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Analysis of the socioeconomic metabolism of nations: methods and applications

Sónia Martins da Cunha

Supervisor: Doctor Paulo Manuel Cadete Ferrão

Thesis approved in public sessions to obtain the PhD Degree in
Sustainable Energy Systems

Jury final classification: Pass with Distinction

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Resumo

Os materiais fornecem serviços vitais para o bem-estar humano, no entanto há inúmeros impactos ambientais associados à sua utilização. A falta de evidência de que o crescimento económico se esteja a dissociar da utilização de recursos é motivo de preocupação e exige que se melhore o conhecimento sobre o papel dos fluxos de materiais no metabolismo socioeconómico (SEM).

Esta tese propõe duas metodologias, que quando integradas, podem ser aplicadas para a analise detalhada do SEM de múltiplos países num determinado período de tempo. O primeiro método, que foi implementado num programa *Python*, descreve uma forma inovadora de quantificar tabelas "input-output" da economia, em unidade físicas, com base em dados oficiais e respeitando os balanços de massa. Os resultados quantificam os fluxos mássicos do SEM para 37 sectores e 17 materiais. A segunda metodologia proposta está organizada em 4 passos para a análise do SEM, integrando a análise da estrutura e fluxos do SEM.

A aplicação destas metodologias é demonstrada por dois casos de estudo. O primeiro caso de estudo analisa as mudanças no SEM durante as transições económica que Portugal atravessou entre 1995 e 2017 e a crise económica de 2007-2008. A aplicação dos métodos ao estudo detalhado de uma economia permite identificar quias foram as mudanças no SEM e a relação entre elas e a transição económica do país. O segundo caso de estudo compara o SEM de quatro países europeus caracterizados por diferentes níveis de extração doméstica, de importação de materiais e de produto interno bruto per capita. O caso de estudo demonstra a plicação do método numa analise comparativa e identifica fatores que influenciam a relação entre o crescimento económico e o input de materias.

Esta tese contribui com o desenvolvimento de metodologias pioneiras para o estudo detalhado do SEM de vários países, ajudando a compreender as suas dinâmicas e usando essa informação para fundamentar o desenvolvimento de políticas e iniciativas para a promoção de um futuro mais sustentável.

Palavras-chave: desenvolvimento sustentável; contas de fluxos de materiais para a economia; tabelas input-outpu físicas; metabolismo socioeconómico; ecologia industrial

Abstract

Material resources are vital for human well-being and development, yet they are also associated with severe environmental impacts. The lack of evidence of decoupling resource use from economic growth is cause for concern and calls for a more detailed understanding of material use and its implication on socioeconomic metabolism (SEM).

This thesis proposes two methodologies that, when integrated, can be used for a detailed analysis of the SEM of multiple countries over a time period. The first methodology was implemented as a Python program and describes an innovative process for calculating Physical Input-Output tables (PIOTs) based on official data and the mass balance principle. Its results quantify the flows into, out of, and within 37 economic sectors for 17 different materials. The second methodology consists of a 4-step framework for the analysis of the SEM. The first two steps of this framework are based on Economy-Wide Material Flow Accounting. The third and fourth steps integrate the data from the PIOTs with monetary data to explore the economic structure and the physical and monetary flows of the SEM.

The two methodologies are showcased in two case studies. The first case study provides insights into material use and economic growth dynamics by quantifying the socioeconomic flows associated with the structural changes that affected the Portuguese economy between 1995 and 2017. The second case study compares the SEM and development of four European countries characterized by different levels of domestic material input and gross domestic product per capita. The results identify the various factors associated with the different resource productivity values and decoupling levels between the economies.

The work described in this thesis contributes with novel methodologies that, when integrated, can be used to study the SEM of multiple countries in detail. Understanding the SEM dynamics is crucial for creating policies and initiatives that will lead to a more sustainable economic development.

Keywords: sustainable development; economy-wide material flow accounting; physical input-output tables; socioeconomic metabolism; industrial ecology

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Acronyms and abbreviations

C

CO_2 - Carbon dioxide

CO_{2eq} – Carbon dioxide equivalent

D

DE – Domestic extraction

DMC – Domestic material consumption

DMI - Domestic material inputs

E

EEIOTs – Environmentally extended input-output tables

EKC – Environmental Kuznets Curve

EU – European Union

EW-MFA - Economy-wide material flow accounting

G

GDP – Gross domestic product

I

IOA - Input-output analysis

IOT – Input-output table

IRP – International Resource Panel

ISIC - International Standard Industrial Classification of All Economic Activities

M

MFA – Material flow analysis

MIOT - Monetary input-output table

MRIO - Multi-regional input-output

P

PIOT - Physical input-output table

R

RP – Resource productivity

S

SEM - Socioeconomic metabolism

SNA - System of national accounts

V

VA – Value added

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1 Introduction

Material goods support human well-being and development. For example, materials provide humans with shelter, nourishment, clothing, and transport. It is then not surprising that material use also increases as the population increases and develops. Between 1970 and 2017, the population doubled, and economic activity grew four times, contributing to a three times increase in resource use, as seen in Figure 1.1 (UNEP International Resource Panel, n.d.; United Nations, 2018; World Bank, 2019).

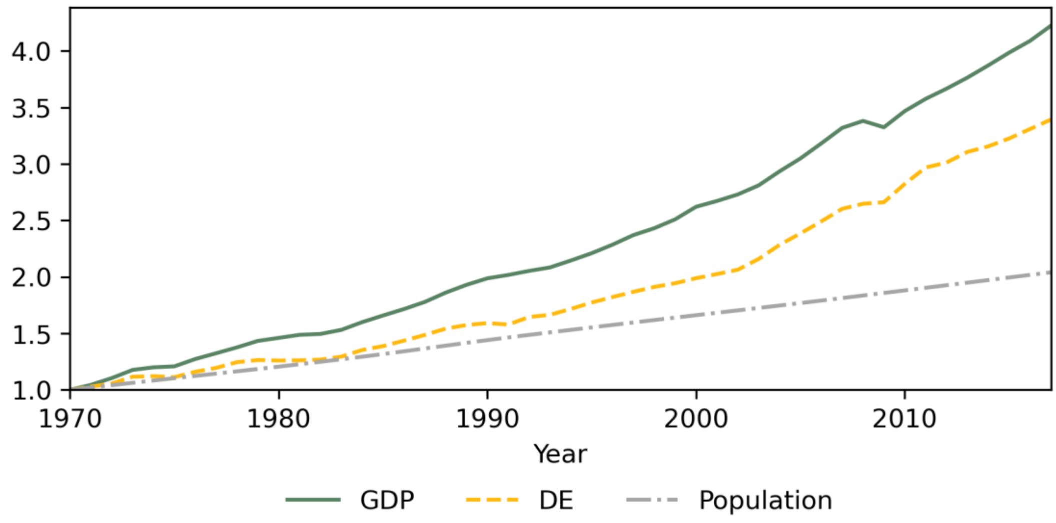

Figure 1.1 - Evolution of global gross domestic product (GDP) (in constant 2010 US$), extracted resources, and world population relative to 1970. Table 9.1. provides the data used for the construction of the figure.

The use of a product is part of a chain of processes that include extracting natural resources from the environment, their processing, and transport before being used. When the useful life of the product reaches its end, the product is disposed of to nature once again. The use of a product is then associated with emissions and the creation of residues and waste, meaning that these processes, especially extraction and disposal to nature, impose pressure on the natural environment, with impacts such as damage to human health and climate change (Bringezu et al., 2003; Oberle et al., 2019).

Human activities have now been linked to climate change and extreme weather events (IPCC, 2021), which will affect human well-being and economic activities, making sustainable development a top priority for policymakers. Policymakers and other stakeholders must now find ways to promote economic growth and well-being while ensuring sustainable development. Humanity is now anticipating, strategizing, and planning to respond to epochal changes (Pauliuk & Hertwich, 2015). New initiatives may include geoengineering, technological development, economic instruments (taxes and subsidies), new regulations, standards, and the development of informed consumers and lifestyle changes.

A body of scientific work, reports, goals, actions, and works, some going back to 1972, prove the concern over sustainable development. The United Nations Conference on the Human Environment in 1972 later resulted in the creation of the United Nations Environment Programme, which in turn organized a series of conferences and created the Intergovernmental Panel on Climate Change (IPCC) (Johnson, 2012). Some of the Sustainable Development Goals also support the responsible and sustainable use of resources, like *Sustainable cities and communities* or *Responsible consumption and production* (United Nations, 2019). More recently, the European Commission restated its commitment, in the European Green Deal, to work on transforming the European Union (EU) into a competitive, resource-efficient prosperous society while decoupling economic growth from resource use (European Commission, 2019). The Global Resources Outlook 2019 is a report from the International Resource Panel (IRP) that promotes sustainable development by exploring material use, and the effects policy and societal actions may have on the transition towards sustainability (Oberle et al., 2019).

Climate change may affect human health and well-being, directly and indirectly, due to supply chain disruption (Ghadge et al., 2019). The sustainable use of resources is currently one of the major concerns for policymakers, private companies, and citizens. The same material flows on which humanity depended for its wellbeing and development are now negatively affecting our natural environment, health, and economic activities. The sustainable use of resources is a field with significant interest.

1.1 Problem statement

Climate change is a complex problem associated with various aspects, such as energy use, manufacturing technologies, housing, or waste management. The sustainable use of natural resources and its link to economic development are essential aspects of the fight against climate change. However, there is not a comprehensive enough understanding of the flows (material and monetary) that support the socio-economic system.

Understanding the socio-economic system that supports human activities is necessary to design sustainable development strategies and instruments. Mass and energy flows, from and to the natural environment (the biosphere), support the socio-economic system. The mass and energy flows brought into the economy and exchanged within it, along with the corresponding monetary flows, create the socioeconomic metabolism (SEM) of our societies. This system is complex, with tangible and intangible connections. It starts with the extraction of resources from the natural environment and ends with returning waste to the biosphere, including the mechanisms involved in the supply chains of each product and their consumption.

The study of sustainable development is then a significant priority. It requires an understanding of the relations between the use of resources and economic development, as described by the relation between monetary and material flows. Several methods and studies have been developed focusing on the relationship between economic development and the use of resources in the economy, such as economy-wide material flow accounting (EW-MFA) or input-output analysis (IOA). However, none of these methods have covered all the dimensions needed for a detailed and replicable analysis, as illustrated in Figure 1.2.

EW-MFA typically provides easily replicable results, but that are too aggregated, without sectorial resolution or detailed flows. It is possible to use a bottom-up approach for EW-MFA to have more detailed results, but they are not easily replicable for various countries.

IOA can take various forms, including monetary input-output tables (MIOTs), Environmentally extended input-output tables (EEIOTs), and multiregional input-output tables (MRIOTs), which have a sectorial resolution. They are available for various countries and years, yet they do not describe the material flows, only monetary and sometimes emissions, waste, or other environmental dimensions. Physical input-output tables (PIOTs) give a detailed account of the material flows in an economy. However, they are not available for different years or countries and are compiled using different methods from country to country, making the results hard to compare.

So far, there is no study or replicable method that analyses monetary and material flows with enough resolution to give a detailed picture of the socioeconomic system of the different economies.

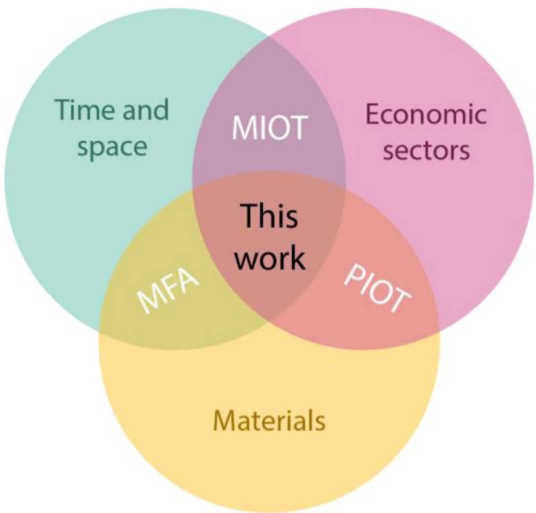

Figure 1.2 - Dimensions typically covered by the various methodologies and the gap covered by this work.

The work presented in this thesis focuses on developing a model that can take data from official sources that are available and comparable for different years and countries to create PIOTs. These PIOTs will produce a significant amount of information that can become too complex to analyze, especially when considering the corresponding material flows and focusing on changes in time and between economies. The complexity of the analysis is tackled by integrating the results of the PIOTs and MIOTs into a 4-step methodological framework for the analysis of the SEM. This framework structures the analysis of the SEM, facilitating the interpretation of a large amount of data on a complex system. These methods can be used for the detailed analysis of an economy through different stages of development, as structural changes take place, and for the comparative analysis of various economies, enabling the identification of the different drivers of their resource use and the dynamics within the economy through time. These methods are applied to various case studies to validate them and establish their contribution to the design of sustainable development policies.

1.2 Research questions

The research questions addressed in this thesis are:

- How to describe the material flows in an economy with enough resolution while ensuring the replicability and comparability of results for different countries?
- How to use the available monetary and physical data on material flows to find valuable insights on the SEM of a country or a group of countries?
- What are the impacts of a changing SEM on the resource productivity of a country?
- What are the critical aspects of the SEM that can determine the development pathway and resource productivity of different countries?

1.3 Scientific approach

The research questions expressed in the previous section were supported by a comprehensive literature review on a variety of topics linked to sustainable development, including methodologies for its characterization, different development pathways, and drivers of resource use. The goal of this literature review was first to understand the system associated with using natural resources to identify which aspects should be covered in its study and then to know what are the existing methodologies and their shortcomings.

It was found that EW-MFA fails to characterize structural changes in an economy that may impact the demand for certain materials in different stages of the development of a country. EW-MFA also fails to establish the link between the economic sectors and how the demand from one sector may impact the demand from others. Additionally, without a comparable description of both monetary and physical flows between economic sectors, the roles of specific sectors in the use of resources may be under or over-estimated. The primary gap identified is in the coverage and resolution of the existing models for the analysis of the SEM through different development stages.

This gap was addressed through the development of two integrated methodologies:

- A methodology for the calculation of PIOTs that is based on official data that is available for a relevant time series and number of countries, thus providing detailed results on the physical flows of materials within an economy;
- A 4-step framework for the analysis of the SEM that integrates data from PIOTs with data from MIOTs, providing meaningful and valuable insights about the SEM of one or more countries.

These methods can be easily applied as described in this thesis to describe the SEM of European countries between 1995 and 2015. Simple changes to the method can be made to extend this period by including other data sources. The results cover 17 materials and up to 37 economic sectors, and are available in monetary and physical units. The values in the PIOTs can be used to calculate interesting indicators, like the resource productivity of an economic sector. The method for calculating the PIOTs was validated based on existing data and sensitivity analysis. The features of the methods are showcased through two case studies, one focused on the detailed analysis of a country, Portugal, through different stages, and another on the comparative analysis of four European countries, Estonia, Finland, Croatia, and the United Kingdom, at two levels of economic development and resource use.

1.3.1 Method for the quantification of PIOTs

The method described in this thesis for quantifying the values of PIOTs follows an innovative and easily replicable approach based on data available from official sources, assumptions from previous studies, and new assumptions. The existing PIOTs are not available for many economies or years and are usually developed by national statistics offices, following different methods and having different resolutions. On the other hand, MIOTs, even with environmental extensions, have been found to overestimate the contribution of the services sector to the SEM. This new approach for the quantification of PIOTs provides significant sectorial resolution. At the same time, the method is easily replicable for all the countries covered by the data sources suggested here. The method was programmed in Python, which adds to its ease of use. It is also possible to quantify the PIOTs of countries not covered by these data sources, as long as it is possible to find alternatives or proxies to estimate the required data.

This method is described in detail in chapter 3. It has also been published in the first paper associated with this work, titled «A framework to analyze the dynamics of the socioeconomic metabolism of countries». The validation of this method was done within the limits of the existing data for the Portuguese economy. The data sources used were compared with alternatives. A sensitivity analysis was performed to test how uncertainties in the data sources could impact the results. Finally, the validity of the most significant assumption, the homogeneous price assumption, was explored on data from PRODCOM. The method was first applied to the Portuguese case study, resulting in intuitive results.

In the second paper, titled «Can structural changes lead to dematerialization? Lessons from the Portuguese socioeconomic metabolism between 1995 and 2017», covered by chapter 5, a more detailed analysis of the Portuguese economy was performed, covering more years.

The third paper, presented in chapter 6, comprises the SEM of 4 European countries. The method had to be extended to more countries, thus showcasing how the methods can be applied to various economies and provide comparable results.

1.3.2 A 4-step framework for the analysis of the SEM

The PIOTs with 37 sectors for 17 different materials and the corresponding MIOT will result in a significant number of data points (32 922) per year and country. The 4-step framework for the analysis of the SEM was developed to facilitate the analysis of the SEM within this "data-rich field" created by the PIOTs.

This novel framework integrates indicators from the EW-MFA method and new data from the input-output tables (IOTs). The framework steps are described and illustrated in chapter 4 and in the research paper titled «A framework to analyze the dynamics of the socioeconomic metabolism of countries». The four steps of the framework are:

- The analysis of economic development, use of resources, and productivity, enabling the identification of different stages, when and if relevant for the goal of the analysis;
- The identification of the types of materials used by the economy;
- The analysis of the economic structure (value added (VA), use of resources, and resource productivity by sector);
- The study of the critical physical and economic flows that is facilitated by plotting the IOTs in chord diagrams.

This framework was applied to two case studies. The first focuses on the detailed analysis of the Portuguese SEM through various stages, as described in chapter 5 or in the mentioned second paper. The third paper, whose corresponding work is presented in chapter 6, demonstrates how the framework can be used to compare different economies.

1.4 The Portuguese case-study

The Portuguese economy was chosen to validate the methods as the first case study due to the data availability and coverage. The Portuguese economy went through an economic transition during the period covered by the data sources, making it an interesting case study.

The detailed study of the SEM of an economy during an economic transition was showcased in this case study. It was possible to observe the key factors and the dynamics involved in the transition from a more industrial economy to an economy where services play a more significant role. Because the time series also covers the economic recession of 2007-2008, the analysis also shows how the SEM of a country may change during a recession, which has been previously linked to the decoupling of economic growth from resource use.

1.5 Four European economies

The methodology proposed for quantifying the PIOTs was developed in a way that ensured that it could be easily applied to other countries and that it provided comparable results. The second case study showcases the replicability and comparability of results between countries.

The analysis shows how the different steps of the framework can provide meaningful insights in comparing economies, like identifying the aspects of each economy that may impact its economic growth or level of resource use, from its natural resources to its economic structure. Like the Portuguese case study, the time series for these countries also cover the economic recession, adding another dimension to the analysis.

1.6 Scientific contributions

In general, this thesis offers methods of scientific relevance with usefulness for policy development. Perhaps the main scientific contribution of this thesis is the method proposed for the quantification of PIOTs, based on official data and tested assumptions. The other existing methods used to study material flows either lack resolution and physical data or cannot be easily replicated for various years and countries.

This method results in the quantification of 17 material flows into and out of the economy, but also between 37 economic sectors. Additionally, it can be easily applied to any European country since 1995, based on the proposed data sets. The method was programmed for all European countries between 1995 and 2015, increasing its ease of use. It can also be extended to 2018, as new OECD MIOTs have since been published, requiring only the update of the correspondence tables to cover the now further disaggregated sectors, which will only add value to the results. In theory, the method can also be extended to other countries and years, depending on identifying alternative data sources or other assumptions or proxies to estimate missing data.

The second contribution of this thesis is the 4-step framework for the analysis of the SEM. The application of the method to quantify PIOTs results in a very significant amount of data that can be challenging to assess. This framework proposes four standardized steps for the SEM analysis, which identify different development stages and trends. It also enables the study of the different materials in the economy, the analysis of the roles of the different sectors, and the exploration of the SEM flows in monetary and physical units. The first and second steps are commonly found as part of a variety of EW-MFA studies. On the other hand, the third and fourth steps are novel steps enabled by the results from the quantification of the PIOTs.

The first case study showcases how these methods can be used in a detailed analysis. It also provides valuable insights into the Portuguese economy and any economy in a similar development pathway, as is the case of various European countries that have joined the EU in the latest years. The results established the link between mining, construction, and services. They also suggest that to decouple economic growth from material use, the economy may first require an investment in the construction of infrastructures. The construction sector is responsible for significant consumption of materials and environmental impacts and is also associated with sectors with low resource productivity. These insights can aid public policy in transitioning economies and support the importance of sustainable construction methods and policies.

The final contributions of this work come from the study of the four European economies. Aside from demonstrating how the methods can be applied to a study with more than one country, they contribute with insights on European sustainable development. Not only the population density of the different countries but also the type of natural resources, the economic structure, and the productivity of the economic sectors ought to be considered in any European policy or initiative for sustainable development. While all within the European context, European countries are dissimilar enough to require different development policies, as their specificity will no doubt impact their ability to decouple economic growth from resource use.

This work contributes with novel to a better understanding of the effects of structural changes and provides insights for more efficient policymaking, especially for emerging economies, which are still developing their major infrastructures.

1.7 Publications

The work developed in this thesis resulted in three research papers, conference presentations, and scientific posters.

Research paper I (Cunha & Ferrão, 2021)

The first research paper, "A framework to analyze the dynamics of the socioeconomic metabolism of countries – A Portuguese case study» by Sónia Cunha and Paulo Ferrão, was published in the Journal of Industrial Ecology in 2021.

Research paper II (Cunha & Ferrão, 2022)

The second research paper, «Can structural changes lead to dematerialization? Lessons from the Portuguese socioeconomic metabolism between 1995 and 2017» by Sónia Cunha and Paulo Ferrão, was published in the journal Resources, Conservation and Recycling in 2022.

Research paper III (draft)

The third research paper is a complete draft that is being reviewed by the various authors and has not been submitted to any journal at the present moment. It covers the results presented in Chapter 6 and is authored by Sónia Cunha, Edgar Hertwich, and Paulo Ferrão.

Conference presentation I

The conference presentation «Clustering the metabolism of nations: An assessment of material productivity and economic development of 60 nations» by Sónia Cunha, Carlos Silva, and Paulo Ferrão, was presented at the ISIE 2019: 10th International Conference on Industrial Ecology, in Beijing, China, that took place from the 7th to the 11th of July 2019.

Conference presentation II

The conference presentation «Analysis of the socioeconomic metabolism of nations: PIOTs compiled from freely available data» by Sónia Cunha was presented at The ISIE Socioeconomic Metabolism perpetual online conference - Session 9: Progress in modeling the socioeconomic metabolism - combining material flow principles and input-output analysis, on the 17th of May 2021.

Poster presentation I

The poster «Key sectors in the socioeconomic development of the Portuguese economy between 1995 and 2017» by Sónia Cunha and Paulo Ferão was presented at the virtual International Industrial Ecology Day 2021, organized by the ISIE on the 21st of June 2021, having the second place in the poster competition.

1.8 Document structure

This thesis is organized into seven chapters. The first chapter contextualized the work, presented the research questions, and summarized the scientific approach and scientific contributions. Chapter 2 presents a literature review of essential concepts for this work, drivers of resource decoupling, and methods for the analysis of the SEM that can account for such drivers. The methodology to quantify the PIOTs is described in Chapter 3. This chapter also includes the efforts to validate the method. Chapter 4 describes the four steps of the 4-step framework for the analysis of the SEM. The Portuguese SEM is explored in Chapter 5. This case study shows how the methods can be applied for the detailed study of an economy and how they can contribute valuable insights to a transitioning economy during an economic recession. The final case study covers the SEM of the European countries Estonia, Finland, Croatia, and the UK. It demonstrates how the methods offer critical insights in the comparative study of various economies, such as the ones described here. Chapter 7 presents a collection of the conclusions drawn from this work and shares possible research opportunities for the expansion and application of the work presented here.

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2 Decoupling and the dynamics in socioeconomic metabolism: a literature review

The decoupling of the use of resources from economic growth has become a significant concern, as evidenced by a variety of policies, studies, and efforts from organizations like the European Commission or the International Resource Panel (IRP) of the UN (European Commission, 2019; Johnson, 2012; Oberle et al., 2019; United Nations, 2019). The studies on the use of materials by an economy have led to the development of various concepts and methodologies and resulted in identifying some key aspects that may impact the level of resource use in an economy or its ability to decouple economic growth from resource use.

This literature review will start by introducing the concept of decoupling between economic development and resource use. Next, it will present previous work on decoupling, including an analysis of previously identified drivers of decoupling. The final subsection will focus on relevant methodologies, thus identifying the gaps the newly proposed methods should fill and the drivers that should be covered by the methods.

2.1 Key concepts

There are some key concepts that one must know when studying the relationship between economic development and material use. The following concepts are introduced in the next subsections: absolute and relative decoupling, resource productivity, and socioeconomic metabolism (SEM).

2.1.1 Decoupling between the use of resources and economic development

UNEP (2011) defined decoupling in the context of sustainable development as

> *"using less resources per unit of economic output and reducing the environmental impact of any resources that are used or economic activities that are undertaken".*

There can be resource decoupling, which refers to the use of resources, and impact decoupling when directly related to environmental impacts. Resource decoupling can decrease the scarcity and depletion of materials and reduce costs by improving productivity and reducing environmental impacts from the life cycle of certain materials (UNEP, 2011). This work focuses on resource decoupling, which will henceforth often be simply referred to as decoupling.

It is essential to distinguish between two types of decoupling (Giljum et al., 2005; UNEP, 2011): relative and absolute decoupling. The first means that the growth rate of resource use is lower than the growth rate of the economic indicator, like gross domestic product (GDP). On the other hand, absolute decoupling refers to when resource use decreases, irrespective of the growth rate of the economic indicator.

The level of decoupling can be assessed through a Decoupling Index, DI, proposed for the assessment of China as a case study on a report by UNEP (2011) and later used by Sanyé-Mengual et al. (2019) and Y. Wu et al. (2018). The DI is defined in equation (1), with DMI as the measure of environmental impact and GDP as the measure of economic growth.

$$DI_t = \frac{\Delta DMI_t}{\Delta GDP_t} = \frac{\frac{DMI_t - DMI_{t-1}}{DMI_{t-1}}}{\frac{GDP_t - GDP_{t-1}}{GDP_{t-1}}} \quad (1)$$

The different (de)coupling scenarios are illustrated in Figure 2.1. If $\Delta GDP_t > 0$ and:

- $DI_t > 1$, then the increasing rate of DMI keeps pace or is growing more than GDP, and there is **no decoupling**;
- $DI_t = 1$, then the economy is at the turning point between absolute coupling and relative decoupling;
- $0 < DI_t < 1$, it means that the DMI growth rate is lower than the economic growth rate, and there is **relative decoupling**;
- $DI_t = 0$, the economy is growing with constant resource use;
- $DI_t < 0$, then the level of resource use decreases while the economy keeps growing, and there is **absolute decoupling**.

If $\Delta GDP_t \leq 0$ (stable or decreasing economic output), while the $DI \neq 0$ and the ΔDMI_t shows a slight positive or negative variation, it is considered that the decoupling is stagnant and that any variation is linked to the economic stagnation (Sanyé-Mengual et al., 2019).

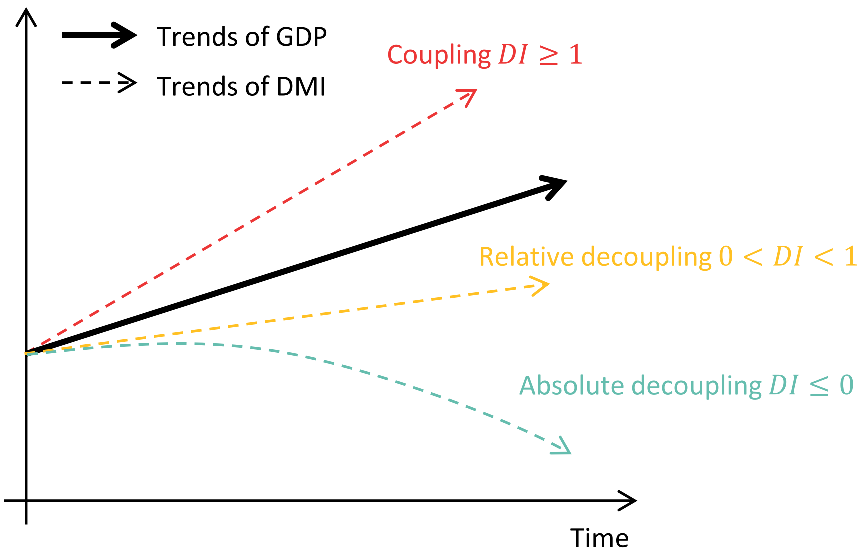

Figure 2.1 - Different (de)coupling scenarios. Adapted from UNEP (2011).

There have been numerous studies on decoupling, many of which have been reviewed by Haberl et al. (2020) and Krausmann et al. (2017). Several studies have focused on the analysis of global trends in the use of resources and GDP (Baninla et al., 2019; Behrens et al., 2007; Bithas & Kalimeris, 2018; Bringezu et al., 2004; Canas et al., 2003; Krausmann et al., 2009; Pothen & Schymura, 2015; Schaffartzik et al., 2014; Schandl et al., 2018; Schandl & West, 2010; Steinberger et al., 2013). In particular, Steinberger et al. (2010) focused on the drivers of resource use by comparing 175 countries.

Besides the studies on global trends, there are also works focusing on regions or specific countries. Some have focused on the level of decoupling in Europe and what drives resource use in these developed countries (Agnolucci et al., 2017; Bringezu et al., 2004; Karakaya et al., 2020; Steger & Bleischwitz, 2011; Vehmas et al., 2007; Weisz et al., 2006). The decoupling and general resource use analysis has also been done on one economy alone and for countries on all continents. Examples in Europe include the detailed study of the use of resources in the UK (Schandl & Schulz, 2002), Austria between 1995 and 2007 (Wenzlik et al., 2015), a study on the Spanish use of resources (Cañellas et al., 2004), and an analysis of the Spanish transition to industrial metabolism (Infante-Amate et al., 2015). Other European countries whose use of resources has been studied include Portugal (Niza & Ferrão, 2006), Finland (Hoffrén et al., 2000; Hoffrén & Hellman, 2007), Czech Republic (Kovanda, 2019; Kovanda et al., 2008, 2010; Kovanda & Hak, 2011; Ščasný et al., 2003; Weinzettel & Kovanda, 2011) and Romania (Nita, 2012). In Asia and Oceania, China, Japan, South Korea, the Philipines, and Australia have been often chosen as the focus of work on resource use and decoupling with some of the studies comparing some of these countries (Dong et al., 2017; Schandl & West, 2012; Yabar et al., 2012) while others focused on one country alone (Chiu et al., 2017; Hashimoto et al., 2008; Krausmann et al., 2011; Lee et al., 2014; Martinico-Perez et al., 2017, 2018; Schandl et al., 2008; Schandl & Turner, 2009; Z. Wang et al., 2017; Wood et al., 2009; XU & ZHANG, 2007). The material flows of Singapore (Schulz, 2007) and Russia have also been the focus of studies. Studies on material flows can be found for Chile (J. & Hubacek, 2008), Mexico (Gonzalez-Martinez & Schandl, 2008), and the US (Kelly et al., 1989).

Bringezu et al. (2003) explored the suitability of MFA (material flow accounting) indicators to assess environmental performance. The type of indicators used to evaluate decoupling has also been discussed. Some authors question the use of GDP as an indicator of the level of development of quality of life (Bithas & Kalimeris, 2016, 2018; S. Zhang & Zhu, 2020). Wiedmann et al. (2015) explored the role of hidden flows. They concluded that when the material footprint of nations is considered, the actual level of decoupling is significantly lower, with very few examples of absolute decoupling. Haberl et al. (2012) observed the effects of trade on resource decoupling.

Modeling (Gan et al., 2013) and scenario analysis (Meyer et al., 2018) have been used to determine the key drivers of resource productivity that could contribute to decoupling. However, the real possibility of decoupling as a possible development pathway has also been questioned (Ward et al., 2016). Some suggest that the only way to become sustainable is degrowth and radical dematerialization (Kallis, 2017).

Resource decoupling is a critical concept and a focus of various research projects, especially since 2000. While there have been some indications that it is possible to decouple the use of materials from economic growth (Bringezu et al., 2004; O'Neill, 2012; Steinberger et al., 2013), there is still some skepticism on whether decoupling is a feasible strategy for designing a sustainable future. A more detailed analysis of the metabolism of each country's economy can contribute to a better understanding of the mechanisms that couple material use and economic development. Additionally, such an analysis will also improve the knowledge of what distinguishes each economy and why they might develop differently or require different policies.

2.1.2 Resource productivity

Historically, economic productivity was associated with labor, as the contribution of natural resources to the economic system, the notion of productivity was extended to resources(Bleischwitz, 2001). Resource productivity (RP) is an essential concept in sustainable development. Improved resource productivity is the translation of more efficient use of resources, meaning getting more economic benefits from a limited amount of resources (Gan et al., 2013).

Eurostat (2016) proposes the quantification of resource productivity as the ratio between the materials used directly by an economy (measured by the domestic material consumption, DMC) and GDP. However, it has been suggested that the DMI (domestic material input) may be more suited because the DMC will not account for the exports (Gan et al., 2013; Vehmas et al., 2007). Equation (2) presents the formulation of resource productivity based on DMI. Exports often contribute significantly to the national income. If DMC is used to calculate resource productivity, the indicator will not transpire the actual efficiency in the use of resources, especially for countries with a high level of exports. Indeed, several studies opt to use DMI instead of DMC (Canas et al., 2003; Vehmas et al., 2007; P.-C. Wang et al., 2014).

$$RP = \frac{GDP}{DMI} \tag{2}$$

2.1.3 Socioeconomic metabolism

SEM is the study of resource flows to understand the relationship and dynamics between economic processes and environmental pressures (Krausmann et al., 2017). Adding the analysis of the SEM to decoupling studies will offer new data that could further the research in the field.

Pauliuk & Hertwich (2015) discussed the origin and concept of SEM. The concept has its origins in the works of Karl Marx and Engels from 1867, who referred to the "metabolism between man and nature"(Fischer-Kowalski, 1998). Pauliuk & Hertwich (2015) present the various definitions proposed in previous works and go on to present some principles that should be taken into consideration, resulting in the following definition:

> *"Socioeconomic metabolism constitutes the self-reproduction and evolution of the biophysical structures of human society. It comprises those biophysical transformation processes, distribution processes, and flows, which are controlled by humans for their purposes. The biophysical structures of society ('in use stocks') and socioeconomic metabolism together form the biophysical basis of society."*

This holistic approach covers the study of the dynamics of the material flows between the natural environment and the economy and the identification of drivers that lead to new material use patterns. A schematic illustration of the concept can be found in Figure 2.2.

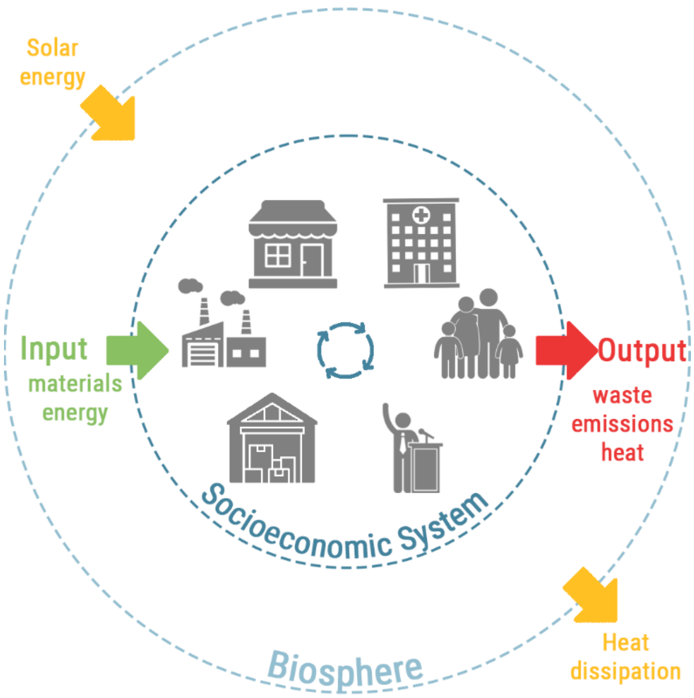

Figure 2.2 – Simplified representation of socioeconomic metabolism adapted from Haas et al. (2005).

Studies focusing on economic sectors and the value chain between them play an essential role in producing actionable science that can result in policies that promote sustainable consumption and production (UNEP, 2021). This approach can identify drivers and barriers to the operations of the different value-chains by accounting for the complex feedback loops in the SEM of a country. By considering the different parts of the system and the interactions between them, this approach can be instrumental in designing strategies that can change the system.

2.2 Sustainable development and decoupling drivers

Decoupling economic growth from material use and its environmental impacts has been considered fundamental for sustainable growth (Krausmann et al., 2017), leading to various works assessing the different levels of decoupling. These works have been based on various methodologies, and some resulted in the identification of drivers of resource use.

There are currently three different suggestions for future paths of resource use and economic development. There is the Environmental Kuznets Curve (EKC) hypothesis, the Jevon's paradox, and the path of dematerialization and degrowth.

The EKC hypothesis supports a path of decupling, where economies will eventually maintain economic growth without increasing the use of resources (Auty, 1985; Dinda, 2004). This hypothesis proposes that in the first stages of economic development, the economy is dominated by resource-intensive activities when increasing income is a bigger priority than protecting the environment. After this, as income increases, the share of industrial activity decreases, leading to a rise in the services industry. Environmental protection gains new relevance, thus resulting in dematerialization and sustainable development. Other authors have found evidence supporting this idea. Bringezu et al. (2004) studied the relationship between resource use and economic development in various countries. They found that there may be a higher and a lower limit for the use of resources (DMI) from a particular stage in economic development. The authors also suggested that after a certain threshold, a higher amount of material inputs (DMI) can be associated with an inefficient use of resources and not lead to increasing economic performance in the long run. On the other hand, it suggests that the lower limit is related to technology and can only be surpassed with technological development.

Jevon's paradox describes an alternative type of development that questions future, lasting dematerialization (Jevons, 1865; Sorrell, 2009). This paradox states that as technological development improves, the efficiency with which a resource is used increases contributing to less material being used per product/service. On the other hand, the falling price and rising income result in an actual absolute increase in the use of that resource. A possible "rebound effect" may also hinder future sustainable development. The "rebound effect" may be a consequence of more efficient use of resources: as efficiency in material use increases, the prices could drop, which coupled with increased affluence may well lead to increased absolute material use, similar to what has been proposed for energy flows (Cleveland & Ruth, 1998).

While, on the one hand, the Jevon's paradox implies that decoupling will never happen on the other, the EKC hypothesis states that decoupling will occur after a certain point in development is reached. Kemp-Benedict (2018) found arguments both in favor and against both and investigated whether decoupling was even theoretically possible. Based on his assumptions, the author concluded that relative decoupling might occur when resources are relatively abundant. However, absolute decoupling will only occur if resource prices grow faster than GDP or, possibly, during structural transitions.

The lack of actual evidence of absolute decoupling has led some authors to question whether it is possible, suggesting that sustainable development can only be achieved through dematerialization and degrowth (Kallis, 2017; Pothen, 2017). However, the economic degrowth may only be a transitory stage before a steady-state economy (Kerschner, 2010).

The development of the economy of a country and its relationship to material flows is the result of a variety of drivers, some of which are illustrated in Figure 2.3. Research shows that economic development (GDP/cap) is the primary driver of material use (Krausmann et al., 2017; Schandl et al., 2018). As countries develop and the GDP/cap increases, resource productivity tends to increase as well, often leading to relative decoupling and, in some cases, absolute decoupling. The income per year (GDP/cap/year) contributes to increases in resource productivity (Gan et al., 2013). Income can also explain, to some extent, the differences in DMC/per capita between countries, particularly regarding fossil and mineral materials (Steinberger et al., 2010). It is then not surprising that there are significant differences in the material use and extraction of mature industrialized economies and emerging ones(Steinberger et al., 2013).

Bringezu et al. (2004) found different resource use and productivity levels within the same GDP/cap interval in a study of European countries. A variety of factors, aside from GDP/cap, can impact the material consumption of a country, such as population density, climate, trade dependency, and the structure of the economy (Steinberger et al., 2010; Weisz et al., 2006). For example, countries in cold climates with low population density and high extraction of natural resources and trade more often than not have above-average consumption of materials (Krausmann et al., 2017).

Figure 2.3 - Some of the drivers of resource productivity, based on the literature review.

Gan et al. (2013) found that, after GDP/cap, the population density was the second most important driver of resource productivity, followed by economic structure. Their study covered the economy of 51 different countries in 2000 and found that, for the same income level, countries with higher population density tended to coincide with higher resource productivity. Countries with higher population density will have to rely on improvements in resource productivity from technological advancement, economic structure, and policy improvements to compensate for a higher resource burden (Gan et al., 2013). On the other hand, mining activities are more limited in countries more densely populated, like the Netherlands or Belgium, making these countries import construction materials (Weisz et al., 2006). Lower population density can also lead to a higher per capita demand for built infrastructure for transport, for example, as the Finnish economy indicates (Hoffrén et al., 2000).

Historically, the level of use of resources and resource productivity has changed with the changes in economic structure (Gan et al., 2013). The transition from low value added and high resource-intensity activities, like agriculture, to activities that create a higher value added, like services, will increase resource productivity (Krausmann et al., 2017). A smaller proportion of agriculture in the economy corresponds to higher resource productivity, especially in less economically developed countries (lower GDP). Countries tend to move from agricultural economies to industrial. A higher proportion of industry in the economy will typically lead to higher productivity in low-income countries, but the same is not valid for high-income countries. Finally, an increased share of services in post-industrialized economies is usually associated with higher resource productivity and a better chance of decoupling. The Uk and Japan are among the few countries that have exhibited absolute decoupling, partly attributed to deindustrialization (slow economic growth may have also contributed) (Krausmann et al., 2017).

Other factors that may impact material consumption include construction activities and the size of the infrastructure (Steger & Bleischwitz, 2011). The construction sector is considered a driver of material use (Steger & Bleischwitz, 2011). However, in the long run, the built infrastructure (like roads or buildings) supports a long-term relative decoupling (Steinberger et al., 2013). For example, the decline in manufacturing and construction has been pointed out as one of the main reasons for the decoupling in the UK (Schandl & Schulz, 2002).

Technological advancement is expected to reduce material use and increase resource productivity (Behrens et al., 2007). In a study between 1979 and 2010, Schandl et al. (2018) found that since 2000 there was a surge in material extraction globally, and material efficiency showed signs of declining. The authors attributed this to a shift of global production from very efficient economies to less efficient ones. Steinberger et al. (2013) concluded that, based on their analysis, increased material efficiency was not sufficient for absolute decoupling.

Historically, recessions and other significant events have affected resource productivity. The period after WWII was characterized by a rapid increase in the use of resources driven by both population and economic growth (Bringezu et al., 2004; Krausmann et al., 2017). The economic crisis of 2007-2008 has preceded a decline in the average per capita material consumption in OECD countries (Krausmann et al., 2017). Wu et al. (2019) looked at the effects of economic recession on 157 countries between 1980 and 2011 and concluded that absolute dematerialization had only happened in periods of recession. These findings supported the work of Shao et al. (2017) significant and strong correlation between periods of recession and the use of material resources, particularly in countries where services played a meaningful role in the economy. The authors also linked the dematerialization associated with periods of recession with construction minerals.

Trade has also been linked to the values of material extraction (Gan et al., 2013; Schandl et al., 2018). Countries like Chile, the largest producer, and exporter of copper, will typically present larger DMI values for obvious reasons, but also of DMC, has the DMC will account for the waste created from mining activities.

Energy may also influence resource productivity and the consumption of resources (Weisz et al., 2006). Higher proportions of alternative and nuclear energy are associated with higher resource productivity (Gan et al., 2013). The energy composition has also been pointed out as a contributing factor to the decoupling in Germany.

Steinberger et al. (2010) highlighted the importance of looking at the different material groups. Biomass consumption is mainly driven by population, while minerals show stronger correlations with economic development. These findings support the earlier work of (Bringezu et al., 2004).

Many factors can drive and affect the use of resources and resource productivity. A lot of the drivers are linked. Additionally, various of these sectors can be connected, like population density and technological advancement, economic structure and GDP/cap, trade, or the type of materials. The design of decoupling policies will require one to account for these factors, among others. Any methodology designed for the effective study and possible modeling of the SEM and its flows must consider all of these factors.

2.3 Methodologies for the characterization of the socioeconomic metabolism

The study of decoupling requires methods that can describe the dynamics within the SEM while at the same time offering sufficiently detailed and relevant information that can be used to observe the impacts of the various possible drivers. Several methods have been developed or adapted to study material flows in an economy. These methods provide results that can be integrated into other methodologies depending on the goal of the project. EW-MFA and IOT, in particular, have had various applications as methods for quantifying mass flows and describing the economic structure.

2.3.1 Material flow accounting

MFA is a method derived from the SEM framework (Clift & Druckman, 2015) and provides the essential data for calculating resource productivity (Bleischwitz, 2001). The primary objective of MFA is to provide an overview of the exchanges between the various economies and the natural environment. Bringezu et al. (2003) summarized the different types of MFA depending on the interest of the study: it can be focused on one substance or material, on the impacts of specific products, or on the metabolic performance of an entire system such as a company, region or national economy, for which all material flows are accounted. The third type is commonly designated as economy-wide material flow analysis (EW-MFA). EW-MFA entails the description and monitoring of the SEM of a nation by accounting for all material flows (typically air and water are excluded) that cross the SEM boundary between the 'environment' and the 'economy' (Krausmann et al., 2017).

A description of the method, as standardized by Eurostat (2018a), can be found in the *Economy-wide material flow accounts – Handbook 2018 edition*. MFA describes the interaction between the economy and the natural environment through statistical accounting of material flows. The possible inputs of materials in the economy include domestic extraction, imports (IMP), and balancing items. The outputs account for the domestic processed output, exports (EXP), and other balancing items. Aspects that need to be considered include knowing where the boundaries of the system are and how are bulk materials (air and water) accounted for. According to the framework from Eurostat, the typical boundaries are that of the system of national accounts (SNA) (European Commission et al., 2009). Air and water are typical not accounted for, with a few exceptions when they are included in balancing items.

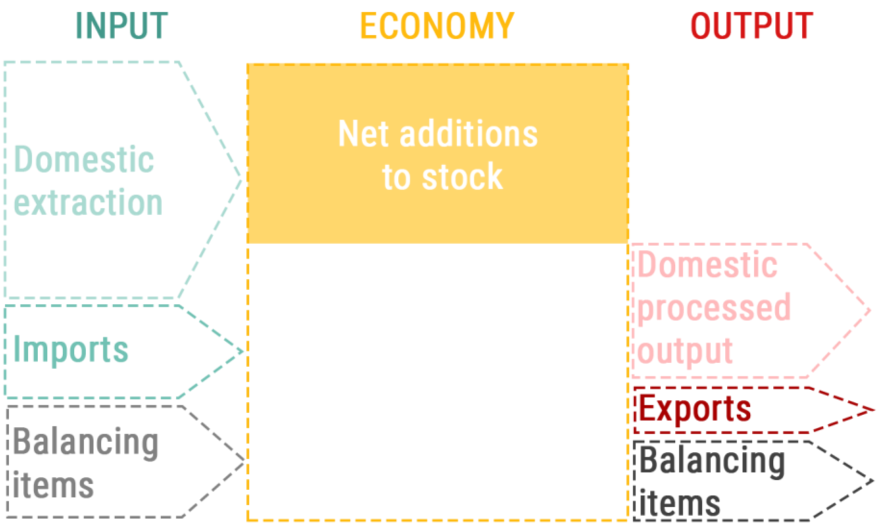

Figure 2.4 – Simplified scope of economy-wide material flow accounts, adapted from Eurostat (2018a).

Typical MFA indicators are (Eurostat, 2018a; Ferrão & Fernández, 2013; Krausmann et al., 2017):

- Domestic extraction, which accounts for the natural resources obtained from the natural environment within the country;
- Imports ;
- Raw material equivalents of imports;
- Domestic material inputs (DMI), given by the sum of domestic extraction and imports;
- Exports;
- Raw material equivalents of exports;
- Physical trade balance, given by the difference between imports and exports;
- Domestic material consumption (DMC), given by domestic extraction plus imports minus exports;
- Resource or material productivity, which measures the value added produced per unit of material used, can be calculated as the ratio between GDP and DMI or GDP and DMC.;
- Resource or material intensity, which is the inverse of resource productivity.

