 2023 based on analysis of Richardson et al., 2023).

The biophysical preconditions for human development can be approached from the perspective of Earth’s sustaining capacity in relation to the scale of human activities. This planetary boundary-based approach emphasises the significance of environment in terms of providing wellbeing for human societies. The interconnection of planetary boundaries leads to a situation where transgression of a boundary puts other boundaries under risk as the framework of planetary boundaries concerns biophysical preconditions for human development from systemic view. (Rockström et al., 2009.)

2.2 Social metabolism

Defined by Fisher-Kowalski and Haberl in 1997 the concept of social metabolism was standardised as the societal form of establishing and maintaining material inputs and outputs between society and nature and organizing the exchange of matter and energy in natural environment. It describes the material-based relations between society and nature. The concept refers to biological metabolism being an analogy to it, as social metabolism recognizes the flows of material and energy within the society to maintain its functions. (González de Molina & Toledo, 2014; Fisher-Kowalski & Haberl, 1997.)

The origin of the concept of social metabolism dates in the nineteenth century even though it did not receive further interest in the socioenvironmental studies until late twentieth century. (González de Molina & Toledo, 2014; Fisher-Kowalski & Haberl, 1997.) The concept is mentioned already in the works of Karl Marx. Around the midterm of twentieth century Ayres and Kneese (Ayres & Kneese, 1969) developed the concept further in their works approaching the social metabolism from the perspective of material balances on which the modern concept of social metabolism bases on. In the centre of the modern concept of social metabolism was that continuous material and energy flows are a prerequisite for the functioning of physical structures of society. These physical structures comprehended the infrastructure, the biophysical elements, such as humans, and the artifacts of the socioeconomic systems both spatial and temporal scales. Social metabolism is thus a theoretical and methodological tool to socioecological system change which can be operationalised through the economy-wide material flow accounting. (Krausmann et al., 2017.)

2.2.1 Process of social metabolism

The process of social metabolism occurs between society and nature. From the theoretical point of view, it begins with material and energy being harnessed from natural environment by society and ends to the disposal of artefacts, such as waste, to the natural environment, that society has produced during the metabolic process. Input flow, inner flow, and output flow are the three flows of material and energy of social metabolism. The metabolic process within the society is represented in five functions of appropriation, transformation, circulation, consumption, and excretion. These functions and their relations are described in the Figure 2. (González de Molina & Toledo, 2014.)

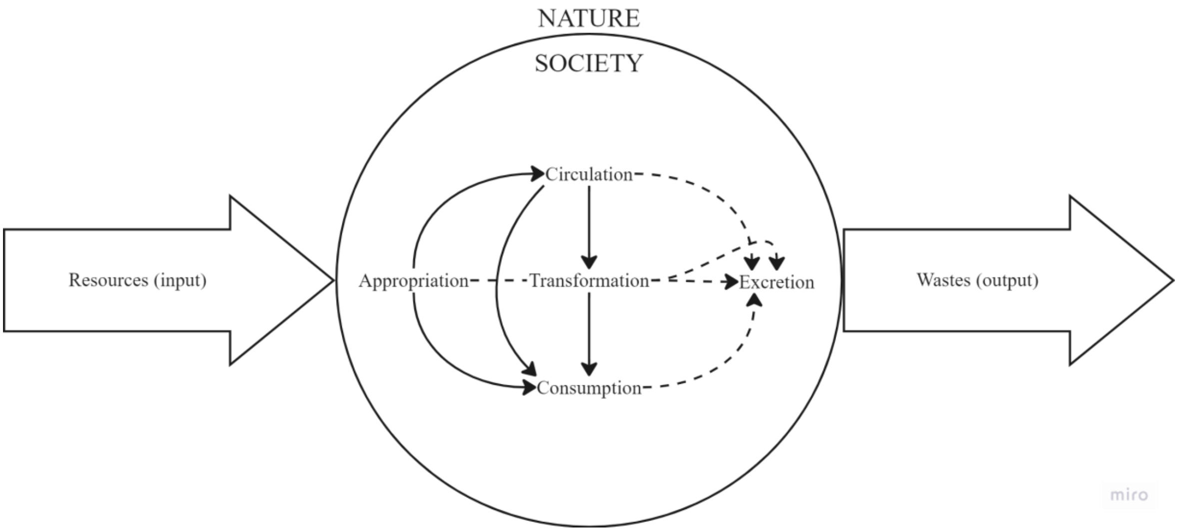

Figure 2. The five functions of the process of social metabolism (González de Molina & Toledo, 2014).

The function of appropriation considers the exchange of material and energy between society and nature. Society is dependent on this exchange that enables its functions by providing material and energy for needs of human beings and their artifacts. The function of transformation considers the modification of extracted material or energy from nature to new form it is further consumed when the function of circulation considers the circulation of extracted material and energy from nature. It begins when appropriation unit, that is responsible for carrying out the appropriation, meets the need of consumption with its production. The function of consumption considers the utilization of material and energy and their products resulted from appropriation, transformation, and circulation. (González de Molina & Toledo, 2014.)

2.2.2 Regimes of social metabolism

From the process of social metabolism to its regimes, the societal use of material and energy has changed during the human history. The number of materials extracted has drastically increased within growing population and per capita consumption. The way societies use materials, and the composition of used materials has also changed. (Fisher-Kowalski & Haberl, 1997; Krausmann et al., 2008 & 2017.)

According to Fischer-Kowalski and Haberl, the three main regimes of social metabolism are hunter-gatherers, agriculturalists, and industrial society. These socio-metabolic regimes are justified by the fundamental system characteristics that define the regime. Metabolic transition occurs when these biophysical requirements are transcended by emerging metabolic regime. The Neolithic revolution, from hunter-gatherer to agrarian regime, and industrial revolution, from agrarian to industrial regime, are the major socio-metabolic transitions from the global historical perspective. The metabolic regimes are characterised by their metabolic profiles. (Fisher-Kowalski & Haberl, 1997; Krausmann et al., 2008.)

Domestic material consumption per capita is one of metabolic indicators of which metabolic profile of a regime is characterised by. In Table 1 the domestic material consumption per capita is presented as for three different socio-metabolic regimes. The used domestic material consumption per capita of industrialised societies is a typical value for economies fully industrialised. (Krausmann et al., 2008.)

Table 1. Domestic material consumption per capita of metabolic regimes (Krausmann et al., 2008).

	Hunter-gatherers	**Agrarians**	**Industrials**
Domestic material consumption per capita (tonnes/capita/ year)	0.5—1	3—6	15—25

The metabolic profiles were investigated by Krausmann et al. in 2017 who analysed the material and energy use of regimes in a long-term. They suggested that the global material use has increased from 0.003—0.006 gigatonnes per year to 1.8—3.6 gigatonnes per year from the Neolithic Revolution to the beginning of the Industrial Revolution. In 2010 the global material use reached a level of 70 gigatonnes per year. The increase in material extraction within the industrialisation growth has been drastic as in 1900 the global material use was 7.1 gigatonnes per year and in 1950 14.0 gigatonnes per year. A trajectory of the transition from the biomass-based agrarian society to fossil- and mineral-based industrial society is described in various material flow accounting studies. (Krausmann et al., 2017.)

Still, in a global scale the transition from agrarian to industrial regime is not achieved as the industrial transformation is in a constitutional stage in a majority of economies when considered from the perspective of socio-metabolic indicators. For example, the domestic material consumption per capita of nations, which are considered as developing countries by United Nations classification principles, is three to four times smaller than in industrialised nations on average. (Krausmann et al., 2008.)

2.3 Environmental degradation

The environmental challenges of transgressed planetary boundaries are results of the production and consumption patterns engendered in industrialization and economic growth. The strong increase in extraction of natural resources has been an enabler of global economic growth of recent decades but at the same time, the global economy has been driven by the growing population and advanced living standards. (OECD, 2019.) The number of wastes and emissions has surged within the increased use of natural resources since the beginning of industrialization. Consequently, not only global but also most regional problems related to sustainability are direct or indirect consequences of material use and its byproducts of wastes and emissions. (Gonzales de Molina & Toledo, 2014; Krausmann et al., 2017.) In the Figure 3 the scheme of social metabolism and related environmental impacts are described.

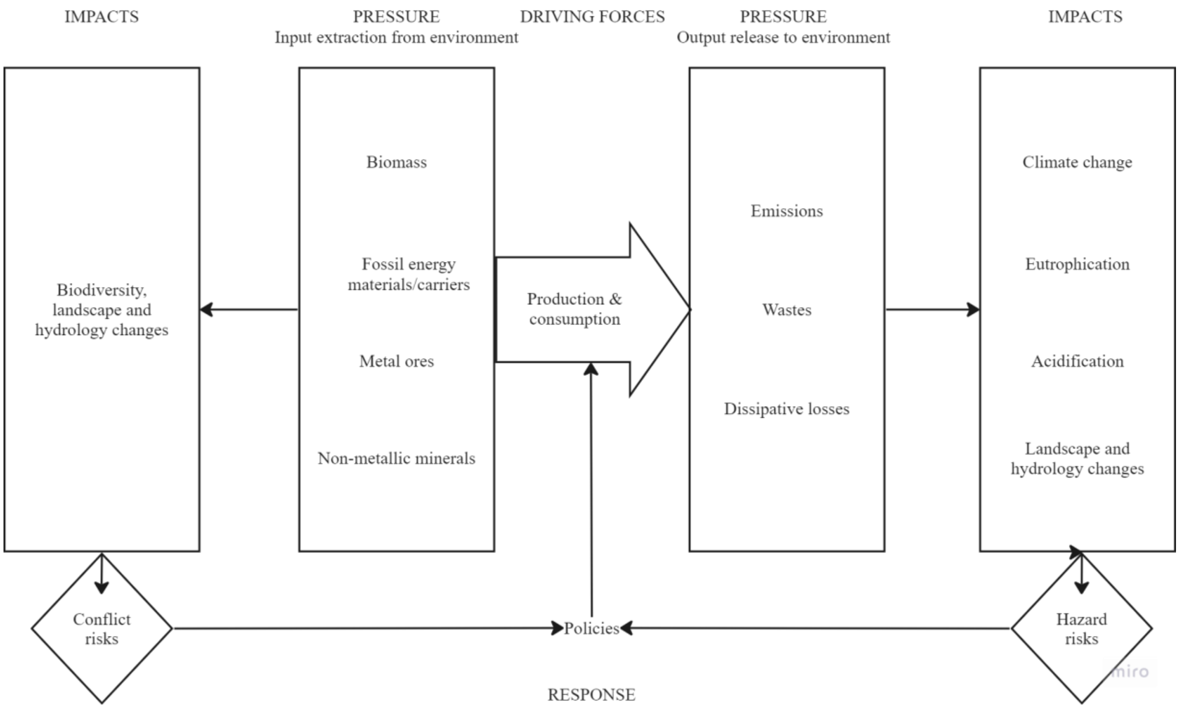

Figure 3. The scheme of social metabolism and examples on its environmental impacts (Bringesu, 2015).

Consumption of material and energy is fundamental to the survival of societies. The satisfaction of material needs of individuals that form societies, such as the need of nutrition, and the immaterial needs, such as cultural activities, rely on consumption. The connection between society and nature provides the possibility to consume as materials extracted from the biosphere and lithosphere of the planet constitute the physical basis of human society. Still, higher resource consumption does not provide happiness endlessly as there is not a significant increase in so called happiness index after material footprint obtains a level of 5 tonnes per capita per year, which industrial nations have already exceeded manifold (Cibulka & Giljum, 2020; Bruyninckx, 2023). The ongoing metabolic crisis underwrite the need for socioecological transition in all the modern life regimes and the unequal exchange of society and nature requires reconnection and decoupling between the resource consumption and economic development. (Krausmann et al., 2017; O’Neill et al., 2018.)

The term decoupling in an environmental economics context refers to the disconnection of environmental and economic variables. For example, when the growth rate of a variable describing environmental pressure, such as domestic material consumption, falls below its economic variable or an economic driving force, such as gross domestic product, over a designated period, decoupling occurs. If the economic driving force grows whilst the environmental variable is stable or decreases, decoupling is absolute. Decoupling is relative if the changing rate of an environmental variable is lower than the changing rate of an economic variable. (OECD, 2019.)

Relationship between environmental implications of production and consumption patterns, economic affluence, and quality of life, have been examined in several studies. To advocate absolute decoupling instead of relative decoupling, the planetary boundaries were introduced by ecological economists. Economic growth narratives, such as degrowth, and production and consumption perspectives, such as resource efficiency and sufficiency, are in the centre of discussions on decoupling. Concluded by Cibulka and Giljum the sustainable development will not however be realised by decoupling if the transgression of planetary boundaries has already occurred. (Cibulka & Giljum, 2020; Bringezu, 2015.)

2.4 Sustainable consumption corridor

One of the contentious issues related to the economy-wide material flow accounting indicators, such as domestic material consumption, when promoting sustainability and considering sustainable level of material use is the lack of agreements on the matter. Quantifying global targets for material use is challenging for variety of reasons. The definition of safe operating space within the planetary boundaries is dependent on the scale of observation and system perspectives. The considerations pertain not only to environmental aspects, but also social factors, such as social acceptance and equity. Rather than using concrete target values for describing potential safe operating space for human activities and natural resource use in a global scale, several studies have thus suggested using a sustainable consumption corridor, a range of target values, instead. (Bringezu, 2015.)