EW-MFA can provide a general picture of the SEM of an economy and allows researchers to identify general trends in resource productivity and material consumption at the global scale (Bithas & Kalimeris, 2018; Krausmann et al., 2009), at the regional scale (Baninla et al., 2019; Behrens et al., 2007; Schandl et al., 2018), and focusing on one country alone (Cañellas et al., 2004; Hoffrén et al., 2000; Infante-Amate et al., 2015; Kovanda & Hak, 2008a; Niza & Ferrão, 2006; Schandl & Schulz, 2002). Advantages of the use of EW-MFA include the data availability and the comparability between studies. However, suppose a more detailed picture of the economy is intended. In that case, the mentioned advantages are lost because it would likely, be necessary to take a bottom-up approach that can require considerable effort and whose results may no longer be comparable. Bringezu et al. (2003)explain how a change in an indicator may not imply an improvement or the contrary for the sustainability of a country. For example, the same amount of material extracted in one place can have different impacts compared to the same amount and material extracted in another. Additionally, it does not relate to different economic components, thus giving no insights into the underlying processes and dynamics between the economic sectors that make up the economy.

2.3.2 Input-output analysis

IOA is a framework that describes the distribution of products from and industry across an economy and was developed by Professor Wassily Leontief in the 1930s (Leontief, 1936; Miller & Blair, 2009). Leontief developed IOA using physical units (Leontief, 1951a, 1951b, 1986; Leontief et al., 1953). However, most IOA applications have been carried out in monetary units so far.

IOA is a well-suited methodology for studying the flows into and out of an economy and within it. Most applications have been in monetary units, hindering the creation of the link between tangible flows ad policy targets. It is valuable for understanding economy-environment relationships through material and economic flows. Unlike EW-MFA, IOA provides data at the sector level and facilitates quantifying the decoupling of material use from economic development at the sector level if both economic and mass data are available. Such an analysis must be done in units that correlate economic activities with their environmental impacts in direct or indirect forms. There is renewed interest in PIOTs, which quantify material flows across economic sectors in physical units.

Unlike the standard MFA data published by Eurostat or other bulk MFA methodologies, PIOTs quantify the flows between any pair of sectors and materials with resource extraction, trade, use, demand, and waste production. A plethora of possible purposes of national PIOTs have been summarized by Eurostat (2001). They include evaluating the increase of material intensity and efficiency, studying underlying reasons for changes in material flows, and estimating material efficiencies per production branch.

It was only in the 1990s that the original framework was applied in physical units because of the lack of physical data availability (Hubacek & Giljum, 2003). First, for Austria with data from 1983 and high aggregation of sectors (Katterl & Kratena, 1990). The next PIOTs were for:

- Germany 1990 (Stahmer et al., 1997), and 1995 (Statistisches Bundesamt, 2001);
- Denmark 1990, which included 27 sectors and nine sub-tables for different material groups (Gravgård, 1998);
- Italy 1995 with 12 sectors (Nebbia, 2000):

- Finland 1995 with 30 sectors, resulting from an effort to account for unobservable material flows in order to ensure a mass balance (Mäenpää, 2002);
- for the UK (76 sectors).

These PIOTs are discussed in terms of methodological differences by Giljum & Hubacek (2009). Examples of the uses of PIOTs include the assessment of environmental impacts and pressures or the assessment of direct and indirect land requirements associated with the production of exports (Hubacek & Giljum, 2003; Weisz & Duchin, 2006).

PIOTs can have different spatial resolutions. Urban studies have used PIOTs to open the box of material flow analysis in urban areas. For example, there is the case of a bottom-up study of two neighborhoods in Stockholm in 2016, where Papageorgiou et al. (2020) adapted the three-dimensional structure of PIOTs proposed by (Xu & Zhang, 2008). These three-dimensional PIOTs included the creation of sub-tables, one per material, plus two supplementary tables, that can be summed to obtain the final PIOT in which the mass balance is respected, unlike what happens in the sub-tables. Pina et al. (2016) compared the physical structure of four urban economies based on a methodology that included the development of national PIOTs based on freely available data and concordance tables. More recently, the MRIO database EXIOBASE has been updated to include a hybrid table that includes both physical and monetary data (Merciai & Schmidt, 2018).

Authors have discussed the importance of a methodology that enables PIOTs comparability and the challenges in finding all the required data in physical units (Kovanda, 2019; Weisz & Duchin, 2006). Several of the PIOTs published so far are only focused on one specific material (Bösch et al., 2015; Konijn et al., 1997; L. Zhang et al., 2018), a country (Liang et al., 2017), or even a cluster of countries (Hubacek & Giljum, 2003).

While IOA offers very detailed data on the flows within the economy, they are only available for some countries and years in monetary units (OECD, n.d.). Other approaches to the original methodology, like the hybrid version of the MRIOTs from EXIOBASE, are still being developed and are only available for a few years (Merciai & Schmidt, 2018).

2.3.3 Other methods

Given the amount of data and the complexity of the dynamics between the various parts of the SEM, authors have complemented their studies, based on EW-MFA or IOA, with other methodologies or frameworks. Examples of these are structural decomposition analysis (SDA), Logarithmic Mean Divisia Index (LMDI), IPAT equation, cluster analysis, panel analysis, and regressions.

SDA is a method that facilitates understanding the underlying factors behind the changes in a specific endogenous variable. The formulation of SDA was proposed by Arto & Dietzenbacher (2014). SDA decomposes the changes in one variable into the differences of its constituent parts, and these parts will depend on the variable chosen for the study. Changes in the MFA indicator RMC, for example, could be decomposed into changes in material efficiency, production recipe, import structure of intermediate demand, import structure of final demand, final demand composition, final demand per capita, and population. The LMDI is robust to zero-values and improves the decomposition. It was initially proposed for energy decomposition (Ang & Liu, 2001) and later applied to explain changes in raw material consumption and integrated with SDA (Pothen, 2017). Plank et al. (2018) stated some limitations to the methods they used (MRIO and SDA), including dependency problems and issues derived from the aggregation and assumptions in IO. Additionally, the findings will be dependent on the variables chosen for the analysis.

The IPAT equation (Ehrlich & Holdren, 1971) can be used to ascertain the impact of different drivers of material use. The model is expressed by equation (3), where I stands for environmental impact, P for population, A for affluence, and T for technology. This model has been applied in multiple MFA studies to determine the driving forces behind the consumption of materials (Chiu et al., 2017; Gonzalez-Martinez & Schandl, 2008; Kovanda & Hak, 2008b; Martinico-Perez et al., 2017; Maung et al., 2014; Schandl et al., 2018; Schandl & West, 2012; West et al., 2014). The IPAT equation can be adapted to MFA studies by using DMC as the environmental impact variable, GDP/cap as affluence, and DMC/GDP as the technology variable. While this method provides a very standardized way of evaluating three specific drivers, material use and productivity can be affected by others that this model does not describe.

$$I = P \times A \times T \quad (3)$$

Bringezu et al. (2004) used panel analysis to determine the relationship between resource flows and economic growth, particularly the EKC hypothesis. The authors proposed four different regression equations to describe the proposed hypothesis. Steinberger et al. (2013) used both cluster and panel analysis to study the resource dependency of developing, emerging, and mature industrialized economies. Cluster analysis was used to determine the developmental status groupings and used standardized Euclidean distances. The purpose of the panel analysis was to add insights gained by the cluster analysis by testing time series attributes.

EW-MFA is a very robust and widely used method for analyzing the use of materials, resource productivity, and decoupling. There are datasets for EW-MFA covering all countries for a significant period (UNEP International Resource Panel, n.d.). However, this analysis does not allow for much detail when it comes to the flows within the economy, potentially failing to provide evidence on some of the factors affecting resource use that are relevant in policymaking. IOA provides very detailed data on the exchanges within the economy. However, there are very few tables in physical units, and monetary tables are not adequate for providing insights between specific policies and the use of resources. Additionally, MIOTs may underestimate the contribution of some sectors and overestimate the contribution of services for the use of resources in the economy (Liang et al., 2017). Other methods have been integrated into MFA, but most will only be suited for studies with very concrete objectives or for studying the impact of drivers chosen ahead of the study.

The methods proposed in the following sections will propose methodologies to tackle the shortcomings of the methods discussed in this literature review while ensuring their suitability for the analysis of the SEM and the drivers of resource productivity. The first method quantifies comparable PIOTs for various countries during a significant period.

The second method is a framework integrating data from EW-MFA and PIOTs to study the SEM and identify relevant aspects contributing to the resource productivity of the analyzed case.

3 Development of a new method for quantifying replicable and universal PIOTs

IOA provides relevant information on the flows of the SEM, especially if in physical values, as is the case of PIOTs. However, most of the available IOTs are in monetary units. This chapter proposes and validates a methodology for quantifying PIOTs based on data available from official sources and the mass balance principle.

The compilation of PIOTs is still a challenging task. Efforts have been made to standardize methods to track material flows, like the System of Environmental-Economic Accounting 2012 by the United Nations (2014) or the hybrid Supply and Use tables (SUT) EXIOBASE (Merciai & Schmidt, 2018). Nevertheless, there is no official data source for material flows between economic sectors in physical units that can be used in comparative studies covering a variety of countries and years.

Pina et al. (2016) developed a methodology to produce PIOTs from MIOTs. The values are collected from official sources or calculated based on the mass balance principle and the homogeneous price assumption. This assumption is based on the idea that each sector will sell bundles of products at a constant price per mass unit, regardless of the sector they sell to (Merciai & Heijungs, 2014).

The data sources proposed here have data available for various countries (primarily European) between 1995 and 2015, making the method easily applicable to any of the countries covered in these data sources. The replicability of the method is further enhanced by having programmed it in *Python*. The PIOTs can also be calculated for other countries not covered by the proposed data sources, as long as there are alternative data sources or it is possible to establish proxies, for example, to estimate the missing data.

The quantification of the PIOTs requires data from the MIOTs, and the resulting tables will follow the same structure making the values in each table comparable. The biological data will enable the calculation of the resource productivity by sector, for example.

The physical and the monetary flows will provide different information that can complement each other, thus giving a better account of the flows in the SEM. The physical flows will strengthen the link between the study of the SEM and the corresponding environmental impacts. Additionally, it contributes to the knowledge about the mechanisms related to dematerialization. The reproducibility facilitates comparing the SEM of different countries and identifying the similarities and differences associated with one country being more or less efficient in using resources than another.

This chapter first describes a methodology improved from the initial work of Pina et al. (2016). This version of the method results in the compilation of 18 different PIOTs (1 per material plus one with all the materials summed) with up to 37 different economic sectors, resulting in a three-dimensional IOT structure, similar to the ones in the works of Papageorgiou et al. (2020) and Pina et al. (2016). The second part of the chapter shares the efforts to validate the method.

3.1 Description of the new method for quantifying PIOTs in mass units

This subsection describes the steps for quantifying PIOTs in a replicable way and allows for comparability of results between different economies over a considerable period. The key aspects of the method include collecting reliable data from official sources that cover various years and countries and calculating the missing physical flows using the material balance principle coupled with validated assumptions. The method was implemented in a Python script, which automatizes the compilation process, thus making the compilation of PIOTs a more effortless and faster task.

Firstly, the structure of the IOTs is described. Next, the two main parts of the method are described: the data collection and harmonization and the calculation of the unknown flows.

3.1.1 PIOT structure and resolution

The PIOTs presented in this work follow an industry-by-industry approach that is in concordance with the structure used by the MIOTS from OECD (2018). This correspondence between monetary and physical flows, which is assured using the same structure, is a fundamental aspect of the method. It warrants the comparability between monetary and physical flows, thus describing the SEM and enabling the calculation of the unknown flows. The PIOTs will cover the same sectors in the MIOTs and describe the flows of 17 different material groups.

3.1.1.1 Structure

Figure 3.1 illustrates the general structure of the PIOTs developed, alongside the indication of which flows are based on official data and calculated based on the mass balance principle. The three-dimensional structure of the PIOTs is also portrayed in Figure 3.1: a different table is compiled for each different material group, plus one for the whole economy, which is the sum of the material tables. The three-dimensional aspect of the tables is instrumental for calculating the unknown flows, as it ensures that the principle of balance per material group is respected. The different matrixes and vectors in Figure 3.1 are colored according to whether a flow is based on existing data or results from a calculation: non-grey flows (domestic extraction, imports, exports, emissions from animals) are completely defined with existing data; striped flows (emissions from fossil fuels and waste) result from data coupled with some calculations or assumptions; remaining flows in light grey (interindustry deliveries, the various columns of final consumption, gross fixed capital formation and inventories) result from the calculations based on the mass balance principle.

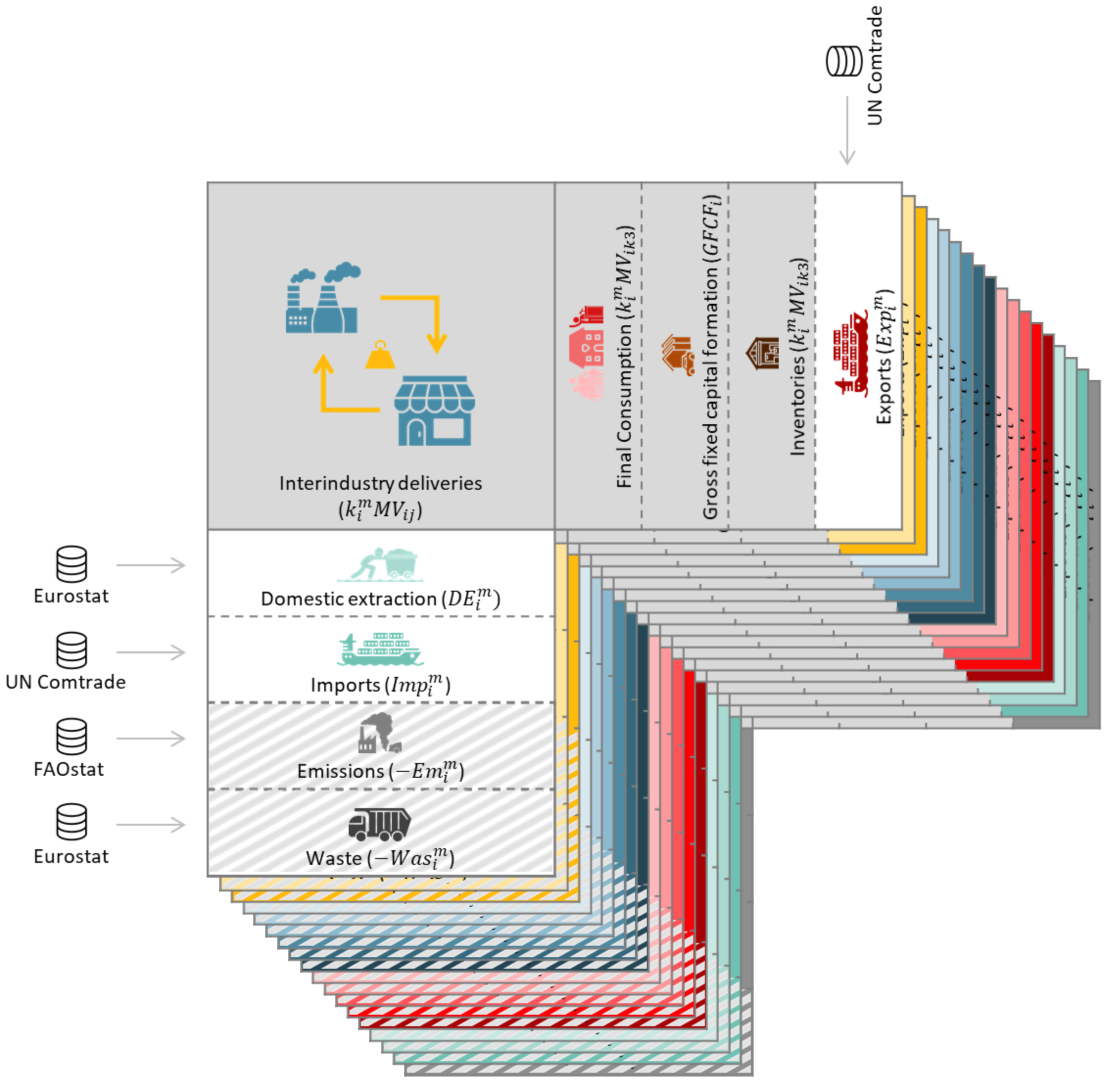

Figure 3.1 – PIOTs structure.

A PIOT, like any IOT, has three quadrants: the first is the interindustry transactions table, the second contains the vectors describing the final demand, and the third covers the inputs to production that do not originate from the industries in the first quadrant (Miller & Blair, 2009). The rows of the interindustry table detail the sales of each sector to other sectors, the sector itself, and final demand. The columns describe the necessary mix of inputs for the economic sector to produce its outputs. For a table in mass units, the sum of a column will quantify the total material inputs used by the sector. The second quadrant of the table captures the final demand disaggregated in several components: final consumption is divided into final consumption of households, non-profit institutions serving households, and general government, plus columns for gross fixed capital formation, changes in inventories, and exports. The sector inputs in the rows of the third quadrant are primary resources (domestic extraction), imports, and waste and emissions from economic sectors. How waste and emissions are integrated into an IOT can vary. In this work, they are viewed as environmental requirements and recorded as negative flows (Dietzenbacher, 2005; Merciai & Heijungs, 2014; Suh, 2004). The model does not cover the waste and emissions from the final demand.

3.1.1.2 Economic sectors

The economic sectors adopted were those of the MIOTs from the OECD (2018). The IOTs cover 36 economic sectors classified according to the International Standard Industrial Classification of All Economic Activities (ISIC) (United Nations. Statistical Division, 2008).

The economic sector disaggregation is relevant to support a homogeneous price assumption used to estimate unknown flows (Weisz & Duchin, 2006). This was taken into account by observing the price distribution per unit mass of the products from each sector which can be found in section 3.2.3. This analysis led to disaggregating the sector *extraction of metallic and non-metallic minerals* because it included products with very different prices. The MIOTs from OECD (2017) for the years before 2005 presented only one mining sector, which was disaggregated using the same approach plus data from the tables of the more recent years (OECD, 2018).

The PIOTs were compiled for each of the 37 sectors (the 36 original ones of the more recent tables, plus one from the disaggregation of the mining sector). An aggregated nomenclature was developed to simplify the presentation of results. The proposed nomenclature is presented in Table 3.1 alongside all the nomenclature used in MIOTs and PIOTs.

Table 3.1 - MIOT and PIOT nomenclature for economic sectors.

Nomenclature in OECD MIOTs (ISIC rev 4)	Description	Simplified nomenclature
D01T03	Agriculture, forestry and fishing	AGRICUL
D05T06	Mining and extraction of energy producing products	$MINING_{FF}$
$D07T08_{MM}$	Mining and quarrying of non-energy producing products (metallic minerals)	$MINING_{MM}$
$D07T08_{NM}$	Mining and quarrying of non-energy producing products (non-metallic minerals)	$MINING_{NM}$
D09	Mining support service activities	SERVICES
D10T12	Food products, beverages and tobacco	FOOD
D13T15	Textiles, wearing apparel, leather and related products	TEXTILES
D16	Wood and products of wood and cork	WOOD
D17T18	Paper products and printing	PAPER
D19	Coke and refined petroleum products	$PETROL_{PROD}$
D20T21	Chemicals and pharmaceutical products	CHEM&PHARM
D22	Rubber and plastic products	PLASTICS
D23	Other non-metallic mineral products	OTH_{NM}
D24	Basic metals	$METALS_{BASIC}$
D25	Fabricated metal products	$METAL_{PROD}$
D26	Computer, electronic and optical products	ELECTRONICS
D27	Electrical equipment	ELEC.EQUIP
D28	Machinery and equipment, nec	MACHINERY
D29	Motor vehicles, trailers and semi-trailers	VEHICLES
D30	Other transport equipment	$TRANSP_{OTH}$
D31T33	Other manufacturing; repair and installation of machinery and equipment	$MANUF_{OTH}$
D35T39	Electricity, gas, water supply, sewerage, waste and remediation services	UTILITIES
D41T43	Construction	CONSTRUC
D45T47	Wholesale and retail trade; repair of motor vehicles	SERVICES
D49T53	Transportation and storage	SERVICES
D55T56	Accommodation and food services	SERVICES

Nomenclature in OECD MIOTs (ISIC rev 4)	Description	Simplified nomenclature
D58T60	Publishing, audiovisual and broadcasting activities	SERVICES
D61	Telecommunications	SERVICES
D62T63	IT and other information services	SERVICES
D64T66	Financial and insurance activities	SERVICES
D68	Real estate activities	SERVICES
D69T82	Other business sector services	SERVICES
D84	Public admin. and defense; compulsory social security	SERVICES
D85	Education	SERVICES
D86T88	Human health and social work	SERVICES
D90T96	Arts, entertainment, recreation and other service activities	SERVICES
D97T98	Private households with employed persons	SERVICES
HFCE	Final consumption expenditure of households	HFCE
NPISH	Final consumption expenditure of non-profit institutions serving households	NPISH
GGFC	Final consumption expenditure of general government	GGFC
GFCF	Gross Fixed Capital Formation	GFCF
INVNT	Changes in inventories	INVNT
CONS_ABR	Direct purchases abroad by residents (imports)	IMP
CONS_NONRES	Direct purchases by non-residents (exports)	EXP
EXPO	Exports (cross border)	EXP
IMPO	Imports (cross border)	IMP
TXS_INT_FNL	Taxes less subsidies on intermediate and final products (paid in domestic agencies, includes duty on imported products)	TXS
TXS_IMP_FNL	Taxes less subsidies on intermediate and final products (paid in foreign countries)	TXS
VALU	Value added at basic prices	VA
	Domestic extraction	DE
	Emissions from fuels and agriculture	CO2 or EMISSIONS
	Generation of waste by sector	WASTE

3.1.1.3 Materials

This method produces 18 tables, as mentioned, one for each of the 17 groups of materials plus one for the whole economy, as indicated before and illustrated in Figure 3.1. These 17 groups of materials, which can be found in Table 3.2, resulted from an update to the classification "MatCat," initially developed by Rosado, Niza, and Ferrão (2014), which was also used by Pina et al. (2016).

In its original form, this classification included 28 different materials. These categories covered materials that resulted from processing other raw materials, such as "Paper and board" which are "Wood" products. For this reason, the classification was modified, resulting in the material groups presented in Table 3.2. Each category is homogeneous in terms of material composition and price per mass unit as much as possible. The group O1 (other) accounts for products whose material composition is unknown, like pharmaceuticals, waste, or sludge. This nomenclature enables each product to be disaggregated in its different materials while ensuring that a mass balance is possible for all the material categories, except for what can be found in O1.

There are several options regarding including air and water in MFA. The economy-wide material flow accounts from Eurostat (2018), for example, do not include bulk material flows of water or air. On the other hand, the Eurostat data include the air used in the combustion process as a balancing item. This model does not account for water or air, this is not untypical, and there are other MFA studies that do not include air as a balancing item (Krausmann et al., 2017).

Table 3.2 - World Metabolist material groups.

Material category	Material group	Description
Fossil fuels (FF)	FF1	Low ash fuels
	FF2	High ash fuels
Metallic Minerals (MM)	MM1	Iron and steel alloying metals
	MM2	Light metals
	MM3	Non-ferrous heavy metals
	MM4	Special metals
	MM5	Nuclear fuels
	MM6	Precious metals
Non-Metallic Minerals (NM)	NM1	Stone (including sand)
	NM2	Cement and limestone
	NM3	Clay
	NM4	Precious non-metallic minerals
	NM5	Other (fibers, salt, inorganic parts of animals)
Biomass (BM)	BM1	Agricultural biomass
	BM2	Animal biomass (including feed)
	BM3	Wood
Other (O)	O1	Non-specified

3.1.2 Known flows

As illustrated in Figure 3.1, the tables result from both known and calculated values. Various operations on the original data are required to integrate the material flows from data sources. Figure 3.2 summarizes the various steps. First, it is necessary to collect data, and then the flows are transformed into flows per material and assigned to the corresponding sectors and places in the tables.

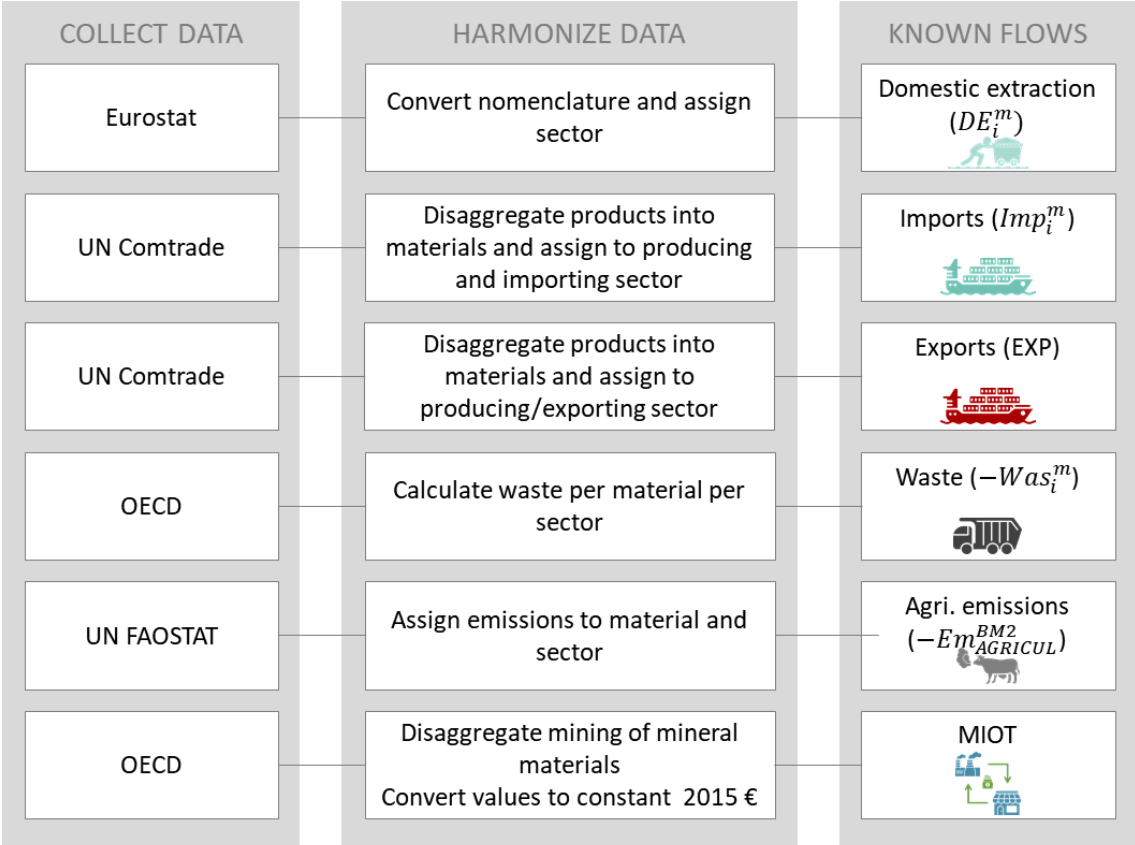

Figure 3.2 - Integration of known flows in the World Metabolist tables.

3.1.2.1 Data collection

The data used in this method originated from different sources. Some databases have application programming interfaces (APIs), whose use was integrated into Python programs whenever possible, contributing to the automatization of the PIOT compilation process.

Domestic extraction

Domestic extraction values were obtained from the Material Flow Accounts published by (Eurostat) 2020). This database currently covers European countries, including countries that do not belong to the EU, between 1990 and 2019, in most cases. Data for other countries can be found on the Global Material Flows database (UNEP International Resource Panel, n.d.).

Imports and exports

Trade (imports and exports) data was downloaded from UN Comtrade (2014) using the available API. This database provides import and export values in monetary and physical units for products classified under the "Harmonized Commodity Description and Coding Systems" (HS). The fact that the data is by product, unlike other data sources that provide data by material (Eurostat, 2020; UNEP International Resource Panel, n.d.), enabled the assignment of the materials in the products to the importing and exporting sectors.

Waste and emissions

Waste collection and emissions data were added to the previous work by Pina et al. (2016). The values for total waste production by economic sector were obtained from Eurostat (2021b), and additional data on the composition of waste was collected from Eurostat (2021c). Like domestic extraction, waste data is also somewhat limited for earlier years and some European countries. The values of the emissions from the digestion and manure of animals were collected FAOSTAT (2020a, 2020b). The emissions from burning fuel result from the estimation of the unknown flows because air is not accounted for in the model.

MIOTs

The monetary data used in the model was collected from OECD (2017, 2018) in the form of MIOTs. These two databases cover OECD countries and some non-OECD ones between 1995 and 2015. They are based on the System of National Accounts (SNA) and use ISIC nomenclature for the economic sectors. A detailed account of the data coverage and data sources used to compile the tables can be found at OECD (n.d.). These are the tables that give the structure to the PIOTs complied, which will be used to describe the monetary flows of the SEM. This structure is illustrated in Figure 3.3.

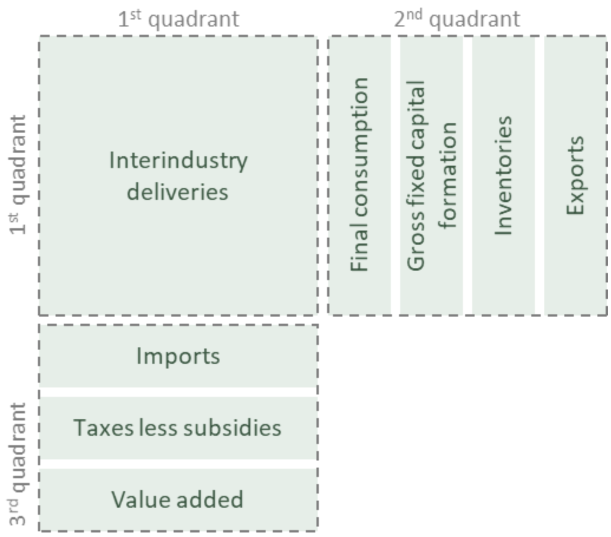

Figure 3.3 – Illustration of the basic structure of the MIOTs from OECD. The original tables provide the imports by producing sector, which are summed in a total row for the purposes of this work.

3.1.2.2 Data harmonization

It was necessary to perform some operations on the data to integrate the data collected in the PIOTs so that the flows were assigned to the corresponding sectors (Table 3.1) and classified under the material nomenclature used (Table 3.2). Some correspondence tables were used in this process, including:

- A table developed to make the correspondence between the material classification in Eurostat and the HS classification;
- An updated version of ProdChar (initially developed by Rosado et al. (2014)), which disaggregates 5052 different products in HS nomenclature in the 17 materials of Table 3.2;
- A correspondence between HS products and their producing sectors according to the classification used (Table 3.1) that can be found in the World Integrated Trade Solution (2013).

Domestic extraction

The data from Eurostat covering domestic extraction is available by material using a specific material classification. To introduce the domestic extraction (DE_m^i) in the PIOTs, it was necessary first to make the correspondence between the Eurostat nomenclature and the HS classification. Next, the correspondence between HS products and sectors was used to assign the products (which in this case are raw materials) to the sectors that extract them. Finally, the correspondence between the HS and the material classification was used to assign the material flows to the corresponding table.

Imports and exports

As mentioned, trade data is obtained from UN Comtrade (2014). These data carry two issues: missing physical values and discrepancies between the exports declared by one country and the imports declared by the partner (Liu & Müller, 2013). The missing mass values were estimated by calculating the average price of the product in question and multiplying it by its monetary value. The average price can be determined by collecting the data disaggregated by trading partners instead of aggregated by the reference country. Whenever these values are absent, the average price considered is the yearly world average price, as proposed by other authors (Liu & Müller, 2013; Merciai & Schmidt, 2018). Additionally, each country declares a monetary value corresponding to 'Commodities not specified according to kind' whose corresponding mass flows cannot be estimated. However, this share is relatively minor for most countries in monetary value.

Next, the trade products were assigned to their producing sectors and disaggregated in their materials, using the concordance tables. At this point, the export flows, Exp_i^m, of each material, m, were known for each of the producing sectors, i, and could be introduced in the corresponding column of the PIOTs. The import flows were also available from their producing sectors. They were assigned to the national importing sector, assuming proportionality between the mass flows and the monetary flows in the import submatrix of the MIOT from the OECD. Finally, the imported flows are summed, Imp_i^m, by importing sector, i, and material, m, and integrated into the corresponding PIOT row.

Waste flows

The waste data obtained from Eurostat is in mass units and already assigned to its producing sector. The waste flows were disaggregated by the 17 material groups based on the domestic extraction and imports of each material per sector and the additional data from Eurostat (2021c).

Emissions

The emissions from the digestion of biomass by animals in the AGRICUL sector can be easily accounted for by introducing the data published by FAOSTAT on the emissions row and the AGRICUL sector column in the table for animal biomass (BM2).

MIOTs

MIOTs can be declared in constant or current prices depending on the source. The use of current prices will not influence the physical results because it is not the values that are relevant but the distribution of the value of the sales. However, whenever the method is used to compare economic data between years, it is essential to convert the prices to constant prices and use the same monetary unit, which was constant 2015 Euros (OECD, 2021; OECD.stat, 2020b).

As mentioned in section 3.1.1.2, where the economic sector classification is presented, the mining sectors were disaggregated due to price differences. The disaggregation was done based on the composition of the products in the updated version of ProdChar and the sales between sectors.

3.1.3 Calculated flows

The flows that cannot be directly collected from any published database were estimated based on the monetary data in the MIOTs and the known flows by applying the homogeneous price assumption and the mass balance principle by material. Other constraints were added to the model to avoid negative flows (except for emissions and waste) and to comply with some particularities of specific sectors and products.

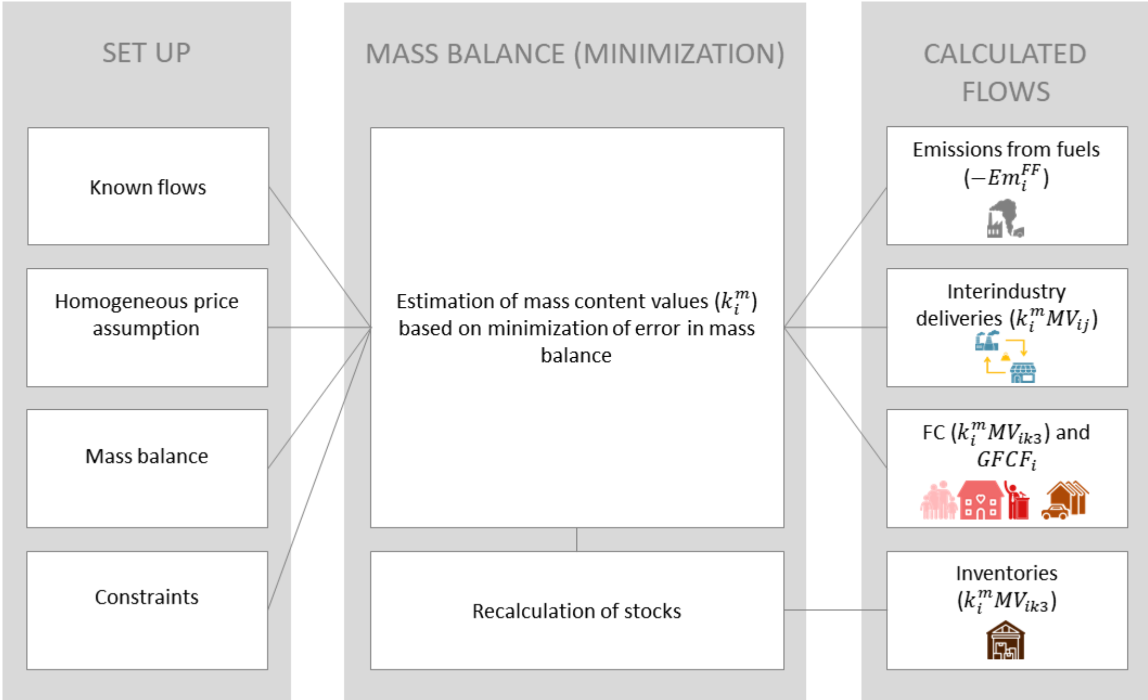

Figure 3.4 – Determination of the remaining flows in the World Metabolist tables.

3.1.3.1 Model assumptions and definition for the calculation of the unknown flows

The homogeneous price assumption suggests that each sector of a PIOT will sell its bundles of products at the same average price to all other sectors. The assumption was applied by assuming proportionality between the monetary and physical flows. As the method quantifies a PIOT per material, the proportionality between monetary and material flows is given by the mass content value (k_i^m), which is unique for each sector and material. The mass flow from sector i to sector j is given by multiplying the monetary value of the corresponding sales (MV_{ij}) by the mass content value (Pina et al., 2016).

One of the rules that define IOTs is that each industry (in the case of the industry-by-industry approach) must be balanced, which translates into the inputs of a sector (sum of sector columns) being equal to the outputs of that same sector (sum of sector row). The same principle must be verified economy-wide, meaning that the sum of the inputs in the economy (third quadrant) must be the same as the sum of the output flows (second quadrant).

The mass balance for each sector i and material m, in mass units, is shown in equation (4). The left side of the equation reflects the flows corresponding to imports (Imp_i^m), domestic extraction (DE_i^m), waste and emissions ($Res_i^m = Was_i^m + Em_i^m$), and the flows received from national sectors $\sum_j k_j^m MV_{ji}$. On the right side are the flows sold by each sector to another sector ($\sum_j k_i^m MV_{ij}$), final consumption expenditures and inventories ($\sum_k k_i^m * MV_{ik}$), gross fixed capital formation ($\mathrm{GFCF_i}$) and exports (Exp_i^m).

$$Imp_i^m + DE_i^m - Res_i^m + \sum_j k_j^m MV_{ji} = \sum_j k_i^m MV_{ij} + \sum_k k_i^m * MV_{ik} + \mathrm{GFCF_i} + Exp_i^m \tag{4}$$

$\mathrm{GFCF_i}$ is estimated based on the System of National Accounts (European Commission et al., 2009). The sectors that produced items mainly classified as fixed capital were identified by creating a list and finding which sectors produced them using correspondence tables. It was considered that the incoming flows from the sectors MACHINERY, VEHICLES, $\mathrm{TRANSP_{OTH}}$, and CONSTRUC result in the capital formation of the sectors acquiring the goods or buildings.

The emissions from fuel-burning are accounted for in a way that ensures the mass balance. Because the model does not explicitly account for air or water, the values on the tables are not the values of the actual emissions, as in other MFA studies that do not include air as a balancing item (Krausmann et al., 2017). To ensure a material balance, the mass of the emissions from fuel burning in this model corresponds to the fuel mass flows that enter each sector from the domestic and non-domestic (imports) sectors $\mathrm{PETROL_{PROD}}$ and UTILITIES and becomes an output of the sector as emissions. The exception is the sector CHEM&PHARM, whose emissions match the flows received from UTILITIES. In contrast, the flows received from $\mathrm{PETROL_{PROD}}$ are assumed to be primarily incorporated in its products and not burned.

The mass content values (k_i^m) are quantified as the values that minimize the difference between inputs and outputs of each material for each sector. They are determined by running several iterations of sequential least squares programming minimizations until the minimum difference in the mass balance is reached. Having estimated the mass content values, it is then possible to calculate the interindustry deliveries, final consumption, and stocks by multiplying each monetary value from the MIOT by the mass content value of each producing sector and material.

Some of the mass content values, obtained from the minimization of the difference in the mass balance, do not precisely close the mass balance, and the value of the inventories assumes this difference. A similar approach is adopted in the Supply and Use Tables (SUT) that are used to produce the MIOTs (European Commission et al., 2009).

3.2 Method validation

Estimating physical flows based on the proportionality between monetary and physical flows can be subject to distortions (Weisz & Duchin, 2006) even when using 37 different sectors. These distortions will primarily affect less meaningful mass flows (smaller values when compared with other flows) that are distorted by more meaningful monetary flows. Material flows like recycling may be misrepresented, given the value of waste. However, the primary physical inputs and outputs in the PIOTs are based on published data, and eventual distortions should not impact the conclusions of the analysis.

The reliability of the method was evaluated through a series of analyses using Portugal 2013 as the case study. Figure 3.5 illustrates the flows from the main PIOT, where all the materials are summed. The chord diagram shows the inputs and outputs of the economy and each sector - the output flows are connected to the block that represents the sector where they originate and are colored according to the sector where they originate. The input flows are detached from the sector receiving them. For example, the darkest blue block represents the $\text{MINING}_{\text{NM}}$ sector, whose primary input is from domestic extraction in the lightest shade of mint and whose main outputs go to OTH_{NM} and CONSTRUC, in the dark blue color. The three outer circles (contribution tracks) of the diagram show the shares of the flows by origin and destination together, then only by origin, and the third (inner circle) shows the shares of the outputs by destination. The table with the PIOT values used to create Figure 3.5 can be found in Table 9.2 of the supporting information of the chapter, sub-section 9.2.

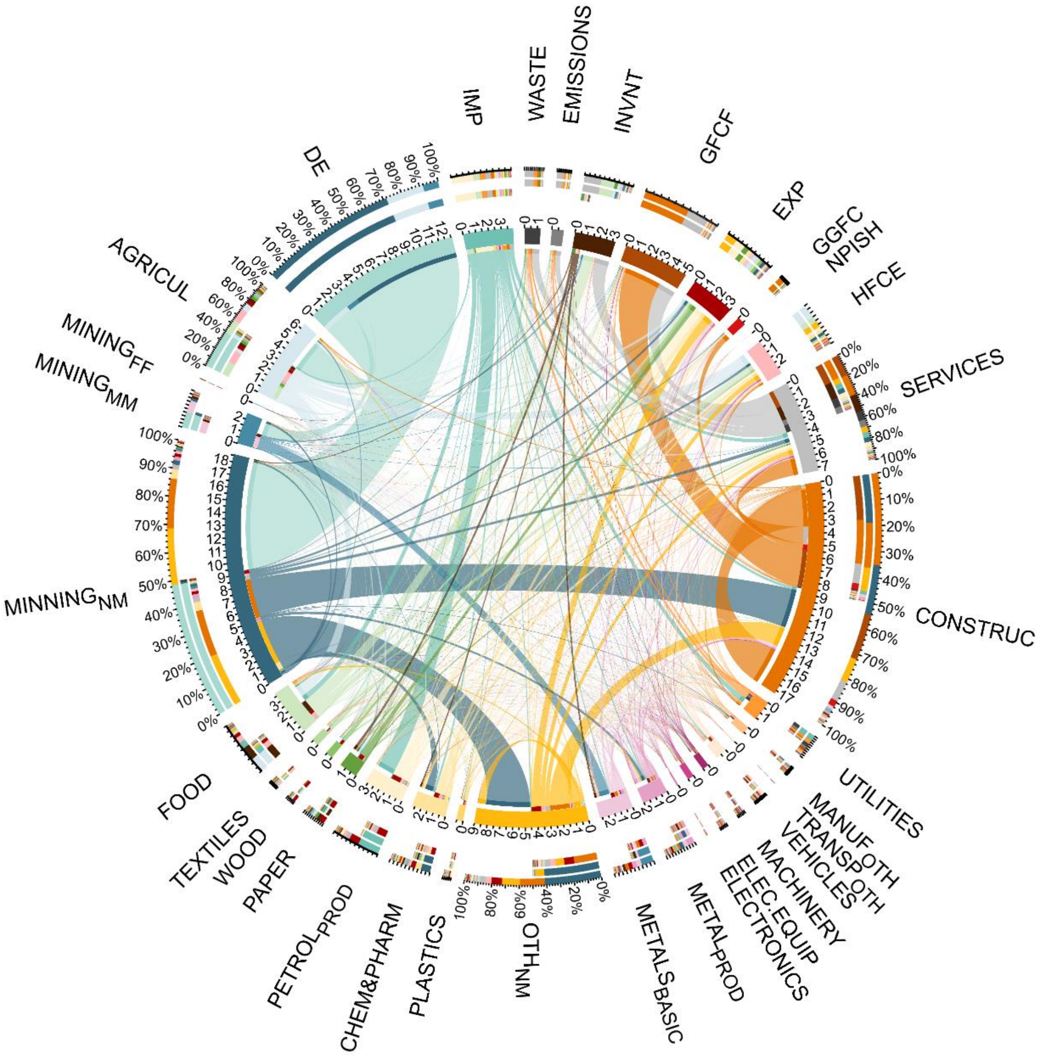

Figure 3.5 – Material flows [t/cap] for Portugal 2013.

The evaluation of the reliability of the model was done by performing a variety of analyses. First, the databases used were compared with alternative sources. Next, the sensibility of the model results was evaluated by varying the values of the primary data sources. The next step was the evaluation of the validity of the homogeneous price assumption under this level of sector disaggregation. Finally, the emission values in the model (burnt fuel) were compared with the carbon content in the carbon dioxide (CO_2) emissions that are published by (Eurostat, 2021a).

3.2.1 Data comparison

Some of the physical flows used in the compilation of the PIOTs can be found in alternative data sources. Eventually, they would all be based on national statistics and be in accordance. However, that is not always the case, as discussed here. The purpose of this analysis is to identify any flows that may be associated with higher levels of uncertainty and whose impact is then explored in the next section. The official, freely available data sources that could be eventually used to develop these PIOTs are presented in Table 3.3.

The statistics from the Portuguese statistics office (INE) stand as an example of possible statistics from national offices whose use would make the compilation of the tables for various countries a more challenging and labor-intensive task. Additionally, the comparability of results could be affected by different accounting methodologies used by the national statistics offices.

The issue with using the data sources for imports and exports other than Comtrade is that they do not allow for the assignment of the material flows to the corresponding sector. Hence they are not compatible with the model. Data in Comtrade is published by product and not by material; therefore, the products and related materials can be assigned to their producing sector.

Table 3.3 - Data sources by material and monetary flow for PIOT compilation.

Source	Flow	Obs.
INE (n.d.)	Domestic Extraction	Alternative
	Imports	Not compatible
	Exports	Not compatible
INE (2018b)	MIOT	Used (2017)
INE (2018a)	National production	Incomplete
Eurostat (2020b)	Domestic extraction	Preferable
	Imports	Not compatible
	Exports	Not compatible
Eurostat (2021b)	Waste by sector	Preferable
Eurostat (2021c)	Waste by material	Used
Eurostat (2018b)	National production	Incomplete
UNEP International Resource Panel (n.d.)	Domestic extraction	Alternative
	Imports	Not compatible
	Exports	Not compatible
UN Comtrade (2014)	Imports by product	Used
	Exports by product	Used
OECD (2016)	Waste by sector	Alternative
OECD (n.d.)	MIOT	Preferable

While the geographic coverage of the domestic extraction from the UNEP IRP (International Resource Panel) is more extensive than the others, it is only disaggregated in 13 materials, and the model uses 17. On the other hand, its methodological description has enough detail that, with additional effort, one can potentially go directly to the sources of the database and collect more disaggregated data.

The differences in the data for domestic extraction, imports, and exports from the various available data sources can be observed in Figure 3.6. An additional series with the data used in the model (Eurostat and UN Comtrade) was also added for comparison. The differences in the values relative to the model value are presented in Table 3.4.

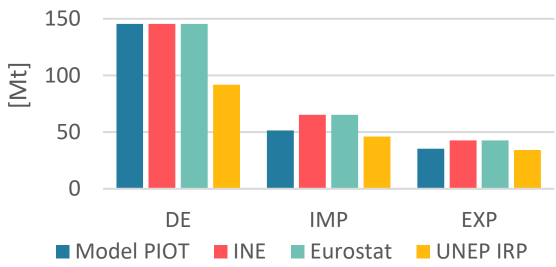

Figure 3.6 - Total material flows for each data source.

The data from Eurostat matches the data from national statistics. The domestic extraction value from the UNEP IRP is 37% smaller. The import value of the model is lower than the value from Eurostat of INE but more significant than the values in UNEP IRP. The value for exports is higher than the value from UNEP IRP but smaller than the others. The imports and exports may be underestimated, which may be related to the mentioned issues associated with UN Comtrade data (used in the model).

Table 3.4 - Differences between data sources for the various flows relative to the proposed model values.

Flow	Model PIOT	INE	Eurostat	UNEP IRP
Domestic extraction	0%	0%	0%	-37%
Imports	0%	27%	27%	-10%
Exports	0%	21%	21%	-3%

The differences between the data sources are not evenly distributed across all the materials. Figure 3.7 shows the primary material flows for the four main material groups from the various data sources plus the values in the model proposed in the paper. The values of the differences relative to the model can be found in Table 3.5.

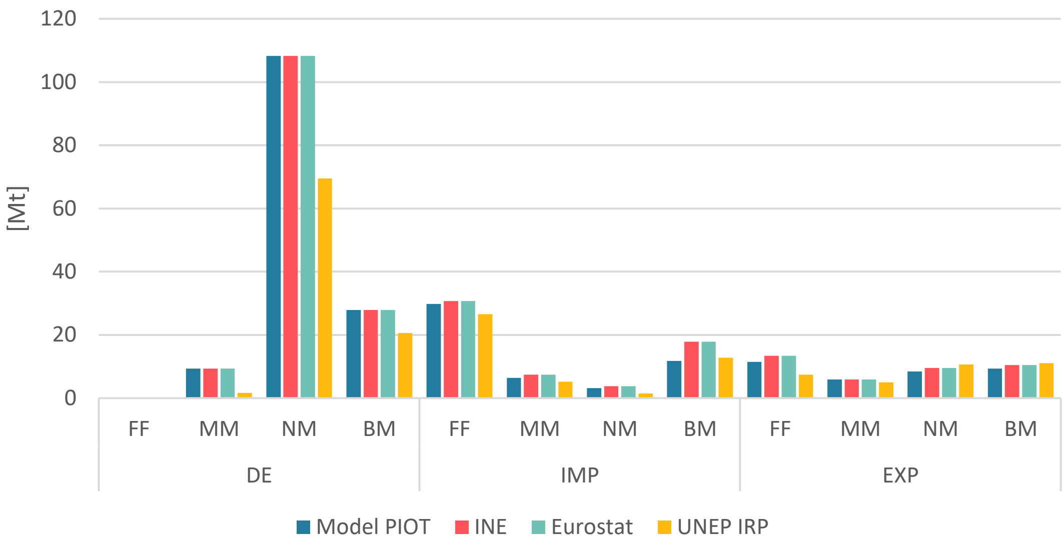

Figure 3.7 – Main flows per material from the various data sources (FF - fossil fuels, MM – metallic minerals, NM – non-metallic minerals, BM – biomass).

The values from UNEP IRP show differences across all materials and flows, being more significant for domestic extraction. Data for imports show that while the values in the model are smaller for all materials compared to INE/Eurostat, this difference is more noticeable in biomass (BM) - the value from Eurostat and INE is 52% higher than the value in the model. The differences for exports between the model and INE/Eurostat are below or equal to 17%.

Table 3.5 - Differences in material flows relative to the model values.

Flow	Material	Model PIOT	INE	Eurostat	UNEP IRP
Domestic extraction	FF	0%	0%	0%	0%
	MM	0%	-1%	0%	-82%
	NM	0%	0%	0%	-36%
	BM	0%	0%	0%	-26%
Imports	FF	0%	3%	3%	-11%
	MM	0%	17%	17%	-18%
	NM	0%	19%	19%	-55%
	BM	0%	52%	52%	9%
Exports	FF	0%	17%	17%	-35%
	MM	0%	0%	0%	-15%
	NM	0%	13%	13%	27%
	BM	0%	12%	12%	18%

The UNEP IRP data has a superior geographical and chronological coverage, yet it shows significant differences compared with national or Eurostat data. The domestic extraction values used in the model match the values from national statistics. The imports and exports used were collected from UN Comtrade. They show differences between 27% (imports) and 21% (exports) compared with Eurostat and National Statistics. This difference is most significant for the imports of biomass. The impacts of variations in the main data sources are investigated in the following section.

3.2.2 Sensitivity analysis

The sensitivity of the model to its primary data sources was tested by running the model for variations of more and less 10% of the values of domestic extraction, imports, and exports. The changes were applied to each specific material and all at once. The impact of the changes was evaluated by observing the resource productivity by sector compared to the original value. The resource productivity value is directly affected by changing the flows and the subsequent balancing of the flows that determine the exchanges between the sectors. It is also a potentially relevant indicator extracted from the method. These variations in resource productivity are shown in Table 3.6.

Table 3.6 - Sensitivity analysis to 10% changes in main data sources.

			AGRICUL	MINING	FOOD	TEXTILES	WOOD	PAPER	PETROLPROD	CHEM&PHARM	PLASTICS	OTHNM	METALSBASIC	METALPROD	ELECTRONICS	ELEC.EQUIP	MACHINERY	VEHICLES	TRANSPOTH	MANUFOTH	UTILITIES	CONSTRUC	SERVICES
DE	-10%	FF	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		MM	0%	1%	0%	0%	0%	0%	0%	1%	0%	0%	3%	1%	1%	1%	1%	1%	1%	0%	0%	0%	0%
		NM	1%	10%	2%	3%	2%	2%	0%	5%	2%	11%	2%	7%	5%	4%	4%	6%	5%	6%	2%	12%	7%
		BM	10%	0%	6%	1%	6%	6%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
		ALL	11%	11%	9%	4%	8%	8%	0%	7%	4%	11%	5%	8%	6%	5%	5%	7%	7%	7%	2%	12%	9%
	+10%	FF	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		MM	0%	-1%	0%	0%	0%	0%	0%	-1%	0%	0%	-3%	-1%	-1%	-1%	-1%	-1%	-1%	0%	0%	0%	0%
		NM	-1%	-8%	-2%	-3%	-2%	-1%	0%	-5%	-2%	-9%	-2%	-6%	-4%	-4%	-3%	-5%	-5%	-5%	-2%	-9%	-7%
		BM	-8%	0%	-5%	-1%	-6%	-5%	0%	0%	-1%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	-1%
		All	-9%	-9%	-8%	-4%	-8%	-7%	0%	-6%	-3%	-9%	-4%	-7%	-5%	-5%	-4%	-6%	-6%	-6%	-2%	-9%	-7%
IMP	-10%	FF	0%	0%	0%	3%	0%	1%	11%	2%	3%	0%	1%	0%	1%	1%	1%	1%	1%	1%	9%	0%	3%
		MM	0%	0%	0%	1%	0%	0%	0%	0%	1%	0%	6%	4%	5%	5%	6%	4%	5%	2%	0%	0%	0%
		NM	0%	0%	0%	1%	0%	0%	0%	1%	1%	0%	0%	0%	1%	0%	0%	1%	0%	0%	0%	0%	0%
		BM	0%	0%	2%	5%	4%	3%	0%	2%	2%	0%	0%	0%	1%	0%	0%	1%	1%	3%	0%	0%	1%
		ALL	1%	0%	3%	10%	5%	4%	11%	5%	8%	0%	7%	5%	8%	7%	8%	7%	7%	6%	10%	1%	4%
	+10%	FF	0%	0%	0%	-2%	0%	-1%	-9%	-2%	-3%	0%	-1%	0%	-1%	-1%	-1%	-1%	-1%	-1%	-8%	0%	-2%
		MM	0%	0%	0%	-1%	0%	0%	0%	0%	-1%	0%	-5%	-4%	-4%	-5%	-6%	-4%	-5%	-2%	0%	0%	0%
		NM	0%	0%	0%	-1%	0%	0%	0%	-1%	-1%	0%	0%	0%	-1%	0%	0%	-1%	0%	0%	0%	0%	0%
		BM	0%	0%	-2%	-5%	-5%	-3%	0%	-2%	-2%	0%	0%	0%	-1%	0%	0%	-1%	-1%	-3%	0%	0%	-1%
		All	-1%	0%	-3%	-8%	-5%	-4%	-9%	-5%	-7%	0%	-6%	-5%	-7%	-6%	-7%	-7%	-6%	-6%	-8%	-1%	-4%
EXP	-10%	FF	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%
		MM	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	-1%	-1%	-1%	-2%	-2%	-1%	0%	0%	0%
		NM	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	0%	-1%	0%	-1%	0%	-1%	-1%
		BM	0%	0%	-1%	-2%	-4%	-1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	-1%	0%	0%	0%
		ALL	0%	0%	-1%	-2%	-4%	-1%	0%	-1%	-1%	0%	-1%	-2%	-2%	-1%	-2%	-3%	-2%	-3%	0%	-1%	-2%
	+10%	FF	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
		MM	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	1%	1%	2%	1%	0%	0%	0%
		NM	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	1%	0%	1%	0%	1%	1%
		BM	0%	0%	0%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
		All	0%	0%	1%	2%	2%	1%	0%	1%	1%	0%	1%	2%	2%	1%	2%	2%	2%	2%	0%	1%	2%

The first noticeable observation is that as the input of materials in the economy increases, resource productivity decreases, which is an expected result of changing the material flows entering and leaving the economy without changing the monetary flows. The results show that the resource productivity of the various economic sectors is most sensitive to changes in domestic extraction and imports.

The Portuguese economy does not extract fossil fuels (FF), so there are no changes in resource productivity from changing the domestic extraction of FF. Changes in the extraction of metallic minerals (MM) will mainly affect the resource productivity of $\text{METALS}_{\text{BASIC}}$ when the changes if for domestic extraction. On the other hand, if the change is in imports, all sectors from $METALS_{BASIC}$ to $MANUF_{OTH}$ are affected between 6% and 2%. MINING, OTH_{NM}, and CONSTRUCT are closely related, as shown in Figure 3.5, and are the most affected by changes in the domestic extraction of non-metallic minerals (NM). When the change affects domestic extraction of biomass (BM), then AGRICUL is the most affected sector, followed by FOOD, WOOD, and PAPER. Finally, if the domestic extraction of all materials is changed by 10%, most sectors are affected by under 10% with few over 10%, except for $PETROL_{PROD}$ and UTILITIES.

The resource productivity of $PETROL_{PROD}$ and UTILITIES are the most affected values by 10% changes in imports. Both these sectors rely on the imports of FF. The same changes in the remaining materials will lead to changes of 1 to 6% in the resource productivity of the sectors that rely most on the type of material being changed. The changes in resource productivity of the economic sectors resulting from the changes in exports are minimal, with the maximum variation at 4%.

The results presented are most sensitive to domestic extraction data, which is reliable as it is collected from Eurostat and matches national statistics. In terms of trade, sector productivity is most sensitive to imports of FF, and a 10% difference affected the results for $PETROL_{PROD}$ and UTILITIES, a maximum of 11%. This is relevant as the maximum difference between the data is only 3%.

This analysis provides a deeper insight into how accounting problems in the data sources can affect the analysis performed using the proposed method. It also shows how the sensitivity of the results can be tested and may indicate areas where special care should be taken depending on the goal of the analysis.

3.2.3 Homogeneous price assumption

The homogeneous price assumption of Merciai and Heijungs (2014) was validated by observing the distribution of the prices of the products from each sector and the distribution of the sales per sector.

The prices of the products sold by each sector can be calculated using data published in Prodcom (Eurostat, 2018b). Prodcom statistics from Eurostat include data on the sales of various products in mass and economic values, which enable the calculation of an average price per product type. Prodcom covers products manufactured and sold by sectors of sections B (mining and quarrying) and C (manufacturing) of NACE 2. It should be noted that these statistics do not cover the entirety of the sales within these sectors. Prodcom only covers enough enterprises to account for 90% of the national production and enterprises with 20 employees or more. Some exceptions allow countries to use different thresholds and not declare values for confidentiality reasons. For the cases in which an enterprise has more than one activity, the statistics of the enterprise are considered for the main activity of the enterprise (the one that generates the largest share of value added). Depending on the product, the type of physical units declared may not be mass, and only some of the non-mass units can be converted into mass. After some price calculations based on trade data (UN Comtrade, 2014), among various other sources, it was possible to collect the prices for 81% of the sales declared in Prodcom for Portugal 2013. Figure 3.9 through Figure 3.13 present violin plots of the distribution of the mass sold per sector per price for the products declared in Prodcom for Portugal 2013. The sectors were aggregated in different figures according to their classification.

The distribution of the relative value of the sales of each sector by the sectors covered in Prodcom is in Table 3.7. This distribution was calculated based on the MIOT used in the model that calculates the PIOT.

The homogeneous price assumption validity check was based on the following: if the distribution of prices in the violin plot is centered in one area around the average price, then the homogeneous price assumption should hold; if the distributions show different areas, but there is no evidence that the product bundles sold have different average prices, then the assumption should still be valid; on the other hand if the prices and sales distributions give indications that a bundle sold to a sector was made of products with a very different price than the bundles sold to the remaining sectors, then the mass flows of the sales for each sector may be under or overestimated.

Sales within the sectors themselves are one of the bundles of products that may have a different price than the remaining bundles sold by the sector to other sectors or final consumption. This difference results from the enterprises selling to each other intermediate products that are still going to be further processed in the sector before becoming the finished products that are sold to other sectors or to final consumption.

Table 3.7 -Distribution of the sales from the sectors in Prodcom

	AGRICUL	MINING	FOOD	TEXTILES	WOOD	PAPER	PETROLPROD	CHEM&PHARM	PLASTICS	OTHNM	METALSBASIC	METALPROD	ELECTRONICS	ELEC.EQUIP	MACHINERY	VEHICLES	TRANSPOTH	MANUFOTH	UTILITIES	CONSTRUC	SERVICES	HFCE	NPISH	GGFC	EXP	GFCF	INVNT
MINING	0%	1%	0%	0%	0%	0%	**12%**	2%	0%	**5%**	**11%**	1%	0%	0%	0%	0%	0%	0%	1%	**4%**	1%	1%	0%	0%	**60%**	1%	0%
FOOD	**4%**	0%	**13%**	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**12%**	**47%**	0%	1%	**22%**	0%	0%
TEXTILES	0%	0%	0%	**10%**	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	0%	0%	**2%**	**28%**	0%	0%	**58%**	0%	0%
WOOD	1%	0%	1%	0%	**22%**	1%	0%	0%	0%	1%	0%	0%	0%	1%	0%	0%	0%	**7%**	1%	**10%**	**4%**	2%	0%	1%	**47%**	1%	0%
PAPER	0%	0%	**3%**	1%	0%	**17%**	0%	1%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	**19%**	**7%**	0%	0%	**45%**	0%	0%
CHEM&PHARM	2%	0%	1%	2%	0%	1%	2%	**10%**	**5%**	1%	0%	1%	0%	1%	0%	1%	0%	1%	0%	1%	**7%**	**10%**	0%	5%	**45%**	2%	0%
PLASTICS	0%	0%	**4%**	2%	0%	0%	0%	1%	**4%**	1%	0%	1%	1%	1%	1%	2%	0%	2%	0%	**3%**	**10%**	3%	0%	0%	**62%**	1%	0%
OTHNM	1%	0%	2%	0%	0%	0%	0%	1%	0%	**9%**	1%	1%	0%	1%	0%	1%	0%	1%	1%	**24%**	**6%**	**6%**	0%	0%	**44%**	1%	0%
METALSBASIC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**5%**	**8%**	0%	2%	2%	**3%**	0%	1%	1%	**7%**	1%	0%	0%	0%	**65%**	1%	0%
METALPROD	0%	0%	3%	1%	0%	0%	0%	0%	1%	1%	2%	**13%**	0%	1%	2%	2%	0%	2%	1%	**8%**	**7%**	3%	0%	0%	**46%**	**6%**	0%
ELECTRONICS	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**2%**	0%	0%	1%	0%	0%	0%	1%	**4%**	**8%**	0%	1%	**77%**	**6%**	-1%
ELEC.EQUIP	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%	1%	1%	0%	1%	1%	**3%**	**3%**	**7%**	0%	0%	**74%**	**4%**	0%
MACHINERY	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	**2%**	0%	0%	1%	0%	**2%**	**3%**	1%	0%	0%	**75%**	**13%**	-2%
VEHICLES	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**8%**	0%	0%	0%	0%	**2%**	**10%**	0%	0%	**76%**	**3%**	0%
TRANSPOTH	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	0%	1%	**10%**	**6%**	0%	**11%**	**60%**	**8%**	-1%
MANUFOTH	0%	0%	2%	1%	1%	1%	1%	1%	0%	1%	2%	1%	0%	0%	0%	0%	0%	**3%**	2%	1%	**12%**	**18%**	0%	2%	**37%**	**14%**	0%

Prodcom presented very sparse data (in terms of the number of different products) for ELECTRONICS ELEC.EQUIP, VEHICLES, and $TRANSP_{OTH}$. Figure 3.8 shows the sales in monetary and mass units across the sectors to illustrate the relative relevance of each sector.

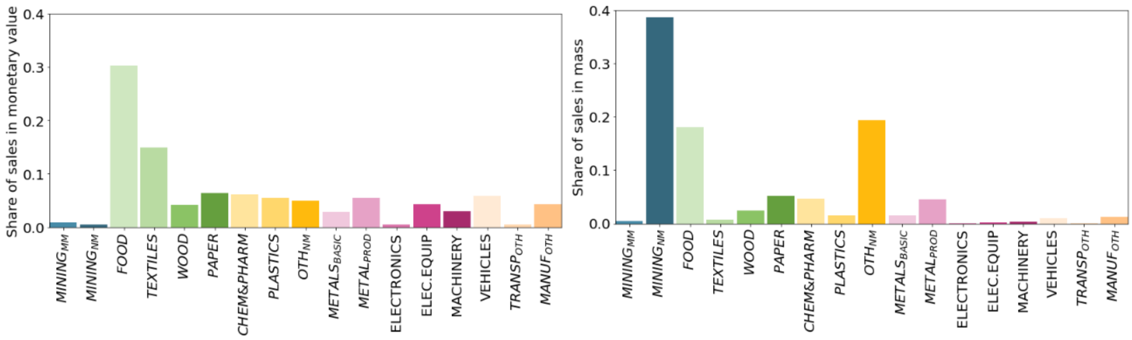

Figure 3.8 - Distribution of the sales in monetary (a) and mass (b) units in Prodcom for Portugal 2013.

$MINING_{NM}$, FOOD, PLASTICS, OTH_{NM}, $METALS_{BASIC}$, $METAL_{PROD}$, ELECTRONICS, ELEC.EQUIP, MACHINERY, $TRANSP_{OTH,}$ and $MANUF_{OTH}$ all show distributions where the prices of most of the products are very concentrated around the average price. However, it should be noted that there are products of the $TRANSP_{OTH}$ sector missing and that the sector $MANUF_{OTH}$ sells a large variety of products with different uses.

$MINING_{MM}$ only had two products with declared data (lead and copper), so its distribution has the shape in Figure 3.9. The distribution of the prices for $MINING_{NM}$ shows how the order of magnitude of the prices of the products of these sectors was different, which is why they were disaggregated. NM and MM materials tend to be sold to very distinct sectors, based on the flows in the MIOT and the product composition of the products of the sectors that by most of the products from these two mining sectors.

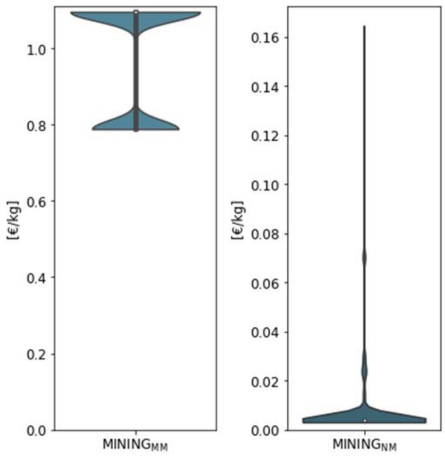

Figure 3.9 – Prodcom sales price distribution for $MINING_{MM}$, $MINING_{NM}$.

The TEXTILES sector sells some products at three times the average price. However, considering the type of products, it is feasible to assume that the bundles of products from TEXTILES have somewhat constant prices, except for the products sold to the sector itself, possibly. The same could be said for the PAPER products.

The two main WOOD products sold were cork and cork products (71% of the sales and 25% of the sold mass) and coniferous wood (7% of the sales and 46% of the sold mass). Except for exports and the sector itself, a considerable part of the sales went to $MANUF_{OTH}$ and construction, but both products may be used in either sector.

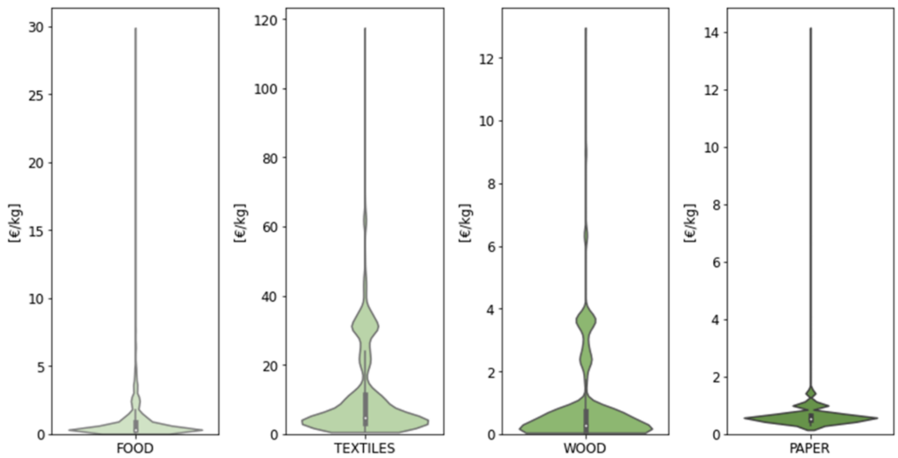

Figure 3.10 – Prodcom sales price distribution for FOOD, TEXTILES, WOOD, and PAPER.

The products from CHEM&PHARMA were very diverse. They included products sold typically to agriculture, such as fertilizers (0.1 to 0.3 €/kg) and more expensive insecticides, herbicides, or fungicides (over 8€/kg). The sector also sells biodiesel at 0.9€/kg, whose typical application is combustion engines. This sector also produced paintings and varnishes, with prices ranging between 1.7€/kg to 5.43€/kg (pigments). Besides these products, the sector also sold a variety of chemicals and other products such as lubricants. Given the variety of products and prices of the products even typically sold to a specific sector, it is hard to make any conclusions on the suitability of the homogeneous price assumption with the available information.

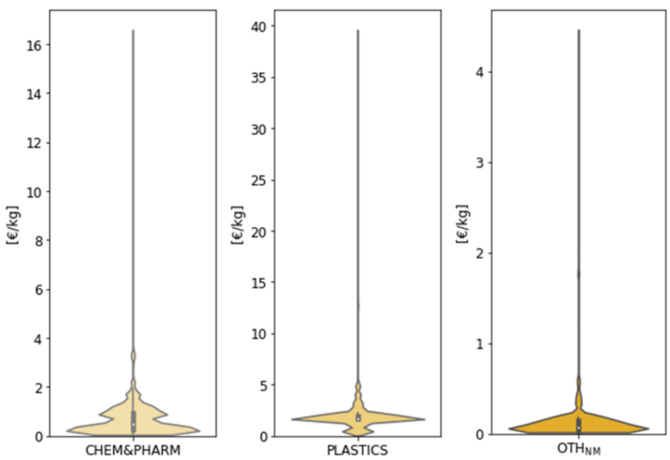

Figure 3.11 – Prodcom sales price distribution for CHEM&PHARM, PLASTICS, and OTH_{NM}.

The prices of the products of the sectors in Figure 3.12 are all concentrated around the average with few outliers. The homogeneous price assumption should be suitable for most sales. One of the exceptions noted was for $METAL_{PROD}$, which sells 72% of the mass produced as cans (likely to FOOD) at a price between 0.04 and 0.14 €/kg. Other products of the sector include aluminum doors (19% of the sales, 3.5% of the mass) at 3.4€/kg. It is possible that the price of the products sold to FOOD and construction may differ and that the mass sold to construction be overestimated.

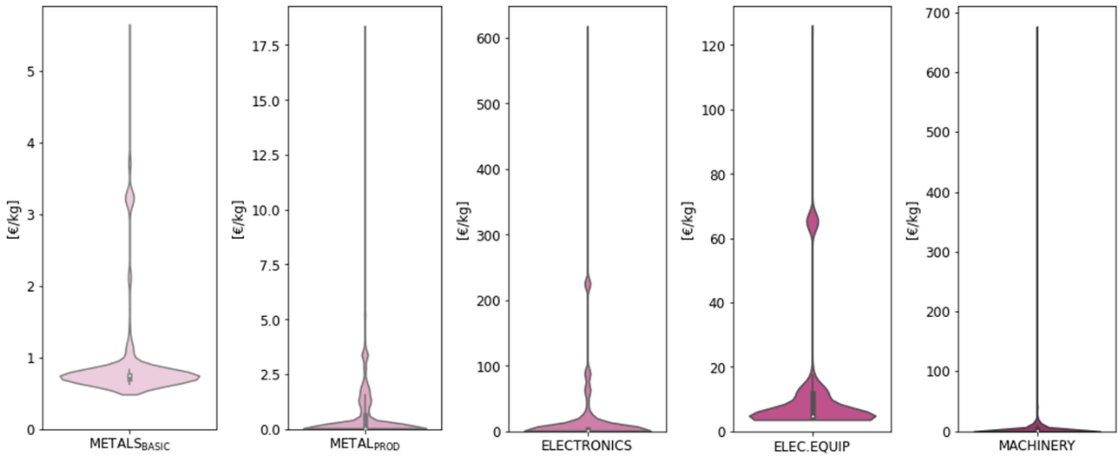

Figure 3.12 – Prodcom sales price distribution for METALS$_{BASIC}$, METAL$_{PROD}$, ELECTRONICS, ELEC.EQUIP, and MACHINERY.

Twenty-seven different products from mattresses to napkins or seats for motor vehicles produced by MANUF$_{OTH}$ were covered in Prodcom. The two areas shown at slightly higher prices correspond to upholstered seats with wooden frames (3.8% share of mass sold at 3.7€/kg) and wooden furniture for the dining room and living room (5.6% share of mass sold at 4.7€/kg). Still, 88% of the mass sold corresponds to 9 products with prices under 1.5€/kg, covering 62% of the sales. The suitability of the homogenous price assumption should not be meaningfully affected.

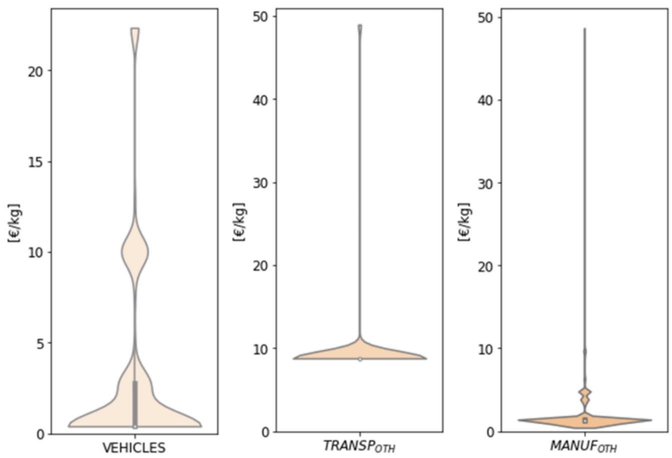

Figure 3.13 – Prodcom sales price distribution for VEHICLES, TRANSP$_{OTH}$, and MANUF$_{OTH}$.

The data from Prodcom does not cover the complete national production, and various products either miss their physical units or are declared in units that cannot be easily converted to mass. Additionally, it does not cover all the economic sectors, and for these reasons, it cannot be compared to the sales values from the PIOT. However, these records give some insight into the price variations of the products of the sectors covered and the types of products sold by each of those sectors. By coupling that with the sales distribution by sector, one can have some indications of whether the homogeneous price assumption is adequate or not and how meaningful the effect of the cases may be.

The mass sold by each sector was concentrated around an average price for most sectors, and the homogeneous price assumption reflects the proportionality between monetary and physical flows.

3.2.4 Emissions

The emissions in the model correspond to the fuel mass that is converted into emissions (including carbon and hydrogen) and therefore cannot be easily validated. Still, it can be compared to the carbon content of the CO_2 emissions in Eurostat (2021a), which is expected to be a lower value as it does not include the weight of the hydrogen. For Portugal in 2013, the total weight of the fuel converted into emissions from FF1 and FF2 was 13 058 kt. The weight of carbon in the emissions of CO_2 from economic sectors in Eurostat is 10 919 kt, a value that makes up 84% of the model's value. These values do not validate the emissions but indicate that the results are not far from the actual value.

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4 A new 4-step framework to analyze the dynamics of the socioeconomic metabolism of countries

Analyzing the SEM of a country and its intertwining of material and economic flows can bring forward new information on the roles of the different economic sectors and material flows (Krausmann et al., 2017). Achieving sustainable development by decoupling material growth from economic development has motivated various EW-MFA studies. However, this method lacks sectorial resolution, as mentioned. On the other hand, applying the method to quantify PIOTs described in the previous chapter delivers over 30 thousand data points (see equation (5)).

$$\begin{aligned}(N_{materials} + 1)(nr\ of\ sectors^2 + nr\ of\ sectors \\ * input\ and\ outputs\ of\ of\ the\ economy) \\ = (17 + 1)(37^2 + 10 * 37) = 31\ 302\end{aligned} \quad (5)$$

This chapter proposes a 4-step framework integrating EW-MFA and the information in the PIOTs and MIOTs, thus facilitating and standardizing the analysis of the SEM. The application of the framework allows for some flexibility to account for the specificities of the case or cases under analysis. The framework creates valuable insights for both the study of the SEM and for policymaking.

This 4-step methodological framework was developed with the following goals: it should account for the various possible drivers and relate them with the evolution of the resource productivity of the country and its SEM. These goals are achieved through the four steps of the model, illustrated in Figure 4.1. Steps one and two are based on EW-MFA and cover the calculation of indicators such as DMI, GDP, and resource productivity, providing disaggregation per material consumed. The innovative steps of the methods are steps three and four, that incorporate the data from the IOTs. The third step focuses on the economic structure, and the fourth illustrates the monetary and material flows of the SEM. The following subsections will describe each step and illustrate them with an example.

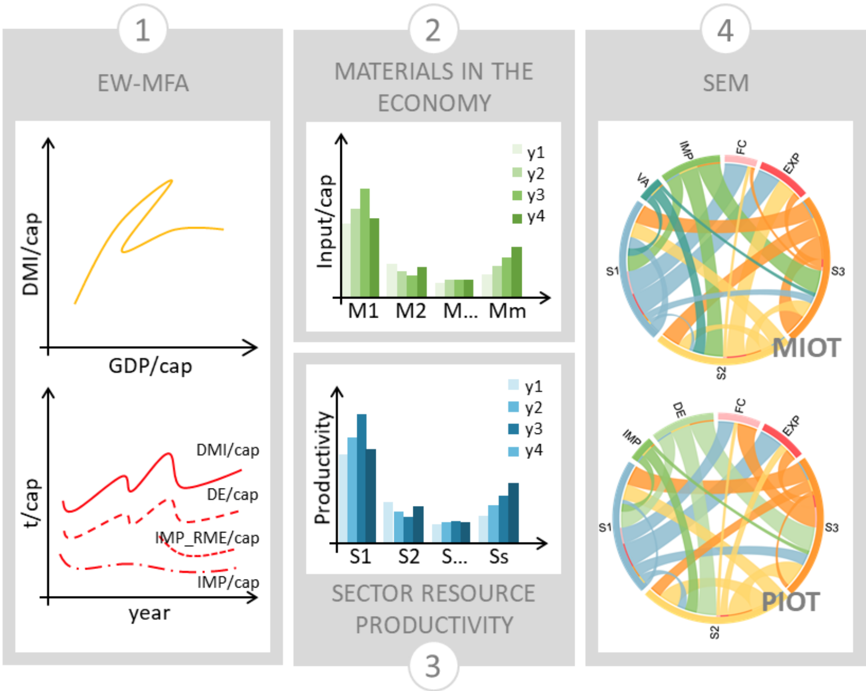


Figure 4.1 – Description of the 4-step methodological framework for the analysis of SEM

4.1 Step 1 – Economic development and resource use

The first step of the framework consists of evaluating the trends of relevant EW-MFA indicators and identifying key years. These indicators include GDP/cap, DMI/cap, resource productivity, and any other that may become relevant depending on the country.

Eurostat (2016) defines resource productivity as the relation between the materials used by the economy, DMC, and GDP. However, this framework proposed the use of DMI instead of DMC. While DMC measures the material use linked with consumption within the geopolitical boundary, DMI measures all the material used to create the GDP, including the materials exported whose value added is included in the GDP (Bringezu et al., 2003).

The plot of DMI/cap versus GDP/cap illustrates how these variables evolved, not accounting for the direct effects of population growth. The plot also gives a first account of the changes in resource productivity through the slope between a pair of years. This way, it is possible to see if the changing resource productivity resulted from a changing GDP/cap, DMI/cap, or both.

For example, by plotting the evolution of domestic extraction, imports, and total material requirements of imports, one can determine if a change in DMI resulted from decreased domestic extraction, imports, or both. Previous research has found that some countries have reached relative decoupling by substituting production with imports and decreasing waste generation in this process (Wiedmann et al., 2015). This kind of dynamic can be verified through the raw material equivalents of imports (IMP_RME), representing the total amount of material extracted to produce an imported product, irrespective of where the material was extracted and the product produced (Eurostat, 2018a).

The required data to create these plots can be found in various sources nowadays. The physical flows can be found in the Material Flow Accounts from Eurostat (2020) or the Global Material Flows Database from UNEP International Resource Panel (n.d.). The GDP can be found in various sources. However, it is essential to ensure that it is measured in constant monetary units, to remove the effect of inflation. When comparing various countries, the GDP should be in constant values and in the same currency.

Application example:

Figure 4.2 illustrates the evolution of the relation between DMI/cap and GDP/cap, and consequently resource productivity, for Portugal between 1995 and 2019. The data points on the plot are connected and colored chronologically. Figure 4.3 shows the chronological evolution of these two variables in detail.

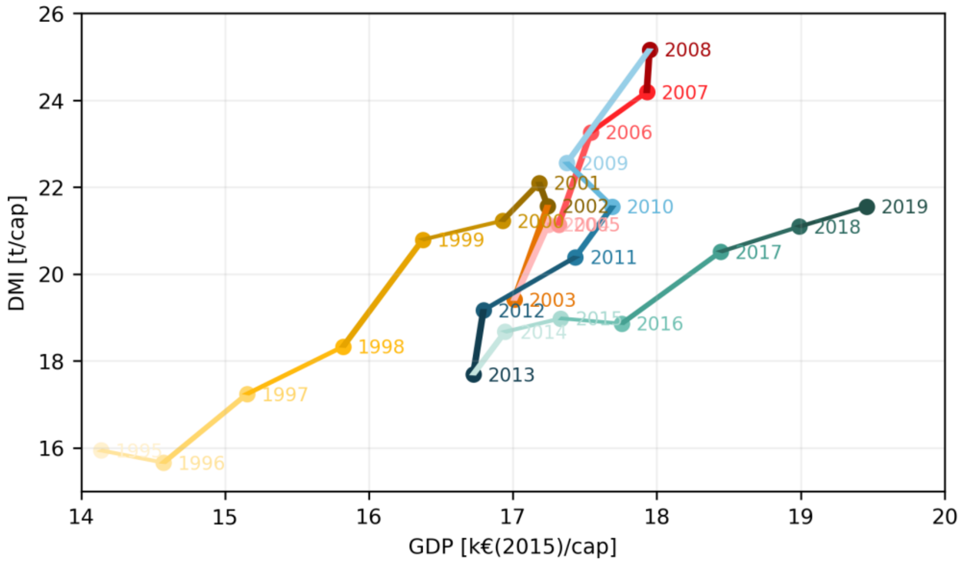


Figure 4.2 - DMI/cap versus GDP/cap for Portugal between 1995 and 2019. The lines connect the years chronologically with different colors for each period of growth/degrowth, and the saturation increases chronologically. The data supporting the figure can be found in Table 9.3. (Eurostat, 2020; OECD.stat, n.d., 2020a; United Nations - Department of Economic and Social Affairs - Population Division, 2019)

In Figure 4.2, it is possible to observe the trends in the GDP/cap versus DMI/cap. One can effortlessly identify different periods and changes in resource productivity. For example, the resource productivity in 2008 must have been lower than in 2019, as the GDP/cap increased and the DMI/cap decreased. The plot also shows how the economic recession affected the DMI/cap between 2008 and 2013

Previous research has found that some countries have managed to reach relative decoupling by substituting production with imports and decreasing waste generation within their borders in this process (Wiedmann et al., 2015). The raw material equivalents of imports (IMP_RME) in Figure 4.3 shows that while domestic extraction decreased between 2008 and 2019 and imports increased, the raw material equivalents of imports were approximately the same in 2008 and 2018.

The data presented in these plots, based on EW-MFA indicators, can be used to identify different periods of development and how the relation between DMI/cap and GDP/cap changes in time. This data, in particular, also suggests that there may have been changes to the SEM that promoted the transition to a higher level of resource productivity.

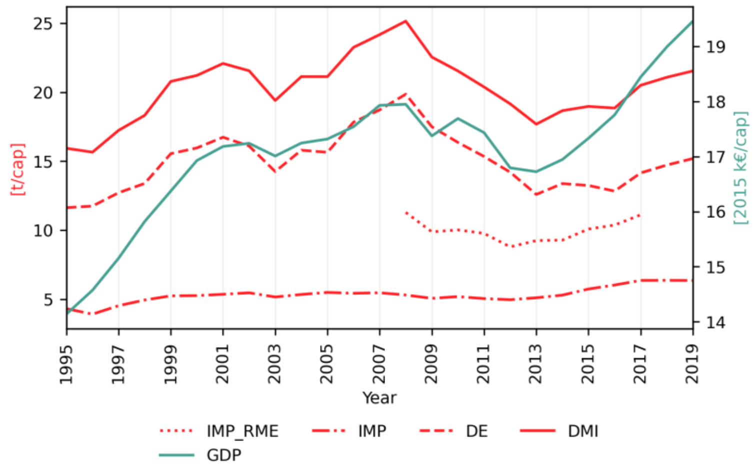


Figure 4.3 – Chronological evolution of DMI, domestic extraction (DE), and imports (IMP) between 1995 and 2019, plus total material requirements of imports (IMP_RME) between 2008 and 2017, with units on the left y-axis. Chronological evolution of GDP, whose units are read on the right y-axis. The data supporting the figure can be found in Table 9.3.

4.2 Step 2 – Materials in the economy

The second step of the analysis focuses on the inputs per material in the economy. The analysis of EW-MFA indicators by material type has been done in previous studies (Steinberger et al., 2013; Z. Wu et al., 2019) and can establish the links between the shares of materials in the economy and economic development. Different materials tend to be associated with different environmental pressures (e.g., more fossil fuels are likely associated with increasing CO_2 emissions), different lifetimes (e.g., mineral products may last over 25 years while biomass will likely be used in the same year it was produced), and different recycling efficiencies, making this information very relevant. It is then proposed to plot the evolution of materials in the economy over time.

The disaggregation of the flows entering the economy from either the natural environment or other economies can also be found in Material Flow Accounts from Eurostat (2020) or the Global Material Flows Database from UNEP International Resource Panel (n.d.), with different levels of disaggregation. The types of natural resources in the country will likely significantly affect the SEM. The observation of changes in the materials can corroborate other changes observed in the first step.

Application example:

Applying the second step to the Portuguese economy resulted in the values presented in Figure 4.4. The figure shows the distribution of DMI per capita for the 17 material categories of the PIOTs for key years, based on the information from step 1. These values were obtained by summing the imported products and the domestic extraction of each material.

In Figure 4.4, it is possible to identify which material exists in a more considerable amount in the Portuguese economy, which is stone and sand (NM1). Given its relevance in the economy, the general trends of DMI follow the trends in the inputs of NM. The plot also shows that the changes observed in the first step impacted each of the various materials, in some cases, differently.

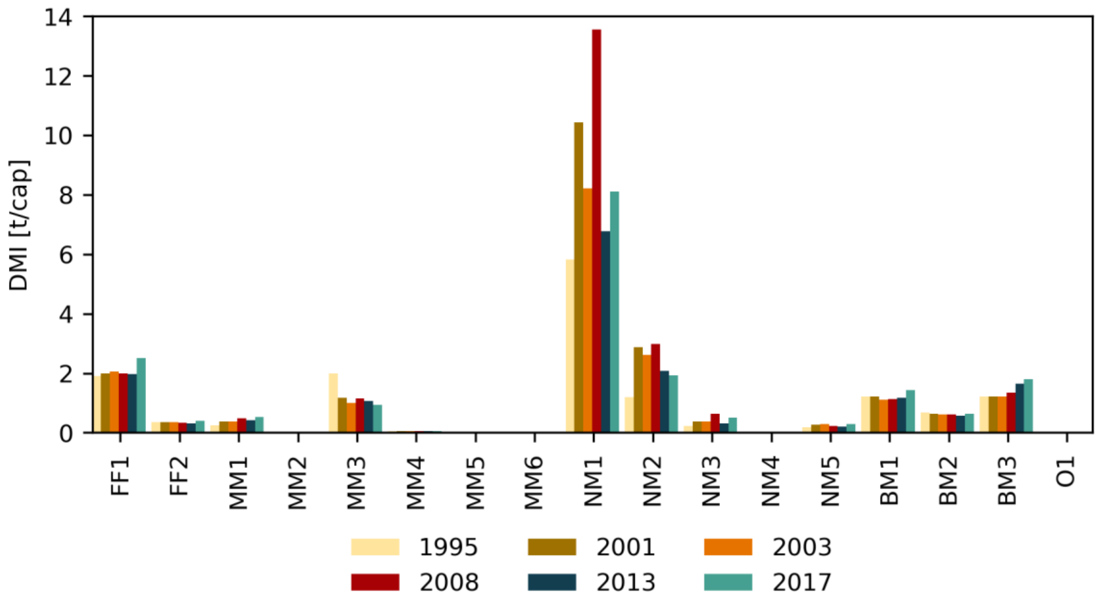


Figure 4.4 - DMI per capita per material for Portugal, the description of the nomenclature used for the materials can be found in Table 3.2. The data supporting the figure can be found in Table 9.4.

4.3 Step 3 – Economic structure

While a great tool to develop a general picture of the SEM of an economy, EW-MFA does not describe the flows within the economy. This framework step can relate the previous observations with changes in the economic structure or the resource productivity of the different sectors. The third step looks at the roles of the different economic sectors in the (un)sustainable development of the economy. It Is proposed that the analysis should consider the value added, the use of resources, and the resource productivity of each sector.

Similarly to whole economy resource productivity, the sector resource productivity is given by the ratio between the value added of the sector and the materials used by that economic sector. It can be used to measure the decoupling between the use of natural resources, and the economic growth of that sector and is a way to measure the contribution of a sector to the sustainable development of an economy.

While the value added of each economic sector can now be easily found in various sources such as the MIOTs from OECD (2017), the same does not happen for the total material input per sector. The total material input per sector includes the domestic extraction, imports, and the flows of materials and products obtained from other sectors. This value can be calculated by summing the columns of each sector in the PIOTs (except for waste and emissions, which are recorded as production requirements, as mentioned).

Application example:

Step 3 is focused on the economic structure. In this step, one might find what the resource productivities of each sector are, what were the sectors that contributed the most to changes in the economy (DMI or GDP), or how the economic structures between countries differ. Figure 4.5 shows the resource productivity, the physical input, and the value added per sector.

At first glance, it is possible to notice that resource productivity varies significantly between sectors. For example, the sectors MINING, $PETROL_{PROD}$, OTH_{NM}, and CONSTRUC have meager resource productivities compared to TEXTILES and SERVICES. From the value added and input per sector, it is possible to determine what contributes most to higher or lower resource productivity. Out of the sectors with low productivity, MINING and CONSTRUC have the highest totals of material inputs in the sector, followed by

OTHNM, SERVICES, and AGRICUL. Despite its average 4.3 t/cap of material, the high productivity (2.6 €/kg average) of the SERVICES results from a very high value added, averaging around 10.6 k€/cap. CONSTRUC has the highest value added of the remaining sectors (0.88 k€/cap), but given its high material input (13.3 t/cap), the average productivity is very low (0.07€/kg).

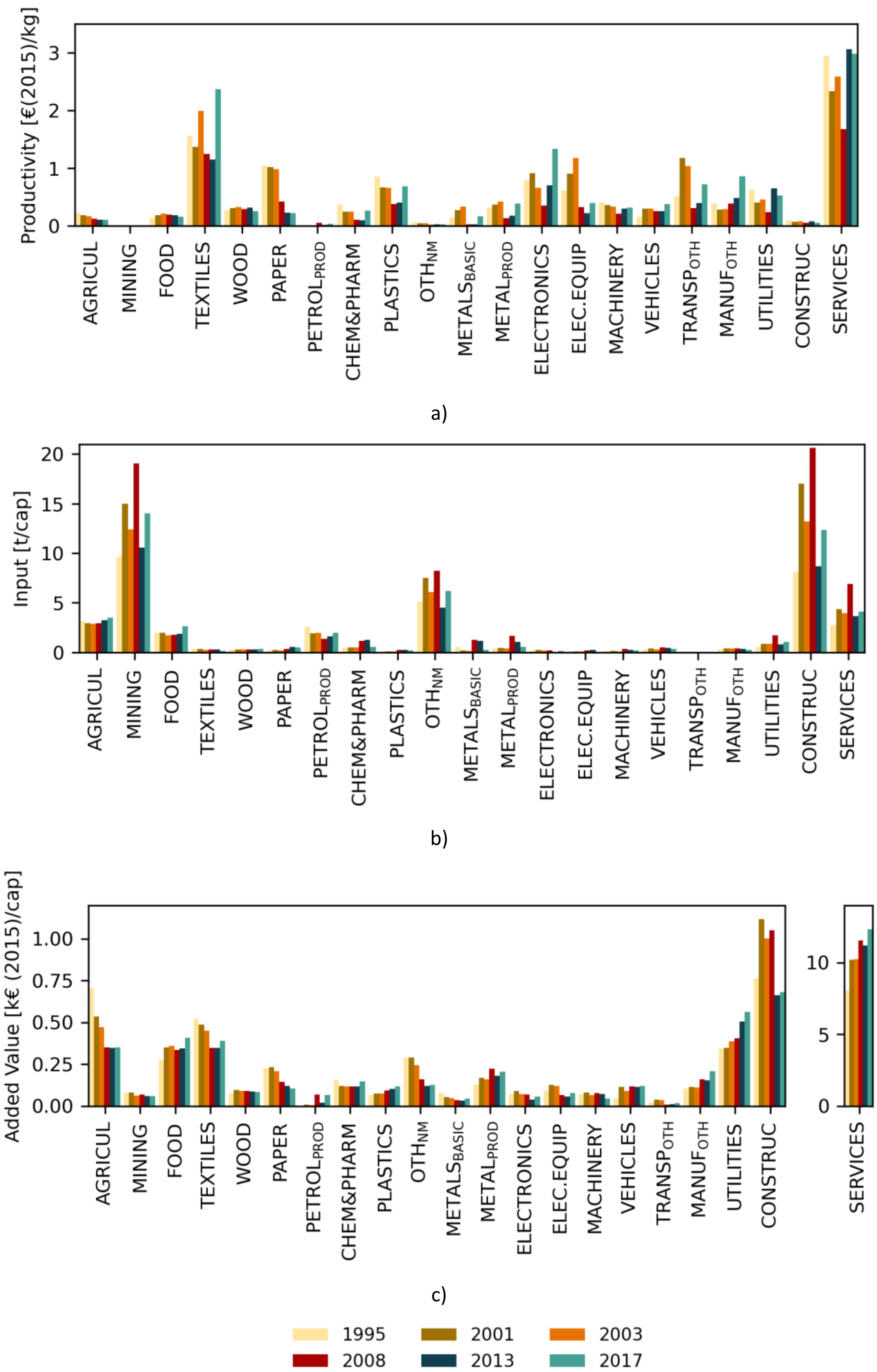


Figure 4.5 - a) Resource productivity per sector. b) Material inputs (domestic extraction, imports, and acquisitions from other sectors). c) Value added per sector. The data supporting the plots can be found in the supporting information in Table 9.5, Table 9.6, and Table 9.7.

4.4 Step 4 – Analysis of the socioeconomic metabolism

The final step of the framework covers the analysis of the monetary and physical flows between the economic sectors. The flows establish the link between nature and the socioeconomic system and between the sectors within the system. These flows are quantified in the PIOTs and MIOTs. These flows contain considerable information from which it can be challenging to extract valuable insights. However, by step four, one already knows the key years and critical sectors in the economy. It is suggested that the flows are represented as chord diagrams, like the one in Figure 3.5, for the key years. In these diagrams, one can identify the significant flows and the sectors associated with them, and the flows associated with the critical sectors from step three. The analysis of the value chains provides new information that can bring forward dynamics that might otherwise go unnoticed.

Application example:

The MIOTs illustrate the exchanges of services in a way that the PIOTs cannot offer. On the other hand, PIOTs evidence the essential contributors to emissions, waste, and demand for natural resources associated with environmental pressures and whose significance might be distorted in a MIOT.

Examples of MIOTs and PIOTs for 2008 (beginning of the recession), 2013 (last year before economic recovery), and 2017 (the latest available year) are represented in Figure 4.6 in the form of chord diagrams, larger versions of the same graphs can be found in Figure 9.1 through Figure 9.6. These plots illustrate the exchanges between each pair of sectors and the changes from one year to another. An explanation of the interpretation of the charts can be found in section 3.2.