In general, sustainable use of natural resources and the material flow related targets should be considered from the perspective of metabolic system, the physical economy. The recognition of the future metabolic system and its capacity to operate within the current biophysical preconditions of the planet should be emphasised when setting these targets. The material and energy supply should be regenerative and the input and output flows of material and energy from and to environment in minimum. (Bringezu, 2015.) For example, the potential sustainable consumption corridor suggested by Bringezu in 2015, derived total material consumption of biotic resources to 2 tonnes/person and abiotic resources to 6 to 12 tonnes/person. The raw material consumption of both biotic and abiotic resources ranged between 3 to 6 tonnes/person in the suggestion for year 2050. In a potential sustainable consumption corridor suggested by the International Resource Panel the level of material consumption ranged between 6 to 8 tonnes/person for year 2050. (Bringezu, 2025; IRP, 2019.)

Regardless of the varying consumption targets, in the centre of the concept of sustainable consumption corridor is the idea of sustainable wellbeing in relation to the Earth system, that enables good life for the current and future generations in a just and equitable way. Rather than focusing on the negative environmental impacts of production and consumption patterns, the concept approaches the issue from enabling a satisfactory life for everyone. Minimum and maximum consumption standards provide guidance for achieving this sustainable wellbeing globally. (Sahakian et al., 2021.) The idea of sustainable consumption corridor is presented in the Figure 4.

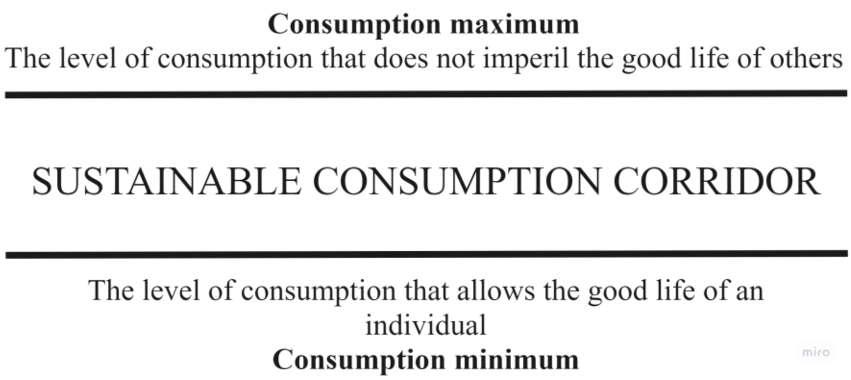

Figure 4. Presentation of the sustainable consumption corridor (Fuchs et al., 2021).

As sustainability is traditionally approached through increased efficiency of production, the consumption-based approach of sustainable consumption corridor emphasises the use of resources, such as who uses the resources and how. The question of what is enough broadens the considerations of the sustainable level of consumption from the carrying capacity of biophysical basis and preconditions of society within planetary boundary framework to social justice in consumption-based approach of sustainable consumption corridor concept. In the centre of the discussion is the issue of what makes life good. Various theories from the fields of science, such as philosophy and sociology, approach the issue from different perspectives. The general understanding of good life considers not only survival of societies but flourishing of its individuals. Good life in relation to sustainable consumption is thus a question of social justice. (Sahakian et al., 2021¸Fuchs et al., 2021.)

When it comes to the social metabolism, the concept of sustainable consumption corridor emphasises the socio-ecological aspects of the transformation towards more sustainable societies. Minimum and maximum standards of consumption enable good life for current and future generations in a just and equitable way without compromising the Earth's carrying capacity and the biophysical preconditions for human development. When minimum standard for consumption is the level of consumption where the needs of individual are meet, maximum consumption is the level of consumption that is sustainable from the perspective Earth's system dynamics and environmental, economic, and societal resources. The interdependency between the minimum and maximum standard of consumption should also be acknowledged as low minimum standard enables high maximum standard of consumption. (Sahakian et al., 2021¸Fuchs et al., 2021.)

Regardless of the defined minimum and maximum standards for consumption, implementing sustainable consumption corridors within a society is challenging because of the complex political, societal, and economic context and the restraining nature of consumption corridor from the perspective of individual freedom. Still, limiting the consumption of natural resources is crucial to the survival of planet and its individuals. (Sahakian et al., 2021¸Fuchs et al., 2021.)

3 Measurement of environmental pressure

This chapter concerns the main indicators used in this master's thesis. The economy-wide material accounting framework and its indicators of material footprint and domestic material consumption are introduced and provided with a general view on the global material use.

3.1 Economy-wide material flow accounting

The functioning of an economy is dependent on the external relations of material and energy exchanges. A metabolic profile of an economy consists of the physical throughput of these flows. Economy-wide material flow accounts (EW-MFA) is methodology derived from social metabolism framework (Krausmann et al., 2017), describing the material flows into and out of a socio-economic system, an economy. (Eurostat, 2018.)

In the conceptual framework of the economy-wide material flow accounting a national economy of a country is defined through a set of economic activities, such as production, consumption, and accumulation, that resident institutional units of that country carry out and the resident owned stocks of produced assets. To enable the analysis of material flows of a socioeconomic system, the definition of system boundaries is needed. The material flows are thus studied as flows from environment to an economy, domestic extractions, and as flows from an economy to environment, domestic processed outputs. Material flows within an economy are not included into accounting, as they are internal transfers. Domestic extraction of material from domestic environment, physical imports from other economies and balancing items from input side, are included in material inputs into national economy. Domestic processed output to domestic environment, physical exports to other economies and balancing items from output side, are included in material outputs from national economy. Solid, gaseous, and liquid materials are studied within the physical interaction between a national economy, other economies, and natural environment. The framework does not include bulk flows of water and air. (Eurostat, 2018; UNEP, 2021.) In the Figure 5 the system boundary of the economy-wide material flow accounting framework is described.

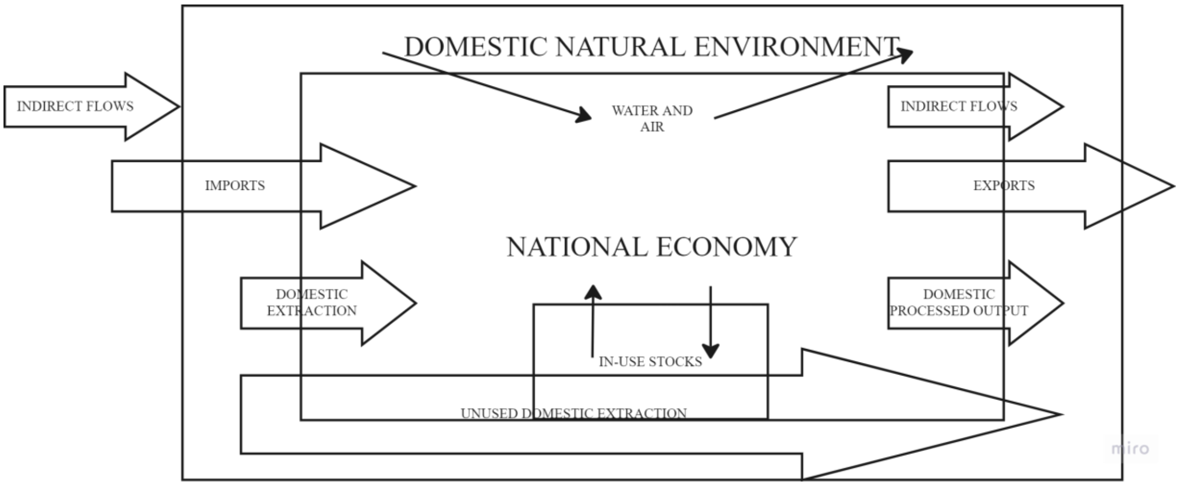

Figure 5. The system boundary of economy-wide material flow accounting framework (Eurostat, 2018).

Economy-wide material flow accounting framework is a standardised and widely used methodology in sustainability science and sustainability reporting internationally and nationally. It provides information on the quality and quantity of material extracted, traded, and consumed by industrial economies. It is consistent with environmentally extended input-output analysis. Reporting of economy-wide material flow accounting data has been obligatory to European Union member states since 2011. (Krausmann et al., 2017.)

3.1.1 Indicators of material footprint and domestic material consumption

Material footprint (MF) and domestic material consumption (DMC) are accounting metrics of economy-wide material flows. These sustainability indicators gauge the use of resources providing information for the authorities. Together with the indicator of domestic material consumption, the indicator of material footprint addresses the issues of production and consumption of an economy. (UN, 2022ab.)

Domestic material consumption describes the actual amount of material consumed within an economy, when material footprint is the virtual amount of material required throughout the supply chain to meet the final demand of an economy. (UN, 2023.) The sum of material footprints of biomass, fossil fuels, metal ores and non-metallic minerals constitute the total material footprint of a nation. Material footprint is defined as domestic extraction of materials plus raw material equivalent of imports minus raw material equivalent of exports and domestic material consumption is defined as the domestic extraction plus imports minus exports. The unit of these indicators is thousand tonnes. (UN, 2022ab.)

The material footprint by raw material type and the material footprint per capita by type of raw material can be calculated using the following equations:

$$MF = DE + RME_{IM} - RME_{EX}$$

$$MF\ per\ capita = \frac{MF}{Annual\ average\ population}$$

Where *MF* is the material footprint, *DE* is the domestic extraction of materials, RME_{IM} is the raw material equivalent of imports and RME_{EX} is the raw material equivalents of exports. (UN, 2022a.)

The domestic material consumption and the domestic material consumption per capita, referred also as metabolic rate of nation, can be calculated using the following equations:

$$DMC = DE + IM - EX$$

$$DMC\ per\ capita = \frac{DMC}{Annual\ average\ population}$$

Where *DMC* is the domestic material consumption, *DE* is the domestic extraction of materials, *IM* is the direct imports and *EX* is the direct exports. (UN, 2022b.) In the Figure 6 the economy-wide material flow accounting indicators and their relations are described.

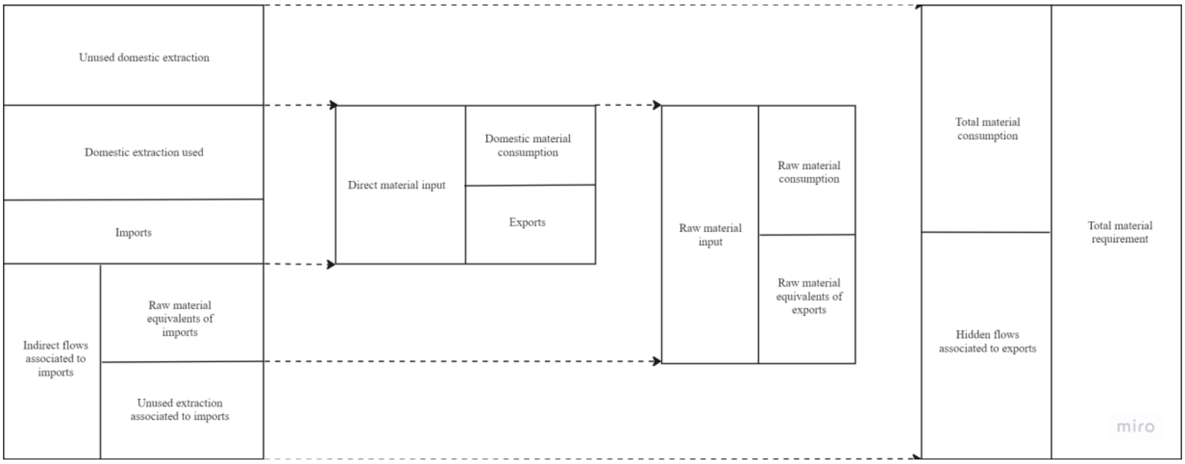

Figure 6. Economy-wide material flow accounting indicator relations (Bringesu, 2015).

The limitation of sustainability indicator of domestic material consumption is the exclusion of imported and exported raw material upstream that limits the material usage to the direct use of raw materials within the economy. The nature of global supply chains, the geographical distribution of production and consumption, distort the affiliation of used resources and the environmental impacts among countries. The indicator of material footprint overcomes the limitation of physical consumption of raw material within an economy by concluding the production chain from its beginning of raw material extraction from natural environment to the end of consumption of a good or service. Enumeration of this link can comprehend several countries and economies. (UN, 2022ab; Wiedmann et al., 2013.)

When it comes to the social metabolism, the concept of material footprint emphasizes the importance of shared responsibility by disclosing the impacts of natural resource extraction, processing, and consumption. The goal of the indicators is to improve global resource efficiency in production and consumption, together with decoupling of economic growth from environmental degradation. (UN, 2022ab.)

3.2 Global material use

In 1990 global material footprint was 43 billion metric tons and in 2000 54 billion metric tons. In 2017 global material footprint was 92 billion metric tons. Global material footprint has thus increased by 70 % since the year 2000 and 113 % since the year 1990. Further growth is projected, as global material footprint is estimated to grow to 190 billion metric tons by 2060. At the global level, material footprint is equivalent to domestic material consumption. For the consistency, global material use is thus discussed through the indicator of material footprint in this chapter. (UN, 2023.)

In the Figure 7, the growth index of population, gross domestic product and material footprint are presented using a baseline situation where 2000 equals 100. The Figure 7 describes how the growth rates of population and gross domestic product are lower that the growth rate of material footprint. Increase in material footprint surpasses the increase in population and gross domestic product addressing the failure in decoupling of economic growth and natural resource use at the global level. (UN, 2023.)

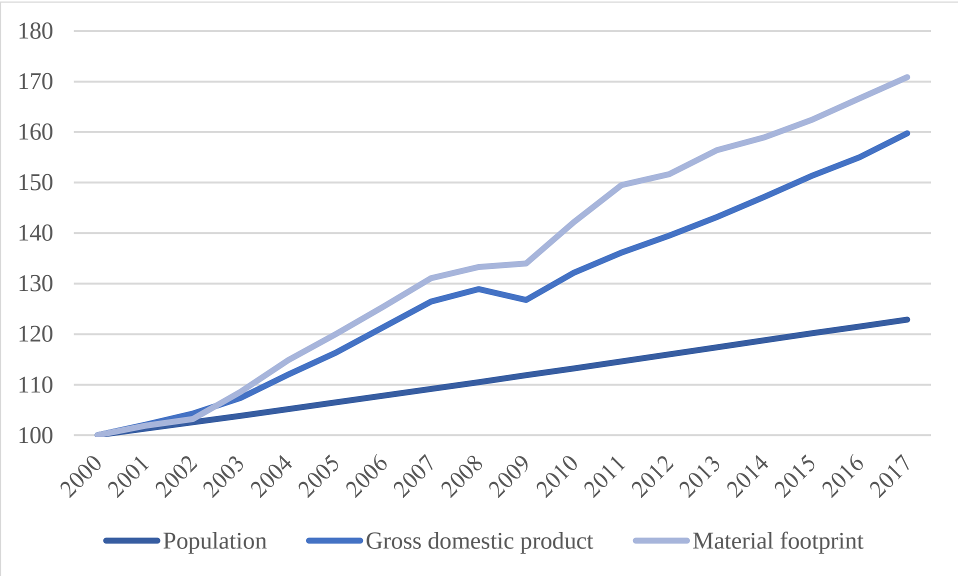

Figure 7. Growth index of population, gross domestic product, and material footprint in a baseline situation where 2000 equals 100 (UN, 2023).

The material footprint per capita has increased within the global material footprint. In 1990 global average material footprint per capita was 8.1 metric tonnes, in 2002 8.8 metric tonnes and in 2017 12.2 metric tonnes. The increase in material footprint per capita at the global level has thus been 50 % since the 2000. In the Figure 8 the material footprint per capita in 2000 and 2017 are presented as metric tons per person.

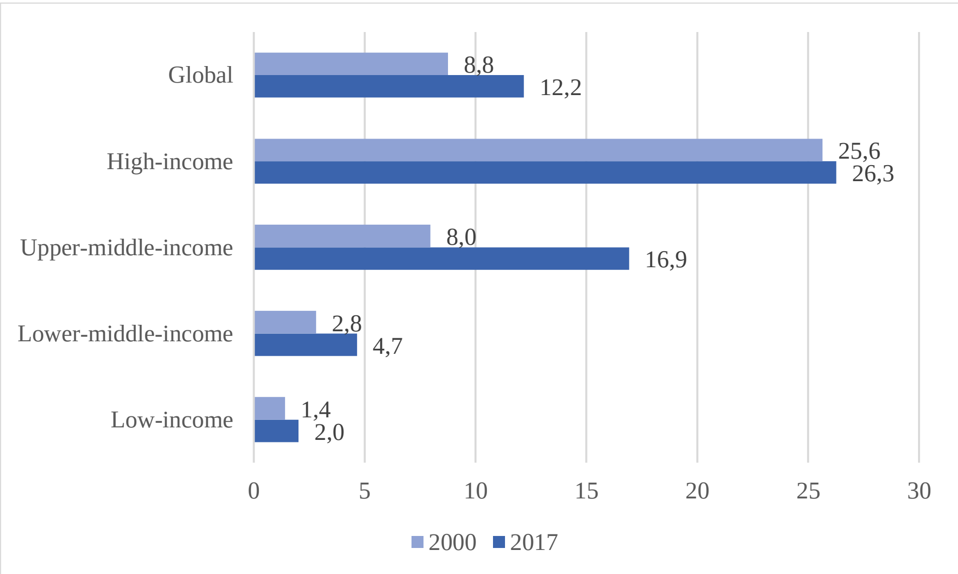

Figure 8. Material footprint per capita in 2000 and 2017 as a metric tons per person (UN, 2023).

Population growth and economic development have been the main drives for increasing material resource in a global scale. (OECD, 2019.) Environmental degradation has accompanied this social and economic development leading to the transgression of planetary boundaries. A sustainable level for material footprint per capita is suggested to be 8.0 metric tonnes (Hoekstra & Wiedmann, 2014). The unsustainable production and consumption patterns of especially high- and upper-middle-income nations are the main drivers of the over-extraction of natural resources. (UN, 2023.)

The national wealth does not relent pressure on natural resources, on the contrary. Increase of 10 % in gross domestic product increases national material footprint by 6 % on average. Generally, as nations become wealthier, domestic material extraction is reduced through international trade, but the mass of material consumption increases in its entirety. (Wiedmann et al., 2013.) In addition to stage of socio-economic development, several other factors affect the material footprint and the domestic material consumption of a nation, such as consumption patterns of national population and level of circularity. Also, regional characteristics, such as land use system, impact on the quality and quantity of material flows thus material footprint and domestic material consumption of a nation. (EEA, 2023; UNEP, 2021.)

The increase of material resource consumption from 27 billion tonnes in 1970 to 89 billion tonnes in 2017 is estimated to further increase within population growth and economic development (OECD, 2019). The trajectories of global material use vary between the scenarios and projections. Schandl et al. suggested that if the global material extraction would develop following the path of business-as-usual, by 2050 the material use would reach approximately 180 billion tonnes and 20 tonnes per capita per year (Schandl et al., 2016). The International Resource Panel on the other hand estimated that even if industrial nations would stabilise their domestic material consumption per capita to the level of the year 2000 followed by other nations, by 2050 the material consumption would still increase to 140 billion tonnes and 16 tonnes per capita per year in a global scale (IRP, 2019.).

4 Case study

This chapter concerns the case study of this master's thesis. The issue of social metabolism in Finland is approached through the national material flows of biomass, fossil energy materials/carriers, metal ores and non-metallic minerals and their domestic material consumption. The case study demonstrates how the methodology of economy-wide material flow accounting framework can be utilised in a context of social metabolism through a national material flow analysis.

4.1 Approaching

In the centre of this case study is the material dimension of social change. The examination of the material flows of organic and mineral resources that constitute the material basis of society provides information on the effectiveness of reduction of these material flows on social metabolism. It enables the transition towards sustainable society as one of the requirements for sustainability is limiting the social metabolism within the capacity of the natural environment, the planetary boundaries. The sociological dimension, the flows of information, of social metabolism are not further addressed in the case study which leaves the analysis of social metabolism incomplete thus constituting only a partial view of the issue. In addition to immaterial processes within the society this approach also leaves out the processes occurring inside the society. Regardless of that the immaterial dimension of information flows provides the framework for material processes. (Krausmann et al., 2017; González de Molina & Toledo, 2014.)

The reduction of social metabolism in Finland is approach through the reduction of domestic material consumption of biomass, fossil energy materials/carriers, metal ores and non-metallic minerals. The availability of national material footprint data that was limited to total material footprints of biomass, fossil fuels, metal ores and non-metallic minerals and the constitution of material footprint of a material flow was not further specified. This impeded the defining of the hotspots of material flows from the national material footprint data. The material flows are thus considered from the perspective of domestic material consumption instead of material footprint as initially intended. The data source was Official Statistics of

Finland’s databases. The domestic material consumption data also included material categories of other products and waste imported/exported for final treatment and disposal. These material categories were not included in the analysis of the domestic material consumption.

Economy-wide material flow accounting framework is applied to the data of Official Statistics of Finland that the quantitative research on national material flows in this master’s thesis bases on. The concept of social metabolism is thus operationalised through the economy-wide material flow accounting framework. Also, the system boundary of the case study is defined according to economy-wide material flow accounting framework. Material flows are studied as flows from environment to an economy, domestic extractions, and as flows from an economy to environment, domestic processed outputs. Solid, gaseous, and liquid materials are studied within the physical interaction between a national economy, other economies, and natural environment. Material flows within an economy are not included into accounting. These physical structures of society, defined as material stocks, compromise humans, livestock, and in-use artifacts. The framework does not include bulk flows of water and air. (Krausmann et al., 2017; Eurostat, 2018.)

The year 2019 was the last year before the Covid-19 pandemic, which had a high impact on the industrial supply chains and production and consumption patterns globally. It was also the most recent year there were material footprint data available. To enable the additional analysis of national material footprint and domestic material consumption data abreast, the year 2019 was selected as a reference point of time when considering the consumption of biomass, fossil energy materials/carriers, metal ores and non-metallic minerals in Finland.

4.2 Operationalising

In this chapter, the material flows in Finland are described and their hotspots identified. To illustrate the relationship between social metabolism and domestic material consumption, the domestic material consumption of these hotspots was decreased by 50 %. This is further referred as a 50 % reduction scenario. Theoretically, the domestic material consumption of the hotspots of the material flows would be reduced by 50 % by simply outsourcing the identified material intensive industrial processes to other countries, as the domestic material consumption describes the actual amount of material in an economy. However, this kind of an approach would not be considered sustainable as the environmental burden would only be shifted from one place to another. Another theoretical approach for reducing the domestic material consumption of hotspots would be the decrease in domestic material consumption of materials in absolute terms.

In this master's thesis the reduction of social metabolism is thus approach through the reduction of actual amount of material that is further allocated to the reduction of production. It is assumed that domestic material consumption of hotspots is not replaced or displaced by another material and the domestic material consumption is reduced in absolute terms. The implications of reduced domestic material consumption are considered from the perspective of economic activities and provided with examples considering various sectors. The relationship between social metabolism and total domestic material consumption, described as the metabolic rate, is also presented in this chapter.

4.3 Material footprint and domestic material consumption in Finland

Material footprint and domestic material consumption of biomass, fossil energy material/carriers, metal ores and non-metallic minerals between the years 2010—2019 in Finland are described in the Figures 9 and 10. The metabolic rate and its development is described in the Figure 11.

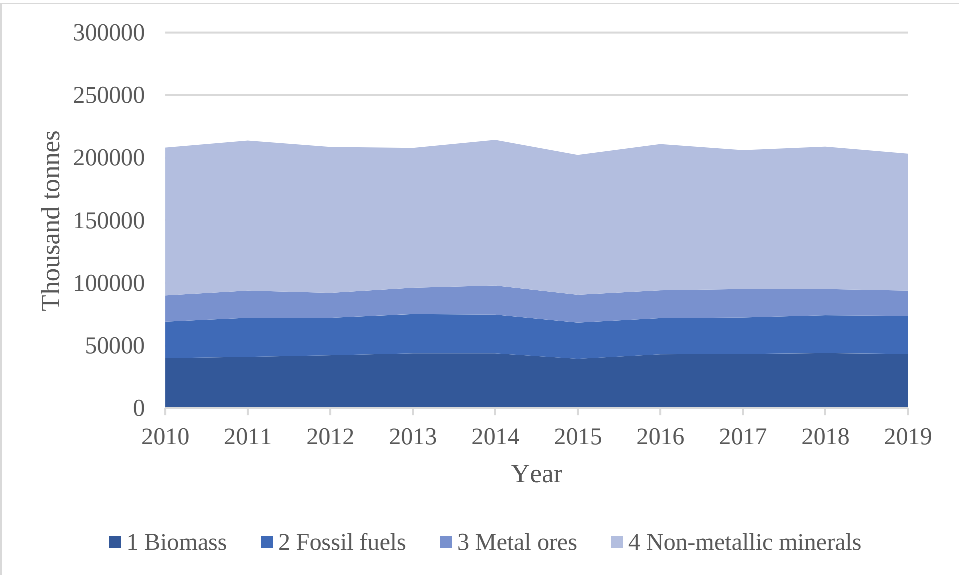

Figure 9. Material footprint of biomass, fossil fuels, metal ores and non-metallic minerals in Finland between 2010—2019 (OFC, 2023).

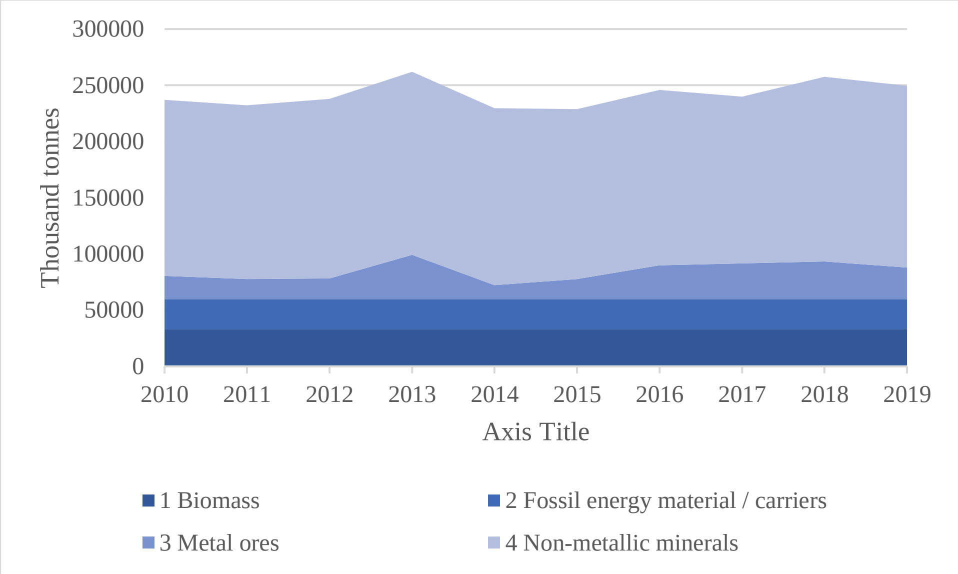

Figure 10. Domestic material consumption of biomass, fossil energy material/carriers, metal ores and non-metallic minerals in Finland between 2010—2019 (OFC, 2023).