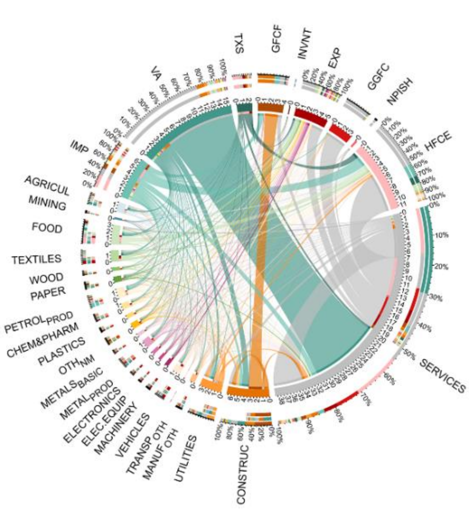
The contribution of SERVICES for gross value added had already been observed in Figure 4.5. In Figure 4.6, it is possible to identify the sectors linked to SERVICES. Final consumption (FC) and the sector itself (SERVICES) represent the largest share of sales from SERVICES. One can also observe changes in time. The demand for SERVICES by FC decreased during the recession, yet by 2017 it was more significant than in 2008. The values in the MIOTs pinpoint CONSTRUCT as the sector most affected by the recession, not having entirely recovered. By 2017, its economic output was still 46% lower than in 2008.

While the importance of the exchanges between SERVICES and CONSTRUC is not very clear in the monetary flows, the chord diagrams for the PIOTs identify an essential connection between CONSTRUC and SERVICES. SERVICES represent the most significant demand for CONSTRUC material flows (22%, 16%, and 18% for 2008, 2013, and 2017 respectively). It is evident that the quantity of materials used by CONSTRUC reduced significantly from 2008 and 2013 (-57%). The supply chain of the CONSTRUC shows a decrease in the total input of both OTH_{NM} (43%) and $MINING_{NM}$ (45%). The demand for CONSTRUC from SERVICES reduced by 68%. While SERVICES recovered economic output, CONSTRUC did not (either monetary or material flows).

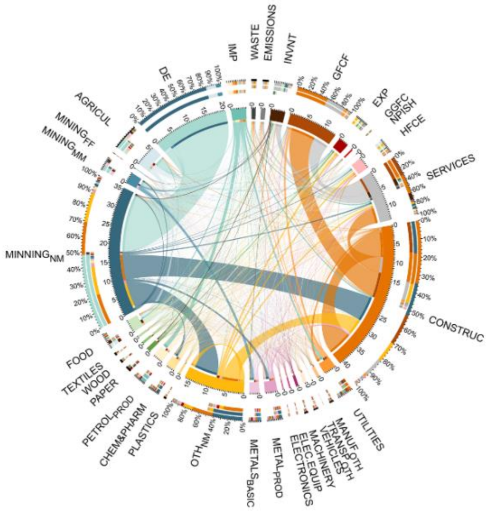
Besides the changes in these *major* sectors, the diagrams also illustrate the roles of other sectors in the SEM. FC of material was approximately constant between 2008 and 2013 while showing a 10% decrease in the monetary values. Products from AGRICUL represent the largest share of demand in FC. The values in the PIOTs that originated the graphs show that the demand for CONSTRUC from the general government between 2008 and 2013 increased, consistent with the findings of (Bringezu et al., 2004). Both imports and exports increased between 2008 and 2013. In terms of monetary flows, the sectors that contributed the most to the increase in exports were SERVICES, followed by $PETROL_{PROD}$.

Unlike with the MIOTs, with the PIOTs, it is possible to track waste flows from economic activities. The waste generated accompanied the evolution of DMI: first, a 22% decrease between 2008 and 2013, followed by an increase of 8% from 2013 to 2017, and an overall decrease of 15% for this period. However, the generation of waste per unit of material input was 7%, 8%, and 7% for 2008, 2013, and 2017 respectively, suggesting that the waste reduction resulted from a decrease in the materials entering the economy and not from any behavioral, technological, or structural change that could have improved the efficiency of material use.

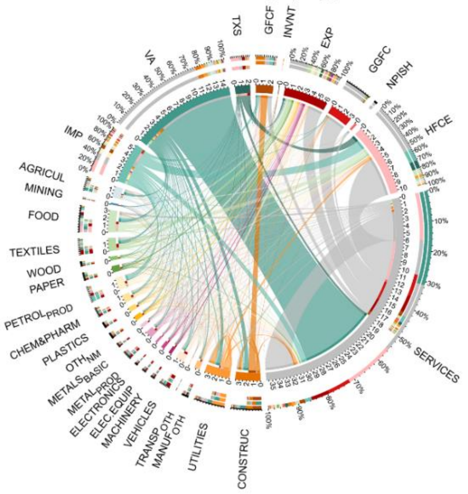
This illustrative example of the last step of the 4-step framework proposed shows the variety of observations found in the PIOTs and MIOTs and the possible connections between sectors that can be established.



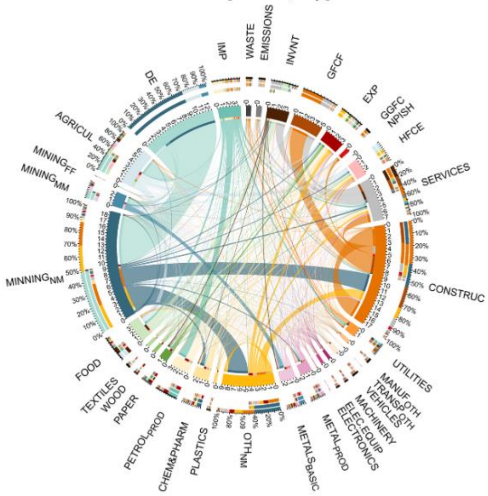
MIOT 2008 [k€/cap]



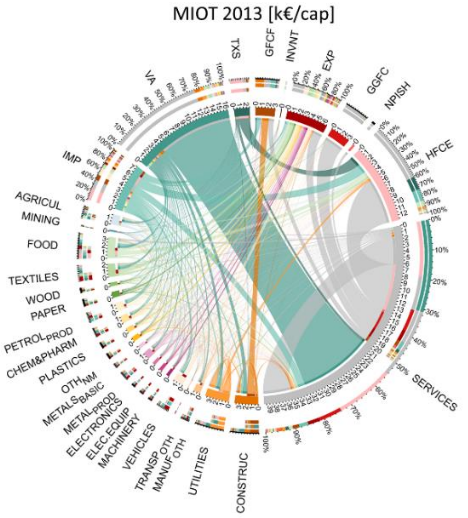
PIOT 2008 [tonnes/cap]



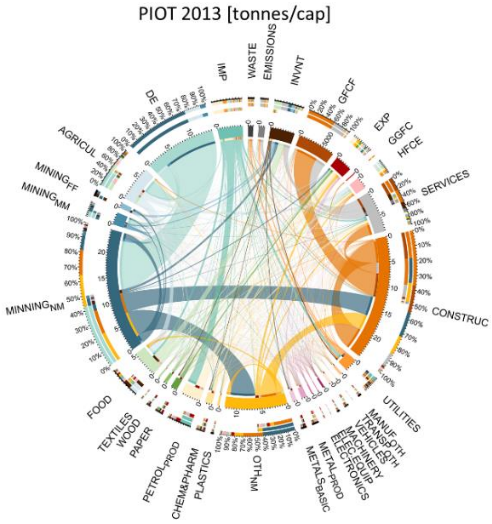
MIOT 2013 [k€/cap]



PIOT 2013 [tonnes/cap]



MIOT 2017 [k€/cap]



PIOT 2017 [tonnes/cap]

Figure 4.6 - Portuguese SEM described in MIOTs and PIOTs represented in chord diagrams for 2008, 2013, and 2017. A larger version of the figures can be found in Figure 9.1 through Figure 9.6 in the supporting information.

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5 The critical changes in the evolution of the socioeconomic metabolism of Portugal between 1995 and 2017

In this chapter, the methodologies of chapters 3 and 4 are applied to the Portuguese SEM economy between 1995 and 2017. This application of the methods has two main goals. One goal is to demonstrate the features of the methods when applied to the study of a transitioning SEM. The second goal is to find possible impacts of a changing SEM on the resource productivity of a country.

The chapter identifies the different periods through EW-MFA and then analyzes the flow of different materials in the economy. Applying the third step of the methodological framework will identify the critical sectors in possible structural changes based on monetary and physical units. The last part of the analysis focuses on the monetary and physical flows into, out of, and between the economic sectors. These results point to the areas where policy efforts should be focused, on the different periods of development, to guide the economy to more sustainable paradigms.

5.1 The Portuguese economy between 1995 and 2017

The case study selected for this analysis was Portugal from 1995 to 2017. During this period, the efforts toward sustainable growth increased progressively, and the country went through different stages of economic development and material use.

The Portuguese actions towards achieving sustainable development started in 1971 to prepare for the United Nations Conference on the Environment in 1972. They were reinforced several times before 1995, resulting in various policy documents such as the Agenda 21 in 1992 or The National Environmental Policy Plan in 1995 (Ribeiro &

Rodrigues, 1997). After the reinstatement of the democratic regime in 1974, Portugal eventually joined the EU in 1986, which contributed to the Portuguese economic development. Portugal has received support from the EU to tackle its environmental issues since 1994 (Medeiros, 2020). Later, the Portugal 2020 program (2014-2020) included a variety of measures to develop the Portuguese economy and its resource efficiency (like the promotion of energy efficiency and improved management of natural resources) (Agência para o Desenvolvimento e Coesão (ADC), 2014). However, by 2013 Portugal still had a long way to go to reach its sustainable development goals (Medeiros, 2020).

The relation between economic growth and resource use or environmental impacts in Portugal has been observed in previous studies that support the relevance of studying the roles of the different economic sectors. The transition of the Portuguese economy has been analyzed before by Niza and Ferrão (2006). The authors found evidence supporting the transition of the Portuguese economy towards services after a material-intensive period during which the necessary infrastructure was built. A comparative study of Portugal and Spain between 1975 and 2012, with a resolution of 13 sectors, concluded that the relationship between economic growth and environmental impacts should be analyzed at the sector level, as the effects of the introduction of renewable energy production were not the same across all sectors (Moutinho et al., 2017).

5.2 Portuguese economic development and material use

The Portuguese SEM has gone through various stages of economic development and material use since 1995. These stages can be identified based on what was proposed in the first step of the methodological framework. Figure 5.1 illustrates the evolution of the GDP/cap, DMI/cap, and resource productivity relative to 1995, with the different periods identified based on the evolution of the three indicators.

Period 1 (P1), between 1995 and 2001, was characterized by rapid economic development, leading to a 21% GDP/cap increase and increasing material use (39%), which shows that despite the first policy efforts towards sustainable development

(Ribeiro & Rodrigues, 1997), a decreasing resource productivity (-12%) was observed. The economic development in the nineties has been attributed to the changes from the reinstatement of the democratic regime in 1975 and the joining of the EU in 1986 (Alexandre et al., 2016).

By the start of the new millennium, the Portuguese economy started to show signs of change - by 2003, resource productivity had increased 13% relative to 2001, and the economic growth slowed in 2002 and decreased in 2003. This short but significant phase, during which absolute decoupling was identified, is defined as period 2 (P2). At the time, this change was viewed as a cyclical correction that should not affect the convergence with the more developed European countries, whose path to development Portugal could follow at a lesser cost (Alexandre et al., 2016).

However, Portugal did not converge with the other developed European countries. In the following years, the economy grew at a slower pace. Between 2003 and 2008, identified as period 3 (P3), the GDP/cap increased again (6%) but at a slower annual rate when compared with the first period. Material use increased significantly (30%), leading to decreasing resource productivity (-19%) until 2008, when a minimum was reached (0.71 €/kg).

The international economic crisis that followed caused the Portuguese economy to enter a recession in 2008 that lasted until 2013 - period four (P4). The GDP/cap decreased 7% from 2008 until 2013, when it reached a value slightly lower than that of 2000, 13 years before. The use of resources decreased by 30%, resulting in improved resource productivity (33% increase relative to 2008) and absolute decoupling.

Finally, period five (P5) was defined between 2013 and 2019. P5 was when the economy recovered, and GDP/cap increased by 17%, as did the use of resources, by 22%. However, unlike in P1, resource productivity remained relatively constant and comparable to 1995. In 2016, absolute decoupling was recorded without decreasing GDP/cap. In 2015, 2018, and 2019, relative decoupling was observed. After the different periods of growth and degrowth, by 2017, the economy managed to maintain a growing GDP/cap without a significant decrease in resource productivity. These variations suggest that the Portuguese economy has undergone structural changes during these periods, enabling its more sustainable growth.

Having defined and characterized the most significant changes in each period, it is also possible to determine the key years for the analysis of the structural changes, and these are 1995, 2001, 2003, 2008, 2013, and 2017[1].

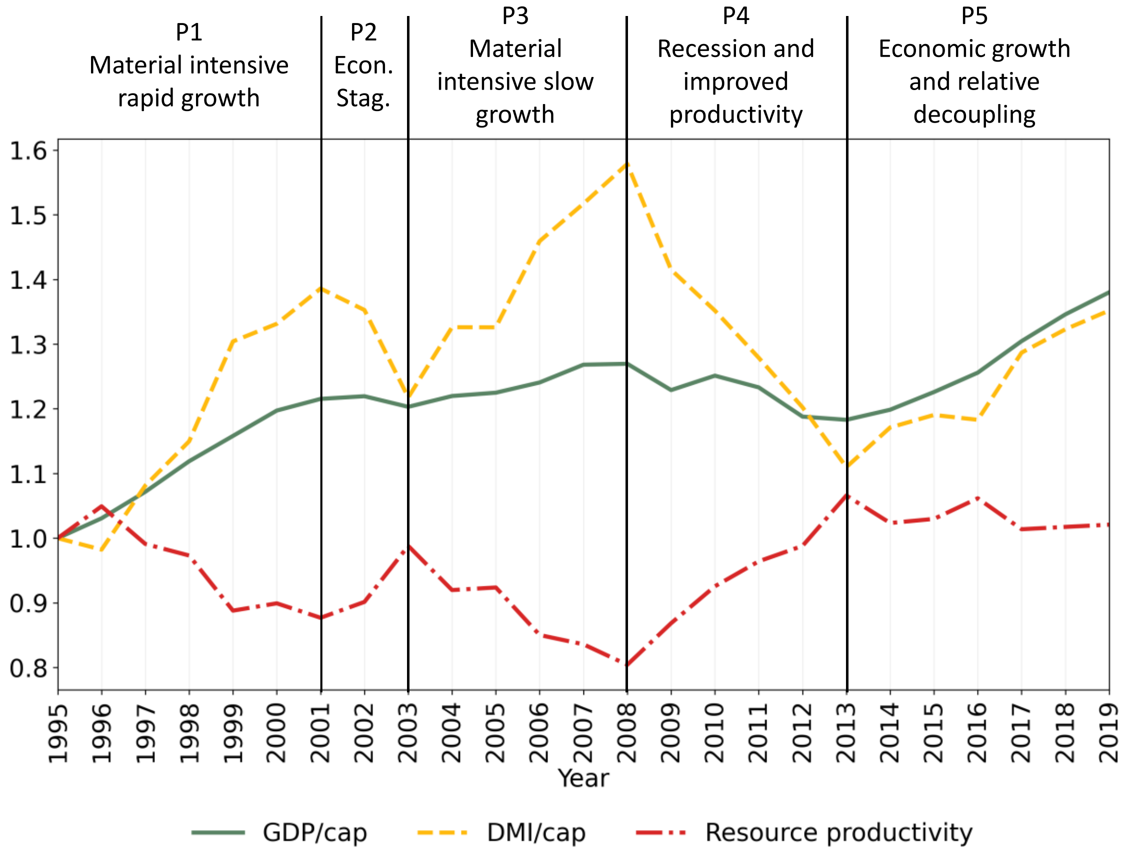


Figure 5.1 - The five periods of economic development of the Portuguese economy between 1995 and 2019 based on GDP/capita, DMI/cap, and resource productivity relative to the 1995 value. The data supporting this plot can be found in Table 9.8 in the supporting information (Eurostat, 2020; OECD.stat, n.d., 2020a; United Nations - Department of Economic and Social Affairs - Population Division, 2019)

[1] The year selected is 2017 and not 2019, as 2017 is the latest year for which MIOTs had been published at the time of this study.

5.3 Evolution of the material structure of the Portuguese economy

Figure 5.2 illustrates the evolution of the DMI/cap of the different materials in the Portuguese economy. Figure 5.3 presents the evolution of the shares of those materials in the economy. NM materials make up the majority of the flows in the Portuguese economy (49%-71%), followed by BM (13%-21%), FF account for the third-largest share (10%-15%), and metallic minerals take up the lowest share (8%-15%).

Weisz et al. (2006) found a strong correlation between construction materials and the evolution of the GDP/cap. Figure 5.2 shows that the use of construction minerals (mainly NM1) increased during growth periods. However, the correlation between materials and economic development also changed. For example, the economic growth in P5 was more significant than in P3, yet the increase in NM1 is substantially higher in P3 than in P5. Additionally, in P2, the GDP/cap presented a year of minimal growth followed by a slight decrease compared with the decrease during the economic recession of P4. However, the overall negative slopes in the DMI/cap of NM1 are similar for both P2 and P4.

For the remaining materials, the variations are not as significant. The values of FF in the DMI/cap remained constant except for the last period, during which they increased. MM3 shows a decrease during the first two periods, which is related to a decrease in the domestic extraction of copper and tin (Eurostat, 2020). MM1 shows an overall increase resulting from imports in P1, P3, and P5 (Eurostat, 2020). While the DMI of the different BM categories stayed mostly constant during P1, BM3 has been increasing since 2001, BM2 presented a slight decrease in P2, and BM1 has shown minor variations. None of the BM categories seem to have been significantly affected by the recession in P4.

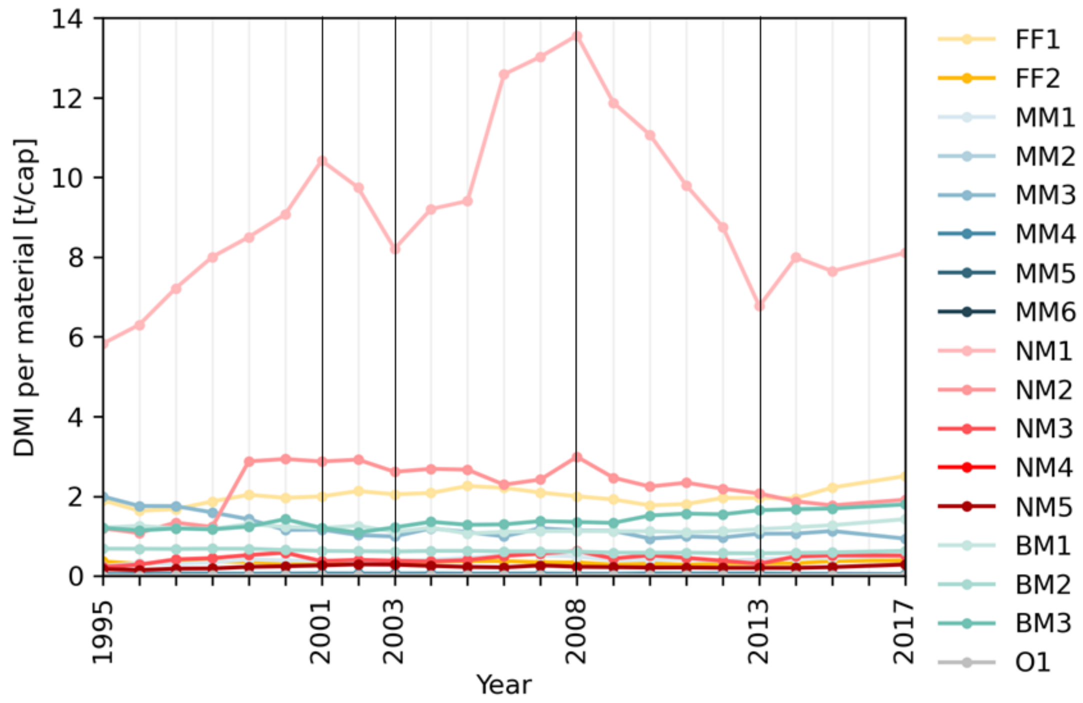


Figure 5.2 -Evolution of the different material flows in the Portuguese economy between 1995 and 2017. The DMI/cap per material for the key years can be found in Table 9.9 in supporting information.

With regards to the shares of materials in the economy, illustrated in Figure 5.3, the share of NM1 in the economy increased during the periods of positive economic growth, more significantly in P1 (from 39% to 50%) and P3 (from 45% to 55%), while in P5 it only increased from 41% to 42%. The share of FF1 in 1995 was the same as in 2017 (13%), despite variations during the various periods, with a minimum share being observed in 2008 (8%) when the share of NM1 was maximum. The share of MM3 (associated with copper and tin) was 13% in 1995. After 1995 it decreased, varying between 6 and 5%. The shares of BM all decreased in the first and third periods. When comparing 1995 with 2017, the variations in shares were all around 1%, with the exceptions being MM3, whose share decreased by 8%, NM1, whose share increased by 4%, and NM2, which increased by 2%.

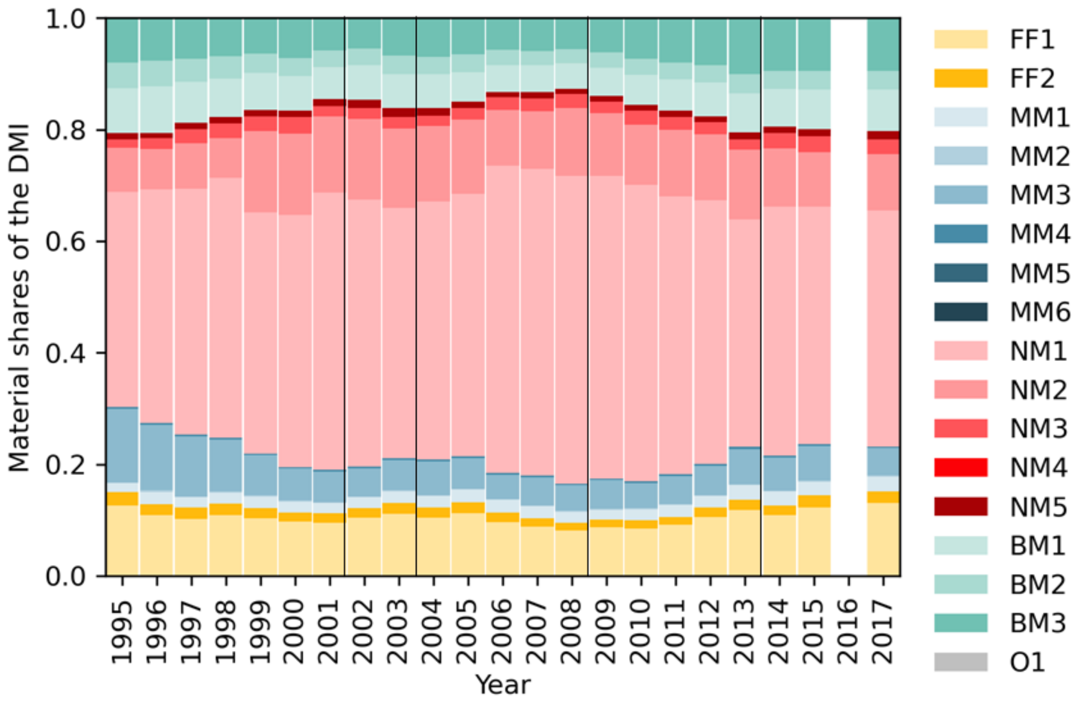


Figure 5.3 - Shares of the different materials in the Portuguese economy. The shares of the different materials for key years can be found in Table 9.10 in supporting information.

5.4 Structural changes in the economy

In the previous two steps, it has been observed that the economy went through various stages and that the material consumption varied between them. NM1 varied significantly even though the 2017 value is similar to the 1995 value. The input of MM3 decreased due to the reduction in domestic extraction of MM3. Overall, the material shares in 2017 were very similar to 1995, but the GDP/cap was significantly higher. Suggesting that the changes from 1995 to 2017 may have changed the economy. The analysis of the economic structure in terms of VA/cap and materials per sector may reveal the sectors that were instrumental in these changes.

5.4.1 Changes in the value added of each sector

The value added per sector was observed in the MIOTs as a function of the changes in the total value added in each period. Figure 5.4 shows a plot illustrating the contribution of each sector to the overall change in VA/cap per period. The values in the plot are given by the ratio between the difference in VA/cap for each sector over the absolute difference in the total VA/cap in each period, as described by equation (6), where ΔVA_s, is the difference in VA/cap for sector s, between year i and year j, and $|\Delta VA|$ is the absolute of the difference in VA/cap between year i and year j. The value addedof each sector for the key years can be found in Table 5.1.

$$\frac{\Delta VA_s}{|\Delta VA|} = \frac{VA_{s,j} - VA_{s,i}}{|VA_j - VA_i|} \qquad (6)$$

The sector that contributed the most to the growth in P1 was the SERVICES sector (84%), followed by CONSTRUC (14%). The contribution from SERVICES and CONSTRUC can be explained by a group of factors (Alexandre et al., 2016). During this period, the government supported a program to provide funds to economically challenged families, young professionals, and emigrants looking to buy a home. This program stimulated the CONSTRUC sector and banking and real estate services. There was also an increase in average income and employment, enabling mass consumption of products and services. Finally, the government had a more active role in public services and invested in developing health, education, and other social services.

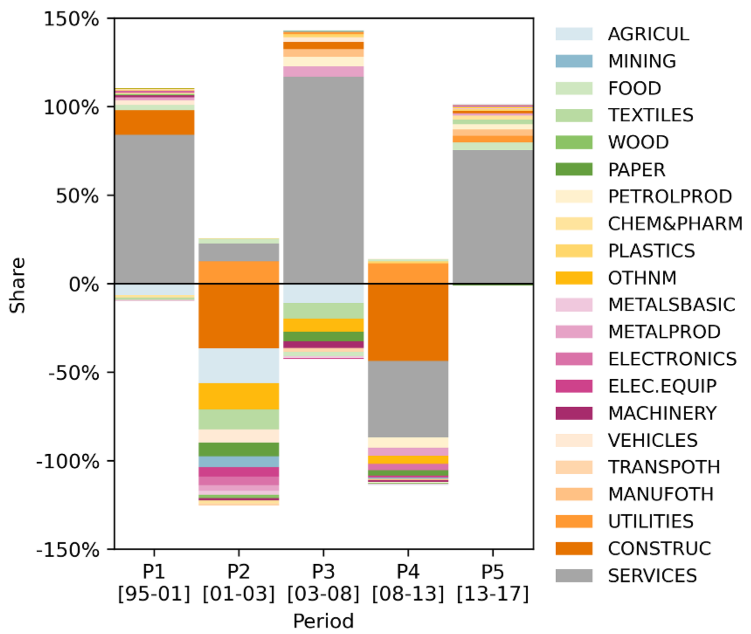


Figure 5.4 - Sector contribution to the change in VA/cap during each period, calculated as the difference in VA/cap for each sector over the absolute total VA/cap change. The values represented in the plot can be found in Table 9.11 in supporting information.

By 2000 the government put an end to the mentioned housing program, possibly causing the significant drop in the contribution of the CONSTRUC sector during P2 to the total VA/cap, as shown in Figure 5.4. After this, the government started investing in public infrastructures such as schools and stadiums, contributing to the recovery of the CONSTRUC sector between 2003 and 2008, as shown in the values of Table 5.1 (Alexandre et al., 2016). However, the GDP/cap remained relatively stagnant during P2 and P3.

In 2008 the economic crisis took over developed countries, and the Portuguese debt (both public and private) matched its GDP (Crisis and Reis, 2013). During this recession, the SERVICES (-43%) and CONSTRUC (-44%) sectors were the main contributors to the total VA/cap decrease. UTILITIES was one of the few sectors whose value added increased during this period.

After 2013, the economy started to recover. Between 2013 and 2017, almost all sectors contributed positively to the increase in VA/cap, with the most significant contribution being from the SERVICES sector (75%).

Table 5.1 shows that, despite increasing relative to 2013, the actual VA/cap of the CONSTRUC sector in 2017 was smaller than that of 1995, something that was also observable for other extractive and industrial sectors such as the AGRICUL, the MINING, PAPER or the OTH_{NM}, among others. Table 5.1 also shows how UTILITIES is one of the few sectors that never showed a decrease in VA/cap (constant prices) during these periods. The table also shows that the share of the VA/cap of SERVICES out of the total increased from 66% in 1995 to 76% in 2017.

Table 5.1 – Portuguese value added per sector in [k€/cap], constant 2015 euros.

	1995	2001	2003	2008	2013	2017
AGRICUL	0.71	0.54	0.47	0.35	0.35	0.35
MINING	0.08	0.08	0.06	0.07	0.06	0.06
FOOD	0.28	0.35	0.36	0.34	0.34	0.41
TEXTILES	0.52	0.49	0.45	0.35	0.35	0.39
WOOD	0.08	0.10	0.09	0.09	0.09	0.08
PAPER	0.23	0.23	0.21	0.15	0.12	0.10
PETROLPROD	0.00	0.01	0.01	0.07	0.02	0.07
CHEM&PHARM	0.16	0.12	0.12	0.12	0.12	0.15
PLASTICS	0.07	0.08	0.08	0.09	0.10	0.12
OTHNM	0.29	0.29	0.24	0.16	0.12	0.13
METALSBASIC	0.08	0.06	0.05	0.04	0.03	0.04
METALPROD	0.13	0.17	0.16	0.22	0.18	0.21
ELECTRONICS	0.07	0.08	0.07	0.07	0.04	0.04
ELEC.EQUIP	0.07	0.09	0.07	0.07	0.06	0.06
MACHINERY	0.09	0.13	0.12	0.08	0.07	0.08
VEHICLES	0.05	0.12	0.09	0.12	0.11	0.12
TRANSPOTH	0.02	0.04	0.04	0.01	0.01	0.02
MANUFOTH	0.11	0.11	0.11	0.16	0.16	0.21
UTILITIES	0.35	0.35	0.39	0.40	0.50	0.56
CONSTRUC	0.76	1.12	1.00	1.05	0.66	0.68
SERVICES	8.05	10.21	10.24	11.57	11.19	12.33

Figure 5.5 illustrates the shares of the VA/cap of each sector out of the total VA/cap of the economy. The chart clearly shows a constant increase of SERVICES in the economy, except for P5, during which the share remained approximately constant. The share of CONSTRUC presents some variation. It increased in P1, remained constant in P3, and decreased in the other periods, showing an overall decrease during the analysis period. The decrease in the share from AGRICUL is also evident. These results are consistent with what has been observed previously: as economies develop, the contribution of the agriculture sector decreases.

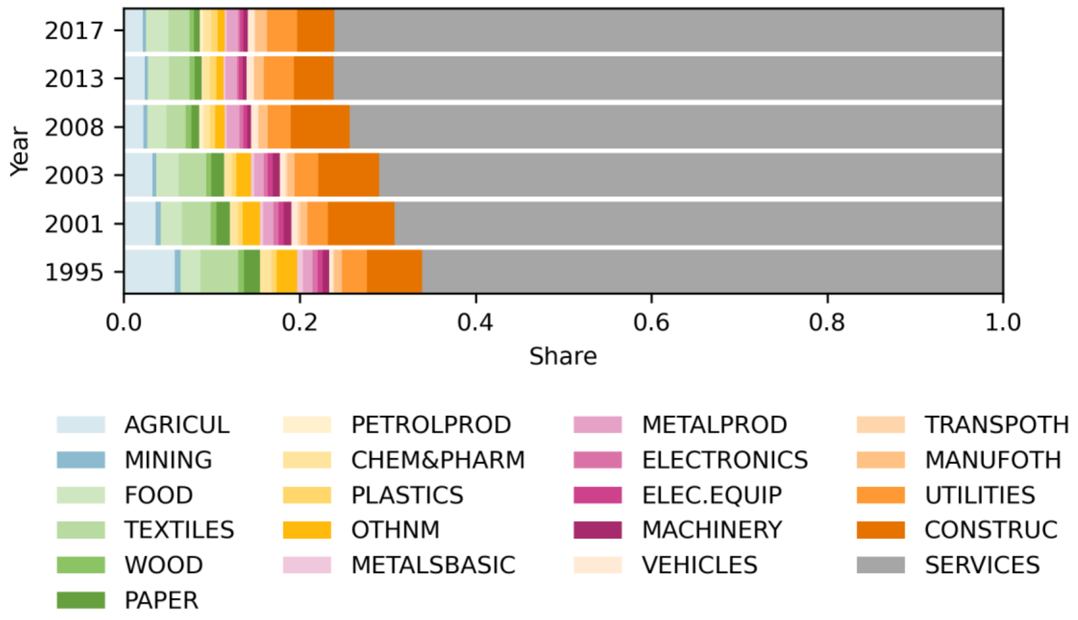


Figure 5.5 – Value added shares by sector for key years for Portugal in key years. The values represented in the figure can be found in Table 9.12 in supporting information.

Previous work has attributed changes in the development of the Portuguese economy to various factors (Alexandre et al., 2016). One of these factors was the support sectors associated with non-tradable goods (construction, retail, and public services) received from the government and financial sectors. Another factor was the inefficiencies created by the monopolies established before the reinstatement of the democratic regime.

5.4.2 Changes in material use

The relation between economic growth and material use was not the same in the various periods. To better understand how the use of resources changed from period to period, the material flows entering and leaving the economy from each sector are explored. However, this analysis cannot be done the same way as the monetary flows. Comparing the material input per sector with the materials in the economy would double-count the same materials in different sectors. For example, the same rock being accounted for in *mining* for when it was extracted, in OTH_{NM} when it was transformed into a product, in CONSTRUC when it was included as a product part of a building, and in SERVICES when the building was sold as fixed capital to a service company.

For this reason, this subsection focuses on identifying how each sector impacted the demand for materials on the input and output sides. The input side accounts for the total input of materials in the economy by sector as imports and DE. For example, the rock would only be accounted for in MINING, the sector that extracted it, and not in the following sectors in its supply chain. The output side accounts for the final output flows by sector: the sales to final consumption, exports, emissions and waste, inventories, and fixed capital formation. For example, the rock would be accounted for in the SERVICES sector if the building had been sold to SERVICES or in the CONSTRUCTION sector if the building had not been completed and sold).

The contribution to change in materials entering the economy on the input side is presented in Figure 5.6 a), given by the ratio between the difference in the inputs, IN, in the economy through each sector s, and the absolute value of the difference in DMI between the year i and j, according to equation (7). The inputs in the economy through each sector are given by the sum of imports and domestic extraction of each sector.

$$\frac{\Delta IN_s}{|\Delta DMI|} = \frac{IN_{s,j} - IN_{s,i}}{|DMI_j - DMI_i|} \tag{7}$$

The same analysis on the output side is presented in Figure 5.6 b) by illustrating the ratio between the difference in output, OUT, of the economy through each sector s, and the absolute value of the difference in DMI between the year i and j, according to equation (8). The total DMI of the economy will match the total output of the economy, based on the mass balance principle. The output of each sector is given by the mass value of its sales to final consumption, exports, inventories, GFCF, waste, and emissions.

$$\frac{\Delta OUT_s}{|\Delta DMI|} = \frac{OUT_{s,j} - OUT_{s,i}}{|DMI_j - DMI_i|} \tag{8}$$

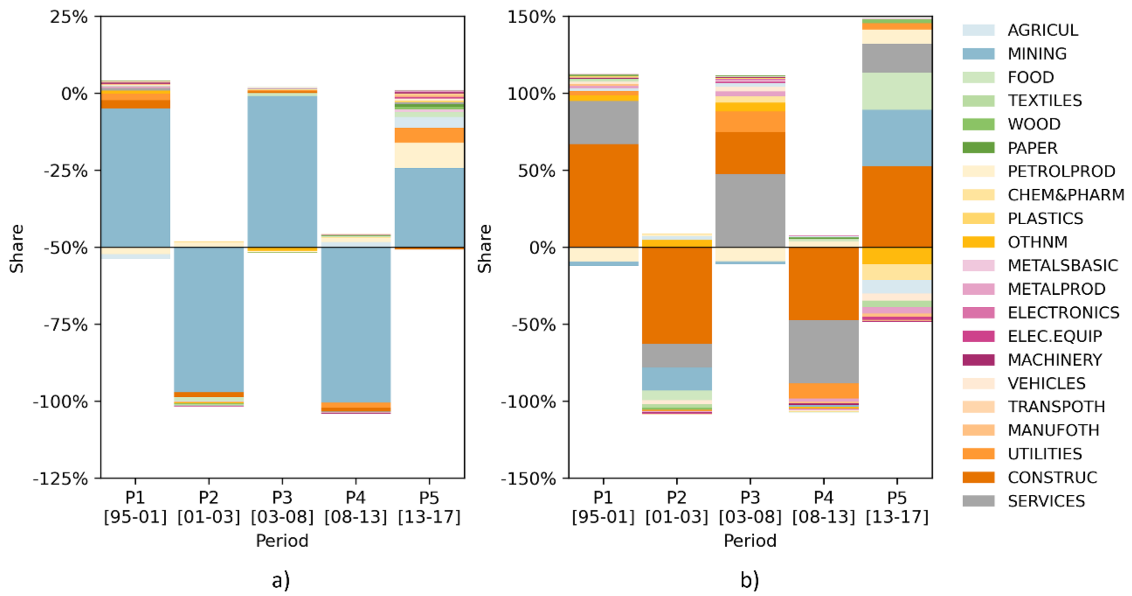


Figure 5.6 - a) Ratio between the change in imports/cap and extraction/cap of each sector and the absolute difference in DMI/cap in each period. b) Ratio between the change in final consumption, waste, and emissions per capita for each sector and the absolute difference in DMI/cap in each period. The values plotted in the figures can be found in Table 9.13 and Table 9.14 in supporting information.

Figure 5.6 a) shows that the sector through which the materials enter the economy that contributed the most to the changes in DMI was MINING. The significant role of MINING is observed in all five periods, with a significant decrease in share in P5 compared to the others. In P5, the $\text{PETROL}_{\text{PROD}}$, the UTILITIES, and the AGRICUL sectors have a more significant role than in previous periods.

On the output side (Figure 5.6 b), one can observe how the final demand from each sector impacted the DMI/cap between 1995 and 2017. The figure shows that demand for CONSTRUC always had a meaningful impact on the changes in the use of materials, as did the demand for SERVICES[2]. On the output side, it is also visible that, as the DMI/cap increased in P1, P3, and P5, the sector that contributed the most to that increase was not always the same. In P1, it was almost entirely led by the demand for outputs from CONSTRUC and SERVICES, which is not surprising given that Portugal was

[2] Unlike other sectors, the final material output from services corresponds, not to products, but to GFCF, INVNT, EMISSIONS, and WASTE, which are the physical capital that supports the operation of the sector.

still developing its infrastructures (Niza & Ferrão, 2006; Ribeiro & Rodrigues, 1997). In P3, SERVICES took over CONSTRUC, and UTILITIES account for a larger share of the increase in DMI/cap. In the last period, where there was a less significant increase in the materials entering the economy relative to the GDP, the role of SERVICES is much diminished, being surpassed by CONSTRUC, MINING, and FOOD. This decrease in SERVICES suggests a decrease in the inputs to SERVICES infrastructure.

Something familiar to both plots in Figure 5.6 is that the significant difference in the sectors contributing to the change in DMI, either on the input or output side, is in P5, when the economy started to grow while keeping material productivity somewhat constant and at a level comparable to that of 1995. The value added from SERVICES contributed the most to the increase in GDP/cap, but its contribution to the increase in material use decreased.

The total material input per sector, including DE, imports, and the inputs from other sectors, is presented in Table 5.2. Here it is possible to observe that despite the decrease in value added for AGRICUL, the total material input did not. It increased between 1995 and 2017. The same happened with MINING, PAPER, $OTH_{NM,}$ and CONSTRUC. Additionally, the use of materials by CONSTRUC and SERVICES increased most significantly in P1 and P3, reaching maximum values in 2008 and having values for 2017 that are lower than those of 2001.

Table 5.2 - Total material input per sector in [t/cap], including domestic extraction imports and acquisitions from other sectors.

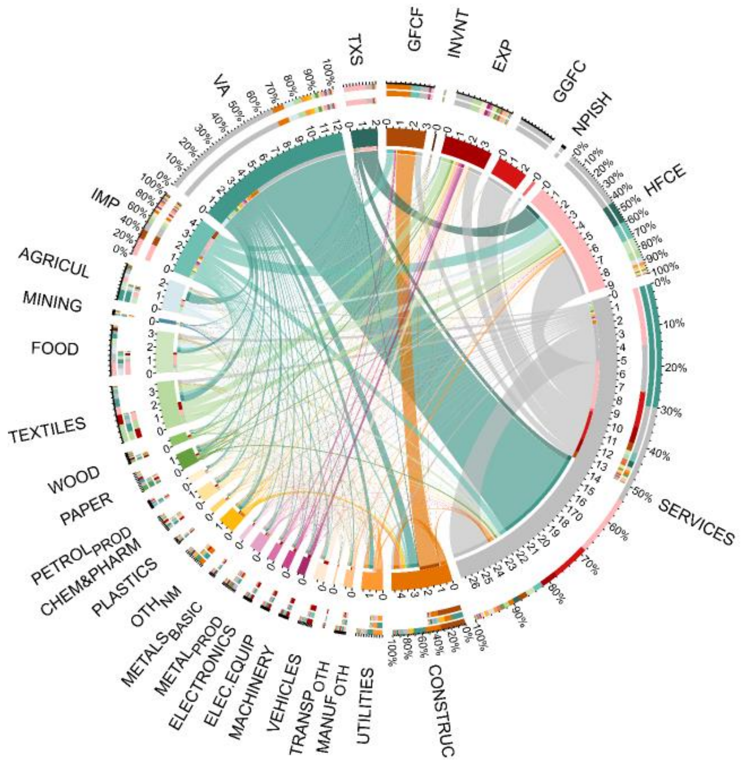
	1995	2001	2003	2008	2013	2017
AGRICUL	3.13	2.96	2.87	2.93	3.24	3.49
MINING	9.67	15.01	12.42	19.04	10.55	14.02
FOOD	1.99	1.96	1.71	1.75	1.87	2.61
TEXTILES	0.33	0.36	0.23	0.28	0.30	0.16
WOOD	0.29	0.32	0.28	0.32	0.28	0.33
PAPER	0.22	0.23	0.21	0.35	0.53	0.48
PETROLPROD	2.56	1.94	2.00	1.37	1.60	1.97
CHEM&PHARM	0.43	0.50	0.48	1.16	1.25	0.57
PLASTICS	0.08	0.11	0.11	0.25	0.26	0.17
OTHNM	5.12	7.52	6.12	8.23	4.54	6.21
METALSBASIC	0.56	0.21	0.15	1.25	1.19	0.27
METALPROD	0.41	0.46	0.38	1.68	1.04	0.53
ELECTRONICS	0.09	0.10	0.11	0.20	0.06	0.04
ELEC.EQUIP	0.15	0.14	0.10	0.21	0.26	0.20
MACHINERY	0.18	0.23	0.20	0.37	0.24	0.14
VEHICLES	0.30	0.39	0.31	0.48	0.45	0.32
TRANSPOTH	0.04	0.03	0.04	0.03	0.03	0.03
MANUFOTH	0.27	0.40	0.40	0.42	0.32	0.25
UTILITIES	0.56	0.88	0.85	1.73	0.78	1.08
CONSTRUC	8.05	17.02	13.19	20.62	8.69	12.37
SERVICES	2.73	4.38	3.96	6.93	3.65	4.13

5.5 Effects of the structural changes on the socioeconomic metabolism

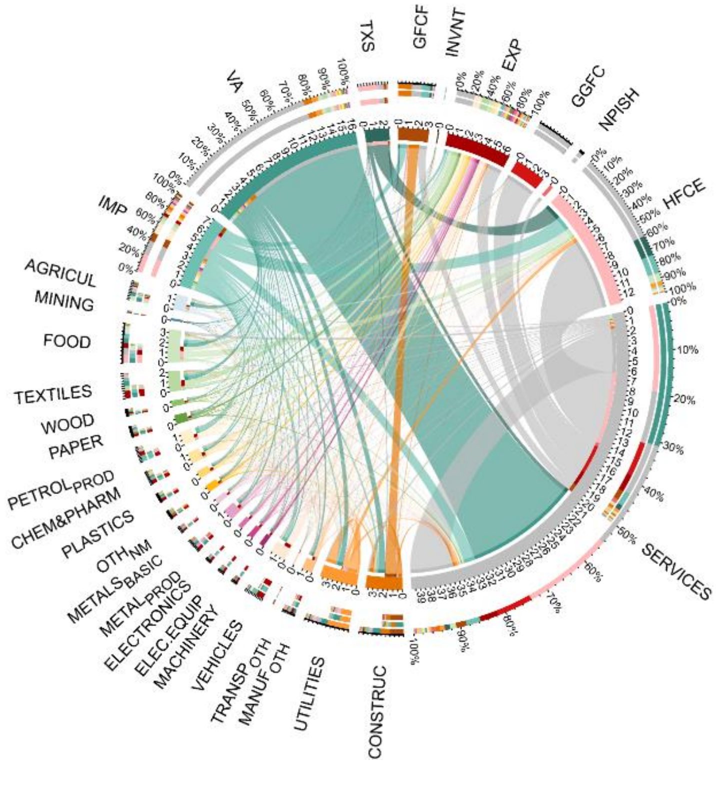
By 2017 the economy had grown 38% relative to 1995, maintaining similar productivity. During this time, the economy went through various periods of growth and degrowth at different productivity levels. The most significant changes in the types of materials were observed for NM1, which is typically used for construction. The sectors that contributed the most to this were the CONSTRUC and SERVICES sectors. Additionally, it was observed that the contribution of the SERVICES sector to the total value added increased by 10%. After a peak in material use in 2008, the material use of the CONSTRUC and SERVICES sectors in 2017 decreased to a level similar to the late 90s.

This subsection provides a more refined analysis of the complex intertwining between economic sectors explaining the roles of these sectors in the supply chains and the changes in the SEM from 1995 to 2017. Figure 5.7 a) and b) illustrate the monetary flows from the MIOTs, and Figure 5.8 a) and b) the mass flows in the PIOTs.

Figure 5.7 shows that SERVICES was the foremost contributor to the VA/cap in 1995 and 2017. The share of VA/cap of SERVICES increased from 66% to 76%, supporting the theory that the economy went through structural changes in this period that enabled it to reach higher values of GDP/cap with higher productivity. The flows show that most of the SERVICES sales were to HFCE. This value almost doubled from 1995 to 2017, with the share of sales to HFCE going from 29% to 39%. The remaining output mainly went to the sector itself, followed by GGFC and exports. Other visible differences include the 81% increase in the value of imports by economic sectors (not accounting for final consumption) and the decreases in total sales for AGRICUL (-33%), TEXTILES (-43%), and CONSTRUC (-21%).



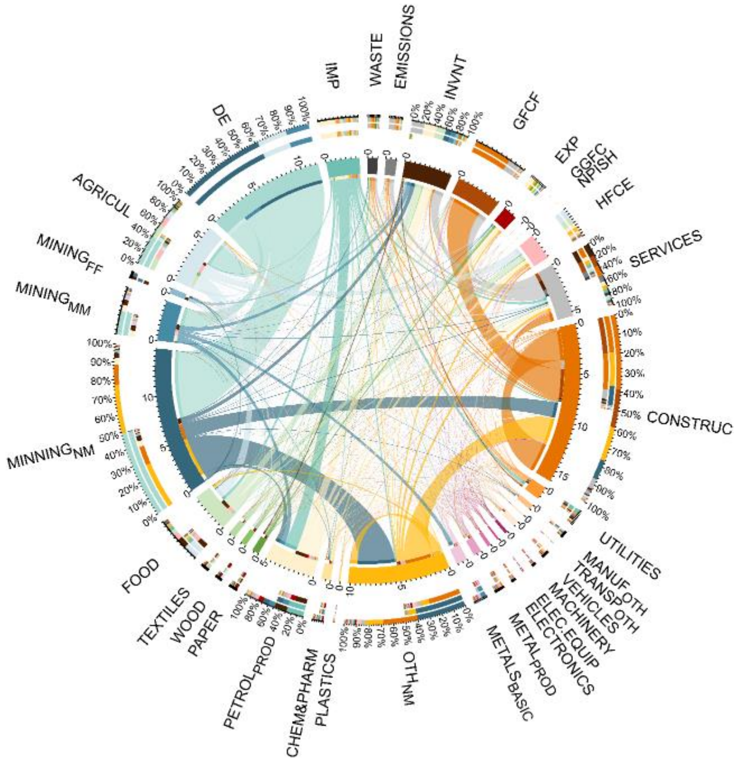
a)



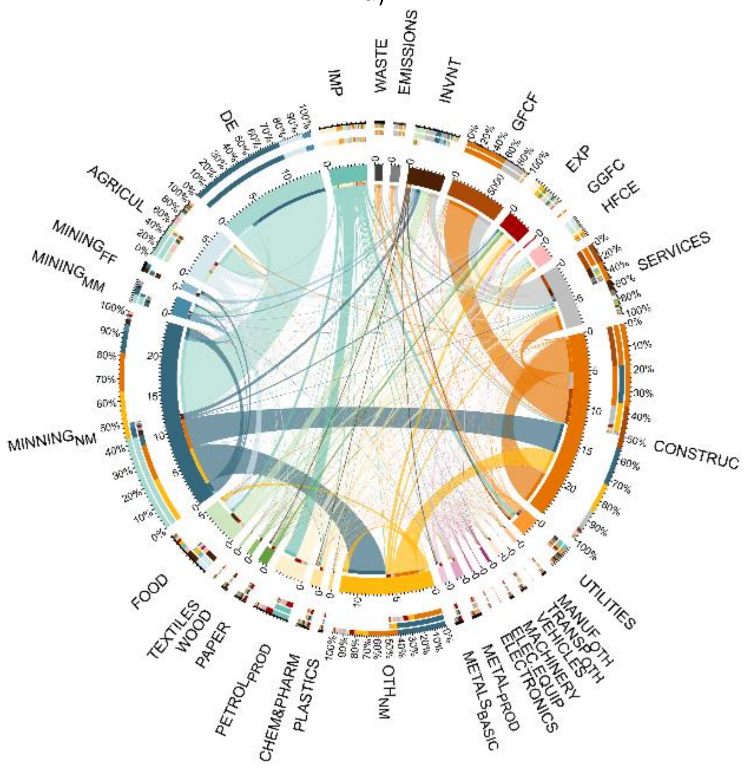
b)

Figure 5.7 - Chord diagram of the flows in the MIOTS [k€/cap] for 1995 (a) and 2017 (b).