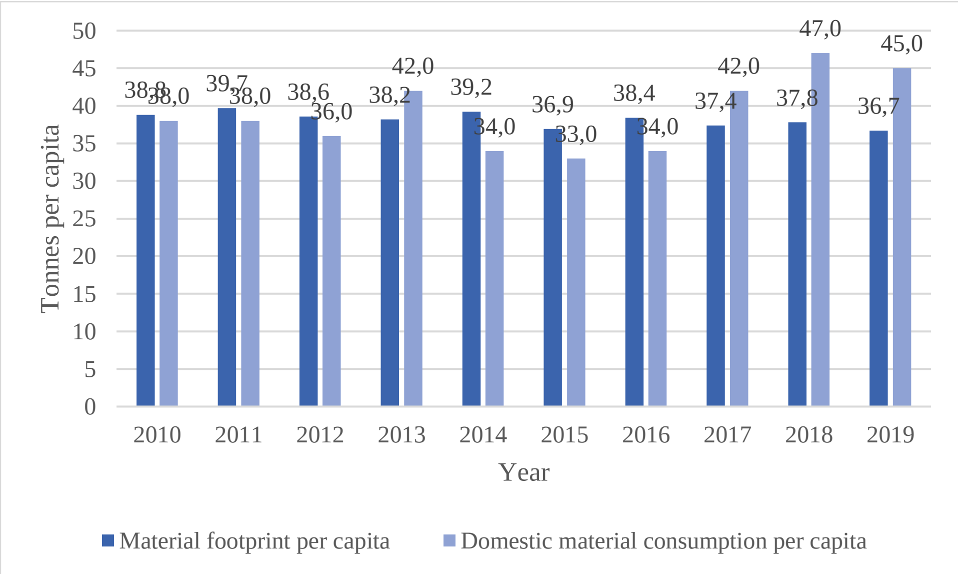

Figure 11. Material footprint per capita and domestic material consumption per capita, the metabolic rate, in Finland between 2010—2019 (OFC, 2023).

The consumption of raw materials follows the development of gross domestic product in Finland (Syke, 2020). Compared to most EU Member States the consumption of material and energy per capita is high in Finland and due to this, also large amounts of waste are generated (EEA, 2015).

The production and consumption patterns in Finland are partially based on structural factors. For example, the climate conditions, such as cold winters, and spatial distribution of the population, such as long geographical distances, constitute demand for resources in a form of heating and road construction. The major users of resources are also the forest, mining, and construction industries. In addition to climate conditions and spatial distribution of the population, the material-intensive goods' exports explain the placement of Finland within other Member States of EU, still and all the wealth of natural resources Finland has. (EEA, 2015.)

The Finnish environment Institute and Thule-institute calculated Finnish material use and efficiency trends for years 2008—2030 in a study for National Material Efficiency Programme. Study estimated that the domestic material consumption would increase by 59 % from 208 million tonnes to 331 million between the years 2008—2030 and the raw material consumption by 14 % in from 209 tonnes to 239 million tonnes in total. The domestic material consumption per capita would consequently increase 45 % from 39 tonnes/person to 57 tonnes/person and raw material consumption per capita 4 % from 39 tonnes/person to 41 tonnes/person. (EEA, 2015.) The trajectories are described in the Figures 12 and 13.

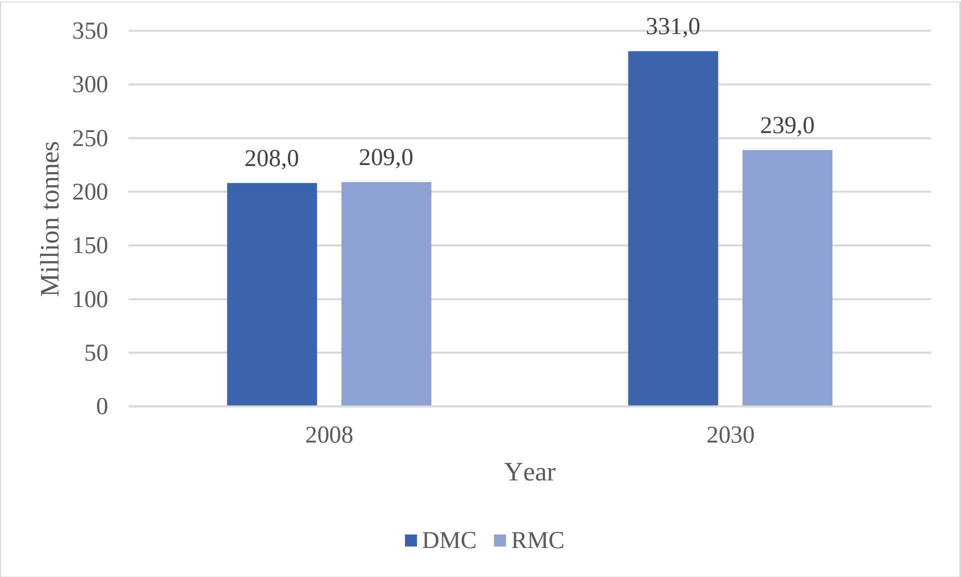

Figure 12. The trajectory of domestic material consumption and raw material consumption (EEA, 2015).

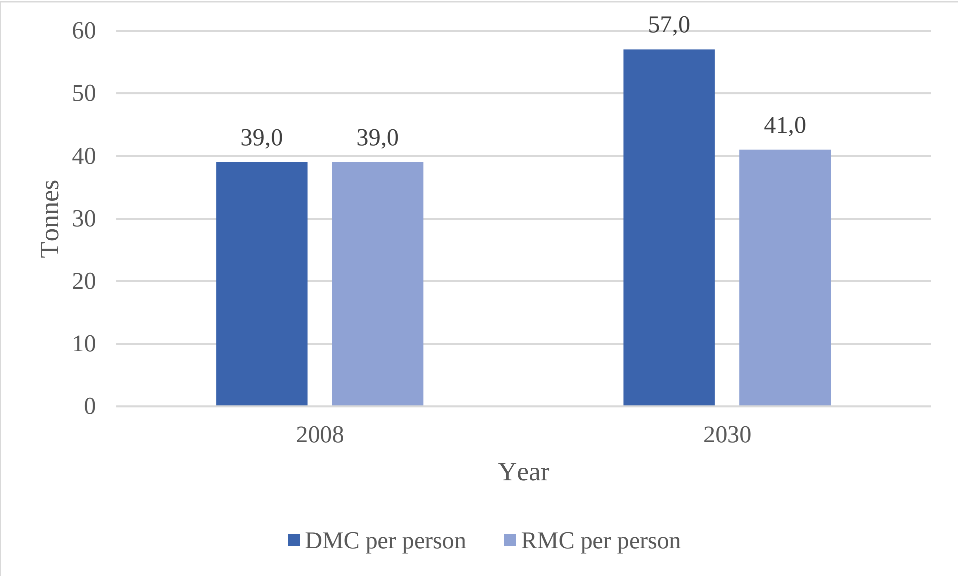

Figure 13. The trajectory of domestic material consumption and raw material consumption per person (EEA, 2015).

The domestic material consumption of biomass, fossil energy material/carriers, metal ores and non-metallic minerals is further described in this chapter.

4.4 Biomass

In 2019 the material footprint of biomass was approximately 43 000 thousand tonnes and the domestic material consumption 39 000 thousand tonnes. In the Figure 14 the constitution of domestic material consumption of biomass is further described. (OFC, 2023.)

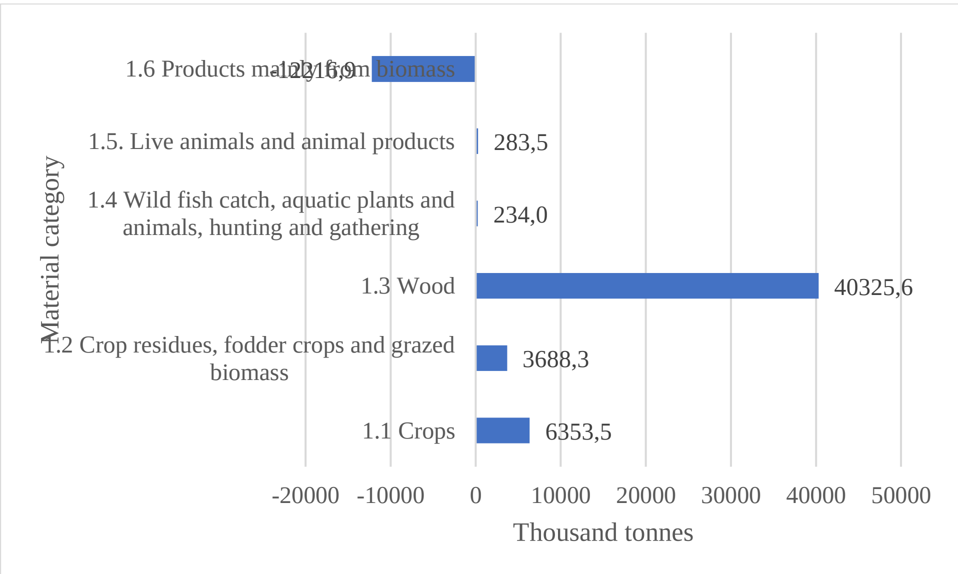

Figure 14. Domestic material consumption of biomass in 2019 in Finland (OFC, 2023).

The material flow of biomass was further categorised to six items of 1.1 Crops, 1.2 Crop residues, fodder crops and grazed biomass, 1.3 Wood, 1.4 Fild fish catch, aquatic plants, and animals, hunting, and gathering, 1.5 Live animals and animal products and 1.6 Products mainly form biomass. The material subcategory of 1.3 Wood accounted for the highest share of domestic material consumption within the biomass. It was thus selected as a hotspot of this material flow. (OFC, 2023.)

4.4.1 Wood

The domestic material consumption of wood was approximately 40 000 thousand tonnes in 2019. Timber, industrial roundwood, accounted for approximately 34 000 thousand tonnes and wood fuel and other extraction approximately 6 300 thousand tonnes of the total domestic material consumption of addressed material subcategory. (OFC, 2023.) The 50 % reduction on hotspot would decrease the amount of domestic material consumption of wood from approximately 40 000 thousand tonnes to approximately 20 000 thousand tonnes as presented in the calculation below, where the domestic material consumption of wood is distributed by two:

$$\frac{40\ 326.6\ thousand\ tonnes}{2} = 20\ 163.3\ thousand\ tonnes \sim 20\ 000\ thousand\ tonnes$$

Measured in million dry-matter tons of wood the total consumption of wood material was approximately 39 in 2019. Based on the mass balance of forest sector approximately 16 million tons, 41 %, of used wood material was classified to forest industry products and approximately 23 million tons, 59 %, classified to other user categories. The used mass balance of forest accounts converts industry’s raw materials and products into a uniform unit of measurement which allows the comparison between different material and product categories. (Luke, 2019.)

Within the category of forest industry products, the approximately shares of subcategories were Sawn goods 28 %, Wood based panels 4 %, Exports of wood pulp 25 %, Paper 24 % and Paperboard 19 %. The approximately shares of subcategories within the category of other user categories, were Wood in energy generation 98 %, Exports of forest industry byproducts and wood 0.5 % and Wood waste 2 %. Of the subcategory Wood in energy generation, 86 % was used in heating and power plants and 14 % as a fuelwood in small-scale housing. In the Figure 15 the shares of different subcategories are presented. (OFC, 2023.)

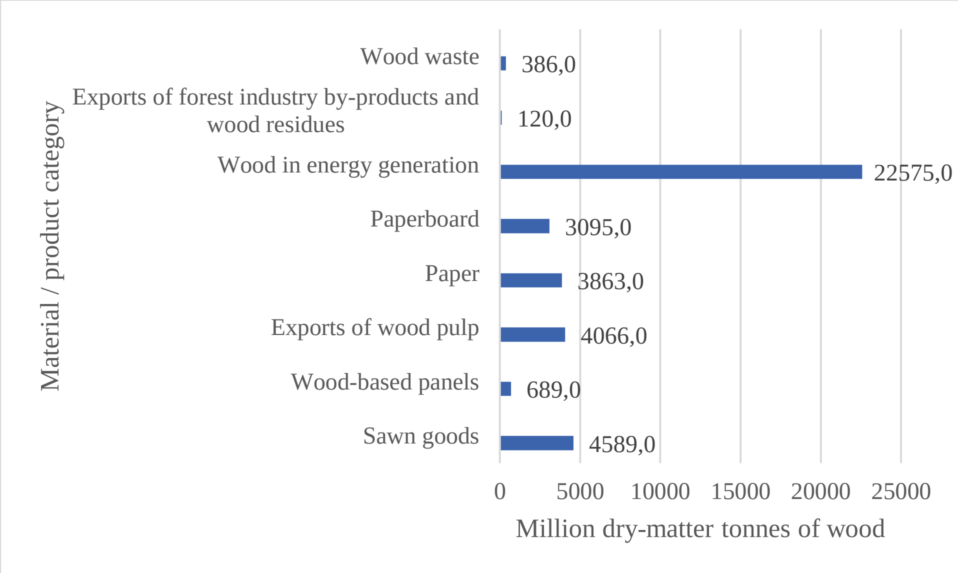

Figure 15. The shares of used wood materials and products in 2019 (OFC, 2023).

It is assumed that constitution of domestic material consumption of wood follows the percentual shares of mass balance of the forest sector. In the Figure 16 the percentual shares of different material and product categories are presented.