The link between $MINING_{NM}$, CONSTRUC, and SERVICES is even more apparent from the physical flows. Most of the physical flows into SERVICES, in either 1995 or 2017, originated in CONSTRUC, accounting for 32% and 52% of the total mass acquired by SERVICES, respectively. In turn, the main inputs into CONSTRUC are from the sector itself, from $MINING_{NM,}$ and from OTH_{NM} (whose primary input is from the mentioned mining subsector). Thus, the relation between the primary material inputs in the economy from the MINING sector and the CONSTRUC and SERVICES sectors is established.



a)



b)

Figure 5.8 - Chord diagram of the flows in the PIOTS [t/cap] for 1995 (a) and 2017 (b). The PIOTs with the values represented in the figures can be found in Table 9.15 and Table 9.16 in the supporting information.

In summary, the major contributor to the value added of the Portuguese economy is SERVICES, whose activities are supported by the addition of fixed capital from CONSTRUC and whose materials enter the economy mostly from MINING, originating in DE. To better understand the evolution of these critical flows, they were plotted in Figure 5.9. It is possible to observe increases in the physical and monetary flows associated with the sales of CONSTRUC fixed capital (e.g., buildings and other infrastructure) to SERVICES in three of the periods, two of which are followed by significant decreases. Due to the low productivity of the CONSTRUC outputs, it is not surprising that the changes are more significant in the physical flows when compared with the corresponding monetary flows. The SEM flows in Figure 5.9 evidence that the inputs in SERVICES originating in CONSTRUC fueled the increased value added created by SERVICES. What is also observable from Figure 5.9 is that after each increase and decrease in the sales of CONSTRUC to SERVICES, the value added created by SERVICES suffered slight fluctuations but a continuously growing trend. In terms of the demand for SERVICES, one can observe that the demand from HFCE has been increasing, while GGFC has shown different trends.

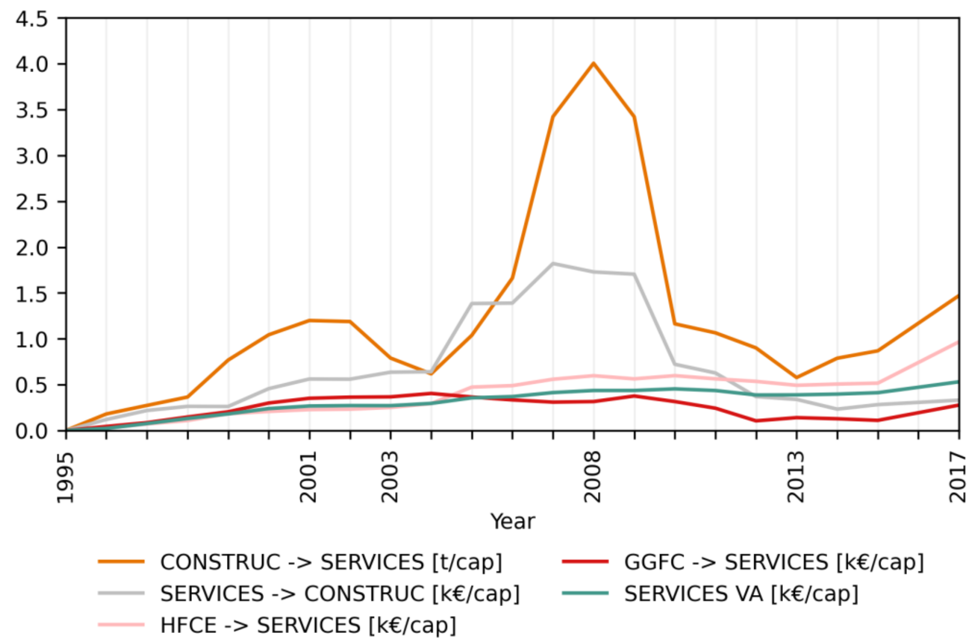


Figure 5.9 - Evolution of the most significant monetary and material flows of the Portuguese SEM between 1995 and 2017, relative to 1995. The values can be found in supporting information in Table 9.17.

5.6 Summary of the analysis of the Portuguese SEM

This chapter analyzed the structural changes associated with the different periods of economic growth of the Portuguese economy and their impacts on the SEM. The data in the PIOTs, created using the novel method described in chapter 3, together with MIOTs, was leveraged to study the structural changes the Portuguese SEM went through between 1995 and 2017. The analysis focused on identifying the different periods, followed by observing the different materials in the economy and the contribution of each sector to those changes. Finally, the SEMs of the initial and the final year were compared, and the links between the sectors were established.

The Portuguese economy presented five different periods between 1995 and 2017 – material-intensive rapid economic growth, economic stagnation, material-intensive slow economic growth, economic recession linked to improved productivity, and economic growth with relative decoupling. After various periods of decreasing and increasing resource productivity, the Portuguese economy has been growing at somewhat constant productivity since 2013.

During the analysis period, the most consumed material in the Portuguese economy was stone (including sand). This material also showed the most significant variations during the various periods.

The economic output from SERVICES contributed the most to the increase in VA/cap from 1997 to 2017. CONSTRUC was the sector most connected to the decreases in GDP/cap and the changes in material use when observing the output side (except for P3 when it was SERVICES, and whose materials come primarily from CONSTRUCT). The changes in CONSTRUC are consistent with the variations in the consumption of stone (including sand), as it is a material typically used for construction.

Observing the representation of the exchanged monetary and physical flows made it possible to establish the connection between final demand, SERVICES, CONSTRUC, and MINING. From the various aspects observed, it was found that it was only after the necessary infrastructure for services and households was built that the final demand for resources reverted to distribution like 1995, but with an increased share of value added from *services*, which enabled the economy to continue to grow at somewhat constant resource productivity.

These results support the conclusions of other authors and provide further detail on the dynamic interactions between the economic sectors (Acosta-Fernández & Bringezu, 2007; Steger & Bleischwitz, 2011; Steinberger et al., 2013). The increase in the share of SERVICES in the economy meant an improvement in the productivity of the economy after the most considerable infrastructure for SERVICES was built. The CONSTRUC sector has a negative impact on the economy in the short term but contributes to later improved productivity.

The results from this chapter point to the importance of sustainable planning and construction. The results are particularly relevant in developing economies, which tend to have poor sustainable construction practices (Durdyev et al., 2018; Isa et al., 2013), and that is in the process of creating infrastructure and going through a period during which the right policies can have the most significant impacts. In developing countries, the role of the construction materials flows, while less impactful, still represents a significant part of the SEM as cities expand and older infrastructures are replaced (Stephan & Athanassiadis, 2018).

6 The different socioeconomic metabolisms in Europe – comparative analysis of 4 European countries

Previous research has found that various factors can impact the SEM of a country and its ability to decouple. As described in section 2.2, these factors include GDP/cap, income per capita per year, economic structure, population and population density, climate, trade, technological development, natural resources, and historically significant events.

While European countries share a somewhat socioeconomic context and have been expected to converge, the plot in Figure 6.1 shows significant differences in the development of these countries. Figure 6.1 plots the evolution of the DMI/cap against the GDP/cap. The DMI values were obtained from Eurostat (2020), the GDP values from OECD.stat (2020a), and converted to 2015 € using the data from OECD.stat (n.d.). The values were calculated by capita using the yearly population values from the United Nations - Department of Economic and Social Affairs - Population Division (2019).

According to the EKC hypothesis, environmental degradation should increase with economic growth during the first stages of development up to a level. After this level is reached, the environmental degradation should start decreasing with economic growth, creating an inverted U-shaped curve if environmental degradation is plotted as a function of economic growth. Canas et al. (2003) used DMI/cap as a proxy for environmental degradation and plotted it as the dependent variable of GDP/cap for multiple countries. The results suggested that the curves would follow the inverted-U shape, with most data concentrated on the first half of the curve between 1960 and 1998. However, in Figure 6.1, there is no single dominant shape, nor are the countries converging for certain levels of resource use.

In Figure 6.1, it is possible to observe that, despite sharing a similar socio-economic context, the economies exhibit curves of various shapes, meaning that there are various trends in the relationship between economic development and the use of resources. It is also possible to see that for the same GDP/cap (perhaps the foremost driver of resource productivity), there are significantly different levels of DMI/cap. For example, the United Kingdom (UK) and Estonia (EST) exhibit different curves.

Some countries have very particular GDP/cap and DMI/cap values compared with the rest. Tax haven countries will have higher GDP/cap, as the GDP/cap of the country will not correspond to the resources used in that country alone because companies move their headquarters there while keeping the majority of activities elsewhere. Cyprus, Ireland, Luxembourg, Malta, and the Netherlands are tax havens (Coppola et al., 2021). The high DMI/cap from Norway results from its domestic extraction and exports of fossil fuels. Hence, while Norway has a high GDP/cap, its DMI/cap is also relatively high, making its productivity in 2015 comparable to the Portuguese resource productivity.

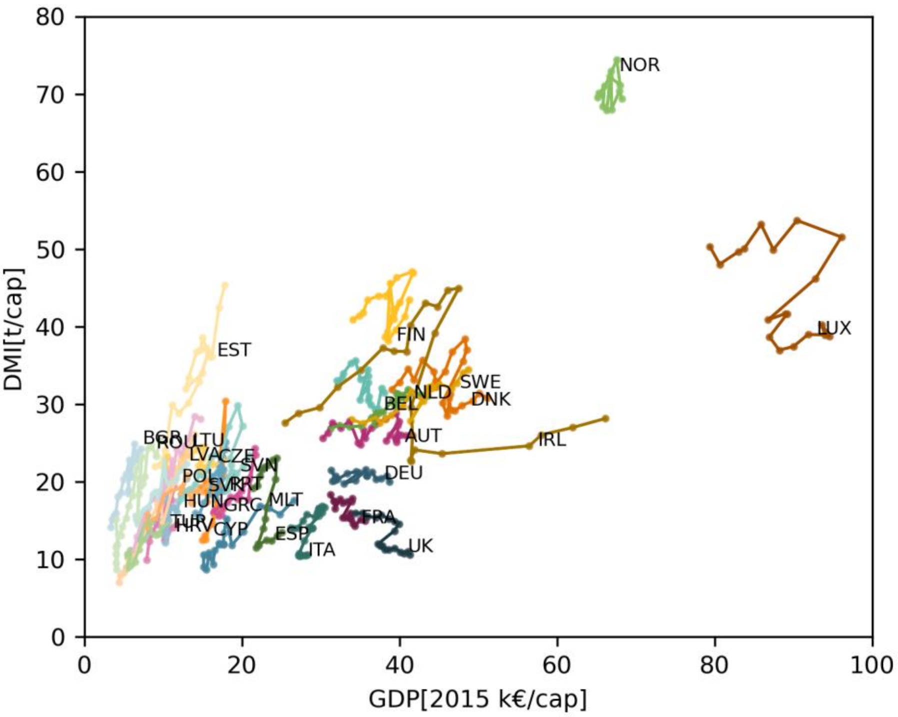


Figure 6.1 -DMI/cap and GDP/cap between 1995 and 2018, some countries may have a few earlier values missing, depending on data availability. The DMI/cap values are from Eurostat (2020), and the GDP/cap values are in constant 2015 euros and were collected from (OECD.stat, 2020a).

Evidence of decoupling has often been observed during periods of economic recession (Shao et al., 2017). Various decoupling behaviors can be observed in the European countries during and after the 2007-2008 economic recession. Figure 6.2 shows the level of decoupling achieved by each European country between the last year before the GDP/cap decreased in 2017. It is possible to observe that while most countries decoupled economic growth from resource use, a few did not, or their GDP/cap in 2017 was still lower than before the recession.

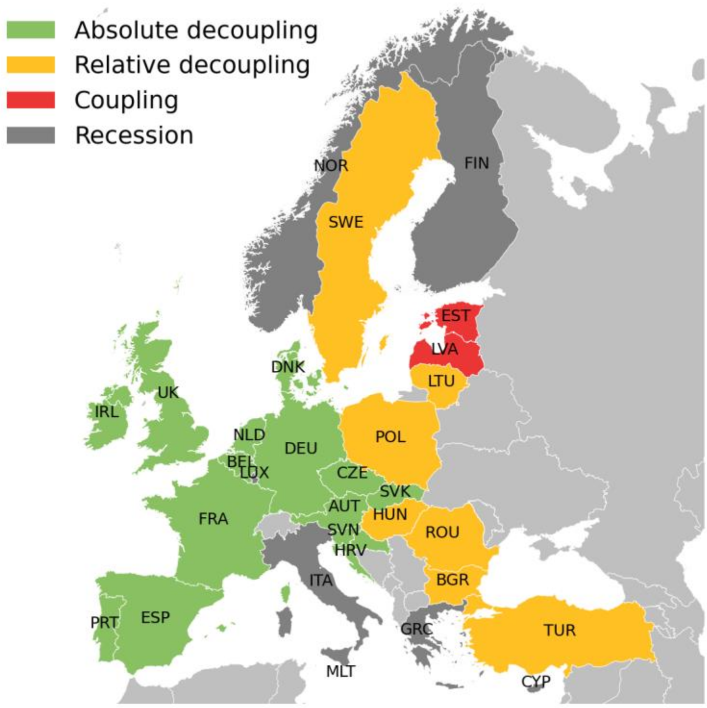


Figure 6.2 - Level of decoupling for European countries. The decoupling index was calculated between the last year before the GDP/Cap of each country started to decrease and 2017 (the latest year for which all countries had available GDP/cap data. The data sources are from Eurostat (2020) and (OECD.stat, 2020a).

This chapter aims to identify critical factors that contribute to European countries having different levels of resource productivity and developing differently. This is accomplished by exploring the SEM of four European countries with two DMI/cap and GDP/cap levels. The countries selected were Croatia, Estonia, Finland, and the United Kingdom (UK). Croatia and Estonia have similar low GDP/cap values, but Croatia has a lower DMI/cap than Estonia. Finland and the UK have higher GDP/cap values and, like the other two countries, different DMI/cap levels.

Additionally, these countries show different decoupling trends. The UK and Croatia decoupled economic development from resource use after the economic recession. On the other hand, the economic development of Estonia is still coupled with resource use, and Finland has not yet recovered from the economic recession.

6.1 Economic development and use of resources

The following subsections will describe the trends and changes in the DMI/cap, GDP/cap, resource productivity, and population density.

6.1.1 Resource productivity, DMI/cap, and GDP/cap

Figure 6.3 presents four plots describing the evolution of resource productivity, GDP/cap, and DMI/cap for the four countries. The four countries exhibit two levels of resource use and two levels of economic development, as seen in Figure 6.3 a). There are three key years identified in the figures. Year 1 is the first year before the GDP/cap started to decrease, year 2 is the last year before the GDP/cap increased continuously, and year 3 is 2015, the latest year for which the PIOTs were calculated. Figure 6.3 a) clearly shows how the four countries are distributed between 2 levels of GDP/cap and DMI/cap.

It is clear that all four countries have been *taking* different development pathways and that the economic recession did not impact the development of these countries in the same way. In Estonia, the use of natural resources increased with economic development and continued increasing after the economic crisis. The general trend was not significantly impacted by the economic recession, except for the decrease in GDP/cap and DMI/cap between 2007 and 2009, as shown in Figure 6.3 c) and d).

In Finland, like in Estonia, resource use increased with increasing GDP/cap before the economic recession. The DMI/cap decreased in some years after the economic recession, but it has been increasing since 2015, while the GDP/cap has not recovered to the values before the economic recession.

After the recession, the correlation between DMI/cap and GDP/cap in Croatia changed. Before, DMI/cap showed significant increases, but that changed after the recession, as shown in the charts in Figure 6.3. While the DMI/cap has been increasing since 2014, it has been doing so at a much lower rate than before 2008.

The UK is the only country of the four exhibiting a decreasing use of resources even before the economic recession. The economic recession accelerated the decrease in DMI/cap from 2007 to 2009. After that, the UK returned to its previous general trend as the economy recovered.

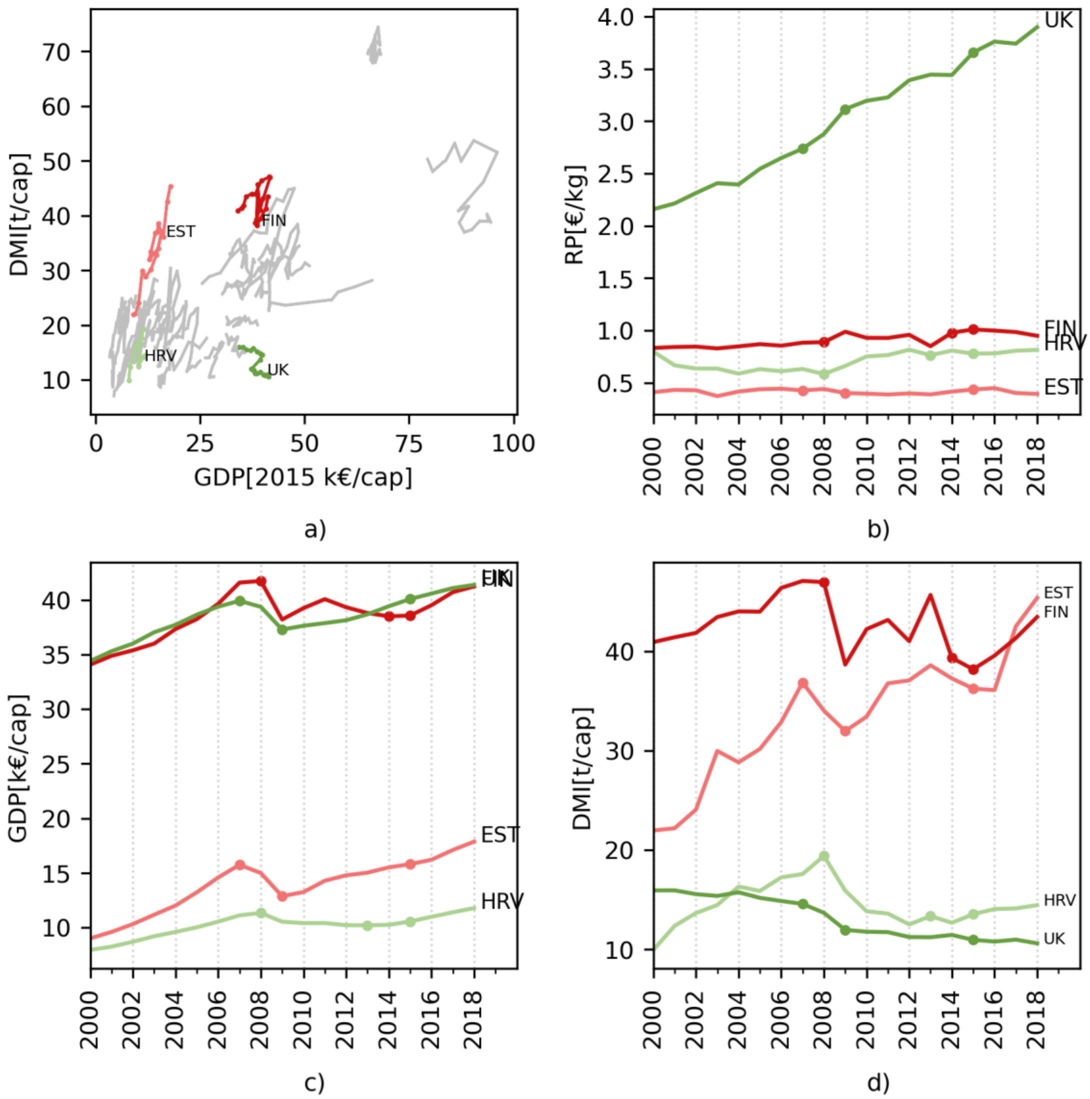


Figure 6.3 - Countries selected for comparative analysis of the SEM. a) DMI/cap versus GDP/cap plot in the European context. b) Resource productivity. c) GDP/cap. d) DMI/cap. The countries are colored according to their GDP/cap and DMI/cap levels. Green is for lower DMI/cap and red for higher. Lighter shades are for lower GDP/cap, and more saturated tones were used for the countries with higher GDP/cap. Circles in the time series identify key years. The data represented in the plots can be found in Table 9.18 in supporting information.

6.1.2 DMI/cap versus GDP/cap

These four European countries are at different levels of resource use and economic development within the European context, but they are also developing differently and not necessarily converging. Figure 6.4 shows the DMI/cap versus GDP/cap plots for each of the four countries in further detail. It is clear that all four countries have recorded different development pathways and that the economic recession did not impact the development of these countries in the same way. In Estonia, the correlation between DMI/cap and GDP/cap after the recession was similar to before. In Finland, the correlation changed after the recession, but there is no clear trend, except for the increase in DMI/cap after 2015. The trend in Croatia changed after the recession, associated with improved resource productivity. In the UK, the trend after the recession was similar to that before the recession, but, unlike Estonia, the UK is decoupling economic growth from resource use.

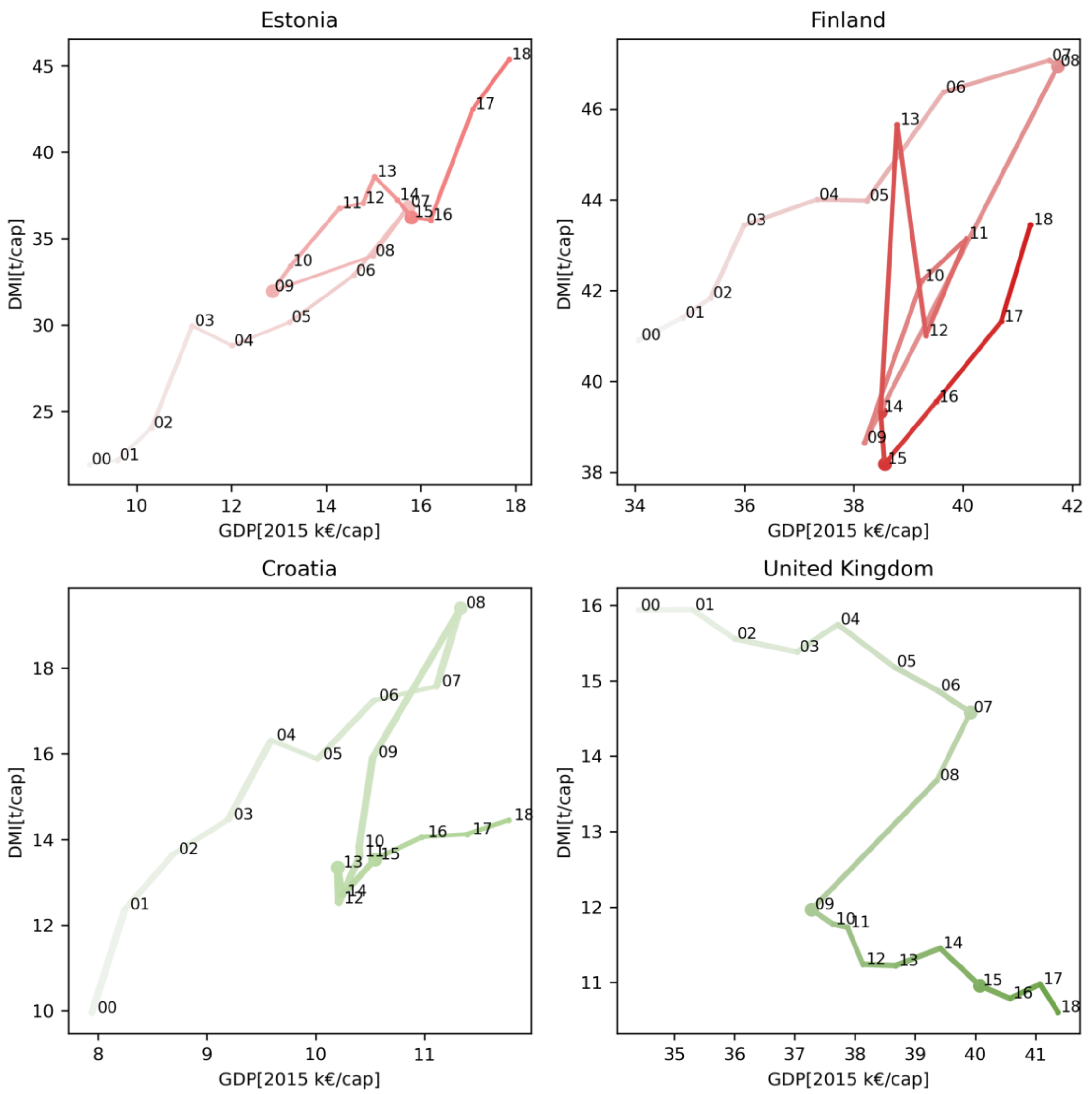


Figure 6.4 – Plots of the DMI/cap versus GDP/cap for each selected four countries. The data represented in the plots can be found in Table 9.18 in supporting information.

6.1.3 Population density

The population density has been pointed out as one of the driving factors of resource use, as discussed in section 2.2. These four countries exhibit significantly different population density values, as seen in Figure 6.5. High population density is associated with higher resource productivity (Gan et al., 2013). On the other hand, low population density can be associated with a higher per capita use of materials required to build infrastructure (Weisz et al., 2006). The population density of the UK in 2015 was the highest of the four countries and 15 times larger than the population density in Finland, the country with the lowest population density of the four.

Nevertheless, population density does not explain the differences between the countries alone. For example, the difference between population density in the UK and Croatia is significant, much more than the difference in DMI/cap. Also, Estonia has a higher population density and DMI/cap than Finland.

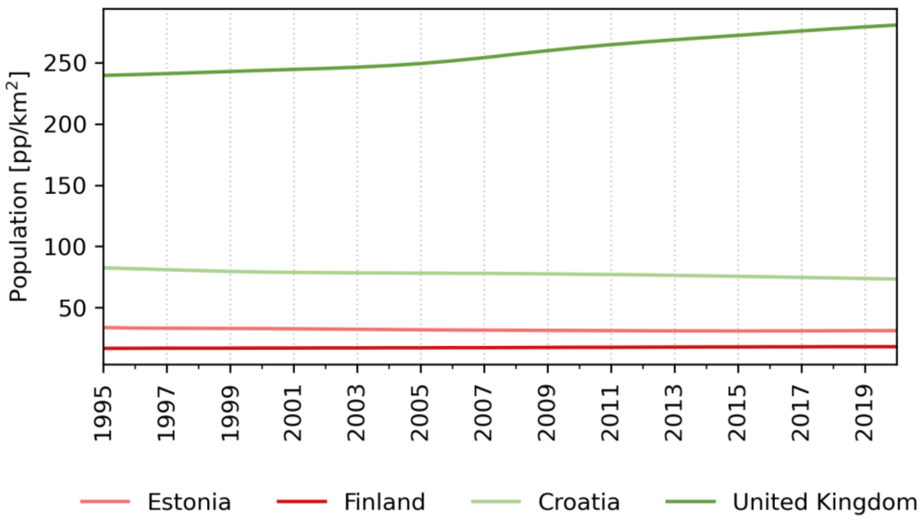


Figure 6.5 - Population density in pp/km^2 for Estonia, Finland, Croatia, and the UK from 1995 to 2020. The data was sourced from the United Nations - Department of Economic and Social Affairs - Population Division (2019).

6.2 Materials in the economy

The materials in the economy may differ in their distribution, absolute value, and origin (whether they were extracted within the country or imported). Moreover, the economic recession may have led to different changes in the materials of the economy. All these aspects are covered in this subsection. The values of the domestic extraction and imports per material for these four countries and key years can be found in Table 9.19 and Table 9.20

6.2.1 Distribution of the materials in the economy

Figure 6.6 illustrates the distribution of the materials in the DMI of each country in the selected key years. These values were calculated, as before, based on the domestic extraction from (Eurostat, 2020) and imports from UN Comtrade (2014), disaggregated in materials using the updated version of ProdChar.

The plots in Figure 6.6 show that both high DMI/cap countries had a more significant amount of wood (BM3) in the economy than the other two countries. The share of BM3 in Estonia varied from 11 to 17% and in Finland from 18 to 21%. Additionally, Estonia had a higher amount of fossil fuels (FF), around 40%. Finland had the only considerable amount of metallic minerals (MM), between 7 to 12%. Finland also had, by far, the highest amount per capita of non-metallic minerals (NM) in the economy (25.73 t/cap in 2008). NM accounted for 50% of the materials in the Finish economy in 2015.

In the countries with lower DMI/cap values, one can observe that Croatia had about double the amount of NM in the economy as the UK, while the UK had almost double the amount of FF when compared to Croatia. Croatia had the lowest absolute value and share of FF in the economy out of the four countries at 13 to 15%. Biomass (BM) per capita is also higher in Croatia than in the UK.

The main impact on the size of the material flows, from key year to key year, is the decreasing amount of NM in the economy of any of the countries. In Croatia, the share of NM, for example, decreased from 61 to 52%. FF also showed decreasing trends in all countries except Estonia. BM1 and BM2 show minor variations from before to after the recession. Both BM and FF increased in Estonia, unlike in the other countries, as did the MM in Finland.

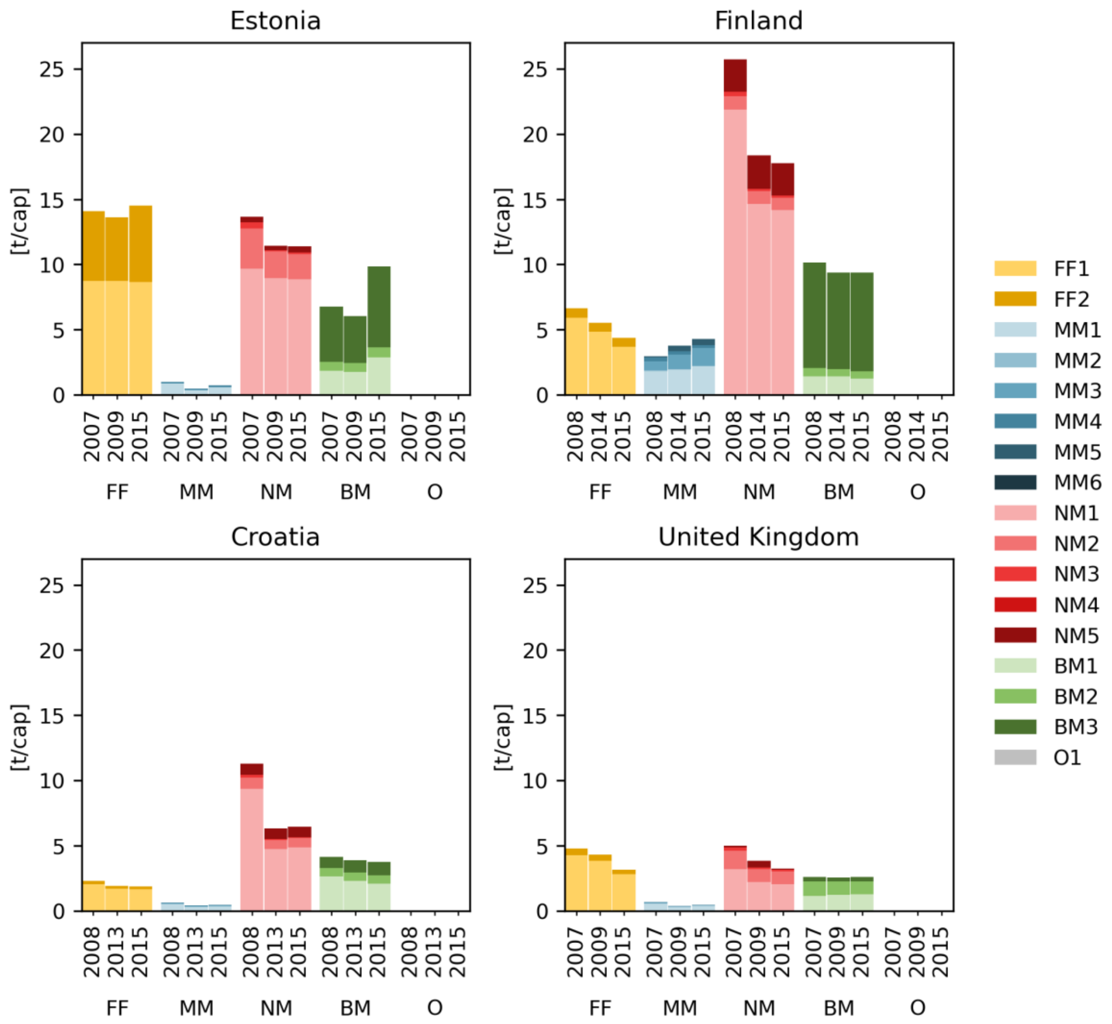


Figure 6.6 – Distribution of the materials of the DMI in each of the countries for the key years of each economy.

6.2.2 Source of the materials in the economy

The origin of the materials also reveals differences between the countries. Figure 6.7 shows the origin of the materials in the economy per material group. Right away, it is evident that the countries with high DMI/cap (Finland and Estonia) had higher domestic extraction than the UK or Croatia.

From Figure 6.7, it is possible to see that the materials that had more significant roles in the high DMI/cap countries and were not as impacted by the economic recession were natural resources of the countries.

Estonia had a larger share of FF in its economy, and the total FF in the economy did not vary significantly in the key years. Figure 6.7 shows that between 74 and 82% of the FF flowing in the Estonian economy originate from within the country. AS for BM3, around 67 to 85% of the materials were nationally extracted.

Most countries import almost 100% of their MM, unlike Finland, which only imports 68 to 35%. As for BM3, the share of domestic extraction was around 71 to 85%.

Most NM and BM originated from within the country of Croatia, while FF and MM were almost completely imported. In the UK, MM is mainly imported, and so are about half of the FF. The remaining FF were extracted within the country, as were most NM and BM materials.

In all countries except Estonia, domestic extraction decreased from before to after the economic recession. As for imports, they decreased in all countries. However, in Estonia and Croatia, imports in Y2 and Y3 were approximately the same.

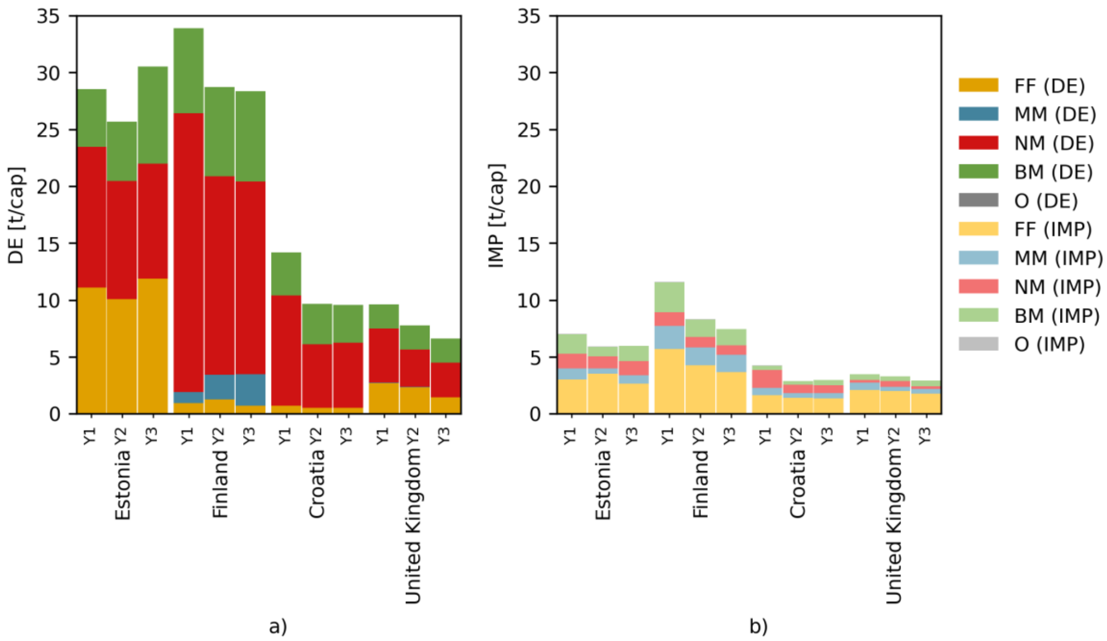


Figure 6.7 – a) Domestic extraction and b) imports by material group for key years and selected countries.

6.3 Economic structure

This sub-section focuses on the economic structure of the economy. The observed variables are the VA/cap, the material outputs, and the resource productivity of each sector.

6.3.1 VA/cap by economic sector

Figure 6.8 plots the contribution of each sector to the total VA/cap in key years. VA/cap is the main contributor to the GDP/cap based on the output approach. The VA/cap values of each sector can be found in Table 9.21.

SERVICES was the main contributor to the total VA/cap, followed by CONSTRUC. SERVICES shares were around 70% for all countries except the UK, where it was closer to 80%, meaning that in the UK, the SERVICES sector had a more significant role in the economy. The contribution of the CONSTRUC sector was around 6% in all countries in 2015. The share of CONSTRUC in the VA/cap decreased in all countries after the recessions, especially in Estonia.

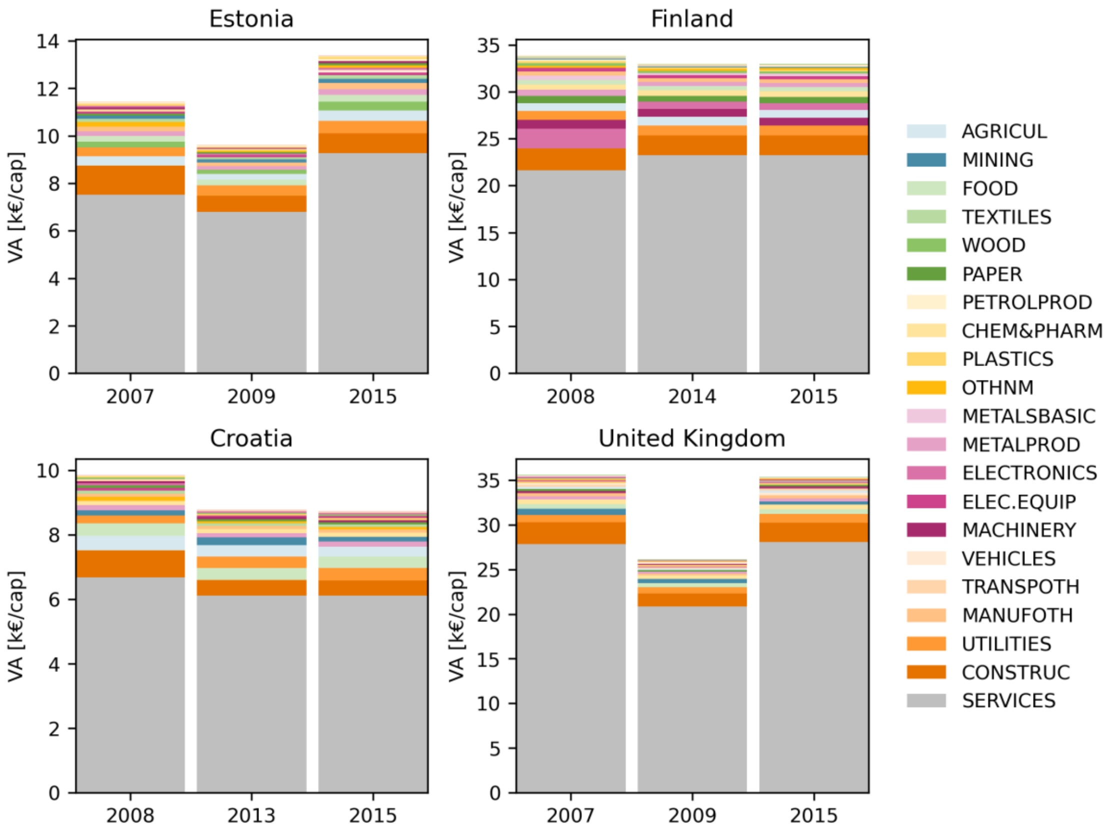


Figure 6.8 – VA/cap by economic sector for selected countries and key years.

The contributions to the VA/cap of all other sectors were relatively small. However, it is possible to observe some differences between the countries in these smaller values. There is the contribution of WOOD in Estonia, PAPER, MACHINERY, and ELECTRONICS in Finland, and AGRICUL and FOOD in Croatia. Additionally, one can also observe that UTILITIES had the third-largest contribution in all countries after the economic recession, while before that was only in the UK.

6.3.2 Material flows and economic sectors

The material flows will enter the economy either by domestic extraction or imports from various sectors. Figure 6.9 distributes the inputs in the economy by their extracting and importing sectors. The values on which the figure was constructed can be found in the supporting information in Table 9.22.

Figure 6.9 shows that in all four countries, most of the material flows entered the economy through MINING and AGRICUL. Given the sectorial resolution of the tables, this is not surprising, as these are the sectors associated with domestic extraction. There are no significant differences between the economic sectors in terms of the input sectors that may explain the differences in development between the countries.

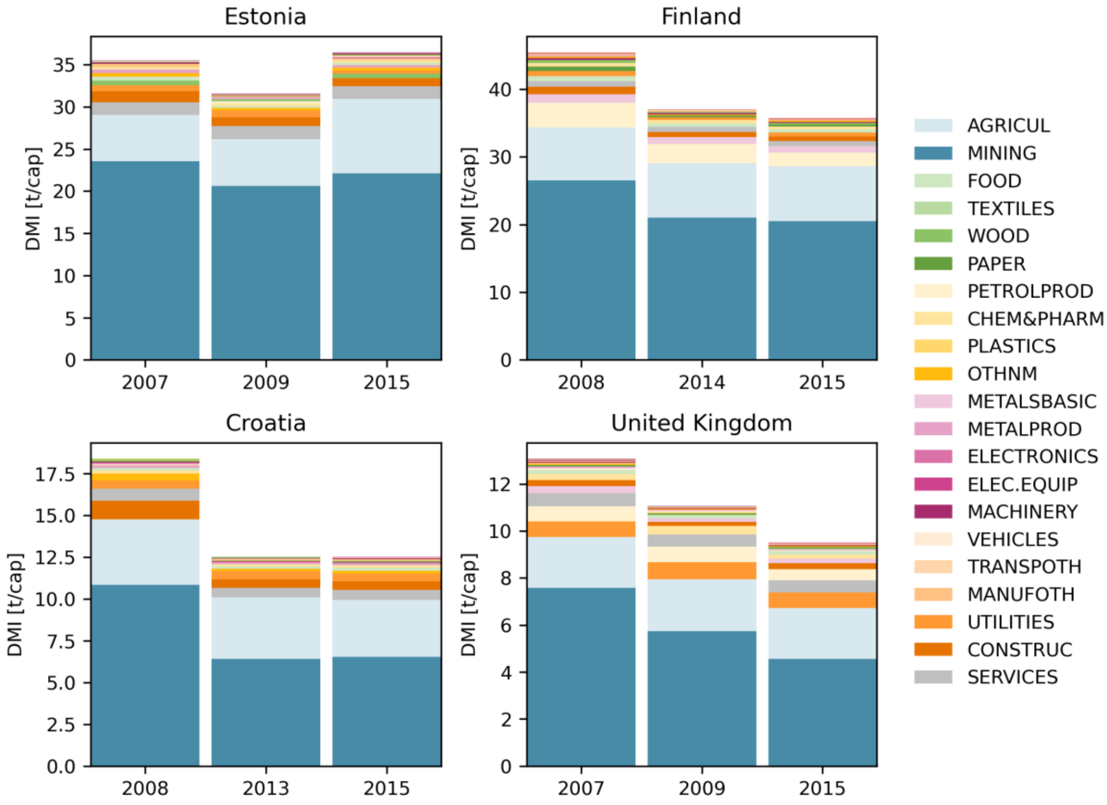


Figure 6.9 – DMI/cap distributed by the economic sectors that either import or extract the materials and products of the DMI, for Estonia, Finland, Croatia, and the UK, for key years.

Figure 6.10 distributes the materials that entered the economy by the sectors from which they left. The values in Figure 6.10 correspond to the outputs of the various sectors to final consumption (HFCE, NPISH, GGFC), GFCF and INVNT, waste, and emissions (the weight of the carbon and hydrogen atoms in the fossil fuels that are burnt). The sum of these values equals the DMI/cap, so there is no double counting. The values used to create the plots can be found in the supporting information in chapter 9 in Table 9.23.

In Figure 6.10, there are significant differences between the countries. Before the recession, in the high DMI/cap countries, most material flows left the economy from

SERVICES. SERVICES have no material products, so these output flows correspond to the fixed capital, inventories, waste, and emissions of the sector. After the economic recession, SERVICES were surpassed by MINING, a sector associated with the domestic extraction of natural resources. It is also possible to observe a more significant contribution of the WOOD and PAPER sectors in these countries, likely linked to the significant amount o BM3 in the economy.

In the low DMI/cap countries, SERVICES account for the largest share in all three years. In Estonia, UTILITIES (whose physical flows are associated with FF) have a more significant role and CONSTRUCT a less significant one compared with other countries. In Croatia, AGRICUL and FOOD have a more significant role, and MINING has a less significant role compared with the other countries.

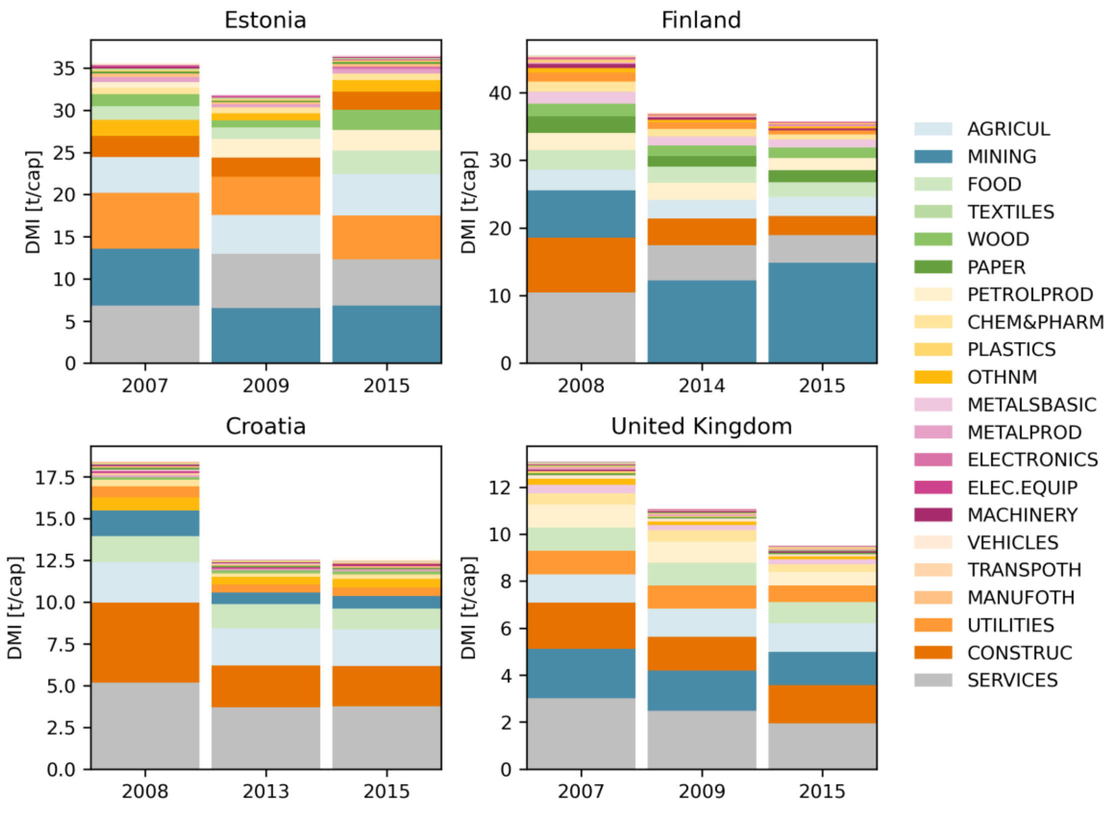


Figure 6.10 – DMI/cap distributed by the economic sectors through which the materials leave the economy for key years for Estonia, Finland, Croatia, and the UK.

6.3.3 Resource productivity by sector

The resource productivity values for the different economic sectors can be found in the supporting information in chapter 9 in Table 9.24 and are illustrated in Figure 6.11. The values were calculated by dividing the VA/cap by the total materials input in each sector.

The UK had the highest resource productivity values, almost ten times those of Estonia and Croatia. Finland had a GDP/cap similar to the UK, but the resource productivity of the economic sectors was approximately only a third. It is also possible to observe that SERVICES had the highest values and that the difference between SERVICES and other sectors was more significant in the UK. For example, TEXTILES and ELECTRONICS had resource productivity values comparable to SERVICES values in Croatia. AGRICUL, MINING, $PETROL_{PROD}$, OTH_{NM}, UTILITIES, and CONSTRUC had the lowest resource productivity values.

The resource productivity changed differently for the different sectors in the various countries. Overall the resource productivity of SERVICES increased in all countries when comparing the value for 2015 with values before the recession.

In Estonia, the critical natural resources identified were wood and fossil fuels. The sectors associated with the products with these materials all have low resource productivity. The resource productivity of WOOD was below 0.5 €/kg, while for SERVICES, the value in 2015 was slightly higher than 1.5 €/kg. The sectors associated with fossil fuels in Estonia, like $PETROL_{PROD}$ or UTILITIES, have even lower resource productivity values than WOOD.

In Finland, the resource productivity values of WOOD and PAPER are all very low. While the resource productivity of $METALS_{BASIC}$ in Finland is also very low, $METAL_{PROD}$, ELECTRONICS, ELEC.EQUIP, and MACHINERY have higher resource productivities. These values suggest that the natural resources in Finland may had a somewhat significant contribution.

The resource productivities in Croatia were all relatively low, despite increases after the economic recession for most sectors.

SERVICES not only had a more significant contribution to the VA/cap in the UK, but the resource productivity of the sector in the UK is also comparatively higher. These two factors contribute to the overall resource productivity of the UK. The resource productivity of almost all sectors in the UK increased after the economic recession.

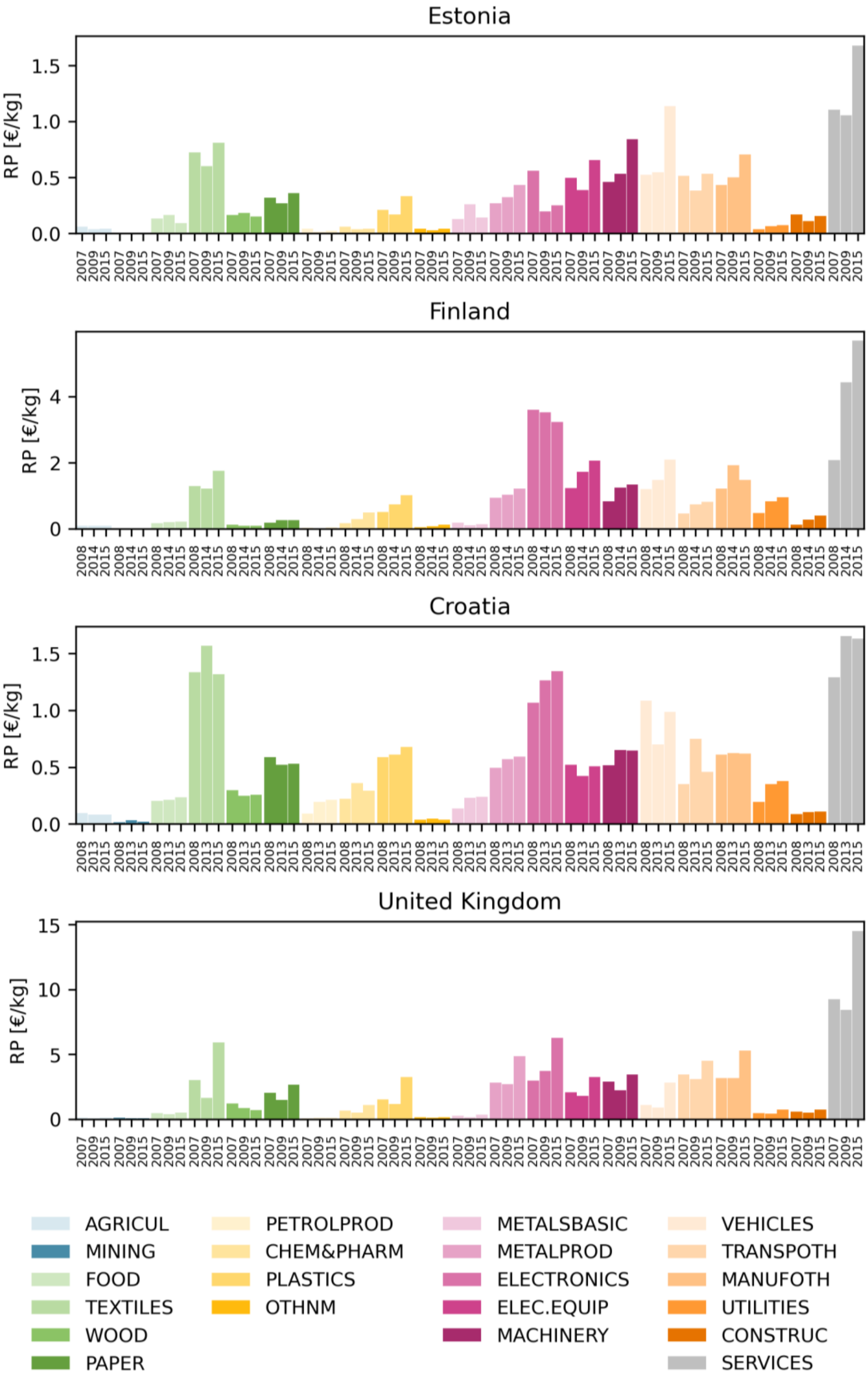


Figure 6.11 – Resource productivity of the different economic sectors for Estonia, Finland, Croatia, and the UK, for key years.

6.4 Socioeconomic metabolism flows

The last part of the analysis focuses on the monetary and mass flows into, out of, and within the SEM. As seen for the Portuguese economy, this analysis illustrates the dynamics within the economy and illustrates the value chains. This step will contribute with further data on the SEM flows, establishing the links and dependencies between the economic sectors.

6.4.1 Monetary flows

The monetary flows of the SEM for 2015 are presented in Figure 6.12 for Estonia, Finland, Croatia, and the UK. The flows are represented in simplified chord diagrams, as were the flows for Portugal in chapter 5, and can be similarly interpreted.

Given the significant contribution of SERVICES to the VA/cap, seen in Figure 6.8, it is not surprising that these were the most significant flows in the monetary chord diagrams. In Finland, Croatia, and the UK, SERVICES mainly satisfied the demand from households (HFCE), accounting for 30%, 27%, and 33% of the output from SERVICES. The second-largest share of the output from SERVICES satisfied the demand of the sector itself (26%, 22%, 27%), followed by exports (10%, 20%, 12%). In Estonia, most of the sales from SERVICES went to the sector itself (27%), the next largest share was exported (24%), and then the demand from households came in third (19%).

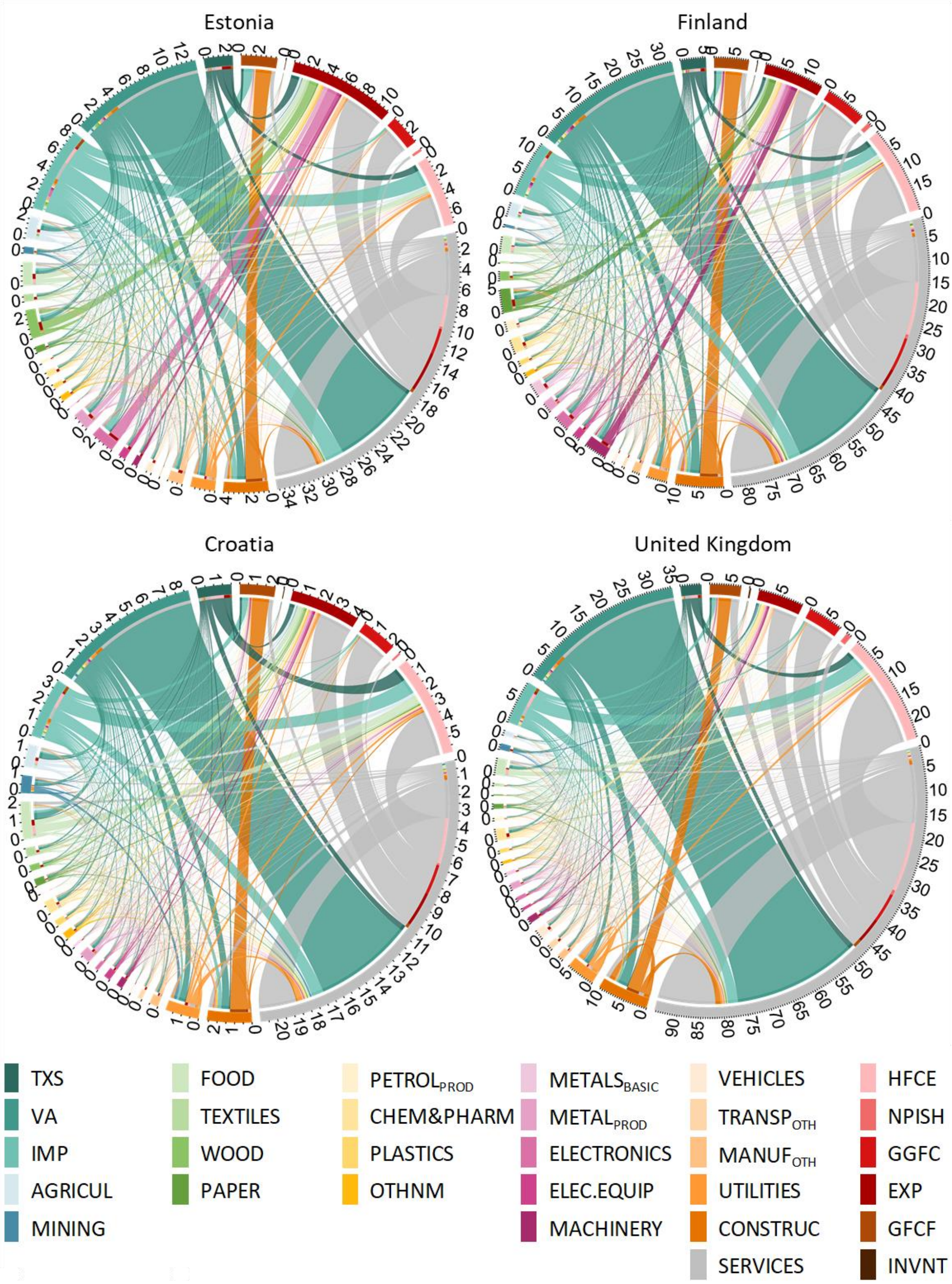


Figure 6.12 - Chord diagram of the flows in the MIOTS [2015 constant k€/cap] for Estonia, Finland, Croatia, and the UK in 2015. The colors on the outer circumference represent the sectors. The flows are colored according to the sector where they originate. For example, the light grey flows represent the sales from SERVICES.

The VA/cap values of Figure 6.8 showed that the second largest share was from CONSTRUC. The flows show that most of the value stayed with the sector as fixed capital in all four countries, likely unfinished and unsold buildings. The other shares went mostly to SERVICES, the sector itself, or HFCE.

One significant difference between Croatia and the other countries was the value of imports and exports, which were significantly lower in Croatia. In Croatia, the value of imports and exports was 3.52 and 4.05k€/cap respectively, while in the other three countries, the smallest trade value was for the imports of Estonia at 8.68 k€/cap. The exports from industrial sectors like WOOD, PAPER, ELECTRONICS, and MACHINERY were higher in the high DMI/cap countries. In Croatia and the UK, SERVICES accounted for more than 50% of exports, while in Estonia and Finland, they accounted for less than 40%.

6.4.2 Mass flows

The mass flows, plotted as chord diagrams in Figure 6.13, reveal more significant differences between the SEMs of these countries, linked with the natural resources and the resource productivity of the sectors.

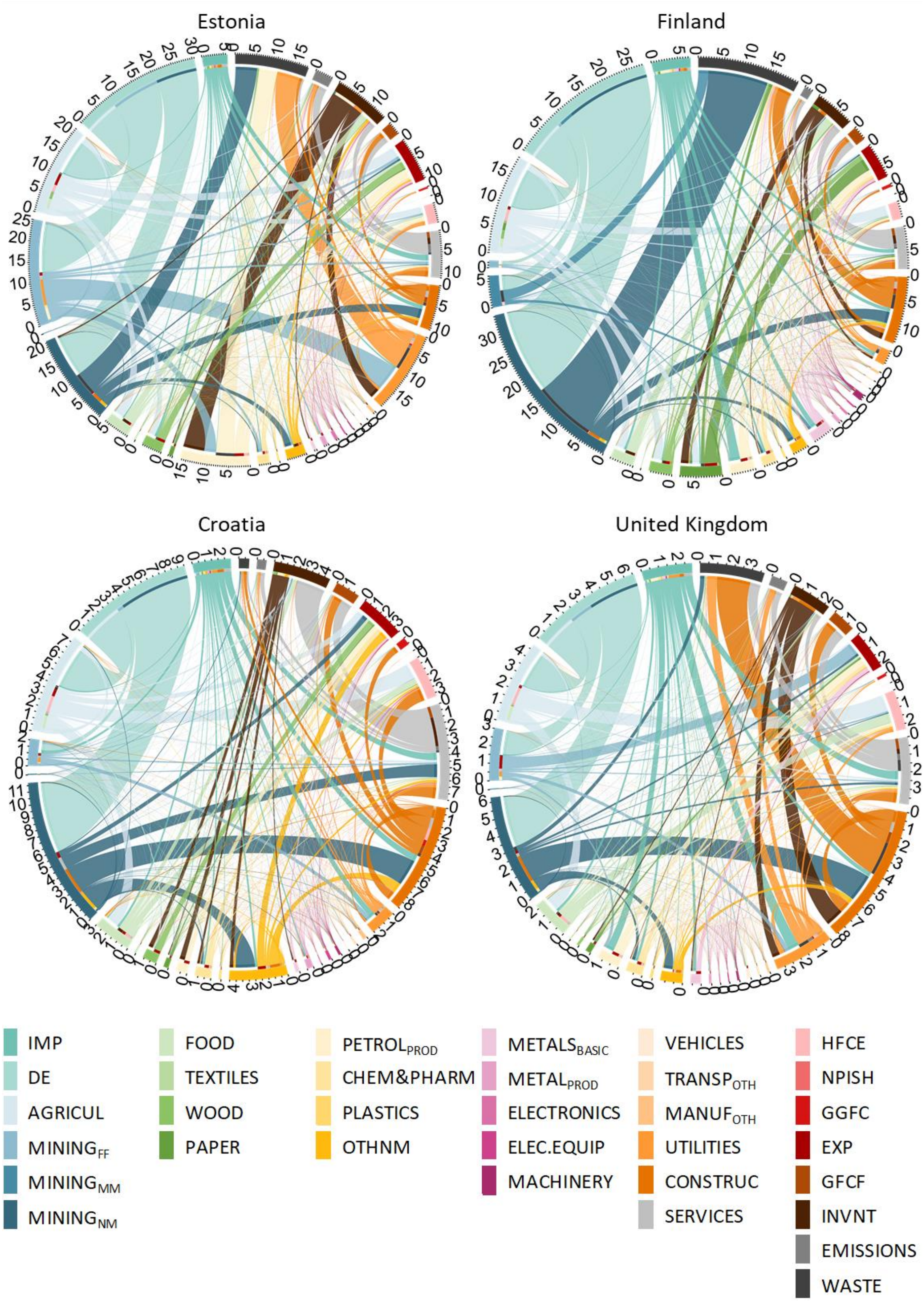


Figure 6.13 - Chord diagram of the flows in the PIOTS [t/cap] for Estonia, Finland, Croatia, and the UK in 2015. The colors on the outer circumference represent the sectors. The flows are colored according to the sector where they originate. For example, the dark blue flows correspond to the material outflows from $MINING_{NM}$. The values represented in these plots can be found in Table 9.25, Table 9.26, Table 9.27, and Table 9.28.

Estonia had fossil fuels and wood as its primary natural resources, aside from non-metallic minerals, which are common in all countries. The extraction of fossil fuels by the $MINING_{FF}$ sector (11.88 t/cap) was mainly sold to UTILITIES (48%), $PETROL_{PROD}$ (22%), SERVICES (13%), and HFCE (8%). Only 7% of the fossil fuels were exported, contributing to the 1% value exported from MINING. There were almost no exports from UTILITIES, and only 22% of the products of $PETROL_{PROD}$ were exported. Additionally, MINING, UTILITIES, and $PETROL_{PROD}$ all have low resource productivities, meaning that while the material flows may be very significant, they will be associated with comparatively small monetary flows. These results suggest that most products produced with the extracted fossil fuels satisfy national demand. The other natural resource that played a role in the Estonian economy was wood (BM3). The wood flows originated in the domestic extraction of AGRICUL and went to the sector WOOD to then be mainly exported (88%).

Wood was also a relevant natural resource in Finland. However, unlike in Estonia, the flows show that the wood extracted by AGRICUL was then directed at the PAPER and WOOD sectors. Furthermore, the flows associated with the PAPER sector were more significant than those associated with the WOOD sector. The majority of the output of both sectors was exported. Metallic minerals were also a crucial natural resource in Finland, unlike in other countries. A considerable share of the extracted metallic minerals became waste (74%). The remaining materials went mostly to $METALS_{BASIC}$, whose inputs also included a significant share of imports. Most of the outputs from $METALS_{BASIC}$ were exported. Finland presented by far the highest value of non-metallic minerals per capita. The flows that did not end up as waste, after being extracted by the $MININ_{NM}$ sector, were sold mainly to CONSTRUC and OTH_{NM}, whose output is also sold primarily to CONSTRUC. The non-waste outputs of CONSTRUC that were sold to other sectors or final demand mainly were sold to SERVICES, followed by GGFC. This distribution of output from the CONSTRUC sector supports the literature that suggests the higher per capita amount of non-metallic materials in countries with lower population density are put the development of public infrastructures.

Despite being about a fifth of the fossil fuel flows in Estonia, the UK had relatively significant fossil fuel flows in its economy. However, unlike in Estonia, the majority of the fossil fuels were exported. The previous results show that the high resource productivity of the UK was primarily related to the country having a higher share of services in its economy and SERVICES having much higher resource productivity. It is then not surprising that while SERVICES in the UK had the highest value added, the sector also had the smallest value of material requirements. On the one hand, the high resource productivity of SERVICES in the UK could be related mainly to the type of SERVICES provided in the country. The UK has the lowest input of materials from the CONSTRUC sector, suggesting that the SERVICES sector has developed more of the infrastructure it needs to operate, while the SERVICES sector in the other countries is still developing.

The majority of the flows in Croatia were non-metallic minerals and biomass. The value added that was not created by SERVICES or CONSTRUC was mainly associated with UTILITIES, FOOD, and AGRICUL. The non-metallic minerals extracted by the $MINING_{NM}$ sector were sold to CONSTRUC and OTH_{NM}. Part of the outputs from OTH_{NM} were exported, but mostly they were sold to CONSTRUC. The major output from CONSTRUC was to HFCE. Croatia had the most significant flows from COSNTRUC to HFCE (0.98 t/cap versus 0.08, 0.01, and 0.02 t/cap for Estonia, Finland, and the UK, respectively). The material flows from CONSTRUC to GGFC were also bigger in Croatia than in the other countries. Some of the flows extracted by the AGRICUL sector were partly sold to the FOOD sector and then exported. However, they were mainly used to satisfy national demand from households. These results suggest that, while Croatia has transitioned to an economy based on SERVICES, it is still developing its infrastructure.

6.5 Critical aspects of these four SEMs

This chapter described the SEM of four different European economies at two DMI/cap and GDP/cap levels, based on the methodologies presented in chapters 3 and 4 of this thesis.

Estonia has the lowest resource productivity of the four, associated with a low GDP/cap and high DMI/cap. The country has two differentiating natural resources, namely fossil fuels and wood. The physical flows associated with these natural resources play a significant role in the SEM but have a minimal contribution to the VA/cap of the economy. Most fossil fuels satisfy national demand while accounting for a significant contribution to WASTE. Wood will be mainly exported. Most economic sectors in Estonia have low resource productivity compared to other countries. The high domestic extraction associated with low resource productivity and low resource productivity of the SERVICES sector contributes to the low GDP/cap and high DMI/cap of Estonia.

Finland has the second-highest resource productivity of the four, despite having a DMI/cap close to Estonia. The major contributor to the higher GDP/cap of Finland was SERVICES. Despite the high input of materials into SERVICES, SERVICES in Finland also had higher resource productivity than in Estonia. The major contributor to the high DMI/cap of Finland were non-metallic minerals (NM). The results suggest that the materials are likely linked to the low population density of the country and the development of public infrastructures. Like in Estonia, wood was also a significant natural resource in Finland, being transformed by the PAPER sector and mainly exported. Another natural resource particular to the Finish economy was metallic minerals. Most of the products produced by sectors associated with these materials were exported. However, a significant share of the metallic minerals extracted end up as waste. Thus, while the flows associated with wood and metallic minerals may contribute to the value added, they are also associated with significant materials flows and waste production.

Croatia has a low DMI/cap and a low GDP/cap. The results suggest that while Croatia is mostly a SERVICES economy, it has not fully transitioned and is still developing infrastructure. Additionally, the resource productivity of SERVICES in Croatia is much lower than in the UK.

Like Estonia, the UK also extracts fossil fuels but exports most of the flows. The UK has transitioned to a services economy, with SERVICES reporting a larger share of the total VA/cap in the UK than in the other three countries. The resource productivity of SERVICES in the UK is also significantly higher, being almost 15 times that of Croatia or Estonia.

Several factors have been found to influence resource productivity and its development. The type of natural resources is one aspect that significantly impacts the SEM. Suppose a country has a natural resource that is significantly important to the economy of the country or that has high export potential. In that case, the chances are that that country will have lower resource productivity associated with the natural extraction of that material, which creates significant waste production, yet a much smaller value added than SERVICES.

Population density will also impact the results to a point. Aside from the effect of technological development suggested in the literature review, a country with a lower population density will also need to create more infrastructure per capita, thus contributing to a higher DMI/cap and lower resource productivity.

Infrastructure is indeed a significant aspect of the SEM. The activities within the SEM, like SERVICES, require spaces, such as offices, to operate. Hence, infrastructure development is a significant part of the transition to services and a population requirement. As GDP/cap increases and the population develops, it is expected that a part of the population will invest in building a house that provides its owners with essential services, such as shelter and protection.

7 Conclusions and future work

As the population grows and economies develop, the use of resources also increases, causing the use of the same resources on which our well-being depends to become harmful to human lives. This issue has motivated various studies focused on the relationship between economic development and resource use. So far, most studies have been primarily based on EW-MFA, MIOTs, or PIOTs. However, none of these methods is replicable for various years and countries while still providing information on the mass flows within the economy.

The work developed in this thesis was motivated by a gap in the study of sustainable resource use and economic development. It was identified that the field could benefit from more detailed data on the physical flows in the economy, and four research questions were proposed. This work proposed two methodologies applied to two case studies to tackle the gaps identified and answer the proposed research questions. The methodologies contribute to the study of material flows and improve the understanding of the SEM and the development of more efficient policies to promote sustainable development.

The first method proposed in this thesis describes how PIOTs can be calculated for various countries and years using official data. MIOTs can underestimate the contributions of industrial and extractive sectors. Furthermore, the link between environmental impacts and physical flows is better. However, the existing PIOTs have been compiled in singular efforts, typically using bottom-up approaches, comparing economies an unviable option. The goal established for the method was that it should be able to describe the material flows in an economy with enough resolution while ensuring replicability and comparability of results for studies with more than one country or year.

The method described for calculating PIOTs is based on data available from official data sources and the mass balance principle. The values in the PIOTs quantify not only the physical inputs and outputs into the economy for 17 materials but also the flows within 37 economic sectors. The method was validated by comparing various data sources, performing a sensitivity analysis, and validating the homogenous price assumption and the assumptions on the emissions flow. These analyses were done for a specific year and country and showed that the method should provide reliable results on which an analysis of the SEM can be done.

The second method proposed is a 4-step framework for the analysis of the SEM. It can take extensive physical and monetary data and find valuable insights in the analysis of the SEM of a country or more. The first step of the framework consists of the analysis of indicators that are typically part of EW-MFA studies. The types of natural resources and their origin are observed in the second step. The data from the PIOTs are essential inputs for the third and fourth steps. The third step explores the economic structure, including analyzing the value added, materials, and resource productivity per sector. The monetary and physical flows of the SEM are analyzed in the fourth step, bringing the previous findings together and establishing relevant links between them. This way, the four steps cover the main aspects of the SEM, from the general trends of the economy to the flows between the sectors and the dependencies between them, resulting in a detailed analysis of the SEM.

These methods were applied to two case studies. The first case study of this work focused on the detailed analysis of the Portuguese SEM during periods of economic transition and economic recession. The goal of this case study, aside from showcasing the methods, was to identify the impacts of a changing SEM on the resource productivity of a country. The analysis of the Portuguese SEM between 1995 and 2017 was done based on the two methods described in this work. The results of the first case study suggested that for an economy to transition to a high resource productivity services economy, it is first necessary to develop the required infrastructure. This case study pointed to the importance of sustainable planning in construction, particularly for developing countries. This case study also showed how the level of detail in the PIOTs and the 4-step framework could provide valuable results from the analysis of the SEM of a country.

The second case study focused on the comparative analysis of four European countries with two DMI/cap and GDP/cap levels. The goal of the case study was to identify critical aspects of each SEM that can be related to different development pathways and levels of resource productivity. The results showed that critical natural resources and low population density are associated with higher DMI/cap. On the other hand, a services economy is associated with a lower DMI/cap and a better chance of decoupling economic development from resource use. The resource productivity of the economic sectors is also a critical aspect that impacts the GDP/cap of the country. If a country is still developing its infrastructure and services economy, the GDP/cap will likely be lower than the GDP of a more developed economy. Critical aspects of the SEM of each economy were identified as well as their roles in the SEM and impacts on the development of the country. Thus, showing how the methods can be applied to a comparative study and the valuable insights extracted.

The different case studies demonstrated how the two novel methods proposed can be applied to studies with different goals and focus. These case studies showcased the features of the methods. These methods can be applied and used for comparative studies of the SEM for multiple countries and years and provide results with enough resolution to offer valuable insights for various stakeholders, including researchers and policymakers. The case studies also furthered the knowledge on SEM and the transition of different economies and their drivers.

7.1 Future work

The future work that can be developed from this thesis can be developed in two main groups: efforts to develop further and improve the methods and new applications of the methods.

The plot of the DMI/cap versus the GDP/cap for European countries in Figure 6.1 shows how there is a variety of shapes in the curves. The case study here presented focused on what differentiates countries. The study of the different clusters of *shapes* and the common factors within each cluster could further the knowledge of the impacts of the different drivers on the SEM. The comparison of the four countries showed that despite the chord diagrams for the MIOTs having similar aspects, the chord diagrams of the PIOTs showed significant differences between the economies. It could potentially be interesting to explore the complexity of the SEM and its relationship with other indicators. One aspect of the PIOTs that was not explored in depth in these case studies was the various PIOTs for each material. It would be interesting to explore the insights gained from these tables and their value. IOA has considerable potential as a modeling tool. This potential was left unexplored in this work but is surely worthy of attention as it may show that these PIOTs are also a helpful modeling tool to explore different policies.

Aspects of the method that can be improved include updating the python script to automatize the method for more of the published MIOTs and including alternative data sources. However, several developing countries have no data available to create PIOTs. One way of tackling this could be developing a set of proxies and models to estimate the missing data based on the available data and the development of the countries for which there is data.

Waste data has had various limitations in the past, which has hindered research in the field. This model integrates waste data in the SEM flows and can create new research opportunities in the field.

The calculation of the emissions in the PIOTs could also be improved so that the values represent tones of CO_{2eq} (carbon dioxide equivalent) instead of the mass of fuels used in combustion and ended up as emissions.

Creating a separate PIOT for energy could also add an exciting dimension to the results that would be useful for various works, given the role of energy production in emissions and climate change. This new PIOT would include the electricity production from renewables as domestic extraction and fossil fuels. The energy balance could be ensured using a unit such as tonnes of oil equivalent and separating the fossil fuels for energy production from the original tables.

Cities have become significant parts of the SEM and are responsible for most resource use in their countries. The development of a similar method for the analysis of Urban Metabolism could contribute new insights into the factors that affect the resource productivity of a city.

The methods proposed in this work create a variety of opportunities for future studies with the potential to unearth new knowledge in sustainable development.

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9 Supporting information

9.1 Supporting information for Chapter 1

Table 9.1 – Evolution of total population, GDP (constant 2010 US$), and domestic extraction relative to 1970, based on data from the UN, World Bank, and UNEP IRP (UNEP International Resource Panel, n.d.; United Nations, 2018; World Bank, 2019).

	Pop	GDP	DE
1970	1	1	1
1971	1.02	1.04	1.03
1972	1.04	1.10	1.05
1973	1.06	1.18	1.12
1974	1.08	1.20	1.12
1975	1.10	1.21	1.11
1976	1.12	1.27	1.16
1977	1.14	1.32	1.19
1978	1.16	1.38	1.24
1979	1.18	1.43	1.26
1980	1.20	1.46	1.26
1981	1.23	1.49	1.26
1982	1.25	1.49	1.27
1983	1.27	1.53	1.29
1984	1.29	1.60	1.35
1985	1.32	1.66	1.39
1986	1.34	1.71	1.43
1987	1.37	1.78	1.49
1988	1.39	1.86	1.54
1989	1.42	1.93	1.57
1990	1.44	1.99	1.59
1991	1.46	2.02	1.58
1992	1.49	2.05	1.64
1993	1.51	2.08	1.66

	Pop	GDP	DE
1993	1.53	2.14	1.72
1994	1.55	2.21	1.77
1995	1.57	2.29	1.82
1996	1.60	2.37	1.87
1997	1.62	2.43	1.91
1998	1.64	2.51	1.94
1999	1.66	2.62	1.99
2000	1.68	2.67	2.02
2001	1.70	2.73	2.06
2002	1.72	2.81	2.16
2003	1.75	2.93	2.28
2004	1.77	3.05	2.38
2005	1.79	3.18	2.49
2006	1.81	3.32	2.60
2007	1.83	3.38	2.65
2008	1.86	3.32	2.66
2009	1.88	3.47	2.82
2010	1.90	3.58	2.97
2011	1.93	3.67	3.01
2013	1.95	3.76	3.11
2014	1.97	3.87	3.16
2015	1.99	3.99	3.23
2016	2.02	4.09	3.31
2017	2.04	4.22	3.39

9.2 Supporting information for Chapter 3

Table 9.2 - PIOT for Portugal 2013 [t/cap].

	AGRICUL	$MINING_{FF}$	$MINING_{MM}$	$MINING_{NM}$	FOOD	TEXTILES	WOOD	PAPER	$PETROL_{PROD}$	CHEM&PHARM	PLASTICS	OTH_{NM}	$METALS_{BASIC}$	$METAL_{PROD}$	ELECTRONICS	ELEC.EQUIP	MACHINERY	VEHICLES	$TRANSP_{OTH}$	$MANUF_{OTH}$	UTILITIES	CONSTRUC	SERVICES	HFCE	NPISH	GGFC	EXP	GFCF	INVNT
AGRICUL	0.24	9E-5	6E-5	6E-5	0.95	0.04	0.13	0.18	9E-4	0.03	0.02	6E-4	2E-3	7E-4	2E-4	5E-4	5E-4	2E-3	1E-4	2E-3	2E-3	4E-3	0.13	0.88	6E-5	0.03	0.24	0.08	0.20
$MINING_{FF}$	0.00	6E-7	0.00	0.00	2E-6	0.00	0.00	0.00	4E-4	1E-5	0.00	0.00	1E-6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4E-5	0.00	3E-6	0.00	0.00	0.00	0.02	3E-3	-1E-2
$MINING_{MM}$	7E-3	2E-4	0.02	0.01	6E-3	7E-4	2E-4	8E-3	5E-4	0.06	2E-4	0.00	0.81	0.03	2E-4	5E-4	2E-3	7E-4	2E-4	6E-3	2E-3	0.00	0.03	0.02	0.00	5E-3	0.04	0.02	0.16
$MINING_{NM}$	0.07	2E-3	0.16	0.15	0.06	7E-3	2E-3	0.08	4E-3	0.63	2E-3	3.75	0.00	0.25	2E-3	4E-3	0.02	7E-3	2E-3	0.06	0.02	3.29	0.31	0.19	0.00	0.05	0.19	0.01	-8E-2
FOOD	0.03	2E-5	2E-5	2E-5	0.11	4E-3	2E-4	1E-3	5E-4	3E-3	3E-4	3E-4	1E-4	2E-4	7E-5	2E-4	1E-4	2E-4	3E-5	3E-4	1E-3	1E-3	0.10	0.40	3E-4	5E-3	0.23	0.03	0.91
TEXTILES	5E-4	1E-5	1E-5	1E-5	8E-4	0.05	2E-4	2E-4	1E-4	7E-4	1E-3	3E-4	9E-5	3E-4	5E-5	2E-4	9E-5	1E-3	6E-5	2E-3	3E-4	9E-4	9E-3	0.13	7E-6	5E-4	0.04	0.03	0.01
WOOD	8E-4	1E-5	2E-6	2E-6	5E-4	3E-4	0.02	1E-3	5E-5	2E-4	2E-4	8E-4	1E-4	4E-4	2E-5	4E-4	1E-4	1E-4	5E-5	6E-3	9E-4	9E-3	3E-3	1E-3	2E-6	6E-4	0.21	0.01	-1E-2
PAPER	2E-3	6E-5	2E-4	2E-4	0.02	6E-3	2E-3	0.09	6E-4	5E-3	2E-3	4E-3	7E-4	2E-3	5E-4	1E-3	8E-4	1E-3	1E-4	2E-3	0.01	2E-3	0.10	0.04	9E-6	1E-3	0.34	0.02	-2E-1
$PETROL_{PROD}$	0.03	6E-4	3E-3	2E-3	1E-2	7E-3	3E-3	7E-3	0.06	0.03	6E-3	0.01	9E-3	5E-3	4E-4	2E-3	2E-3	1E-3	4E-4	5E-3	0.02	0.03	0.29	0.21	0.00	1E-3	0.67	0.03	0.07
CHEM&PHARM	0.03	4E-4	1E-3	1E-3	0.02	0.05	9E-3	0.02	0.04	0.20	0.10	0.02	1E-2	0.01	2E-3	0.02	5E-3	0.02	9E-4	0.01	7E-3	0.02	0.14	0.20	1E-4	0.10	0.30	0.02	-1E-1
PLASTICS	2E-3	1E-4	2E-5	2E-5	0.02	8E-3	1E-3	2E-3	3E-4	5E-3	0.02	5E-3	1E-3	5E-3	2E-3	6E-3	4E-3	0.01	7E-4	9E-3	9E-4	0.02	0.05	0.01	1E-5	9E-4	0.06	9E-3	-1E-2
OTH_{NM}	0.07	1E-3	7E-3	6E-3	0.15	0.02	0.01	0.02	6E-3	0.07	0.02	0.60	0.04	0.10	6E-3	0.04	0.02	0.06	4E-3	0.04	0.04	1.62	0.38	0.39	3E-4	0.02	0.70	0.03	9E-3
$METALS_{BASIC}$	2E-3	9E-4	6E-4	6E-4	4E-3	1E-3	1E-3	3E-3	3E-3	2E-3	7E-3	0.01	0.17	0.26	6E-3	0.06	0.07	0.11	9E-3	0.04	0.02	0.22	0.04	0.01	9E-5	9E-3	0.24	0.02	-2E-1
$METAL_{PROD}$	7E-3	1E-3	2E-3	2E-3	0.05	0.01	6E-3	5E-3	3E-3	8E-3	0.01	9E-3	0.03	0.23	5E-3	0.02	0.04	0.03	4E-3	0.04	1E-2	0.13	0.12	0.06	5E-5	5E-3	0.07	0.03	0.07
ELECTRONICS	2E-4	4E-5	5E-5	4E-5	1E-3	4E-4	1E-4	3E-4	2E-4	3E-4	2E-4	2E-4	5E-4	4E-4	5E-3	1E-3	3E-4	1E-3	6E-5	1E-3	6E-4	1E-3	1E-2	0.02	1E-5	3E-3	2E-3	6E-3	-2E-3
ELEC.EQUIP	7E-4	5E-5	8E-5	8E-5	4E-3	1E-3	3E-4	6E-4	6E-4	8E-4	1E-3	1E-3	2E-3	3E-3	0.01	0.02	4E-3	1E-2	8E-4	7E-3	6E-3	0.02	0.03	0.06	3E-5	4E-3	0.03	0.02	7E-3
MACHINERY	2E-3	6E-4	1E-3	1E-3	9E-3	5E-3	8E-4	2E-3	1E-3	2E-3	2E-3	5E-3	5E-3	0.01	1E-3	6E-3	0.03	6E-3	1E-3	8E-3	4E-3	0.02	0.04	0.01	4E-5	4E-3	0.03	0.04	-2E-2
VEHICLES	2E-4	4E-5	4E-5	4E-5	5E-4	2E-4	7E-5	2E-4	1E-4	2E-4	3E-4	2E-4	2E-4	8E-4	1E-3	7E-4	4E-4	0.09	2E-4	4E-4	9E-4	2E-3	0.02	0.12	3E-5	3E-3	0.07	0.11	0.02
$TRANSP_{OTH}$	3E-4	2E-5	1E-5	1E-5	2E-4	4E-4	4E-5	7E-5	1E-4	9E-5	6E-5	6E-5	2E-4	1E-4	1E-5	1E-4	2E-4	1E-4	1E-3	3E-4	1E-4	5E-4	8E-3	4E-3	0.00	8E-3	3E-3	4E-3	4E-4
$MANUF_{OTH}$	2E-3	4E-4	5E-4	5E-4	8E-3	4E-3	3E-3	3E-3	2E-3	3E-3	2E-3	3E-3	7E-3	3E-3	5E-4	1E-3	1E-3	2E-3	5E-4	0.02	7E-3	4E-3	0.06	0.08	9E-6	9E-3	0.04	0.03	0.01
UTILITIES	3E-3	2E-4	7E-4	6E-4	5E-3	4E-3	2E-3	5E-3	3E-3	5E-3	2E-3	5E-3	5E-3	2E-3	3E-4	7E-4	1E-3	1E-3	1E-4	1E-3	0.13	2E-3	0.05	0.05	1E-6	0.01	8E-8	0.11	-9E-2
CONSTRUC	0.08	3E-3	0.02	0.01	0.02	0.02	0.01	0.02	0.03	0.02	7E-3	0.03	0.01	0.02	3E-3	0.01	8E-3	0.02	1E-3	0.02	0.10	3.06	1.38	0.11	1E-4	0.43	0.00	3.09	3E-4
SERVICES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.45	1.59
DE	2.53	0.00	1.04	9.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
IMP	0.13	5E-3	2E-3	5E-3	0.43	0.06	0.07	0.08	1.44	0.16	0.06	0.08	0.10	0.12	1E-2	0.06	0.04	0.08	5E-3	0.05	0.38	0.22	0.36						
CO2	-6E-2	-1E-3	-4E-3	-4E-3	-2E-2	-1E-2	-6E-3	-2E-2	-6E-2	-5E-3	-1E-2	-2E-2	-2E-2	-9E-3	-1E-3	-4E-3	-3E-3	-3E-3	-7E-4	-8E-3	-2E-1	-5E-2	-4E-1						
WASTE	-5E-3	-6E-5	-6E-3	-5E-2	-3E-2	-9E-3	-1E-2	-6E-2	-2E-3	-9E-3	-7E-3	-4E-2	-2E-2	-3E-2	-1E-3	-8E-3	-5E-3	-1E-2	-6E-4	-1E-2	-3E-1	-1E-1	-2E-1						

9.3 Supporting information for Chapter 4

Table 9.3 - GDP/cap, DMI/cap, IMP/cap, DE/cap, IMP_RME/cap for Portugal between 1995 and 2019.

	GDP [k€/cap]	DMI [t/cap]	IMP [t/cap]	DE [t/cap]	IMP_RME [t/cap]
1995	14.14	15.94	4.31	11.63	
1996	14.57	15.66	3.91	11.75	
1997	15.15	17.24	4.52	12.72	
1998	15.82	18.33	4.94	13.39	
1999	16.37	20.79	5.24	15.55	
2000	16.93	21.23	5.26	15.97	
2001	17.18	22.09	5.35	16.74	
2002	17.24	21.57	5.46	16.11	
2003	17.01	19.41	5.16	14.26	
2004	17.25	21.14	5.34	15.80	
2005	17.32	21.14	5.49	15.65	
2006	17.54	23.26	5.43	17.84	
2007	17.93	24.19	5.46	18.73	
2008	17.95	25.16	5.30	19.87	11.29
2009	17.38	22.56	5.06	17.50	9.88
2010	17.69	21.55	5.19	16.37	10.02
2011	17.43	20.39	5.04	15.35	9.77
2012	16.80	19.17	4.96	14.21	8.79
2013	16.73	17.69	5.10	12.59	9.25
2014	16.95	18.67	5.29	13.38	9.28
2015	17.33	18.98	5.73	13.24	10.08
2016	17.76	18.86	6.02	12.84	10.37
2017	18.44	20.51	6.36	14.16	11.12
2018	18.99	21.09	6.37	14.73	
2019	19.46	21.55	6.35	15.20	

Table 9.4 – DMI/cap disaggregated by material.

Material	DMI per material [t/cap]							
	2004	2006	2008	2009	2011	2013	2015	2017
FF1	2.08	2.21	2.00	1.92	1.81	1.96	2.22	2.51
FF2	0.36	0.38	0.34	0.29	0.28	0.32	0.38	0.39
MM1	0.41	0.53	0.49	0.39	0.42	0.42	0.45	0.52
MM2	0.03	0.04	0.04	0.03	0.03	0.02	0.03	0.03
MM3	1.20	1.00	1.14	1.13	0.99	1.06	1.13	0.94
MM4	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05
MM5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MM6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NM1	9.21	12.58	13.56	11.87	9.80	6.77	7.65	8.11
NM2	2.69	2.29	2.99	2.47	2.34	2.07	1.77	1.92
NM3	0.37	0.50	0.63	0.44	0.46	0.31	0.52	0.51
NM4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NM5	0.26	0.22	0.23	0.22	0.21	0.20	0.22	0.29
BM1	1.21	1.10	1.13	1.12	1.10	1.18	1.27	1.43
BM2	0.63	0.62	0.61	0.59	0.59	0.57	0.59	0.63
BM3	1.36	1.30	1.36	1.33	1.57	1.65	1.69	1.80
O1	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Table 9.5 – Resource productivity by sector for Portugal.

Sector	Resource productivity per sector [€(2015)/kg]							
	2004	2006	2008	2009	2011	2013	2015	2017
AGRICUL	0.15	0.14	0.12	0.12	0.10	0.11	0.10	0.10
MINING	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00
FOOD	0.20	0.21	0.19	0.21	0.19	0.18	0.19	0.16
TEXTILES	2.02	1.36	1.24	1.39	1.12	1.14	1.15	2.33
WOOD	0.33	0.39	0.29	0.27	0.32	0.31	0.27	0.25
PAPER	0.96	0.52	0.42	0.41	0.28	0.23	0.21	0.22
$PETROL_{PROD}$	0.01	0.04	0.05	0.01	0.02	0.01	0.03	0.03
CHEM&PHARM	0.24	0.10	0.10	0.12	0.09	0.09	0.11	0.26
PLASTICS	0.63	0.43	0.38	0.45	0.36	0.40	0.43	0.69
OTH_{NM}	0.04	0.02	0.02	0.02	0.02	0.03	0.02	0.02
$METALS_{BASIC}$	0.36	0.03	0.03	0.03	0.03	0.03	0.02	0.17
$METAL_{PROD}$	0.40	0.24	0.13	0.11	0.15	0.18	0.16	0.38
ELECTRONICS	0.61	0.33	0.35	0.33	0.63	0.69	0.74	1.32
ELEC.EQUIP	1.15	0.45	0.32	0.23	0.23	0.22	0.22	0.39
MACHINERY	0.33	0.23	0.21	0.23	0.27	0.30	0.31	0.31
VEHICLES	0.30	0.23	0.25	0.25	0.24	0.25	0.24	0.37
$TRANSP_{OTH}$	1.34	0.36	0.30	0.36	0.33	0.39	0.23	0.71
$MANUF_{OTH}$	0.33	0.52	0.38	0.41	0.48	0.48	0.45	0.85
UTILITIES	0.48	0.49	0.23	0.31	0.62	0.64	0.65	0.52
CONSTRUC	0.08	0.06	0.05	0.05	0.06	0.08	0.07	0.06
SERVICES	2.68	2.11	1.67	1.86	2.69	3.06	2.66	2.98

Table 9.6 – Total material input per sector for Portugal.

Sector	Total material input [t/cap]							
	2004	2006	2008	2009	2011	2013	2015	2017
AGRICUL	3.18	2.90	2.93	2.87	3.11	3.24	3.47	3.49
MINING	13.60	17.08	19.04	16.57	14.10	10.55	11.46	14.02
FOOD	1.80	1.61	1.76	1.70	1.78	1.87	1.97	2.61
TEXTILES	0.21	0.27	0.28	0.24	0.30	0.31	0.34	0.17
WOOD	0.27	0.26	0.32	0.29	0.28	0.28	0.34	0.33
PAPER	0.21	0.32	0.35	0.31	0.48	0.53	0.60	0.48
$PETROL_{PROD}$	2.23	1.70	1.37	1.20	1.36	1.60	1.63	1.97
CHEM&PHARM	0.49	1.19	1.16	0.94	1.35	1.25	1.24	0.57
PLASTICS	0.12	0.23	0.25	0.20	0.27	0.26	0.28	0.17
OTH_{NM}	6.19	9.81	8.23	6.98	6.30	4.54	5.13	6.20
$METALS_{BASIC}$	0.16	1.11	1.25	1.21	1.18	1.19	1.18	0.27
$METAL_{PROD}$	0.39	0.87	1.68	1.65	1.22	1.04	1.23	0.54
ELECTRONICS	0.20	0.30	0.37	0.31	0.24	0.24	0.26	0.14
ELEC.EQUIP	0.11	0.23	0.20	0.14	0.07	0.06	0.05	0.04
MACHINERY	0.10	0.14	0.21	0.27	0.26	0.26	0.26	0.20
VEHICLES	0.29	0.56	0.48	0.41	0.49	0.45	0.52	0.33
$TRANSP_{OTH}$	0.03	0.03	0.03	0.02	0.03	0.03	0.05	0.03
$MANUF_{OTH}$	0.35	0.29	0.42	0.40	0.34	0.32	0.37	0.25
UTILITIES	0.83	0.89	1.73	1.58	0.79	0.78	0.95	1.08
CONSTRUC	13.01	17.92	20.63	17.80	14.75	8.69	8.55	12.35
SERVICES	3.89	5.23	6.93	6.24	4.30	3.65	4.27	4.13

Table 9.7 – Value added per sector for Portugal.