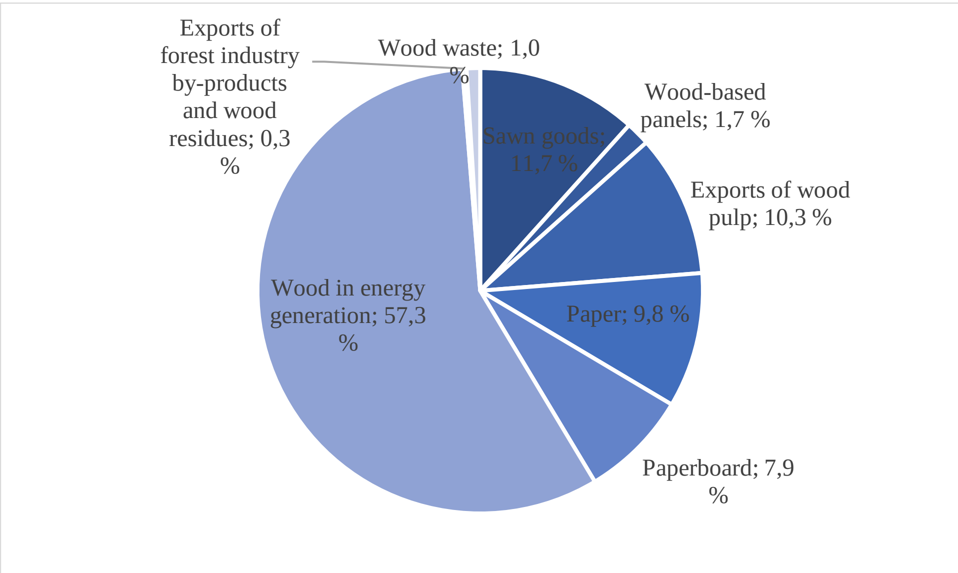

Figure 16. The percentual shares of used wood materials and products in 2019 (OFC, 2023; Luke, 2019).

To provide an example of the potential impacts of the 50 % reduction scenario on economic activity, the implications of reduced domestic material consumption of wood are considered from the perspective of housing sector.

4.4.2 Example of implication of reduction

Wood used in energy generation accounted for approximately 57 % of the domestic material consumption of the hotspot of wood. Of the subcategory of wood in energy generation, approximately 86 % was used in heating and power plants and 14 % as a fuelwood in small-scale housing. (OFC, 2023.) The 50 % reduction in the domestic material consumption of the hotspot would be achieved if the use of wood in heating and power plants would be stopped. The subcategory was accountable for approximately 50 % of the domestic material consumption of the hotspot as presented in the calculation below, where the share of wood in energy generation is multiplied with the share of wood used in heating and power plants:

$$0.573 \times 0.864 = 0.495 \sim 50\ \%$$

In 2019 the share of wood fuels was approximately 28 % of the total energy consumption of approximately 1 400 000 TJ in Finland (OFC, 2020a). The 50 % reduction in the domestic material consumption of the hotspot would thus lead to the reduction of approximately 380 000 TJ in the total energy consumption on a yearly basis as presented in the calculation below, where the total energy consumption is multiplied by the share of wood fuels:

$$1\ 361\ 787.0\ TJ \times 0.280 = 381\ 300.4\ TJ \sim 380\ 000\ TJ$$

In 2019 housing accounted for approximately 230 000 TJ of the total energy consumption. The 50 % reduction in domestic material consumption of wood would thus require reducing the energy consumption in Finnish households by approximately 160 % annually as presented in the calculation below, where the reduction of total energy consumption on a yearly basis is distributed by the energy consumption of Finnish households:

$$\frac{381\ 300.4\ TJ}{234\ 000.0\ TJ} = 1.628 \sim 160\ \%$$

The reduction would occur if the domestic material consumption of the hotspot would not be replaced or displaced by another material or energy source.

4.5 Fossil energy materials/carriers

In 2019 the material footprint of fossil fuels was approximately 30 000 thousand tonnes and the domestic material consumption of fossil energy material/carriers 17 000 thousand tonnes in Finland. In the Figure 17 the constitution of domestic material consumption of fossil energy material/carriers is further described. (OFC, 2023.)

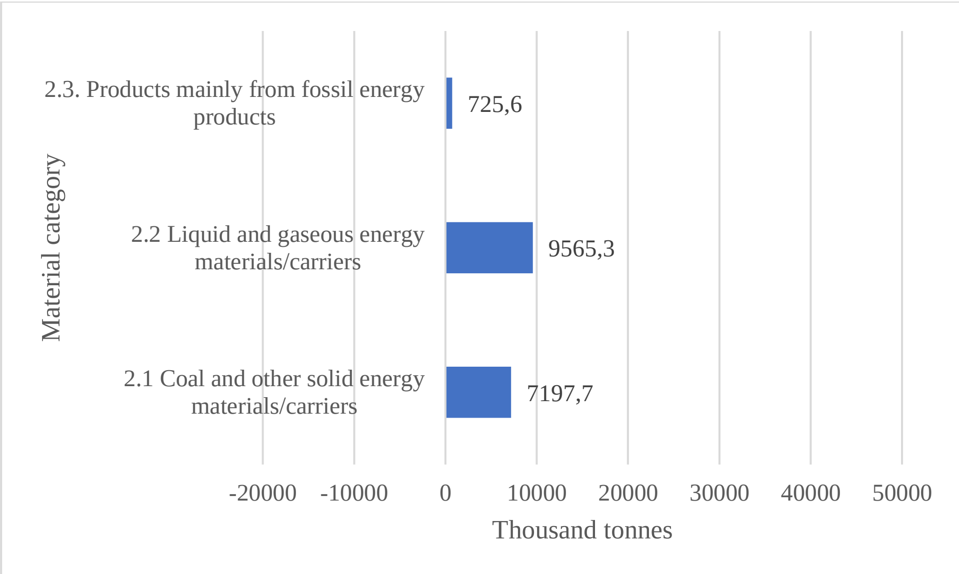

Figure 17. Domestic material consumption of fossil energy materials/carriers in 2019 in Finland (OFC, 2023).

The material flow of fossil fuel materials/carriers is further categorised to three items of 2.1 Coal and other solid energy materials/carriers, 2.2 Liquid and gaseous energy materials/carriers and 2.3 Products mainly from fossil energy products. The material subcategory of 2.2 Liquid and gaseous energy materials/carriers accounts for the highest share of domestic material consumption within the fossil fuel materials/carriers. It is thus selected as a hotspot of this material flow. (OFC, 2023.)

4.5.1 Liquid and gaseous energy materials/carriers

The domestic material consumption of liquid and gaseous energy materials/carriers was approximately 9 500 thousand tonnes in 2019. Crude oil, condensate, and natural gas liquids (NGL) accounted for approximately 7 700 thousand tonnes, natural gas 1 800 thousand tonnes and fuels bunkered 530 thousand tonnes of the total domestic material consumption of addressed material subcategory. (OFC, 2023.) The 50 % reduction on hotspot would decrease the amount of domestic material consumption of liquid and gaseous energy materials/carriers from approximately 10 000 thousand tonnes to 5000 thousand tonnes as presented in the calculation below, where the domestic material consumption of liquid and gaseous energy materials/carriers is distributed by two:

$$\frac{10\,096.6}{2}\ thousand\ tonnes = 5048.3\ thousand\ tonnes \sim 5\,000\ thousand\ tonnes$$

In the Figures 18 and 19 the shares of different subcategories are presented. (OFC, 2023.)

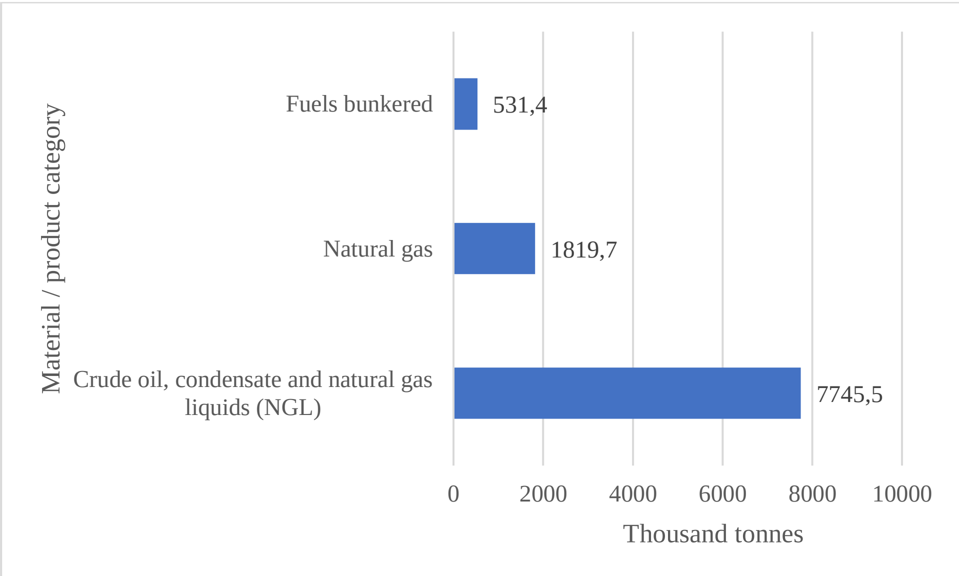

Figure 18. The shares of used liquid and gaseous energy materials/carriers in 2019 (OFC, 2023).

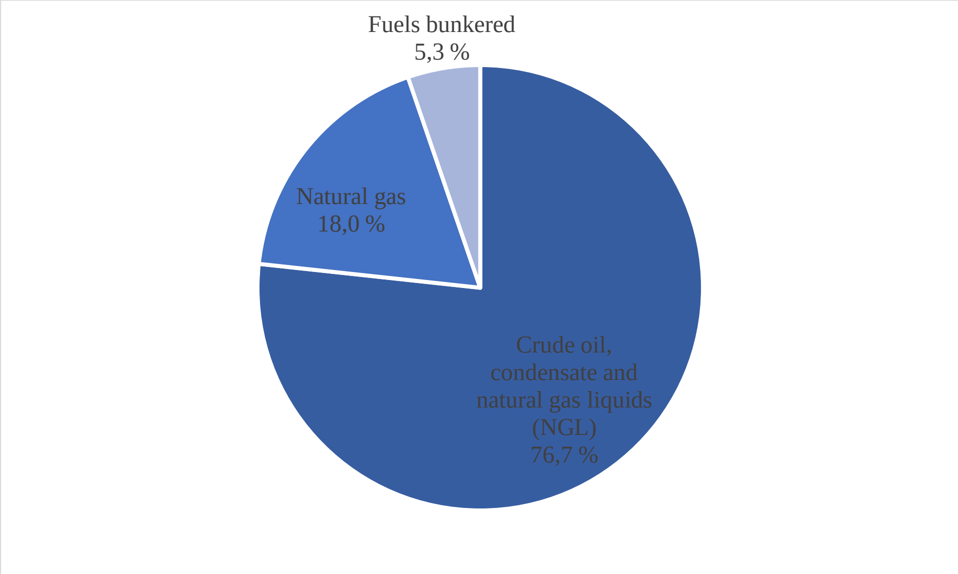

Figure 19. The percentual shares of used liquid and gaseous energy materials/carriers in 2019 (OFC, 2023).

To provide an example of the potential impacts of the 50 % reduction scenario on economic activity, the implications of reduced domestic material consumption of crude oil and NGL are considered from the perspective of transportation sector.

4.5.2 Example of implication of reduction

Crude oil and NGL accounted for approximately 77 % of the total domestic material consumption of the hotspot of fossil energy materials/carriers. (OFC, 2023.) The 50 % reduction in the domestic material consumption of the hotspot would be achieved if the use of crude oil and NGL would be partly stopped. The required reduction in the use of crude oil and NGL in the energy production would be approximately 65 %, as presented in the calculation below, where the domestic material consumption of the hotspot is divided by two and distributed by domestic material consumption of crude oil and NGL:

$$\frac{\frac{10\,096.6}{2}}{7\,745.5}\,thousand\ tonnes = 0.651 \sim 65\ \%$$

In 2019 the share of oil and natural gas was approximately 27 % of the total energy consumption of approximately 1 400 000 TJ in Finland (OFC 2020a). The 50 % reduction in the domestic material consumption of the hotspot would thus lead to the reduction of approximately 240 000 TJ in the total energy consumption on a yearly basis as presented in the calculation below, where the total energy consumption is multiplied by the share of oil and natural gas further multiplied by their required reduction to meet the scenario of 50 % reduction:

$$1\ 361\ 787.0\ TJ \times 0.270 \times 0.651 = 239\ 261.3\ TJ \sim 240\ 000\ TJ$$

In 2019, total of approximately 41 billion car kilometres was driven with passenger cars. On average, approximately 14 000 kilometres were driven with passenger cars as the number of passenger cars in the active passenger car fleet was approximately 3 000 000 in Mainland Finland. Of the total amount of driven kilometres, 98 % were driven with petrol- and diesel-driven cars. The share of low-emission motives was approximately 2 %. (OFC, 2020b.)

As the energy consumption of a fuel vehicle is on average approximately 0.7 kWh/km (Zhang et al., 2019), the reduction of energy consumption of approximately 240 000 TJ would be equivalent to approximately 9 billion car kilometres annually as presented in the calculation below, where the reduction of total energy consumption on a yearly basis is distributed by the energy consumption of a fuel vehicle converted to the unit of km/TJ and multiplied with the share of kilometres driven with petrol- and diesel-driven cars:

$$\frac{239\ 261.3\ TJ}{0{,}727 \times 3{,}6 \times 10^{-6}\,\frac{TJ}{km}} \times 0.980 \sim 9\ billion\ km$$

The number of reduced kilometres would be accountable for the share of 22 % of the total car kilometres driven with passenger cars as presented in the calculation below, where the amount of reduced kilometres annually is distributed by the total amount of kilometres driven with passenger cars annually:

$$\frac{9.0\ billion\ km}{40.0\ \ billion\ km} = 0{,}223 \sim 22\%$$

The reduction would occur if the domestic material consumption of the hotspot would not be replaced or displaced by another material or energy source.

4.6 Metal ores

In 2019 the material footprint of metal ores was approximately 20 000 thousand tonnes and the domestic material consumption of metal ores 28 000 thousand tonnes in Finland. In the Figure 20 the constitution of domestic material consumption of metal ores is further described. (OFC, 2023.)

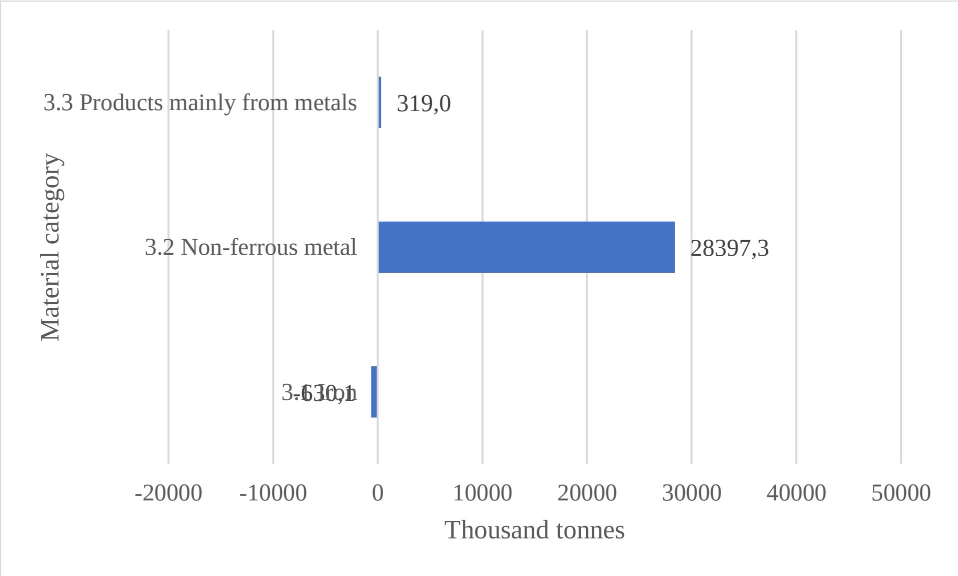

Figure 20. Domestic material consumption of metal ores in 2019 in Finland (OFC, 2023).

The material category of 3.2 Non-ferrous metals accounts for the highest share of domestic material consumption within the metal ores. It is thus selected as a hotspot of material flow of metal ores. (OFC, 2023.)

4.6.1 Non-ferrous metals

The domestic material consumption of non-ferrous metals was approximately 28 000 thousand tonnes in 2019. Copper accounted for approximately 3 300 thousand tonnes, nickel 17 000 thousand tonnes, lead -5 thousand tonnes, zinc 3 500 thousand tonnes, tin 0.1 thousand tonnes, gold, silver, platinum, and other precious metals 2 400 thousand tonnes, bauxite, and other aluminium 18 thousand tonnes, uranium, and thorium -0.5 thousand tonnes and other non-ferrous metals 2 600 thousand tonnes of the total domestic material consumption of addressed material subcategory. (OFC, 2023.) The 50 % reduction on hotspot would decrease the amount of domestic material consumption of non-ferrous metals from approximately 28 000 thousand tonnes to 14 000 thousand tonnes as presented in the calculation below, where the domestic material consumption of non-ferrous metals is distributed by two:

$$\frac{28\,397.3}{2}\ thousand\ tonnes = 14\,198.7\ thousand\ tonnes \sim 14\,000\ thousand\ tonnes$$

In the Figures 21 and 22 the shares of different subcategories are presented. (OFC, 2023.)

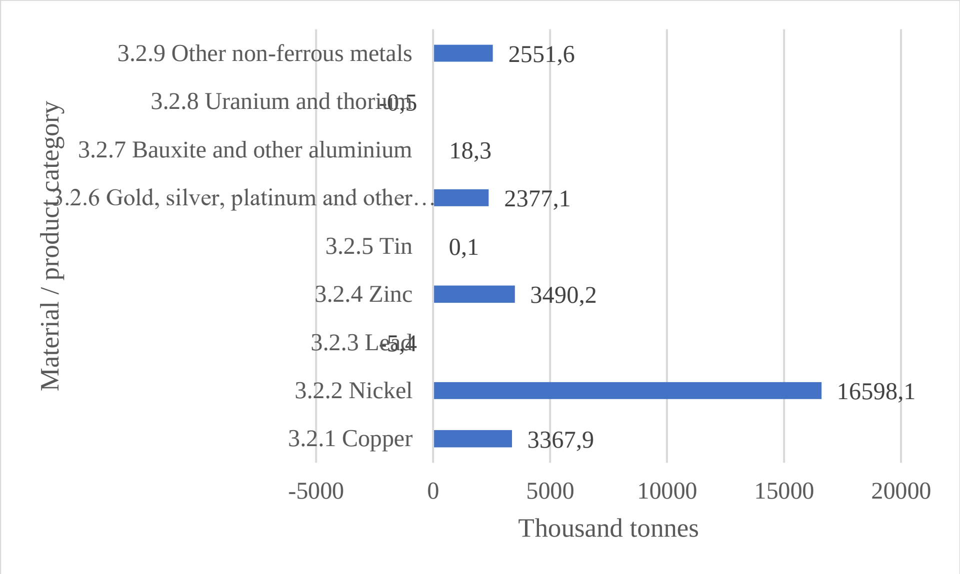

Figure 21. The shares of non-ferrous metal materials and products in 2019 (OFC, 2023).

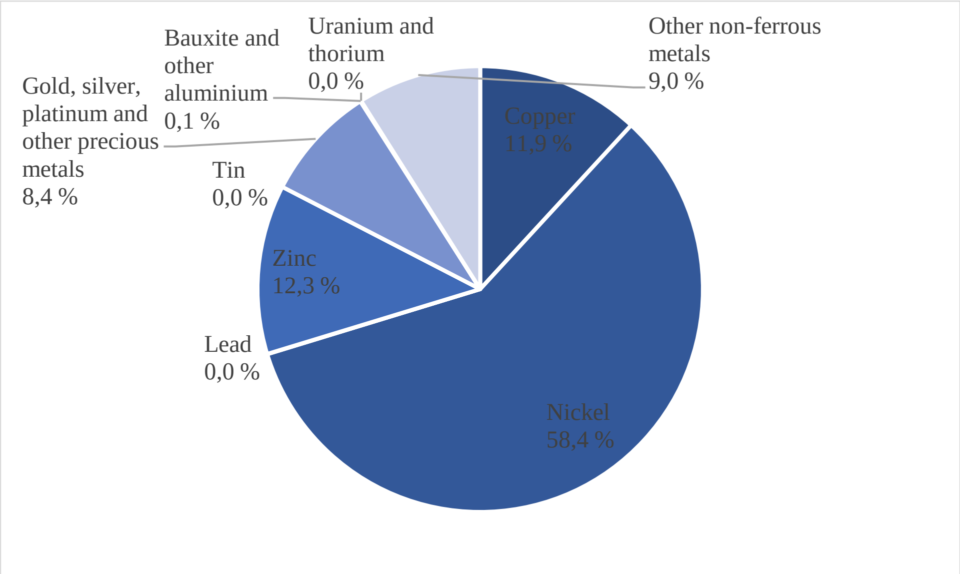

Figure 22. The shares of non-ferrous metals materials and products in 2019 (OFC, 2023).

Finland has a verstile metal refining industry and along with primary manufacturing of metals, also futher processing products, such as pipes, are produced. Copper, nickel and zinc, materials with the highest domestic material consumption within the material subcategory of non-ferrous metals, are used mainly in steel, aerospace, automotive, marine, electronics and construction industries. Copper and its alloys are central raw materials in many technologies. Nickel is an imporant alloying element in stainless steel and zinc is mainly used as a corrosion protection material in steel products, such as in construction and automotive idustries. (Heikkinen & Loukola-Ruskeenieme, 2015; Riekkola-Vanhanen, 1999.)

To provide an example of the potential impacts of the 50 % reduction scenario on economic activity, the implications of reduced domestic material consumption of non-ferrous metals are considered from the perspective of industrial sector.

4.6.2 Example on implication of reduction

Nickel accounted for approximately 58 % of the total domestic material consumption of the hotspot of metal ores. The 50 % reduction in the domestic material consumption of the hotspot would be achieved if the use nickel would be partly stopped. (OFC, 2023.) The required reduction in the use of nickel would be approximately 86 %, as presented in the calculation below, where the domestic material consumption of the hotspot is divided by two and distributed by domestic material consumption of nickel:

$$\frac{\frac{28\ 397.3}{2}\ thousand\ tonnes}{16\ 598.1\ thousand\ tonnes} = 85{,}5\ \% \sim 86\ \%$$

Type 304, a well-known type of stainless steel, contains 8 % of nickel (Nickel Institute, 2024). Outokumpu’s stainless steel plant in Tornio has a steel production capacity of 1.2 million tpa (Outokumpu, 2024.). The 50 % reduction in the domestic material consumption of the hotspot would thus lead to the reduction of approximately 1.0 million tpa on a yearly basis as presented in the calculation below, where the steel production capacity is multiplied by the needed reduction in domestic material consumption of nickel:

$$1\ 200\ 000\ tpa \times 0.855 = 1\ 026\ 000\ tpa \sim 1.0\ million\ tpa$$

The reduction would occur if the domestic material consumption of the hotspot would not be replaced or displaced by another material.

4.7 Non-metallic minerals

In 2019 the material footprint of non-metallic minerals was approximately 110 000 thousand tonnes and the domestic material consumption of non-metallic minerals 160 000 thousand tonnes in Finland. In the Figure 23 the constitution of domestic material consumption of non-metallic minerals is further described. (OFC, 2023.)

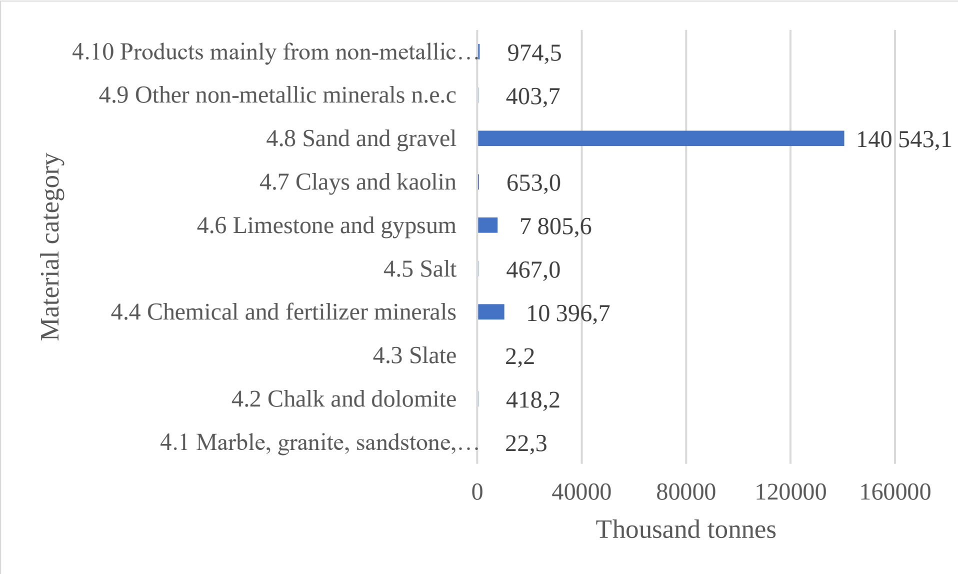

Figure 23. Domestic material consumption of non-metallic minerals in 2019 in Finland (OFC, 2023).

The material category of 4.8 Sand and gravel accounts for the highest share of domestic material consumption within the non-metallic minerals. It is thus selected as a hotspot of material flow of metal ores. It is thus selected as a hotspot of material flow of non-metallic minerals. (OFC, 2023.)

4.7.1 Sand and gravel

The domestic material consumption of sand and gravel was approximately 140 000 thousand tonnes in 2019. (OFC, 2023.) Sand and gravel are mainly used in construction and infrastructure sectors. Approximately 50 % of sand and gravel is used in road construction, 10 % in asphalt production, 10 % concrete production and 15 % in building construction. (GTK 2019.) The 50 % reduction on hotspot would decrease the domestic material consumption of sand and gravel from approximately 140 000 thousand tonnes to approximately 70 000 thousand tonnes as presented in the calculation below, where the domestic material consumption of sand and gravel is distributed by two:

$$\frac{140\ 543.1}{2}\ thousand\ tonnes$$
$$= 70\ 271.6\ thousand\ tonnes \sim 70\ 000\ thousand\ tonnes$$

To provide an example of the potential impacts of the 50 % reduction scenario on economic activity, the domestic material consumption of sand and gravel is considered from the perspective of construction sector.

4.7.2 Example of implication of reduction

Road construction accounted for approximately 50 % of the domestic material consumption of the hotspot of non-metallic minerals. The 50 % reduction in the domestic material consumption of the hotspot would be achieved if the use of sand and gravel in road construction would be stopped. (OFC, 2023.) As construction of 1 kilometre of road requires approximately 200 000 tonnes of sand and gravel (DW, 2019.), the 50 % reduction in the domestic material consumption of the hotspot would thus lead to the reduction of approximately 360 kilometres of road constructed on a yearly basis as presented in the calculation below, where the domestic material consumption of hotspot is distributed by two and then distributed by the amount of sand and gravel required per 1 km of road constructed:

$$\frac{\frac{140\ 543\ 100.0}{2} tonnes}{195\ 951.9 \frac{tonnes}{km}} = 355.6\ km \sim 360\ km$$

The reduction would occur if the domestic material consumption of the hotspot would not be replaced or displaced by another material.