Sector	Added value per sector per capita per sector [k€(2015)/cap]							
	2004	2006	2008	2009	2011	2013	2015	2017
AGRICUL	0.47	0.39	0.35	0.34	0.32	0.35	0.36	0.35
MINING	0.07	0.08	0.07	0.06	0.07	0.06	0.05	0.06
FOOD	0.36	0.34	0.34	0.35	0.34	0.34	0.37	0.41
TEXTILES	0.42	0.36	0.35	0.33	0.33	0.35	0.38	0.39
WOOD	0.09	0.10	0.09	0.08	0.09	0.09	0.09	0.08
PAPER	0.20	0.16	0.15	0.13	0.13	0.12	0.13	0.10
PETROLPROD	0.02	0.07	0.07	0.02	0.03	0.02	0.06	0.07
CHEM&PHARM	0.12	0.12	0.12	0.11	0.12	0.12	0.13	0.15
PLASTICS	0.08	0.10	0.09	0.09	0.10	0.10	0.12	0.12
OTHNM	0.24	0.16	0.16	0.15	0.14	0.12	0.12	0.13
METALSBASIC	0.06	0.03	0.04	0.03	0.04	0.03	0.03	0.04
METALPROD	0.15	0.21	0.22	0.18	0.18	0.18	0.19	0.21
ELECTRONICS	0.07	0.08	0.07	0.04	0.04	0.04	0.04	0.04
ELEC.EQUIP	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06
MACHINERY	0.12	0.07	0.08	0.07	0.06	0.07	0.08	0.08
VEHICLES	0.09	0.13	0.12	0.10	0.12	0.11	0.12	0.12
TRANSPOTH	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.02
MANUFOTH	0.11	0.15	0.16	0.17	0.16	0.16	0.17	0.21
UTILITIES	0.40	0.44	0.40	0.48	0.49	0.50	0.62	0.56
CONSTRUC	1.02	1.02	1.05	0.96	0.84	0.66	0.61	0.68
SERVICES	10.44	11.04	11.57	11.57	11.57	11.19	11.38	12.33

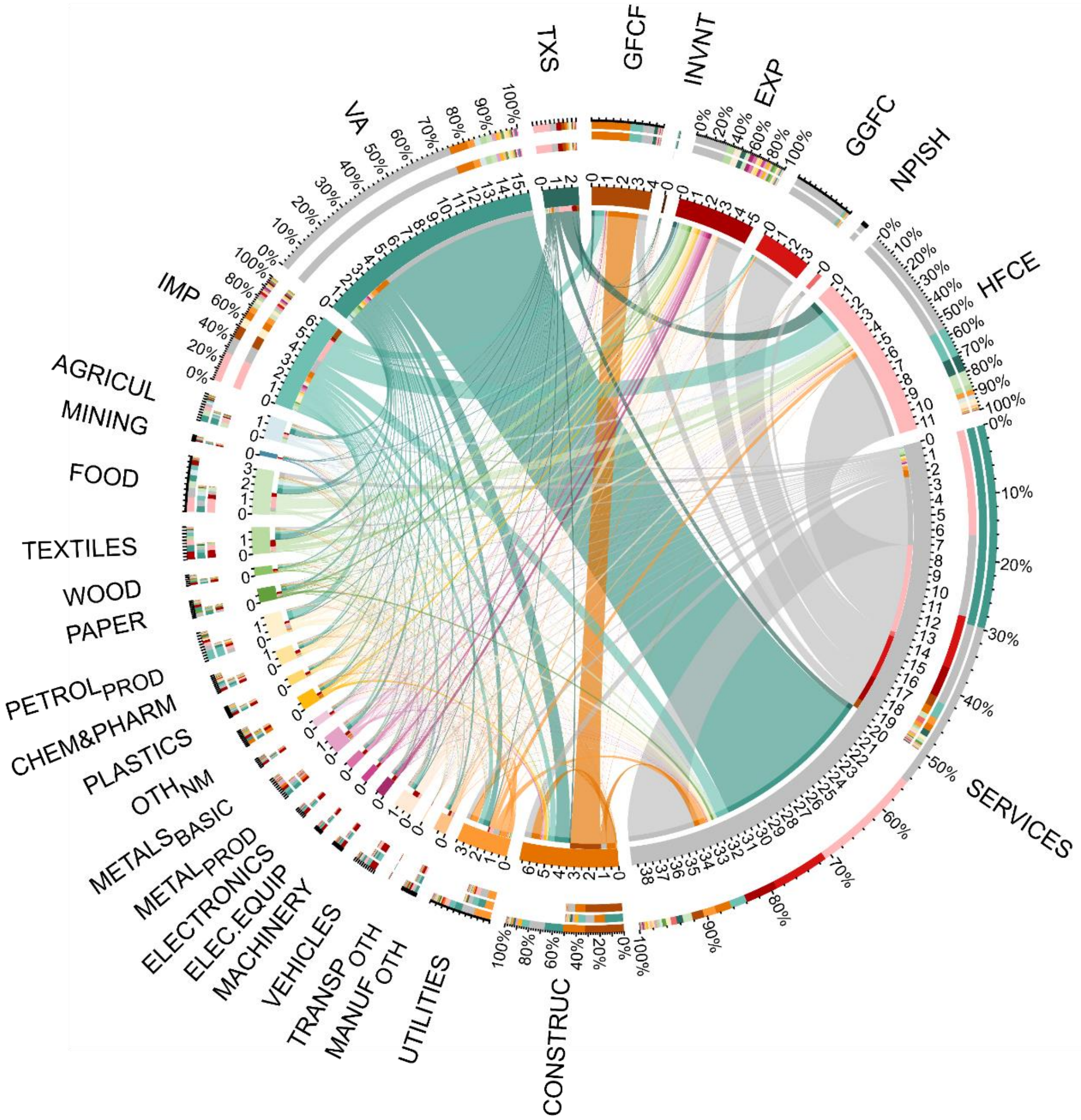

Figure 9.1 -MIOT Portugal 2008 [k€/cap].

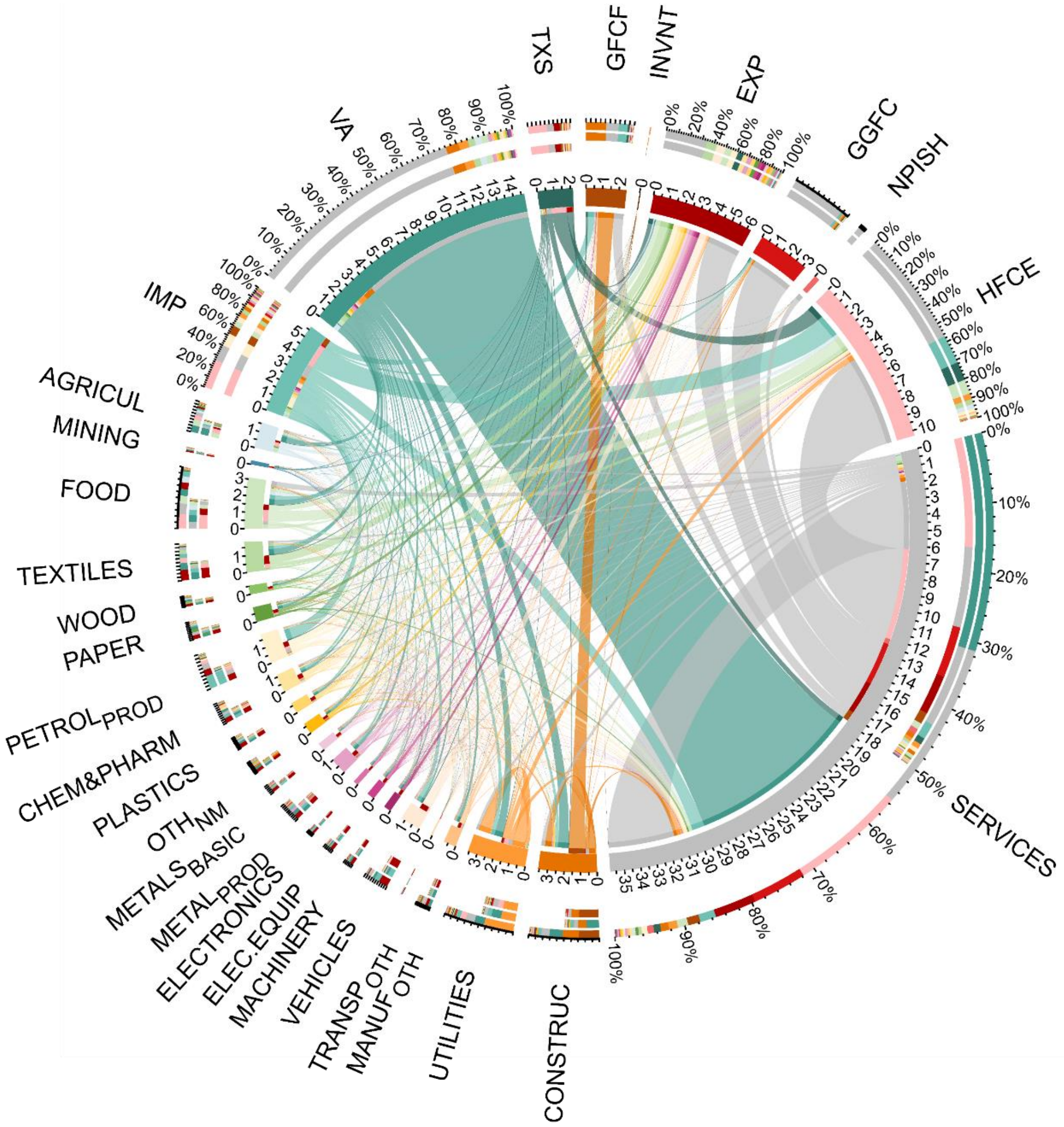

Figure 9.2 - MIOT Portugal 2013 [k€/cap] .

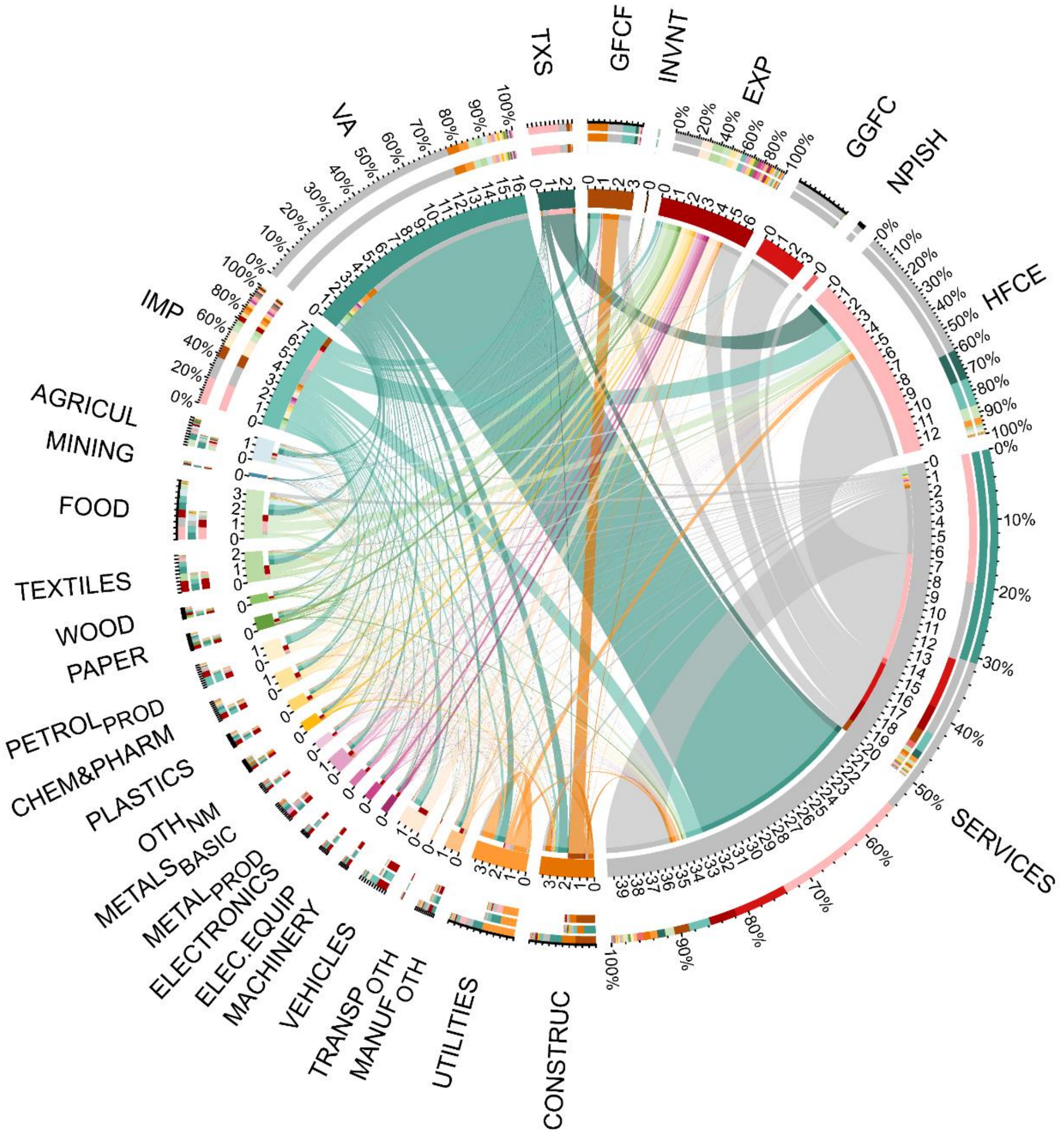

Figure 9.3 - MIOT Portugal 2017 [k€/cap].

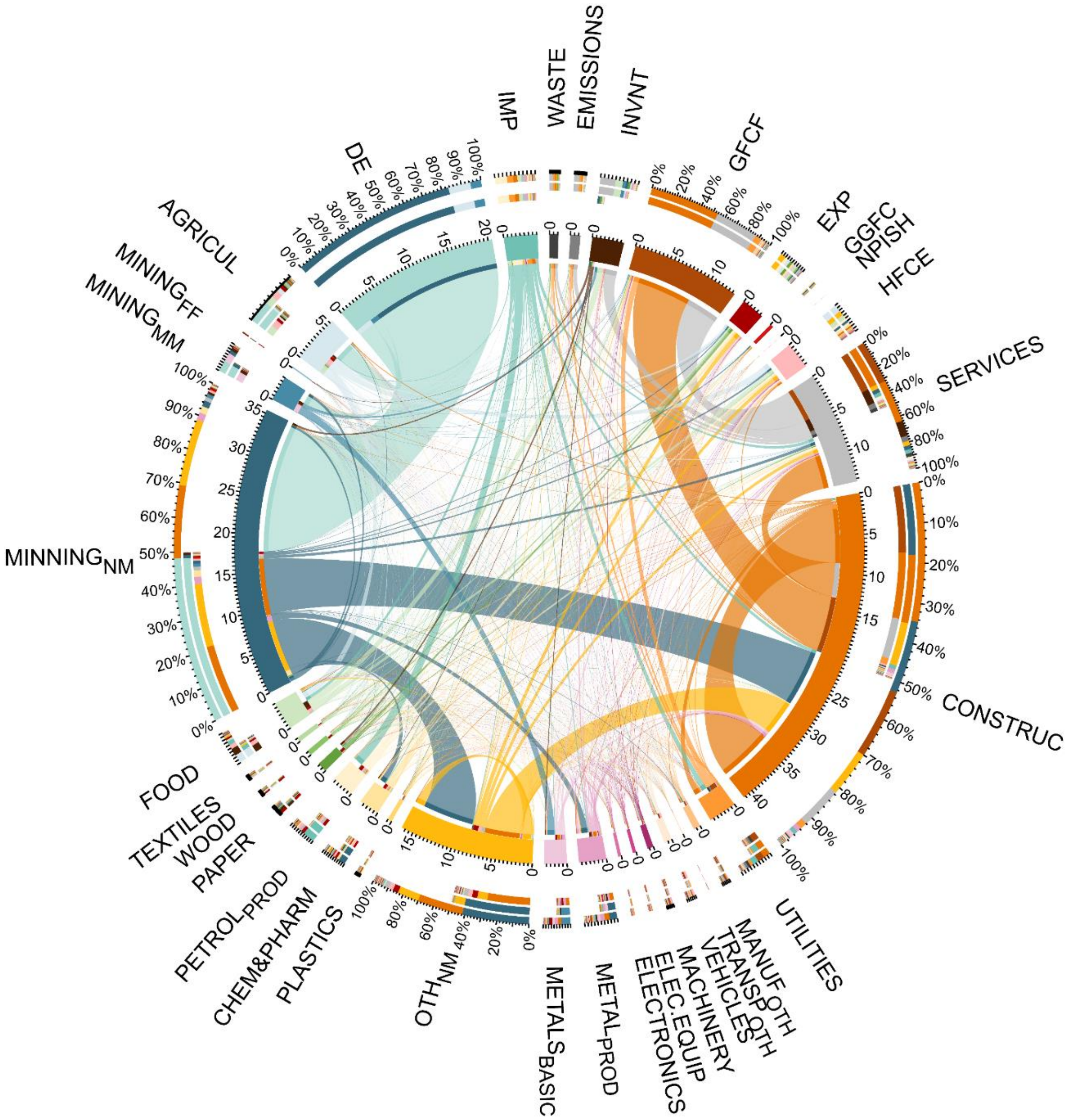

Figure 9.4 -PIOT Portugal 2008 [t/cap].

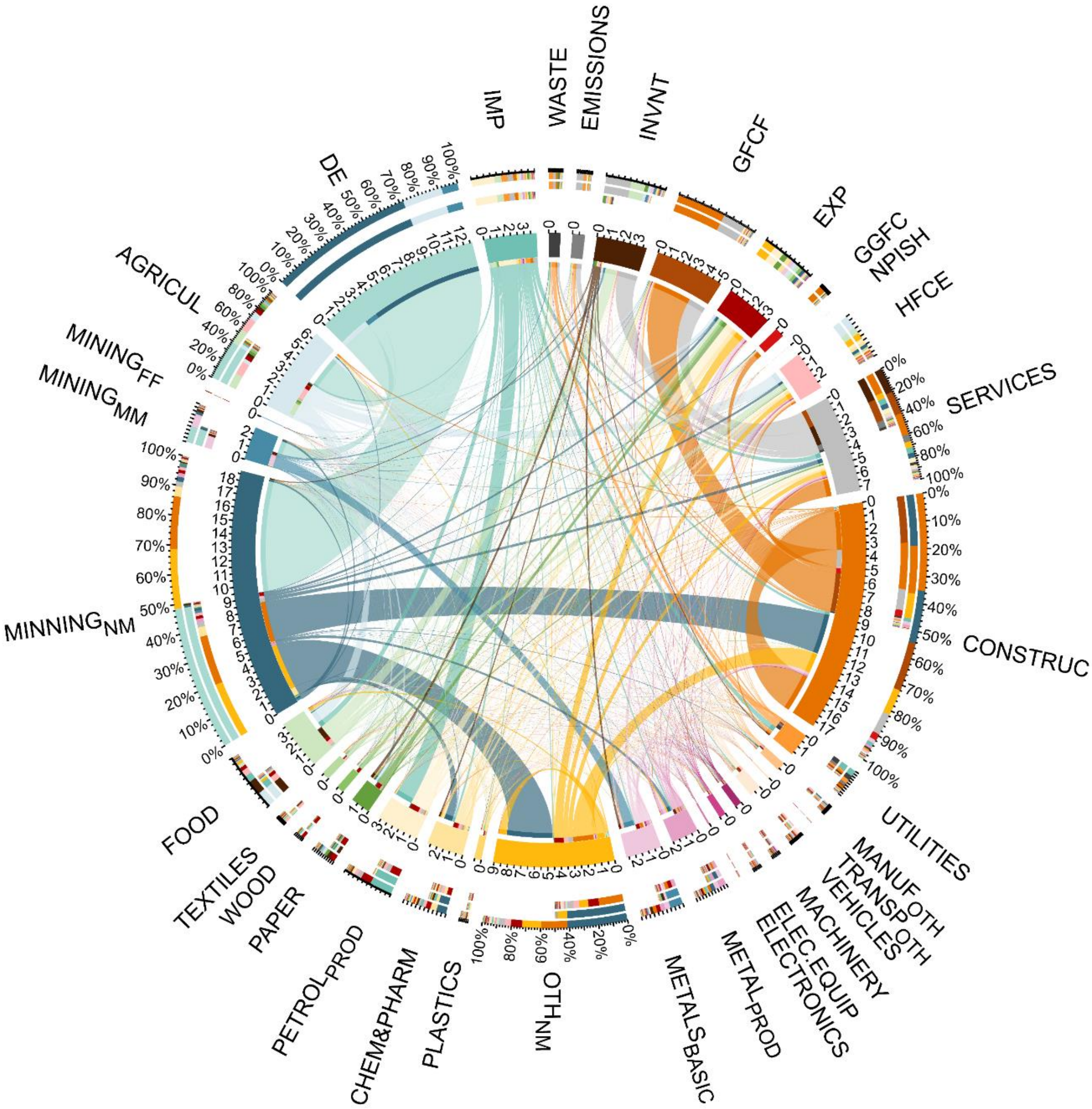

Figure 9.5 -PIOT Portugal 2013 [t/cap].

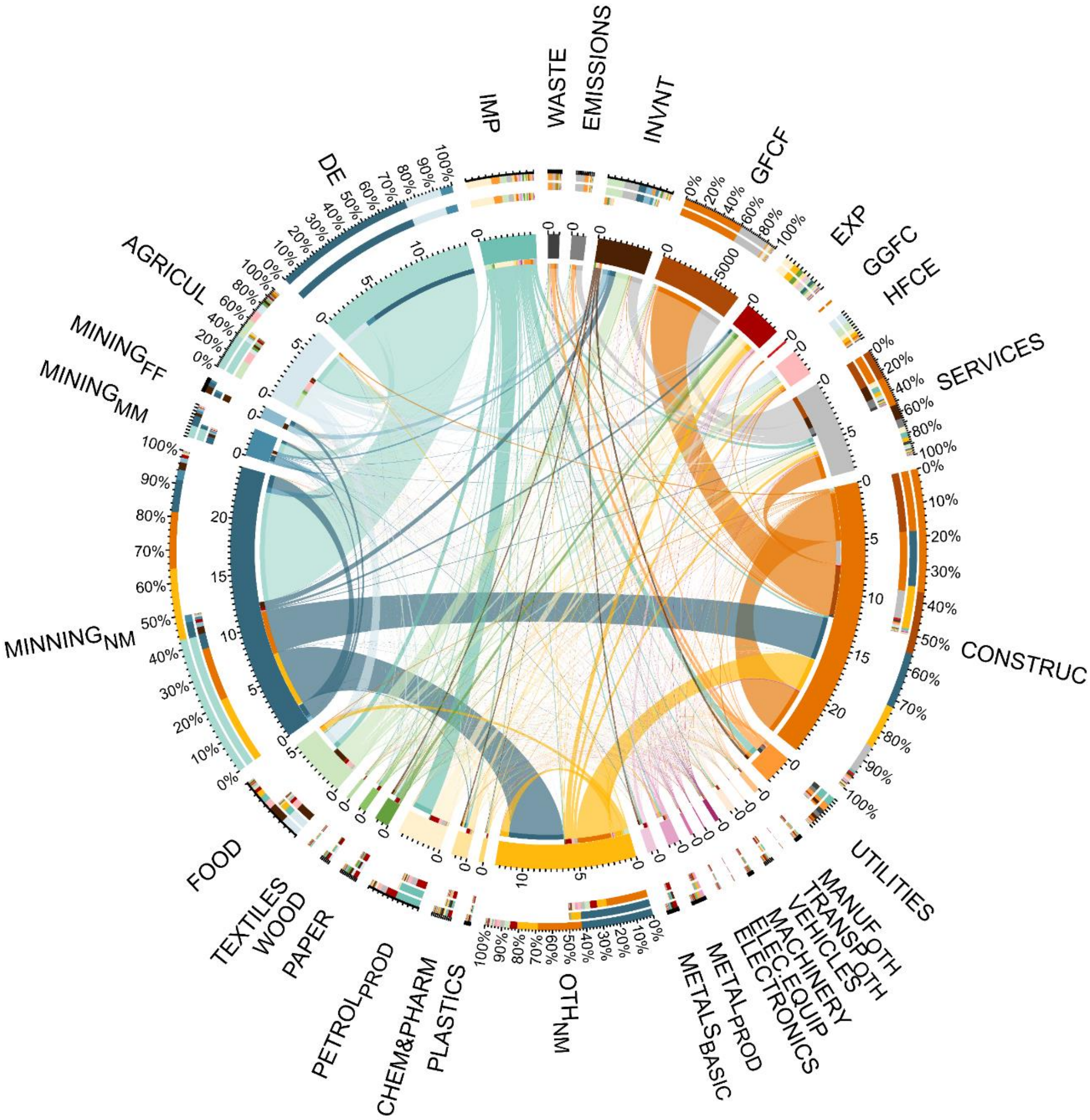

Figure 9.6 -PIOT Portugal 2017 [t/cap].

9.4 Supporting information for Chapter 5

Table 9.8 – GDP/cap, DMI/cap, and resource productivity of the Portuguese economy relative to the 1995 value.

	GDP [k€ (2015)/cap]	DMI [tonnes/cap]	Resource Productivity [€/kg]
1995	1.00	1.00	1.00
1996	1.03	0.98	0.95
1997	1.07	1.08	1.01
1998	1.12	1.15	1.03
1999	1.16	1.30	1.13
2000	1.20	1.33	1.11
2001	1.22	1.39	1.14
2002	1.22	1.35	1.11
2003	1.20	1.22	1.01
2004	1.22	1.33	1.09
2005	1.22	1.33	1.08
2006	1.24	1.46	1.18
2007	1.27	1.52	1.20
2008	1.27	1.58	1.24
2009	1.23	1.41	1.15
2010	1.25	1.35	1.08
2011	1.23	1.28	1.04
2012	1.19	1.20	1.01
2013	1.18	1.11	0.94
2014	1.20	1.17	0.98
2015	1.23	1.19	0.97
2016	1.26	1.18	0.94
2017	1.30	1.29	0.99
2018	1.35	1.32	0.98
2019	1.38	1.35	0.98

Table 9.9 - DMI/cap per material for key years of the Portuguese development.

Material	DMI per material [t/cap]					
	1995	2001	2003	2008	2013	2017
FF1	1.90	2.00	2.05	2.00	1.96	2.51
FF2	0.36	0.36	0.36	0.34	0.32	0.39
MM1	0.25	0.38	0.37	0.49	0.42	0.52
MM2	0.01	0.03	0.03	0.04	0.02	0.03
MM3	2.00	1.17	0.99	1.14	1.06	0.94
MM4	0.05	0.06	0.06	0.06	0.06	0.05
MM5	0.00	0.00	0.00	0.00	0.00	0.00
MM6	0.00	0.00	0.00	0.00	0.00	0.00
NM1	5.83	10.42	8.21	13.56	6.77	8.11
NM2	1.20	2.87	2.61	2.99	2.07	1.92
NM3	0.23	0.37	0.38	0.63	0.31	0.51
NM4	0.00	0.00	0.00	0.00	0.00	0.00
NM5	0.18	0.27	0.29	0.23	0.20	0.29
BM1	1.22	1.21	1.11	1.13	1.18	1.43
BM2	0.69	0.63	0.62	0.61	0.57	0.63
BM3	1.21	1.21	1.22	1.36	1.65	1.80
O1	0.01	0.01	0.01	0.02	0.02	0.02

Table 9.10 – Shares of the different materials for key years of the Portuguese development.

Material	1995	2001	2003	2008	2013	2017
FF1	13%	10%	11%	8%	12%	13%
FF2	2%	2%	2%	1%	2%	2%
MM1	2%	2%	2%	2%	3%	3%
MM2	0%	0%	0%	0%	0%	0%
MM3	13%	6%	5%	5%	6%	5%
MM4	0%	0%	0%	0%	0%	0%
MM5	0%	0%	0%	0%	0%	0%
MM6	0%	0%	0%	0%	0%	0%
NM1	39%	50%	45%	55%	41%	42%
NM2	8%	14%	14%	12%	12%	10%
NM3	2%	2%	2%	3%	2%	3%
NM4	0%	0%	0%	0%	0%	0%
NM5	1%	1%	2%	1%	1%	2%
BM1	8%	6%	6%	5%	7%	7%
BM2	5%	3%	3%	2%	3%	3%
BM3	8%	6%	7%	6%	10%	9%
O1	0%	0%	0%	0%	0%	0%

Table 9.11 - Sector contribution to the change in VA/cap during each period.

Sector	P1	P2	P3	P4	P5
AGRICUL	-7%	-20%	-11%	0%	0%
MINING	0%	-6%	0%	-1%	0%
FOOD	3%	3%	-2%	1%	4%
TEXTILES	-1%	-11%	-9%	0%	3%
WOOD	1%	-2%	0%	-1%	0%
PAPER	0%	-8%	-5%	-3%	-1%
PETROLPROD	0%	-1%	6%	-6%	3%
CHEM&PHARM	-1%	-1%	0%	0%	2%
PLASTICS	0%	0%	2%	1%	1%
OTHNM	0%	-15%	-7%	-5%	0%
METALSBASIC	-1%	-2%	-1%	0%	1%
METALPROD	2%	-3%	6%	-5%	1%
ELECTRONICS	0%	-5%	0%	-3%	0%
ELEC.EQUIP	1%	-5%	-1%	-1%	0%
MACHINERY	1%	-2%	-4%	-1%	0%
VEHICLES	3%	-8%	2%	-1%	0%
TRANSPOTH	1%	-1%	-2%	0%	0%
MANUFOTH	0%	0%	4%	-1%	4%
UTILITIES	0%	12%	1%	11%	4%
CONSTRUC	14%	-37%	4%	-44%	1%
SERVICES	84%	10%	117%	-43%	75%

Table 9.12 – Value added shares by sector for key years for Portugal in key years.

Sector	1995	2001	2003	2008	2013	2017
AGRICUL	0.06	0.04	0.03	0.02	0.02	0.02
MINING	0.01	0.01	0.00	0.00	0.00	0.00
FOOD	0.02	0.02	0.03	0.02	0.02	0.03
TEXTILES	0.04	0.03	0.03	0.02	0.02	0.02
WOOD	0.01	0.01	0.01	0.01	0.01	0.01
PAPER	0.02	0.02	0.01	0.01	0.01	0.01
PETROLPROD	0.00	0.00	0.00	0.00	0.00	0.00
CHEM&PHARM	0.01	0.01	0.01	0.01	0.01	0.01
PLASTICS	0.01	0.01	0.01	0.01	0.01	0.01
OTHNM	0.02	0.02	0.02	0.01	0.01	0.01
METALSBASIC	0.01	0.00	0.00	0.00	0.00	0.00
METALPROD	0.01	0.01	0.01	0.01	0.01	0.01
ELECTRONICS	0.01	0.01	0.00	0.00	0.00	0.00
ELEC.EQUIP	0.01	0.01	0.01	0.00	0.00	0.00
MACHINERY	0.01	0.01	0.01	0.01	0.00	0.00
VEHICLES	0.00	0.01	0.01	0.01	0.01	0.01
TRANSPOTH	0.00	0.00	0.00	0.00	0.00	0.00
MANUFOTH	0.01	0.01	0.01	0.01	0.01	0.01
UTILITIES	0.03	0.02	0.03	0.03	0.03	0.03
CONSTRUC	0.06	0.08	0.07	0.07	0.05	0.04
SERVICES	0.66	0.69	0.71	0.74	0.76	0.76

Table 9.13 - Ratio between the change in imports/cap and extraction/cap of each sector and the absolute difference in DMI/cap in each period.

Sector	P1	P2	P3	P4	P5
AGRICUL	-3%	-1%	0%	3%	7%
MINING	90%	-94%	98%	-101%	51%
FOOD	1%	-2%	2%	0%	3%
TEXTILES	0%	0%	0%	0%	0%
WOOD	0%	0%	0%	0%	2%
PAPER	0%	0%	0%	0%	1%
PETROLPROD	-5%	3%	-1%	3%	16%
CHEM&PHARM	0%	0%	1%	1%	1%
PLASTICS	0%	0%	0%	0%	1%
OTHNM	2%	-1%	-3%	0%	0%
METALSBASIC	0%	0%	0%	0%	2%
METALPROD	1%	0%	0%	0%	1%
ELECTRONICS	0%	0%	0%	0%	0%
ELEC.EQUIP	0%	0%	0%	0%	1%
MACHINERY	0%	0%	0%	0%	1%
VEHICLES	1%	0%	0%	0%	1%
TRANSPOTH	0%	0%	0%	0%	0%
MANUFOTH	0%	0%	0%	0%	1%
UTILITIES	4%	-1%	1%	-3%	10%
CONSTRUC	5%	-3%	1%	-2%	-2%
SERVICES	2%	0%	0%	-1%	1%

Table 9.14 - Ratio between the change in final consumption, waste, and emissions per capita for each sector and the absolute difference in DMI/cap in each period.

Sector	P1	P2	P3	P4	P5
AGRICUL	2%	3%	2%	1%	-9%
MINING	-3%	-15%	-2%	-1%	37%
FOOD	1%	-6%	0%	1%	24%
TEXTILES	1%	-2%	0%	0%	-4%
WOOD	0%	-1%	0%	0%	2%
PAPER	0%	0%	0%	1%	0%
PETROLPROD	-10%	1%	-9%	4%	9%
CHEM&PHARM	1%	0%	4%	0%	-10%
PLASTICS	0%	0%	1%	0%	-1%
OTHNM	4%	4%	6%	-1%	-11%
METALSBASIC	0%	0%	1%	0%	1%
METALPROD	2%	-1%	3%	-2%	-4%
ELECTRONICS	0%	0%	1%	-1%	0%
ELEC.EQUIP	0%	0%	1%	0%	-2%
MACHINERY	1%	-1%	1%	-1%	0%
VEHICLES	1%	-3%	3%	-1%	-5%
TRANSPOTH	0%	0%	0%	0%	0%
MANUFOTH	2%	0%	0%	-1%	-2%
UTILITIES	3%	-1%	13%	-10%	4%
CONSTRUC	67%	-63%	27%	-48%	52%
SERVICES	28%	-16%	47%	-41%	19%

Table 9.15 - PIOT Portugal 1995 [t/cap]

	AGRICUL	MINING$_{FF}$	MINING$_{MM}$	MINING$_{NM}$	FOOD	TEXTILES	WOOD	PAPER	PETROL$_{PROD}$	CHEM&PHARM	PLASTICS	OTH$_{NM}$	METALS$_{BASIC}$	METAL$_{PROD}$	ELECTRONICS	ELEC.EQUIP	MACHINERY	VEHICLES	TRANSP$_{OTH}$	MANUF$_{OTH}$	UTILITIES	CONSTRUC	SERVICES	HFCE	NPISH	GGFC	EXP	GFCF	INVNT
AGRICUL	0.30	2E-5	1E-6	7E-6	1.15	0.07	0.19	0.07	6E-4	6E-3	3E-3	9E-5	0E+0	6E-4	3E-4	3E-5	6E-5	6E-5	3E-5	6E-4	9E-5	6E-4	0.21	0.80	3E-5	4E-4	0.08	0.04	0.12
MINING$_{FF}$	2E-6	3E-5	2E-6	1E-5	1E-5	9E-7	0E+0	1E-6	5E-3	2E-5	0E+0	4E-4	1E-5	2E-6	1E-6	3E-7	3E-7	3E-7	0E+0	2E-5	1E-3	0E+0	3E-5	9E-6	0E+0	0E+0	0E+0	7E-3	0.25
MINING$_{MM}$	7E-3	0.13	8E-3	0.04	0.05	0E+0	0E+0	4E-3	0.55	0.09	0E+0	0E+0	0.40	7E-3	5E-3	1E-3	1E-3	1E-3	0E+0	0.06	0E+0	0E+0	0.11	0.03	0E+0	0E+0	0.05	4E-4	0.45
MINING$_{NM}$	6E-3	0.12	7E-3	0.04	0.04	0E+0	0E+0	4E-3	0.51	0.08	0E+0	4.11	0E+0	6E-3	5E-3	9E-4	9E-4	9E-4	0E+0	0.06	0E+0	1.67	0.10	0.03	0E+0	0E+0	0.05	2E-3	0.45
FOOD	0.06	1E-5	8E-7	4E-6	0.16	6E-3	2E-5	2E-3	0E+0	2E-3	3E-5	6E-5	8E-6	1E-4	4E-5	4E-5	5E-5	4E-5	2E-5	2E-4	9E-5	3E-4	0.17	0.60	3E-5	3E-5	0.07	0.05	0.81
TEXTILES	4E-4	5E-5	3E-6	1E-5	8E-5	0.09	3E-5	1E-4	0E+0	3E-4	3E-4	2E-4	6E-6	7E-5	2E-5	4E-5	7E-4	7E-4	4E-6	4E-3	3E-4	5E-4	5E-3	0.08	6E-6	4E-6	0.04	0.04	0E+0
WOOD	1E-4	5E-7	3E-8	2E-7	2E-4	3E-5	6E-3	4E-4	0E+0	3E-5	3E-5	3E-4	1E-5	1E-4	3E-5	8E-6	6E-5	4E-5	2E-5	2E-3	1E-5	4E-3	8E-4	5E-4	8E-7	8E-7	0.12	0.01	0.10
PAPER	6E-4	2E-4	1E-5	5E-5	7E-3	2E-3	6E-4	0.03	2E-6	2E-3	4E-4	2E-3	1E-4	1E-3	3E-4	4E-4	5E-4	3E-4	1E-4	6E-4	2E-3	3E-4	0.03	0.02	5E-6	2E-5	0.16	0.03	0E+0
PETROL$_{PROD}$	0.03	0.02	1E-3	5E-3	0.01	0.01	3E-3	4E-3	0.03	0.05	1E-3	0.01	1E-3	5E-3	3E-3	2E-3	1E-3	2E-3	8E-4	5E-3	0.06	0.09	0.34	0.36	2E-4	1E-4	0.42	8E-3	1.04
CHEM&PHARM	7E-3	1E-3	6E-5	3E-4	3E-3	0.02	3E-3	9E-3	6E-3	0.05	0.02	6E-3	3E-4	4E-3	9E-4	5E-4	3E-3	2E-3	5E-4	3E-3	7E-4	9E-3	0.04	0.08	9E-4	2E-5	0.15	0.02	0E+0
PLASTICS	1E-4	0E+0	0E+0	0E+0	5E-3	3E-3	5E-4	1E-3	0E+0	1E-3	3E-3	9E-4	5E-5	2E-3	1E-3	4E-3	6E-3	3E-3	2E-4	2E-3	7E-5	3E-3	9E-3	8E-3	0E+0	0E+0	0.01	7E-3	0E+0
OTH$_{NM}$	0.07	2E-3	1E-4	7E-4	0.19	3E-3	8E-3	0.02	9E-4	0.04	7E-3	0.73	0.01	0.07	0.03	1E-2	0.01	0.10	3E-3	0.04	5E-3	2.83	0.33	0.24	3E-4	3E-4	0.17	0.05	0.03
METALS$_{BASIC}$	3E-4	2E-4	1E-5	6E-5	1E-3	2E-3	7E-4	2E-3	3E-4	3E-3	8E-3	0.01	0.08	0.13	0.04	1E-2	0.06	0.04	0.01	0.03	2E-3	0.04	1E-2	2E-3	0E+0	0E+0	0.03	7E-3	0.03
METAL$_{PROD}$	2E-3	3E-4	2E-5	1E-4	0.01	5E-3	2E-3	2E-3	6E-5	3E-3	3E-3	4E-3	2E-3	0.05	0.01	4E-3	5E-3	0.02	5E-3	4E-3	2E-4	0.08	0.05	0.02	1E-5	1E-5	0.02	0.07	0.02
ELECTRONICS	9E-4	3E-4	2E-5	9E-5	1E-3	1E-3	4E-4	5E-4	3E-5	9E-4	2E-3	6E-3	4E-4	2E-3	0.03	2E-3	6E-4	6E-3	2E-3	6E-4	7E-4	0.01	0.01	0.03	2E-5	2E-5	0.01	0.05	5E-3
ELEC.EQUIP	9E-5	1E-5	7E-7	3E-6	3E-4	2E-4	1E-5	1E-4	0E+0	2E-4	4E-5	2E-4	4E-5	2E-4	1E-3	0.03	1E-3	2E-3	9E-5	7E-5	4E-4	4E-4	0.02	0.02	4E-5	3E-5	5E-4	9E-3	2E-3
MACHINERY	3E-5	1E-5	7E-7	3E-6	2E-4	1E-4	1E-5	7E-5	0E+0	2E-4	5E-4	2E-4	2E-4	8E-4	5E-3	0.01	0.03	0.02	8E-4	2E-4	4E-3	0.02	0.02	7E-3	3E-5	1E-5	0.01	8E-3	0E+0
VEHICLES	1E-4	3E-5	2E-6	1E-5	6E-4	4E-4	4E-5	2E-4	0E+0	3E-4	6E-4	1E-4	0E+0	6E-4	3E-4	8E-5	5E-4	0.05	3E-4	3E-4	2E-4	6E-4	0.02	0.10	8E-5	4E-5	0.03	0.07	0.02
TRANSP$_{OTH}$	1E-4	0E+0	0E+0	0E+0	9E-5	5E-5	0E+0	2E-5	0E+0	5E-5	0E+0	2E-5	0E+0	3E-4	2E-5	7E-5	2E-5	2E-5	6E-3	9E-5	5E-5	3E-4	8E-3	7E-3	0E+0	0E+0	5E-3	0.01	2E-3
MANUF$_{OTH}$	0E+0	0E+0	0E+0	0E+0	3E-5	8E-3	8E-4	2E-3	0E+0	2E-4	9E-4	3E-4	4E-3	3E-4	2E-4	0E+0	1E-5	0.01	0E+0	0.03	1E-5	8E-3	0.02	0.13	0E+0	0E+0	9E-3	0.01	0.02
UTILITIES	4E-3	2E-3	1E-4	6E-4	5E-3	7E-3	1E-3	3E-3	7E-5	3E-3	1E-3	0.01	2E-3	2E-3	9E-4	6E-4	7E-4	1E-3	5E-4	1E-3	0.10	3E-3	0.05	0.06	5E-4	1E-4	2E-7	0.04	0E+0
CONSTRUC	0.04	7E-3	4E-4	2E-3	0.05	0.04	0.01	0.03	8E-3	0.02	4E-3	0.04	6E-3	0.06	0.02	7E-3	7E-3	9E-3	2E-3	1E-2	0.04	3.14	0.88	0.05	0E+0	0E+0	0E+0	3.15	0.15
SERVICES	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0.91	1.05
DE	2.50	0E+0	1.98	7.29	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0						
IMP	0.10	0.02	1E-3	6E-3	0.30	0.06	0.06	0.04	1.45	0.09	0.02	0.17	0.05	0.07	0.02	1E-2	0.03	0.03	7E-3	0.03	0.35	0.14	0.30						
GFCF	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0						
INVNT	0E+0	0E+0	0E+0	0E+0	0E+0	8E-3	0E+0	0.14	0E+0	0.03	2E-3	0E+0	0E+0	0E+0	0E+0	0E+0	3E-3	0E+0	0E+0	0E+0	0.09	0E+0	0E+0						
EMISSIONS	-7E-2	-3E-2	0.00	-0.01	-2E-2	-3E-2	-0.01	-0.01	-3E-2	0.00	0.00	-3E-2	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	-0.01	-2E-1	-1E-1	-5E-1						
WASTE	-1E-2	0.00	-2E-2	-9E-2	-4E-2	-5E-2	-4E-2	-6E-2	0.00	-1E-2	0.00	-9E-2	-1E-2	-2E-2	0.00	0.00	-0.01	-0.01	0.00	-0.01	-2E-1	-1E-1	-2E-1						

Table 9.16 - PIOT Portugal 2017 [t/cap]

	AGRICUL	$MINING_{FF}$	$MINING_{MM}$	$MINING_{NM}$	FOOD	TEXTILES	WOOD	PAPER	$PETROL_{PROD}$	CHEM&PHARM	PLASTICS	OTH_{NM}	$METALS_{BASIC}$	$METAL_{PROD}$	ELECTRONICS	ELEC.EQUIP	MACHINERY	VEHICLES	$TRANSP_{OTH}$	$MANUF_{OTH}$	UTILITIES	CONSTRUC	SERVICES	HFCE	NPISH	GGFC	EXP	GFCF	INVNT
AGRICUL	1E-3	0E+0	0E+0	0E+0	5E-3	5E-6	6E-4	7E-4	0E+0	2E-5	3E-5	5E-8	0E+0	2E-7	8E-7	0E+0	0E+0	1E-5	0E+0	2E-6	0E+0	7E-7	5E-4	3E-3	0E+0	0E+0	0.12	1E-3	0E+0
$MINING_{FF}$	1E-6	6E-5	4E-5	2E-4	5E-6	4E-8	3E-7	6E-7	0E+0	1E-5	0E+0	3E-4	2E-6	2E-6	0E+0	0E+0	5E-7	7E-9	2E-8	4E-7	3E-5	0E+0	2E-5	4E-6	0E+0	0E+0	1E-4	9E-5	0E+0
$MINING_{MM}$	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0.05	6E-5	0E+0
$MINING_{NM}$	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0.24	3E-4	0E+0
FOOD	0.02	6E-6	4E-6	2E-5	0.02	5E-4	3E-5	1E-4	1E-5	2E-3	3E-5	3E-5	1E-5	7E-5	2E-5	3E-5	2E-5	3E-5	4E-6	9E-5	6E-5	2E-4	0.04	0.11	0E+0	0E+0	0.24	1E-3	0.09
TEXTILES	2E-4	3E-6	2E-6	1E-5	1E-5	0.02	2E-6	5E-6	2E-8	5E-5	2E-4	5E-5	8E-7	6E-6	7E-5	1E-6	3E-6	8E-4	1E-5	7E-4	6E-6	1E-4	7E-4	0.02	0E+0	5E-7	0.05	4E-4	0E+0
WOOD	2E-5	7E-8	4E-8	2E-7	5E-5	8E-7	5E-4	2E-5	0E+0	3E-6	3E-6	2E-5	2E-6	5E-6	5E-7	9E-8	9E-6	9E-7	5E-7	1E-4	1E-6	2E-4	5E-5	1E-5	0E+0	0E+0	0.15	1E-4	0E+0
PAPER	3E-4	8E-6	5E-6	3E-5	3E-3	3E-4	1E-4	0.01	8E-6	4E-4	2E-4	3E-4	5E-5	1E-4	5E-5	7E-5	5E-5	5E-5	3E-5	3E-4	4E-4	1E-4	1E-2	4E-3	0E+0	1E-5	0E+0	7E-4	0E+0
$PETROL_{PROD}$	0.03	1E-3	8E-4	4E-3	0.02	7E-3	4E-3	5E-3	0.08	0.03	4E-3	0.02	8E-4	6E-3	1E-3	5E-4	2E-3	6E-4	1E-4	8E-3	0.02	0.04	0.43	0.32	0E+0	0E+0	0.78	1E-4	0.05
CHEM&PHARM	2E-3	2E-4	1E-4	5E-4	2E-3	1E-3	8E-4	3E-3	4E-3	0.02	5E-3	2E-3	1E-4	2E-3	2E-4	1E-4	1E-3	6E-4	3E-4	1E-3	1E-3	4E-3	0.01	6E-3	0E+0	3E-3	0.29	5E-4	0E+0
PLASTICS	3E-4	2E-6	1E-6	7E-6	9E-3	2E-3	4E-4	3E-4	0E+0	1E-3	8E-3	1E-3	1E-4	2E-3	1E-3	7E-4	2E-3	1E-3	7E-5	4E-3	2E-4	7E-3	0.01	2E-3	0E+0	0E+0	0.08	3E-4	0E+0
OTH_{NM}	2E-4	3E-6	2E-6	9E-6	1E-3	2E-6	4E-5	3E-5	2E-7	2E-4	1E-5	2E-3	5E-5	4E-4	4E-5	1E-5	9E-5	2E-4	9E-7	1E-4	5E-5	8E-3	7E-4	7E-4	0E+0	0E+0	0.54	1E-3	0E+0
$METALS_{BASIC}$	3E-6	3E-7	2E-7	9E-7	2E-6	5E-6	6E-6	8E-6	0E+0	1E-5	3E-5	4E-5	6E-4	5E-4	4E-4	1E-5	2E-4	3E-4	3E-5	9E-5	5E-6	4E-4	6E-5	3E-6	0E+0	0E+0	0.29	8E-5	0E+0
$METAL_{PROD}$	4E-4	3E-5	2E-5	9E-5	1E-3	6E-4	3E-4	2E-4	9E-5	3E-4	4E-4	4E-4	4E-4	0.03	3E-3	2E-4	1E-3	1E-3	1E-3	3E-3	4E-4	0.02	8E-3	2E-3	0E+0	0E+0	0.08	2E-3	0E+0
ELECTRONICS	1E-4	3E-5	2E-5	1E-4	8E-4	2E-4	3E-6	5E-4	2E-7	3E-4	2E-4	1E-3	7E-6	1E-3	0.01	1E-3	2E-3	2E-3	3E-4	3E-3	3E-4	6E-3	5E-3	7E-4	0E+0	0E+0	0.03	0.01	0E+0
ELEC.EQUIP	5E-7	2E-8	1E-8	7E-8	1E-7	4E-7	0E+0	1E-6	0E+0	4E-5	3E-6	8E-6	0E+0	5E-5	4E-5	4E-3	1E-4	1E-3	2E-5	6E-4	2E-5	1E-4	5E-3	6E-3	0E+0	0E+0	2E-3	1E-3	0E+0
MACHINERY	0E+0	6E-7	4E-7	2E-6	9E-7	2E-6	0E+0	2E-6	0E+0	4E-5	4E-4	4E-5	1E-5	3E-5	3E-4	5E-3	0.01	2E-3	1E-4	4E-3	2E-3	0.03	0.01	0.01	0E+0	0E+0	0.03	2E-3	0E+0
VEHICLES	4E-7	4E-5	3E-5	1E-4	8E-8	6E-7	2E-7	0E+0	0E+0	7E-6	4E-5	4E-7	3E-6	1E-4	2E-5	3E-7	2E-5	0.02	1E-5	2E-5	3E-6	1E-6	5E-3	4E-4	0E+0	0E+0	0.08	0.02	9E-3
$TRANSP_{OTH}$	1E-5	0E+0	0E+0	0E+0	0E+0	7E-6	0E+0	0E+0	0E+0	0E+0	5E-8	0E+0	0E+0	3E-5	3E-6	1E-6	0E+0	2E-5	1E-3	4E-4	0E+0	7E-6	9E-4	1E-3	0E+0	0E+0	4E-3	2E-3	7E-4
$MANUF_{OTH}$	9E-4	7E-5	5E-5	3E-4	4E-3	1E-3	6E-4	1E-3	3E-4	8E-4	6E-4	7E-4	9E-4	7E-4	3E-4	3E-4	4E-4	4E-4	1E-4	5E-3	2E-3	2E-3	0.02	0.01	0E+0	2E-4	0E+0	4E-3	0E+0
UTILITIES	3E-3	3E-4	2E-4	9E-4	1E-2	6E-3	2E-3	7E-3	3E-3	6E-3	3E-3	7E-3	0.01	3E-3	1E-3	5E-4	9E-4	1E-3	2E-4	2E-3	0.27	1E-3	0.08	0.10	0E+0	3E-3	1E-7	2E-3	0E+0
CONSTRUC	1E-3	1E-5	7E-6	4E-5	7E-4	2E-4	1E-4	2E-4	1E-4	2E-4	8E-5	3E-4	7E-5	1E-4	4E-5	3E-5	9E-5	2E-4	3E-5	3E-4	1E-3	0.04	0.02	1E-3	0E+0	2E-3	0E+0	0.05	0E+0
SERVICES	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0.03	0E+0
DE	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0						
IMP	0.12	4E-3	1E-4	2E-4	0.51	0.07	0.11	0.12	1.85	0.19	0.09	0.09	0.14	0.14	0.06	0.01	0.09	0.11	8E-3	0.08	0.63	0.18	0.39						
GFCF	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0						
INVNT	0.02	0.03	0.05	0.24	0E+0	6E-3	0.05	0.27	0E+0	0.15	0.04	0.50	0.17	1E-4	3E-3	9E-4	7E-3	0E+0	0E+0	6E-3	0.14	4E-3	0.28						
EMISSIONS	-6E-2	0.00	0.00	-0.01	-3E-2	-1E-2	-0.01	-1E-2	-8E-2	-0.01	-0.01	-3E-2	-1E-2	-0.01	0.00	0.00	0.00	0.00	0.00	-1E-2	-3E-1	-5E-2	-6E-1						
WASTE	-0.01	-4E-2	0.00	0.00	-3E-2	-1E-2	-1E-2	-4E-2	0.00	-1E-2	-0.01	-4E-2	-2E-2	-2E-2	-0.01	0.00	-1E-2	-0.01	0.00	-0.01	-2E-1	-2E-1	-7E-1						

Table 9.17 - Evolution of the most significant monetary and material flows of the Portuguese SEM between 1995 and 2017, relative to 1995.