4.8 Metabolic rate

The total domestic material consumption in Finland was approximately 250 000 thousand tonnes in 2019 which is referred as a baseline scenario. The material category of biomass was accountable for approximately 39 000 thousand tonnes, the material category of fossil energy materials/carriers 17 000 thousand tonnes, the material category of metal ores 28 000 thousand tonnes and material category of non-metallic minerals for 160 000 thousand tonnes of the total domestic material consumption. (OFC, 2023.) In the Figure 24 the domestic material consumption of the material categories in the baseline scenario are described.

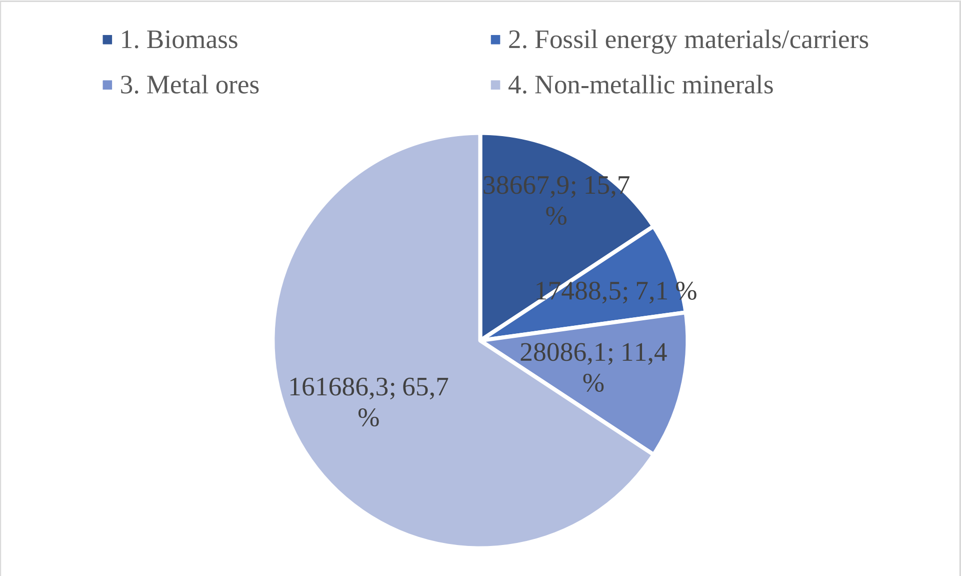

Figure 24. The domestic material consumption of the material categories in the baseline scenario (OFC, 2023).

Within the biomass, the material subcategory of wood was identified as the hotspot of the material category, as it accounted for the approximately 40 000 thousand tonnes of total domestic material consumption of the biomass. The liquid and gaseous energy materials/carriers accounted for the approximately 9 500 thousand tonnes of total domestic material consumption of fossil energy materials/carriers and was identified as the hotspot of the material category. Non-ferrous metals accounted for approximately 28 000 thousand tonnes of the total domestic material consumption of metal ores and sand and gravel 140 000 thousand tonnes of total domestic material consumption of non-metallic minerals and were identified as the hotpots of the material categories. (OFC, 2023.) In the Figure 25 the domestic material consumption of the hotspots in baseline scenario and 50 % reduction scenario are described.

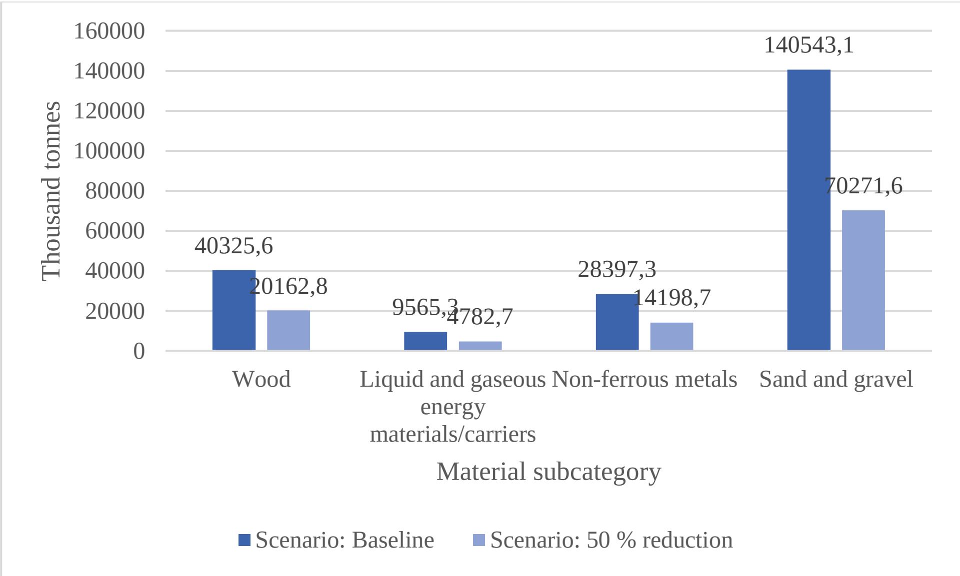

Figure 25. The domestic material consumption of the hotspots in baseline scenario and 50 % reduction scenario.

Halving of the domestic material consumption of the hotspots of the material categories of biomass, fossil energy materials/carriers, metal ores and non-metallic minerals would reduce the total domestic material consumption by approximately 110 000 thousand tonnes as presented in the calculation below, where domestic material consumption of the hotspots in baseline scenario is distributed by two:

$$\frac{(40\ 325.6 + 9\ 565.3 + 28\ 397.3 + 140\ 543.1)\ thousand\ tonnes}{2}$$
$$= 109\ 415.7\ thousand\ tonnes \sim 110\ 000\ thousand\ tonnes$$

The total domestic material consumption would be reduced from approximately 250 000 thousand tonnes to approximately 140 000 thousand tonnes as presented in the calculation below, where the domestic material consumption in baseline scenario distributed by two is reduced from the total domestic material consumption of baseline scenario:

$$(245\ 928.8 - 109\ 415.7)\ thousand\ tonnes$$
$$= 136\ 513.2\ thousand\ tonnes \sim 140\ 000\ thousand\ tonnes$$

The official number of capita of population in Finland was 5 525 292 in 2019 (OFC 2019). The metabolic rate in baseline scenario was approximately 45 tonnes/capita as presented in the calculation below, where the total domestic material consumption is distributed by the capita of population:

$$\frac{245\ 928\ 800\ tonnes}{5\ 525\ 292\ capita} = 44.5\frac{tonnes}{capita} \sim 45\ \frac{\text{tonnes}}{\text{capita}}$$

The metabolic rate in 50 % reduction scenario was approximately 25 tonnes/capita as presented in the calculation below, where the total domestic material consumption in 50 % reduction scenario is distributed by the capita of population:

$$\frac{136\ 513\ 200\ tonnes}{5\ 525\ 292\ capita} = 24.7\frac{tonnes}{capita} \sim 25\frac{\text{tonnes}}{\text{capita}}$$

The metabolic rate would thus decrease approximately 56 % from 45 tonnes/capita to 25 tonnes/capita if the domestic material consumption of hotspots was halved. The 50 % reductions in hotspots would lead to over 50 % reduction in total domestic material consumption because of the characteristics of material category of biomass. The domestic material consumption of wood was greater than the domestic material consumption of the material category of biomass in total which was the result of that the value of the subcategory, 1.6 Products mainly from biomass, was negative. (OFC, 2023.)

5 Feasibility of reductions

This chapter considers the feasibility of proposed reductions of domestic material consumption of the hotspots. The possible implications of the reductions on the sectors of housing, transportation, industrial and construction are considered from the perspective of achievability.

5.1 Housing sector

The 50 % reduction in the domestic material consumption of wood would reduce the amount of energy generated by approximately 380 000 TJ annually. In 2019 housing accounted for 230 000 TJ of the total energy consumption. The 50 % reduction in domestic material consumption of wood would thus require reducing the energy consumption in Finnish households by approximately 160 % annually. Thus, this reduction in the consumption of energy would not be feasible from the perspective of housing sector.

In 2019, heating of residential buildings was accountable for approximately 67 %, heating of domestic water 15 %, heating of saunas 5 %, and electric equipment, cooking, and lighting 13 % of the total energy consumption in housing. (OFC, 2020a.) The energy consumption could be reduced in several ways. For example, every degree of room temperature lowered lowers the energy consumption by 5 % (Kuluttajaliitto, n.d.). On the other hand, it is estimated that between 2000 and 2020 the energy consumption in housing was lowered by approximately 130 000 TJ through improvements in energy efficiency and eco-design requirements of equipment and lighting. In addition, heat pumps lowered the energy consumption by approximately 22 000 TJ and new building norms by 30 000 TJ. These estimates were based on a hypothetical scenario in which no energy efficiency requirements were introduced. (Motiva, 2023.) Energy consumption in housing could thus be lowered to a certain extent for example through consumer behaviour, but naturally the 160 % reduction in annual energy consumption is infeasible.

5.2 Transportation sector

The 50 % reduction in the domestic material consumption of liquid and gaseous energy materials/carriers would reduce the number of kilometres driven by petrol- and diesel-driven cars by approximately 22 % annually. In 2016 the Finnish Transport Agency estimated that for approximately three-fourths of passenger car travels there are no alternative travelling options as a passenger car is the only reasonable option for travelling. For approximately one-fourth of passenger car travels there are alternative traveling options. Over 10 % of these travels could be done by foot or by bicycle and the remaining ones using public transportation. (Kalenoja, 2022; Liikennevirasto, 2018.) The 22 % reduction in the number of kilometres driven by petrol- and diesel-driven cars would thus be feasible from the perspective of transportation sector but it would require changes in urban structures. The use of public transportation would also increase in some extent. (Rajavuori, 2023.)

However, private motoring has a great impact on national economy as it yields a tax income of approximately 4.5 billion euros annually. If the number of kilometres driven petrol- and diesel-driven cars would decrease by 22 % it would thus have an impact on national tax revenues and would potentially require changes in national tax structure also. (Kalenoja, 2022.) On the other hand, if the number of travels done by foot or by bicycle would increase, it would potentially decrease the expenses caused by sedentary lifestyle and save billions of euros annually. (Rajavuori, 2023.)

5.3 Industrial sector

The 50 % reduction in the domestic material consumption of nickel would reduce the production of stainless steel by approximately 86 %. In 2021, the worth of Finnish exports was approximately 77 billion euros in total and one of the top exports was large flat-rolled stainless-steel. The product category accounted for 2.9 billion euros from the total exports. The reduction of approximately 86 % production of stainless steel would thus have a significant impact on exports. The reduction of domestic material consumption of nickel would thus not be feasible from the perspective of industrial sector as it would cause remarkable subtractions on national finances. (OEC, n.d.)

5.4 Construction sector

The 50 % reduction in the domestic material consumption of sand and gravel would reduce the number of roads constructed annually by approximately 360 kilometres. In 2019, the amount of permanent pavement roads was approximately 51 000 kilometres, and 1 700 kilometres of new pavement projects were constructed. The number of new pavement projects was historically low, and for example in 2018 new pavement projects covered approximately 720 kilometres more. (OFC, 2020b.) The number of new pavement projects varies annually and the reduction of approximately 360 kilometres in new pavement projects would be feasible as the yearly variation in pavement projects can be more significant.

However, the Finnish Transport Agency estimated that the number of new pavements projects should be approximately 3 500—4 000 kilometres annually that the number of surfaces in poor condition and maintenance backlog would not increase (Väylävirasto, 2023.). Even though the yearly variation in pavement projects can be greater than the number of kilometres equivalent to 50 % reduction of the domestic material consumption of sand and gravel, the further reduction in pavement projects would lead to increased maintenance backlog. The reduction of 360 kilometres road constructed yearly is thus feasible from the perspective of construction sector, but it would deteriorate the condition of Finnish transport network in the long run. The highway maintenance backlog has a great impact on national economy, as it is accountable for expenses of billions of euros annually. For example, in 2021 the highway maintenance backlog was at 1.6 billion euros. (Tieto.Traficom, 2021.)

6 Discussion

This chapter concerns the process of conducting this master's thesis. The process is described from the selection of indicator to the proposed sustainable levels of material use provided with discussion on the matter.

6.1 Approaching of social metabolism

The initial aim of this master's thesis was to consider the socioeconomic metabolism in Finland from the perspective of national material flows. The presumption was that social metabolism of a nation would be reduced by reducing the material footprint of national material flows of biomass, fossil fuels, metal ores and non-metallic minerals, aggregated into material categories according to standard material flow accounting framework. The intention was to identify the hotspots within material categories based on the high contribution to the total material footprint of the material category. The material footprints of material flows would thus be reduced through the hotspots. The aim was to assess the impact on the total national material footprint thus social metabolism if the material footprints of the hotspots were reduced by certain percentual shares and provide examples on the implementation of these reductions. This seemed to be an applicable approach since there were existing studies on the matter.

However, the availability of national material footprint data hampered the identification of the hotspots. The data consisted of total material footprints of biomass, fossil fuels, metal ores and non-metallic minerals and was not further specified which impeded the identification of the hotspots from the national material footprint data. The indicator of material footprint was thus replaced by the indicator of domestic material consumption. The domestic material consumption is one of the most prominent material flow accounting indicators used for sustainable resource use and sustainable development. The metabolic rate of a nation is described as domestic material consumption per capita of population, assessed also in several studies considering social metabolism. Despite of that, the idea of using material footprint instead of domestic material consumption as an indicator of social metabolism, arose from one of the main limitations of domestic material consumption.

The indicator of material footprint overcomes the limitation of physical consumption of raw material within an economy by concluding the production chain from its beginning of raw material extraction from natural environment to the end of consumption of a good or service. Enumeration of this link can comprehend several countries and economies, the domestic material consumption limiting the material usage to the direct use of raw materials within an economy. Domestic material consumption represents the issue of a production and material footprint the issue a consumption within an economy. The indicator of material footprint emphasizes the importance of shared responsibility by disclosing the impacts of natural resource extraction, processing, and consumption, in the age of globalisation. To provide a comprehensive view on the consumption and production pattern of societies thus their socioeconomic metabolism, both perspectives are needed to acknowledge. Even though the material footprint was not used as an indicator for social metabolism, it is included in this master's thesis as it provides additional information on the matter.

6.2 Operationalising of social metabolism

The national material flows of biomass, fossil energy materials/carriers, metal ores and non-metallic minerals were thus considered from the perspective of domestic material consumption. The source of data was Official Statistics of Finland free databases. To enable the inspection of domestic material consumption and material footprint abreast, the year 2019 was selected as reference point of time as it was the most recent year there were material footprint data available. Also, the year 2019 was the last year before the Covid-19 pandemic, which had a high impact on the industrial supply chains and production and consumption patterns globally. The hotspots were defined as subcategories that had a high contribution to the total domestic material consumption of the material category. These hotspot subcategories were then further described.

The identified hotspots were subcategories of wood within biomass, liquid and gaseous energy materials/carriers within the fossil energy materials/carriers, non-ferrous metals within the metal ores and sand and gravel within the non-metallic minerals. To illustrate the relationship between social metabolism and domestic material consumption, the domestic material consumption of these hotspots was halved. This decreased the total domestic material consumption by approximately 110 000 thousand tonnes. Consequently, the socioeconomic metabolism, in a form of metabolic rate, decreased from approximately 45 tonnes to 25 tonnes.

6.3 Reduction of social metabolism

As the domestic material consumption describes the actual amount of material in an economy, outsourcing of the identified material intensive industrial processes to other countries would reduce the domestic material consumption in Finland. This would lead to an increase in the material footprint, as it describes the virtual amount of material required to service a final demand throughout the supply chain. However, this kind of an approach would not be considered sustainable as the environmental burden would only be shifted from one place to another. Material footprint and domestic material consumption should thus be looked at in combination, as they approach an economy from two different perspectives.

Another approach for reducing the domestic material consumption would be decreasing the consumption of materials in absolute terms. When it comes to the consumption of actual material in an economy, the replacement of material would not in absolute terms reduce the total domestic material consumption, unless the material was outsourced, as the domestic material consumption of replacing material would concurrently increase. To give an example, the Geological Survey of Finland estimated that a direct and complete system replacement of the Finnish fossil fuel industrial ecosystem in 2019 would resemble an energy need of approximately 140 TWh in total. Only replacing fossil fuels in the Finnish transportation fleet by wood-based biofuels would require annually approximately 40 cubic megametres of wood biomass to correspond the energy need of approximately 49 TWh of the replaced fleet. Wood harvests in Finland are already close to levels of what is considered sustainable and leaving aside the further environmental, social, and economic impacts of the replacement, this would lead to the decrease in domestic material consumption of fossil energy materials/carriers but increase the domestic material consumption of biomass. (Michaux et al., 2022.) In this master's thesis the reduction of social metabolism was thus approach through the reduction of actual amount of material that was further allocated to the reduction of production. It was assumed that domestic material consumption of hotspots would not be replaced or displaced by another material and the domestic material consumption would be reduced in absolute terms.

6.4 Limitations of economy-wide material flow accounting

As the material flow accounting indicators measure the environmental pressure economies exert on environment, rather than specific impacts, the critique towards these indicators is often related to the aggregation of materials, that have different impacts on the environment, to one mass. This challenges the context dependent definition and weighting of the impacts. The strength of material flow accounting indicators is argued on the other hand to be the aggregating measurable mass flows and their simplicity. (Krausmann et al., 2017.) All in all, social metabolism, as well as sustainability, is an anthropocentric concept and these global bio-physical parameters illustrate the direct and indirect effects of societies and their operations on Earth. Still, one of the contentious issues related to these indicators when considering the sustainable level of material use is the lack of agreements on the matter.

6.5 Considerations of global material use

Quantifying global targets for material use is challenging for variety of reasons. The definition of safe operating space within the planetary boundaries is dependent on the scale of observation and system perspectives. The considerations pertain not only to environmental aspects, but also social factors, such as social acceptance and equity. (Bringezu, 2015.) Since the industrial transformation is in a constitutional stage in majority of nations from the socio-metabolic perspective, the development status of nations impacts on its material needs. The construction of infrastructure increases the consumption levels of emerging economies when more matured economies use natural resources to supply production of high technology. The growing use of natural resources does not only engender environmental challenges but also societal conflicts as the natural resources are unequally distributed globally and within nations. This emphasises the importance of the fair share of natural resources globally when determining targets for material use. (Bringezu, 2015; Krausmann et al., 2017.) As the definition of sustainable development concludes, the ability of the current nor the future generations to meet their needs should not be compromised (IISD, 2024).

Nonetheless, the trajectories of global material use vary between the scenarios and projections. Schandl et al. suggested that if the global material extraction would develop following the path of business-as-usual, by 2050 the material use would reach approximately 180 gigatonnes and 20 tonnes per capita per year. The International Resource Panel on the other hand estimated that even if industrial nations would stabilise their domestic material consumption per capita to the level of the year 2000 followed by other nations, by 2050 the material consumption would still increase to 140 gigatonnes and 16 tonnes per capita per year in a global scale. The International Resource Panel proposed that the decoupling of the economic growth from environmental degradation would be achievable with a level of material consumption of 6 to 8 tonnes per capita per year in 2050. However, as the growth rate of material consumption currently exceeds the global gross domestic product driven by industrialisation of developing countries, the decoupling is not occurring. (Schandl et al., 2016; IRP, 2019.)

6.6 Implications of reduced domestic material consumption

Halving the domestic material consumption of the hotspots would reduce the total domestic material consumption by approximately 110 000 thousand tonnes and decrease the metabolic rate from 45 tonnes to 25 tonnes. Furthermore, the level of metabolic rate would still remain unsustainable, which describes the scale of the issue. The implications of reduced domestic material consumption were considered from the perspective of economic activities and provided with examples considering various sectors. For example, the 50 % reduction in the domestic material consumption of liquid and gaseous energy materials/carriers would reduce the number of kilometres driven by petrol- and diesel-driven cars by approximately 22 % annually. The example highlighted here is one of the most feasible proposed in the case study. Nevertheless, operationalising this reduction would require significant changes in urban structures, national economy, and contemporary lifestyle to an arguably unrealistic extent.

In the case study the feasibilities of the reductions were considered from the perspective of national economy that follows the path of business-as-usual. However, the issue of reducing the domestic material consumption could also be approached from the concept of sustainable consumption corridor and its possibilities. For example, in 2021 Fuchs et al. estimated sustainable limits for floor space based on the size of a household. Estimates in floor space for a four-person household varied from a minimum standard of 40—42 square metres to maximum standard of 80—120 square metres. (Fuchs et al., 2021.) When it comes to housing for example, introducing a sustainable consumption corridor would offer a pathway to reducing domestic material consumption thus energy consumption in housing as the size of a house impacts on its energy requirements (Stephan & Crawford, 2016). All the same time, from the perspective of construction sector applying a sustainable consumption corridor to reduce domestic material consumption is more complex. One of the challenges is that the reduction of domestic material used in road construction would deteriorate the condition of Finnish transport network in the long run and engender inequality. For example, in 2019 the number of pavement projects decreased in Lapland area by 61 % when in are of Uusimaa the decrease was only 10 % compared to the previous year (OFC, 2020b). The reduction in domestic material consumption would thus have greater impact on population living in areas of dispersed settlements. Implementing sustainable consumption corridors within a society is hence challenging because of the environmental, social, and economic interdependencies, being also a question of social justice. Whether achieving a sustainable consumption corridor is possible without compromising the condition of the Finnish transportation network and in which time frame, is one of the possible questions of further research.

7 Conclusions

In this master's thesis social metabolism in Finland was considered from the perspective of national material flows of biomass, fossil energy materials/carriers, metal ores and non-metallic minerals and their domestic material consumption, aggregated into material categories according to standard material flow accounting framework. Initially, it was presumed that social metabolism would have been reduced through the reduction of material footprint of biomass, fossil energy materials/carriers, metal ores and non-metallic minerals. However, as the data consisted of total material footprints of biomass, fossil fuels, metal ores and non-metallic minerals and was not further specified, the identification of the hotspots from the national material footprint data was impeded. The indicator of material footprint was thus replaced by the indicator of domestic material consumption and the indicator of material footprint was included as an additional information.

Economy-wide material flow accounting framework was applied to the data of Official Statistics of Finland that the quantitative research on national material flows in this master's thesis based on. The concept of social metabolism was thus operationalised through the economy-wide material flow accounting framework and the system boundary of the case study defined according to it. The year 2019 was the last year before the Covid-19 pandemic, which had a high impact on the industrial supply chains and production and consumption patterns globally. It was also the most recent year there were material footprint data available. To enable the additional analysis of national material footprint and domestic material consumption data abreast, the year 2019 was selected as a reference point of time when considering the consumption of biomass, fossil energy materials/carriers, metal ores and non-metallic minerals in Finland.

To illustrate the relationship between social metabolism and domestic material consumption, the hotspots of national material flows were defined based their high contribution to the total domestic material consumption of the material category and halved to demonstrate the potential implications of the reductions on different sectors and metabolic rate. The identified hotspots were subcategories of wood within biomass, liquid and gaseous energy materials/carriers within the fossil energy materials/carriers, non-ferrous metals within the metal ores and sand and gravel within the non-metallic minerals. Halving the domestic material consumption of these hotspots reduced the total domestic material consumption by approximately 110 000 thousand tonnes and decreased the metabolic rate from 45 tonnes to 25 tonnes.

Theoretically, the domestic material consumption of the hotspots of the material flows would be reduced by simply outsourcing the identified material intensive industrial processes to other countries, as the domestic material consumption describes the actual amount of material in an economy. However, this kind of an approach would not be considered sustainable as the environmental burden would only be shifted from one place to another. Another theoretical approach for reducing the domestic material consumption of hotspots would be the decrease in domestic material consumption of materials in absolute terms. In this master's thesis the reduction of social metabolism was thus approachd through the reduction of actual amount of material that was further allocated to the reduction of production. It was assumed that domestic material consumption of hotspots was not replaced or displaced by another material and the domestic material consumption was reduced in absolute terms. The implications of reduced domestic material consumption were considered from the perspective of economic activities and provided with examples considering various sectors. For example, the 50 % reduction in the domestic material consumption of liquid and gaseous energy materials/carriers would reduce the number of kilometres driven by petrol- and diesel-driven cars by approximately 22 % annually. Operationalising the reductions would however require significant changes in urban structures, national economy, and contemporary lifestyle to an arguably unrealistic extent.

This master's thesis described social metabolism in Finland approaching it from the perspective of domestic material consumption of the national material flows using a methodology of economy-wide material flow accounting framework. The relationship between social metabolism and domestic material consumption was illustrated through a case study and provided with general discussion on the matter. This master's thesis was aligned with previous studies on the matter considering the social metabolism in industrial nations and their production and consumption practices, perceiving the use of economy-wide material flow framework and its indicators as an operational tool to delineate socioeconomic metabolism within an economy. However, this master's thesis should be viewed acknowledging the possible uncertainties, characteristics and restrictions related to the conducted study and viewed as directional. Some inaccuracies can occur for example, due to calculation mistakes or incomplete knowledge. In general, material flow accounting indicators measure the environmental pressure economies exert on environment, rather than specific impacts. This aggregation of materials, that have different impacts on the environment, to one mass challenges the context dependent definition and weighting of the impacts.

In the centre of this master's thesis was the material dimension of social change, the examination of the material flows of organic and mineral resources that constitute the material basis of society. The focus of this master's thesis was thus on the material exchange between the society and nature. The sociological dimension, the flows of information, of social metabolism were not further addressed in the study which left the analysis of social metabolism incomplete thus constituting only a partial view of the issue. In addition to immaterial processes within the society this approach also left out the processes occurring inside the society which is a general characteristic of material flow accounting framework. Although the immaterial dimension of information flows provides the framework for material processes. The social dimension in relation to material flows and sufficiency when it comes to the appropriate and sustainable level of material use and social metabolism could thus be the topics of further research.

Altogether, one of the requirements for sustainability is limiting the social metabolism within the capacity of natural environment, which enables the transition towards more sustainable society but the current production and consumption patterns in Finland cannot be considered sustainable from the perspective of planetary boundaries. Still, quantifying global targets for material use is challenging for variety of reasons and the definition of safe operating space within the planetary boundaries is dependent on the scale of observation and system perspectives. Rather than using concrete target values for describing potential safe operating space for human activities and natural resource use in a global scale, several studies have thus suggested using a sustainable consumption corridor, a range of target values, instead. The recognition of the future metabolic system and its capacity to operate within the current biophysical preconditions of the planet should be emphasised when considering a sustainable level of consumption in Finland or globally and setting these targets. As the definition of sustainable development concludes, the ability of the current nor the future generations to meet their needs should not be compromised.

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