	CONSTRUC -> SERVICES [t/cap]	SERVICES -> CONSTRUC [k€/cap]	HFCE -> SERVICES [k€/cap]	GGFC -> SERVICES [k€/cap]	SERVICES VA [k€/cap]
1995	0.00	0.00	0.00	0.00	0.00
1996	0.18	0.12	0.03	0.05	0.02
1997	0.27	0.22	0.07	0.09	0.08
1998	0.37	0.26	0.11	0.15	0.13
1999	0.77	0.26	0.18	0.20	0.18
2000	1.04	0.46	0.21	0.30	0.24
2001	1.20	0.56	0.23	0.35	0.27
2002	1.19	0.56	0.23	0.36	0.27
2003	0.79	0.64	0.25	0.37	0.27
2004	0.62	0.64	0.29	0.40	0.30
2005	1.04	1.38	0.47	0.37	0.36
2006	1.66	1.39	0.49	0.33	0.37
2007	3.42	1.82	0.56	0.31	0.41
2008	4.00	1.73	0.60	0.32	0.44
2009	3.42	1.70	0.56	0.38	0.44
2010	1.16	0.72	0.60	0.32	0.45
2011	1.07	0.63	0.56	0.24	0.44
2012	0.90	0.37	0.54	0.11	0.39
2013	0.58	0.34	0.49	0.14	0.39
2014	0.79	0.23	0.51	0.13	0.40
2015	0.87	0.28	0.52	0.11	0.41
2017	1.47	0.33	0.97	0.28	0.53

9.5 Supporting information for Chapter 6

Table 9.18 – DMI/cap, GDP/cap, and resource productivity for Estonia, Finland, Croatia, and the UK.

	DMI [t/cap]				GDP [k€/cap]				Resource productivity [€/kg]			
	Estonia	Finland	Croatia	United Kingdom	Estonia	Finland	Croatia	United Kingdom	Estonia	Finland	Croatia	United Kingdom
2000	9.00	34.07	7.94	34.40	21.96	40.91	9.94	15.93	0.41	0.83	0.80	2.16
2001	9.59	34.87	8.25	35.30	22.19	41.40	12.36	15.94	0.43	0.84	0.67	2.21
2002	10.31	35.38	8.69	36.00	24.06	41.84	13.65	15.56	0.43	0.85	0.64	2.31
2003	11.17	35.99	9.20	37.03	29.96	43.44	14.46	15.38	0.37	0.83	0.64	2.41
2004	12.01	37.32	9.59	37.72	28.82	44.01	16.32	15.74	0.42	0.85	0.59	2.40
2005	13.22	38.24	10.02	38.65	30.17	43.98	15.88	15.18	0.44	0.87	0.63	2.55
2006	14.58	39.64	10.53	39.38	32.87	46.37	17.25	14.87	0.44	0.85	0.61	2.65
2007	15.74	41.58	11.11	39.92	36.85	47.07	17.58	14.58	0.43	0.88	0.63	2.74
2008	14.98	41.74	11.33	39.36	34.02	46.95	19.40	13.68	0.44	0.89	0.58	2.88
2009	12.86	38.20	10.53	37.28	31.96	38.65	15.92	11.97	0.40	0.99	0.66	3.12
2010	13.25	39.25	10.40	37.63	33.42	42.21	13.84	11.77	0.40	0.93	0.75	3.20
2011	14.28	40.06	10.40	37.87	36.76	43.15	13.60	11.73	0.39	0.93	0.76	3.23
2012	14.78	39.32	10.21	38.13	37.07	41.01	12.51	11.24	0.40	0.96	0.82	3.39
2013	15.02	38.80	10.20	38.67	38.58	45.66	13.34	11.22	0.39	0.85	0.76	3.45
2014	15.50	38.50	10.24	39.42	37.26	39.33	12.68	11.45	0.42	0.98	0.81	3.44
2015	15.80	38.57	10.55	40.08	36.24	38.18	13.54	10.96	0.44	1.01	0.78	3.66
2016	16.20	39.51	10.98	40.58	36.08	39.55	14.06	10.79	0.45	1.00	0.78	3.76
2017	17.10	40.70	11.39	41.08	42.50	41.32	14.12	10.98	0.40	0.99	0.81	3.74
2018	17.86	41.24	11.77	41.37	45.37	43.45	14.45	10.61	0.39	0.95	0.81	3.90

Table 9.19 – Domestic extraction for Estonia, Finland, Croatia, and the UK per material, in t/cap.

Material	Estonia			Finland			Croatia			United Kingdom		
	2007	2009	2015	2008	2014	2015	2008	2013	2015	2007	2009	2015
FF1	5.87	5.35	6.21	0.95	1.27	0.69	0.65	0.47	0.48	2.38	2.03	1.24
FF2	5.20	4.72	5.67	0.00	0.00	0.00	0.05	0.03	0.04	0.31	0.27	0.17
MM1	0.00	0.00	0.00	0.39	0.83	1.18	0.00	0.00	0.00	0.00	0.00	0.00
MM2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MM3	0.00	0.00	0.00	0.46	0.89	1.16	0.00	0.00	0.00	0.00	0.00	0.00
MM4	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.04	0.04	0.03
MM5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MM6	0.00	0.00	0.00	0.10	0.44	0.45	0.00	0.00	0.00	0.00	0.00	0.00
NM1	8.93	8.33	8.19	21.72	14.54	14.06	8.48	4.35	4.53	3.10	2.15	1.94
NM2	3.06	2.01	1.86	0.60	0.48	0.50	0.75	0.62	0.59	1.39	0.98	0.95
NM3	0.34	0.06	0.04	0.00	0.00	0.00	0.06	0.01	0.00	0.21	0.12	0.10
NM4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NM5	0.06	0.02	0.02	2.19	2.45	2.38	0.40	0.62	0.61	0.07	0.07	0.06
BM1	1.57	1.54	2.58	1.17	1.11	0.98	2.47	2.13	1.89	0.95	1.06	1.05
BM2	0.67	0.64	0.69	0.58	0.51	0.52	0.63	0.60	0.60	1.07	1.00	0.96
BM3	2.82	3.02	5.27	5.75	6.23	6.43	0.67	0.83	0.80	0.09	0.08	0.09
O1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 9.20 – Imports for Estonia, Finland, Croatia, and the UK per material, in t/cap.

Material	Estonia			Finland			Croatia			United Kingdom		
	2007	2009	2015	2008	2014	2015	2008	2013	2015	2007	2009	2015
FF1	2.85	3.39	2.46	4.94	3.54	3.00	1.38	1.23	1.17	1.88	1.80	1.58
FF2	0.15	0.15	0.16	0.73	0.70	0.67	0.24	0.17	0.17	0.22	0.21	0.17
MM1	0.84	0.34	0.55	1.43	1.12	1.00	0.50	0.29	0.34	0.55	0.28	0.37
MM2	0.03	0.02	0.03	0.04	0.04	0.04	0.06	0.05	0.05	0.04	0.03	0.03
MM3	0.03	0.02	0.03	0.25	0.21	0.22	0.02	0.01	0.01	0.03	0.02	0.02
MM4	0.09	0.07	0.13	0.31	0.24	0.23	0.05	0.06	0.06	0.02	0.02	0.02
MM5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MM6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NM1	0.73	0.62	0.67	0.14	0.11	0.10	0.89	0.36	0.35	0.09	0.06	0.10
NM2	0.04	0.03	0.09	0.44	0.48	0.43	0.12	0.08	0.10	0.02	0.00	0.02
NM3	0.13	0.05	0.08	0.33	0.19	0.19	0.13	0.07	0.07	0.05	0.03	0.04
NM4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NM5	0.37	0.33	0.43	0.30	0.12	0.12	0.46	0.20	0.20	0.08	0.42	0.05
BM1	0.26	0.24	0.30	0.26	0.29	0.27	0.16	0.15	0.19	0.20	0.19	0.20
BM2	0.05	0.04	0.07	0.03	0.04	0.04	0.02	0.03	0.05	0.03	0.03	0.03
BM3	1.41	0.58	0.95	2.36	1.21	1.11	0.20	0.14	0.21	0.26	0.19	0.26
O1	0.02	0.02	0.02	0.03	0.02	0.02	0.01	0.01	0.02	0.02	0.01	0.01

Table 9.21 - VA/cap in 2015 constant k€ for Estonia, Finland, Croatia, and the UK, for key years.

Sector	Estonia			Finland			Croatia			United Kingdom		
	2007	2009	2015	2008	2014	2015	2008	2013	2015	2007	2009	2015
AGRICUL	0.40	0.24	0.45	0.83	0.92	0.84	0.46	0.36	0.32	0.23	0.16	0.24
MINING	0.12	0.12	0.19	0.13	0.10	0.11	0.17	0.23	0.15	0.72	0.45	0.38
FOOD	0.23	0.24	0.27	0.51	0.49	0.48	0.38	0.37	0.35	0.54	0.46	0.57
TEXTILES	0.15	0.10	0.13	0.11	0.07	0.07	0.10	0.08	0.08	0.11	0.06	0.13
WOOD	0.25	0.18	0.37	0.26	0.22	0.22	0.05	0.04	0.06	0.07	0.04	0.05
PAPER	0.09	0.07	0.10	0.80	0.63	0.66	0.08	0.06	0.07	0.25	0.16	0.20
PETROLPROD	0.04	0.04	0.07	0.13	0.08	0.11	0.00	0.00	0.00	0.08	0.11	0.06
CHEM&PHARM	0.09	0.06	0.06	0.53	0.58	0.61	0.13	0.13	0.13	0.52	0.40	0.50
PLASTICS	0.07	0.04	0.07	0.23	0.19	0.19	0.05	0.05	0.06	0.18	0.13	0.18
OTHNM	0.18	0.07	0.10	0.26	0.19	0.18	0.12	0.08	0.08	0.13	0.08	0.10
METALSBASIC	0.01	0.00	0.01	0.45	0.24	0.29	0.02	0.02	0.02	0.10	0.04	0.08
METALPROD	0.21	0.16	0.25	0.67	0.45	0.46	0.15	0.14	0.15	0.35	0.22	0.36
ELECTRONICS	0.08	0.07	0.10	2.10	0.78	0.71	0.08	0.04	0.05	0.17	0.13	0.16
ELEC.EQUIP	0.09	0.08	0.11	0.37	0.33	0.33	0.08	0.05	0.06	0.11	0.08	0.11
MACHINERY	0.08	0.04	0.09	0.94	0.81	0.85	0.06	0.06	0.07	0.25	0.13	0.22
VEHICLES	0.05	0.04	0.11	0.10	0.08	0.09	0.02	0.01	0.01	0.19	0.11	0.28
TRANSPOTH	0.01	0.01	0.01	0.11	0.08	0.07	0.06	0.04	0.03	0.21	0.15	0.22
MANUFOTH	0.20	0.16	0.25	0.45	0.36	0.36	0.10	0.09	0.10	0.32	0.22	0.33
UTILITIES	0.37	0.44	0.53	0.90	1.09	1.04	0.24	0.37	0.39	0.82	0.71	0.95
CONSTRUC	1.21	0.68	0.84	2.35	2.07	2.11	0.84	0.48	0.47	2.45	1.45	2.14
SERVICES	7.52	6.79	9.26	21.63	23.26	23.23	6.68	6.12	6.11	27.82	20.87	28.11

Table 9.22 - DMI/cap by sector, in t/cap for key years for Estonia, Finland, Croatia, and the UK.

Sector	Estonia			Finland			Croatia			United Kingdom		
	2007	2009	2015	2008	2014	2015	2008	2013	2015	2007	2009	2015
AGRICUL	5.48	5.53	8.85	7.86	8.07	8.12	3.91	3.67	3.40	2.16	2.19	2.15
MINING	23.53	20.64	22.10	26.51	21.02	20.52	10.84	6.42	6.52	7.59	5.74	4.57
FOOD	0.47	0.28	0.30	0.77	0.53	0.48	0.15	0.16	0.18	0.16	0.15	0.15
TEXTILES	0.06	0.05	0.06	0.02	0.02	0.01	0.02	0.02	0.02	0.01	0.01	0.01
WOOD	0.56	0.25	0.56	0.43	0.15	0.20	0.03	0.03	0.05	0.03	0.02	0.04
PAPER	0.08	0.07	0.10	0.68	0.31	0.31	0.05	0.05	0.06	0.06	0.06	0.04
PETROLPROD	0.07	0.26	0.13	3.67	2.82	1.96	0.01	0.01	0.01	0.63	0.66	0.47
CHEM&PHARM	0.29	0.27	0.28	0.53	0.48	0.43	0.17	0.12	0.14	0.26	0.35	0.16
PLASTICS	0.12	0.07	0.11	0.13	0.09	0.08	0.03	0.04	0.05	0.05	0.06	0.02
OTHNM	0.43	0.29	0.33	0.25	0.18	0.17	0.42	0.16	0.18	0.05	0.04	0.04
METALSBASIC	0.01	0.01	0.02	1.23	1.02	1.00	0.06	0.04	0.04	0.30	0.16	0.20
METALPROD	0.42	0.20	0.33	0.21	0.12	0.11	0.14	0.11	0.12	0.07	0.04	0.05
ELECTRONICS	0.04	0.02	0.16	0.11	0.04	0.06	0.02	0.01	0.01	0.02	0.01	0.01
ELEC.EQUIP	0.09	0.06	0.09	0.08	0.07	0.06	0.06	0.05	0.05	0.03	0.02	0.02
MACHINERY	0.09	0.03	0.06	0.26	0.17	0.17	0.05	0.04	0.04	0.05	0.03	0.04
VEHICLES	0.04	0.02	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.08	0.05	0.05
TRANSPOTH	0.01	0.01	0.01	0.04	0.02	0.02	0.06	0.02	0.03	0.03	0.02	0.02
MANUFOTH	0.20	0.12	0.17	0.06	0.04	0.06	0.05	0.04	0.05	0.04	0.02	0.03
UTILITIES	0.68	0.84	0.38	0.74	0.40	0.57	0.49	0.46	0.46	0.67	0.74	0.67
CONSTRUC	1.35	1.02	0.93	1.13	0.79	0.68	1.13	0.51	0.51	0.27	0.17	0.25
SERVICES	1.50	1.53	1.48	0.79	0.70	0.76	0.71	0.57	0.60	0.56	0.53	0.52

Table 9.23 - DMI/cap by output sector, in t/cap for key years for Estonia, Finland, Croatia, and the UK.

Sector	Estonia			Finland			Croatia			United Kingdom		
	2007	2009	2015	2008	2014	2015	2008	2013	2015	2007	2009	2015
AGRICUL	4.25	4.58	4.89	3.11	2.75	2.81	2.39	2.23	2.22	1.20	1.20	1.21
MINING	6.74	6.55	6.81	6.97	12.20	14.83	1.55	0.69	0.76	2.10	1.72	1.42
FOOD	1.60	1.35	2.78	2.86	2.37	2.18	1.58	1.43	1.24	0.99	0.95	0.89
TEXTILES	0.19	0.16	0.15	0.07	0.05	0.04	0.06	0.05	0.05	0.04	0.04	0.02
WOOD	1.44	0.87	2.35	1.89	1.57	1.56	0.17	0.16	0.20	0.05	0.04	0.04
PAPER	0.21	0.17	0.21	2.47	1.60	1.81	0.10	0.09	0.10	0.09	0.08	0.06
PETROLPROD	0.63	2.22	2.48	2.54	2.53	1.75	0.03	0.01	0.01	0.98	0.91	0.57
CHEM&PHARM	0.79	0.69	0.79	1.50	1.14	0.77	0.37	0.23	0.27	0.48	0.50	0.31
PLASTICS	0.19	0.16	0.17	0.24	0.14	0.11	0.06	0.05	0.06	0.08	0.05	0.03
OTHNM	1.92	0.83	1.34	0.70	0.37	0.29	0.77	0.45	0.50	0.25	0.16	0.13
METALSBASIC	0.04	0.02	0.08	1.72	1.31	1.21	0.11	0.07	0.06	0.37	0.21	0.23
METALPROD	0.61	0.38	0.52	0.25	0.16	0.15	0.12	0.10	0.11	0.07	0.05	0.04
ELECTRONICS	0.12	-0.20	0.34	0.17	0.08	0.13	0.04	0.02	0.02	0.04	0.02	0.02
ELEC.EQUIP	0.15	0.14	0.17	0.16	0.10	0.10	0.11	0.09	0.08	0.04	0.03	0.02
MACHINERY	0.17	0.08	0.10	0.57	0.32	0.31	0.09	0.06	0.07	0.07	0.04	0.05
VEHICLES	0.08	0.05	0.09	0.08	0.05	0.04	0.01	0.01	0.01	0.15	0.11	0.09
TRANSPOTH	0.02	0.02	0.02	0.15	0.07	0.06	0.12	0.03	0.05	0.04	0.03	0.03
MANUFOTH	0.42	0.26	0.30	0.18	0.08	0.11	0.10	0.08	0.08	0.07	0.05	0.04
UTILITIES	6.64	4.51	5.19	1.33	0.99	0.62	0.66	0.48	0.50	1.00	0.99	0.72
CONSTRUC	2.49	2.27	2.17	8.14	3.94	2.84	4.79	2.51	2.40	1.98	1.42	1.64
SERVICES	6.81	6.45	5.52	10.42	5.25	4.09	5.18	3.70	3.75	3.01	2.48	1.94

Table 9.24 – Resource productivity in €/kg for Estonia, Finland, Croatia, and the UK, for key years.

Sector	Estonia			Finland			Croatia			United Kingdom		
	2007	2009	2015	2008	2014	2015	2008	2013	2015	2007	2009	2015
AGRICUL	0.06	0.04	0.04	0.09	0.10	0.09	0.09	0.08	0.08	0.09	0.06	0.10
MINING	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.03	0.02	0.09	0.08	0.08
FOOD	0.13	0.16	0.09	0.17	0.20	0.21	0.20	0.21	0.24	0.45	0.38	0.50
TEXTILES	0.72	0.60	0.81	1.28	1.21	1.76	1.33	1.57	1.32	3.00	1.63	5.93
WOOD	0.17	0.18	0.15	0.12	0.09	0.10	0.29	0.25	0.26	1.20	0.85	0.68
PAPER	0.32	0.27	0.36	0.18	0.26	0.26	0.59	0.52	0.53	2.05	1.49	2.67
PETROLPROD	0.04	0.02	0.02	0.03	0.02	0.04	0.09	0.20	0.21	0.06	0.09	0.10
CHEM&PHARM	0.06	0.04	0.04	0.17	0.29	0.49	0.22	0.36	0.29	0.64	0.51	1.09
PLASTICS	0.21	0.17	0.33	0.50	0.74	1.01	0.59	0.61	0.68	1.50	1.15	3.23
OTHNM	0.04	0.03	0.04	0.04	0.08	0.12	0.04	0.04	0.04	0.14	0.12	0.16
METALSBASIC	0.13	0.26	0.14	0.19	0.10	0.14	0.14	0.23	0.24	0.27	0.16	0.33
METALPROD	0.27	0.32	0.43	0.94	1.03	1.22	0.49	0.57	0.59	2.83	2.68	4.86
ELECTRONICS	0.56	0.20	0.25	3.60	3.52	3.22	1.07	1.26	1.34	2.96	3.72	6.28
ELEC.EQUIP	0.49	0.39	0.65	1.23	1.72	2.07	0.52	0.42	0.51	2.08	1.79	3.23
MACHINERY	0.46	0.53	0.84	0.82	1.24	1.34	0.52	0.65	0.65	2.89	2.24	3.42
VEHICLES	0.52	0.55	1.13	1.19	1.48	2.09	1.08	0.70	0.99	1.10	0.89	2.83
TRANSPOTH	0.52	0.38	0.53	0.46	0.74	0.81	0.35	0.75	0.46	3.46	3.09	4.51
MANUFOTH	0.43	0.50	0.70	1.21	1.92	1.48	0.61	0.62	0.62	3.16	3.15	5.27
UTILITIES	0.04	0.07	0.07	0.48	0.82	0.96	0.19	0.35	0.38	0.46	0.41	0.74
CONSTRUC	0.17	0.11	0.16	0.12	0.28	0.40	0.08	0.11	0.11	0.57	0.51	0.72
SERVICES	1.10	1.05	1.68	2.08	4.43	5.68	1.29	1.65	1.63	9.25	8.40	14.50

Table 9.25 - PIOT for Estonia in 2015.

	AGRICUL	$MINING_{FF}$	$MINING_{MM}$	$MINING_{NM}$	FOOD	TEXTILES	WOOD	PAPER	$PETROL_{PROD}$	CHEM&PHARM	PLASTICS	OTH_{NM}	$METALS_{BASIC}$	$METAL_{PROD}$	ELECTRONICS	ELEC.EQUIP	MACHINERY	VEHICLES	$TRANSP_{OTH}$	MANUFOTH	UTILITIES	CONSTRUC	SERVICES	HFCE	NPISH	GGFC	EXP	GFCF	INVNT
AGRICUL	1.56	6E-4	1E-4	5E-4	2.31	0.04	1.56	0.07	0E+0	1E-3	6E-4	1E-3	6E-4	2E-3	2E-3	6E-4	6E-4	6E-4	6E-4	0.03	9E-3	0.03	0.29	1.64	3E-3	0.04	2.54	0.07	0.24
$MINING_{FF}$	0.13	0.58	1E-3	4E-3	0.16	5E-3	0.03	0.02	2.78	0.69	5E-3	0.14	0.03	0.02	0.01	5E-3	5E-3	5E-3	5E-3	0.03	6.01	0.05	0.70	0.36	5E-3	0.02	0.69	0.01	0.02
$MINING_{MM}$	1E-6	3E-6	1E-5	5E-5	6E-6	0E+0	2E-6	6E-7	0E+0	8E-5	6E-7	0E+0	1E-4	1E-6	2E-6	6E-7	0E+0	6E-7	6E-7	6E-7	1E-5	0E+0	4E-5	2E-5	0E+0	4E-6	0.02	8E-4	0.04
$MINING_{NM}$	4E-3	0.01	0.05	0.19	0.02	0E+0	9E-3	2E-3	0E+0	0.29	2E-3	1.62	0E+0	4E-3	6E-3	2E-3	0E+0	2E-3	2E-3	2E-3	0.05	2.38	0.14	0.06	0E+0	0.01	0.42	3E-3	-3E-1
FOOD	0.04	7E-5	2E-5	6E-5	0.08	6E-4	2E-3	7E-4	1E-4	2E-3	3E-4	4E-4	7E-5	8E-4	9E-4	2E-4	2E-4	1E-4	7E-5	2E-3	1E-3	2E-3	0.09	0.49	1E-3	6E-3	0.51	0.02	1.62
TEXTILES	1E-4	0E+0	0E+0	0E+0	2E-4	6E-3	4E-4	8E-5	0E+0	2E-4	2E-4	3E-5	0E+0	1E-4	2E-4	3E-5	5E-5	2E-4	5E-5	2E-3	5E-5	4E-4	3E-3	0.03	0E+0	2E-4	0.04	6E-3	0.03
WOOD	7E-4	4E-5	2E-6	7E-6	1E-4	6E-5	0.02	6E-5	5E-6	2E-4	1E-4	2E-4	5E-6	4E-4	6E-5	1E-4	7E-5	1E-4	6E-5	4E-3	3E-4	6E-3	2E-3	1E-3	0E+0	1E-4	1.73	0.04	0.15
PAPER	4E-4	4E-5	2E-5	6E-5	2E-3	3E-4	1E-3	0.01	0E+0	4E-4	2E-4	2E-4	2E-5	6E-4	4E-4	1E-4	8E-5	2E-5	2E-5	3E-4	3E-4	2E-4	0.04	3E-3	0E+0	8E-5	0.32	7E-3	-2E-1
$PETROL_{PROD}$	0.03	6E-3	1E-3	5E-3	7E-3	2E-3	9E-3	3E-3	0.02	0.02	2E-3	0.02	2E-3	6E-3	5E-3	2E-3	1E-3	1E-3	0E+0	4E-3	0.06	0.04	0.23	0.88	0E+0	0.02	2.29	2E-3	-5E+0
CHEM&PHARM	0.04	2E-3	5E-4	2E-3	0.01	0.02	0.04	0.02	6E-3	0.10	0.06	0.01	6E-3	0.05	0.04	0.03	1E-2	6E-3	2E-3	0.03	0.01	0.03	0.13	0.21	0E+0	0.07	0.44	4E-3	0.01
PLASTICS	8E-4	1E-4	0E+0	0E+0	3E-3	5E-4	2E-3	8E-4	0E+0	8E-4	4E-3	6E-4	5E-5	2E-3	4E-3	2E-3	9E-4	2E-3	1E-4	2E-3	7E-4	6E-3	9E-3	5E-3	0E+0	6E-4	0.07	7E-3	0.04
OTH_{NM}	1E-2	2E-3	3E-4	1E-3	0.02	4E-4	0.03	4E-4	0E+0	8E-3	7E-3	0.12	2E-3	0.03	0.05	0.01	4E-4	8E-3	1E-3	0.01	8E-3	0.56	0.08	0.08	0E+0	4E-3	0.37	0.02	0.65
$METALS_{BASIC}$	9E-7	9E-7	0E+0	0E+0	3E-6	0E+0	4E-6	5E-6	0E+0	2E-6	9E-7	2E-6	2E-5	1E-4	5E-5	7E-5	2E-5	1E-5	2E-6	3E-5	6E-6	3E-5	1E-5	2E-6	0E+0	2E-6	0.35	3E-3	-3E-1
$METAL_{PROD}$	1E-3	5E-4	5E-5	2E-4	2E-3	2E-4	3E-3	4E-4	1E-5	5E-4	6E-4	6E-4	5E-4	0.02	5E-3	3E-3	4E-3	2E-3	4E-4	4E-3	1E-3	0.01	9E-3	3E-3	0E+0	3E-4	0.23	0.04	0.10
ELECTRONICS	5E-4	2E-4	2E-5	9E-5	6E-4	1E-4	6E-4	2E-4	0E+0	2E-4	2E-4	2E-4	2E-4	3E-3	0.04	3E-3	1E-3	9E-4	1E-4	2E-3	9E-4	3E-3	0.01	0.02	0E+0	7E-3	0.01	0.04	0.18
ELEC.EQUIP	1E-4	2E-5	4E-6	1E-5	1E-4	2E-5	1E-4	3E-5	0E+0	2E-5	2E-5	3E-5	0E+0	3E-4	2E-3	2E-3	3E-4	2E-4	0E+0	3E-4	2E-4	1E-3	2E-3	2E-3	0E+0	3E-4	0.08	0.01	0.04
MACHINERY	3E-4	2E-4	3E-5	1E-4	1E-4	2E-5	3E-4	3E-5	0E+0	3E-5	3E-5	1E-4	2E-5	7E-4	4E-4	2E-4	6E-4	2E-4	3E-5	4E-4	2E-4	9E-4	2E-3	6E-4	0E+0	2E-4	0.09	9E-3	-3E-2
VEHICLES	4E-5	5E-6	0E+0	0E+0	1E-5	1E-5	8E-5	5E-6	0E+0	5E-6	5E-6	5E-6	5E-6	2E-4	4E-5	3E-5	6E-5	1E-3	1E-5	7E-5	5E-5	1E-4	1E-3	4E-3	0E+0	2E-4	0.07	4E-3	-2E-3
$TRANSP_{OTH}$	1E-4	3E-5	0E+0	0E+0	3E-5	0E+0	3E-5	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	2E-4	3E-5	3E-5	6E-5	3E-5	9E-4	3E-5	3E-5	2E-4	4E-3	9E-5	0E+0	4E-4	8E-3	2E-3	6E-3
MANUFOTH	4E-3	6E-4	5E-5	2E-4	1E-3	5E-4	3E-3	8E-4	8E-5	4E-4	4E-4	6E-4	3E-4	2E-3	3E-3	8E-4	1E-3	6E-4	2E-4	8E-3	3E-3	4E-3	0.02	0.02	0E+0	2E-4	0.09	0.04	0.08
UTILITIES	0.07	0.02	3E-3	0.01	0.06	0.02	0.08	0.04	6E-3	0.05	0.02	0.04	0.02	0.07	0.05	0.02	0.01	9E-3	2E-3	0.03	0.58	0.05	0.82	0.80	0E+0	0.26	0E+0	0.13	-2E+0
CONSTRUC	0.07	0.01	8E-4	3E-3	0.02	6E-3	0.04	6E-3	2E-3	4E-3	7E-3	0.02	3E-3	0.04	0.04	0.01	8E-3	3E-3	1E-3	0.04	0.13	1.18	1.47	0.08	0E+0	0.02	0E+0	1.18	-6E-3
SERVICES	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	1.47	1.50
DE	8.54	11.88	0E+0	10.11	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0						
IMP	0.32	0.04	0.02	0.04	0.30	0.06	0.56	0.10	0.13	0.28	0.11	0.33	0.02	0.33	0.16	0.09	0.06	0.05	9E-3	0.17	0.38	0.93	1.48						
EMISSIONS	-3E-1	-4E-2	-1E-2	-3E-2	-9E-2	-4E-2	-1E-1	-5E-2	-2E-2	-5E-2	-4E-2	-9E-2	-3E-2	-1E-1	-7E-2	-3E-2	-2E-2	-1E-2	-2E-3	-5E-2	-8E-1	-2E-1	-2E+0						
WASTE	-9E-2	-6E-3	-6E-3	-5E+0	-5E-2	-5E-3	-3E-1	-7E-2	-5E+0	-6E-3	-7E-3	-1E-1	-2E-3	-3E-2	-2E-2	-8E-3	-4E-3	-5E-3	-6E-4	-2E-2	-6E+0	-7E-1	-5E-1						

Table 9.26 - PIOT for Finland in 2015.

	AGRICUL	MINING$_{FF}$	MINING$_{MM}$	MINING$_{NM}$	FOOD	TEXTILES	WOOD	PAPER	PETROL$_{PROD}$	CHEM&PHARM	PLASTICS	OTH$_{NM}$	METALS$_{BASIC}$	METAL$_{PROD}$	ELECTRONICS	ELEC.EQUIP	MACHINERY	VEHICLES	TRANSP$_{OTH}$	MANUFOTH	UTILITIES	CONSTRUC	SERVICES	HFCE	NPISH	GGFC	EXP	GFCF	INVNT
AGRICUL	1.31	1E-4	6E-4	6E-4	1.64	9E-3	1.75	1.45	1E-3	0.03	9E-3	1E-3	0.03	3E-3	0.01	1E-3	6E-3	4E-4	5E-3	0.03	0.03	0.10	0.34	2.17	3E-4	0.06	0.29	0.02	0.19
MINING$_{FF}$	0E+0	0E+0	0E+0	0E+0	4E-3	0E+0	1E-3	0.01	0.36	0.02	1E-3	6E-3	0.08	0E+0	0E+0	0E+0	1E-3	0E+0	0E+0	0E+0	0.17	1E-3	0.02	2E-3	0E+0	0E+0	1E-2	2E-4	9E-4
MINING$_{MM}$	4E-3	5E-5	0.02	0.02	3E-3	5E-5	2E-4	0.02	2E-4	0.07	7E-4	0E+0	0.60	7E-4	1E-3	2E-4	6E-3	5E-5	1E-3	3E-3	3E-3	0E+0	0.02	5E-3	0E+0	4E-3	0.04	3E-3	0.14
MINING$_{NM}$	0.03	3E-4	0.13	0.12	0.02	3E-4	1E-3	0.13	1E-3	0.42	4E-3	1.17	0E+0	4E-3	7E-3	1E-3	0.04	3E-4	7E-3	0.02	0.02	2.31	0.14	0.03	0E+0	0.02	0.25	3E-3	0.02
FOOD	0.01	3E-6	4E-5	4E-5	0.04	1E-4	3E-4	2E-3	3E-4	2E-3	2E-4	2E-4	2E-4	2E-4	3E-4	1E-4	5E-4	3E-5	1E-4	2E-4	7E-4	2E-3	0.05	0.18	4E-5	5E-3	0.12	0.01	1.69
TEXTILES	3E-5	0E+0	3E-6	3E-6	7E-5	1E-3	3E-5	2E-4	1E-5	9E-5	7E-5	2E-5	6E-5	9E-5	2E-4	3E-5	1E-4	2E-5	9E-5	5E-4	7E-5	2E-4	2E-3	0.02	0E+0	9E-5	5E-3	2E-3	2E-3
WOOD	4E-3	6E-5	6E-4	6E-4	3E-3	4E-4	0.22	0.06	9E-4	6E-3	3E-3	4E-3	2E-3	7E-3	4E-3	3E-3	9E-3	1E-3	5E-3	0.04	9E-3	0.19	0.11	0.02	0E+0	3E-3	0.92	9E-3	0.32
PAPER	4E-3	2E-5	1E-3	1E-3	0.02	2E-3	7E-3	0.36	2E-3	0.01	6E-3	7E-3	6E-3	4E-3	7E-3	4E-3	1E-2	7E-4	9E-4	4E-3	0.01	0.02	0.24	0.08	1E-5	0.01	2.44	0.03	-2E+0
PETROL$_{PROD}$	0.03	1E-4	6E-3	6E-3	1E-2	1E-3	5E-3	0.02	0.07	0.05	3E-3	1E-2	0.02	5E-3	4E-3	3E-3	9E-3	6E-4	1E-3	5E-3	0.05	0.05	0.33	0.35	0E+0	3E-3	1.25	0.01	0.05
CHEM&PHARM	0.02	6E-5	2E-3	2E-3	8E-3	5E-3	9E-3	0.05	0.02	0.13	0.04	8E-3	0.02	1E-2	0.01	8E-3	0.01	1E-3	3E-3	5E-3	8E-3	0.02	0.08	0.12	1E-5	0.07	0.50	0.01	-1E-1
PLASTICS	7E-4	9E-6	1E-4	1E-4	4E-3	4E-4	1E-3	5E-3	4E-4	2E-3	7E-3	8E-4	1E-3	2E-3	4E-3	3E-3	7E-3	1E-3	8E-4	2E-3	9E-4	0.01	0.02	0.01	0E+0	4E-4	0.05	5E-3	-3E-2
OTH$_{NM}$	8E-3	5E-5	7E-3	7E-3	0.02	1E-3	0.01	0.01	1E-3	0.02	8E-3	0.12	0.03	0.02	0.04	0.01	0.03	3E-3	5E-3	9E-3	0.01	0.76	0.10	0.10	0E+0	0.02	0.08	9E-3	-5E-3
METALS$_{BASIC}$	3E-3	8E-5	2E-3	2E-3	4E-3	6E-4	3E-3	0.01	3E-3	9E-3	4E-3	5E-3	0.22	0.15	0.02	0.03	0.15	8E-3	0.01	0.02	0.02	0.15	0.07	0.02	0E+0	7E-3	0.57	0.02	0.21
METAL$_{PROD}$	2E-3	3E-5	4E-4	4E-4	5E-3	2E-4	4E-3	4E-3	1E-3	3E-3	2E-3	2E-3	0.01	0.03	8E-3	7E-3	0.05	2E-3	4E-3	8E-3	4E-3	0.05	0.03	0.01	0E+0	7E-4	0.05	0.02	0.01
ELECTRONICS	7E-4	2E-5	2E-4	2E-4	1E-3	2E-4	7E-4	3E-3	7E-4	2E-3	7E-4	6E-4	8E-4	1E-3	0.01	3E-3	5E-3	4E-4	4E-4	1E-3	2E-3	4E-3	0.05	0.02	1E-4	0.06	4E-3	0.02	0.01
ELEC.EQUIP	3E-4	4E-6	9E-5	9E-5	7E-4	7E-5	4E-4	1E-3	3E-4	6E-4	4E-4	3E-4	1E-3	1E-3	6E-3	1E-2	8E-3	5E-4	8E-4	2E-3	3E-3	0.01	0.01	0.02	8E-6	4E-3	0.04	0.01	8E-3
MACHINERY	5E-3	8E-5	3E-3	3E-3	6E-3	1E-3	3E-3	0.01	3E-3	4E-3	2E-3	3E-3	0.01	9E-3	0.01	9E-3	0.08	4E-3	6E-3	0.01	1E-2	0.04	0.09	0.04	2E-5	0.01	0.09	0.10	0.03
VEHICLES	5E-5	0E+0	2E-5	2E-5	8E-5	1E-5	4E-5	1E-4	3E-5	7E-5	4E-5	3E-5	9E-5	1E-4	8E-5	6E-5	8E-4	6E-4	6E-5	7E-5	1E-4	5E-4	2E-3	4E-3	0E+0	2E-4	0.05	5E-3	-2E-2
TRANSP$_{OTH}$	2E-4	0E+0	2E-5	2E-5	1E-4	1E-5	7E-5	2E-4	6E-5	9E-5	6E-5	5E-5	3E-4	4E-4	2E-4	2E-4	1E-3	7E-5	7E-3	2E-4	2E-4	1E-3	0.01	2E-3	0E+0	2E-3	0.02	0.01	0.02
MANUFOTH	4E-3	4E-5	7E-4	6E-4	4E-3	5E-4	2E-3	7E-3	2E-3	2E-3	9E-4	2E-3	1E-2	4E-3	5E-3	3E-3	0.01	5E-4	2E-3	0.01	8E-3	0.01	0.04	0.04	0E+0	1E-3	7E-3	0.03	4E-3
UTILITIES	5E-3	1E-4	3E-3	2E-3	0.01	2E-3	5E-3	0.04	6E-3	0.01	4E-3	7E-3	0.03	8E-3	5E-3	3E-3	0.01	7E-4	1E-3	3E-3	0.09	8E-3	0.20	0.09	0E+0	2E-3	0E+0	0.08	-4E-1
CONSTRUC	0.01	9E-5	6E-5	6E-5	5E-3	6E-5	6E-3	0.02	7E-3	1E-2	3E-3	6E-3	9E-3	0.01	8E-3	5E-3	0.02	9E-4	1E-3	0.02	0.07	0.83	1.37	0.01	0E+0	0.30	0E+0	0.88	-1E+0
SERVICES	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	1.48	1.58
DE	7.93	0.69	2.78	16.94	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0						
IMP	0.19	2E-3	0.09	0.02	0.48	0.01	0.20	0.31	1.96	0.43	0.08	0.17	1.00	0.11	0.06	0.06	0.17	0.02	0.02	0.06	0.57	0.68	0.76						
EMISSIONS	-8E-2	-4E-4	-2E-2	-1E-2	-3E-2	-4E-3	-1E-2	-8E-2	-8E-2	-1E-2	-1E-2	-2E-2	-8E-2	-2E-2	-1E-2	-9E-3	-3E-2	-2E-3	-3E-3	-1E-2	-2E-1	-1E-1	-8E-1						
WASTE	-4E-4	-2E-4	-2E+0	-1E+1	-1E-1	-2E-3	-3E-1	-7E-1	-1E-2	-2E-1	-5E-2	-7E-2	-3E-1	-3E-2	-5E-3	-3E-3	-7E-3	-9E-4	-1E-3	-1E-2	-6E-1	-3E+0	-2E-1						

Table 9.27 - PIOT for Croatia in 2015.

	AGRICUL	MINING$_{FF}$	MINING$_{MM}$	MINING$_{NM}$	FOOD	TEXTILES	WOOD	PAPER	PETROL$_{PROD}$	CHEM&PHARM	PLASTICS	OTH$_{NM}$	METALS$_{BASIC}$	METAL$_{PROD}$	ELECTRONICS	ELEC.EQUIP	MACHINERY	VEHICLES	TRANSP$_{OTH}$	MANUFOTH	UTILITIES	CONSTRUC	SERVICES	HFCE	NPISH	GGFC	EXP	GFCF	INVNT
AGRICUL	0.39	2E-3	1E-4	3E-4	1.02	9E-3	0.11	0.02	0E+0	9E-3	7E-4	1E-3	4E-4	8E-4	4E-4	7E-4	5E-4	0E+0	2E-3	9E-4	3E-3	1E-2	0.19	1.30	0E+0	0.03	0.54	0.02	0.19
MINING$_{FF}$	0.02	0.18	2E-4	5E-4	0.02	9E-4	2E-3	5E-3	5E-3	0.05	6E-3	0.02	7E-3	3E-3	2E-4	2E-3	1E-3	4E-4	2E-3	2E-3	0.34	7E-3	0.16	2E-3	0E+0	7E-3	0.07	0.03	0.07
MINING$_{MM}$	2E-4	6E-5	9E-5	2E-4	6E-5	8E-6	2E-5	4E-5	0E+0	4E-4	8E-6	0E+0	1E-3	1E-4	0E+0	2E-5	2E-5	0E+0	2E-5	7E-5	1E-4	0E+0	3E-3	2E-5	0E+0	8E-6	1E-4	1E-3	0.04
MINING$_{NM}$	0.06	0.02	0.03	0.09	0.02	3E-3	6E-3	0.01	0E+0	0.16	3E-3	1.57	0E+0	0.04	0E+0	9E-3	9E-3	0E+0	6E-3	0.03	0.04	2.17	1.06	9E-3	0E+0	3E-3	0.41	3E-3	4E-3
FOOD	0.04	8E-4	4E-5	1E-4	0.09	2E-3	2E-3	1E-3	0E+0	6E-3	3E-3	9E-4	2E-4	1E-3	5E-4	1E-3	7E-4	1E-4	7E-4	2E-3	1E-3	6E-3	0.12	0.50	2E-4	0.03	0.21	0.06	0.38
TEXTILES	2E-4	7E-5	3E-6	7E-6	1E-4	3E-3	1E-4	1E-4	0E+0	1E-4	1E-4	6E-5	6E-6	7E-5	3E-5	5E-5	4E-5	2E-5	1E-4	5E-4	9E-5	4E-4	3E-3	0.01	3E-6	1E-3	0.02	9E-3	3E-3
WOOD	6E-4	1E-4	8E-6	2E-5	1E-3	2E-3	5E-3	2E-4	0E+0	2E-4	2E-4	2E-4	1E-5	2E-4	4E-5	1E-4	1E-4	1E-5	2E-4	1E-3	2E-4	4E-3	4E-3	0.02	0E+0	8E-4	0.49	9E-3	-3E-1
PAPER	5E-5	2E-4	2E-5	5E-5	4E-3	3E-4	6E-4	0.01	0E+0	1E-3	4E-4	6E-4	2E-5	3E-4	2E-4	3E-4	2E-4	8E-6	1E-4	4E-4	5E-4	8E-4	0.02	0.02	1E-4	6E-3	0.09	9E-3	-6E-2
PETROL$_{PROD}$	2E-62	6E-63	8E-64	2E-63	3E-63	0E+0	3E-63	0E+0	0E+0	6E-63	0E+0	3E-63	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	3E-63	9E-63	1E-62	1E-61	5E-61	0E+0	3E-63	0.43	3E-4	-4E-1
CHEM&PHARM	0.01	2E-3	9E-5	2E-4	0.01	2E-3	2E-3	3E-3	2E-5	0.03	9E-3	3E-3	1E-3	2E-3	6E-4	2E-3	8E-4	1E-4	9E-4	1E-3	9E-3	6E-3	0.08	0.10	0E+0	3E-3	0.32	0.02	-2E-1
PLASTICS	2E-4	4E-4	3E-5	8E-5	3E-3	4E-4	5E-4	2E-3	0E+0	1E-3	3E-3	6E-4	7E-5	8E-4	5E-4	1E-3	9E-4	2E-4	6E-4	1E-3	4E-4	6E-3	8E-3	9E-3	0E+0	6E-6	0.03	6E-3	-6E-4
OTH$_{NM}$	0.02	0.02	2E-3	5E-3	0.06	3E-3	0.02	4E-3	0E+0	0.02	3E-3	0.18	5E-3	0.02	0.01	0.02	0.01	2E-3	0.01	0.03	0.02	0.81	0.23	0.13	0E+0	3E-3	0.62	0.01	-3E-1
METALS$_{BASIC}$	3E-5	1E-4	2E-6	7E-6	1E-4	9E-6	4E-5	1E-4	0E+0	4E-5	4E-5	9E-5	3E-4	2E-3	8E-5	5E-4	6E-4	5E-5	3E-4	4E-4	9E-5	2E-3	1E-3	2E-3	0E+0	5E-5	0.13	3E-3	-9E-2
METAL$_{PROD}$	3E-3	4E-3	1E-4	3E-4	7E-3	6E-4	3E-3	1E-3	0E+0	2E-3	2E-3	2E-3	1E-3	0.02	1E-3	5E-3	8E-3	7E-4	4E-3	7E-3	2E-3	0.04	0.03	9E-3	0E+0	2E-3	0.05	0.02	8E-3
ELECTRONICS	1E-3	6E-4	2E-5	5E-5	7E-4	8E-5	2E-4	3E-4	0E+0	2E-4	1E-4	3E-4	1E-4	4E-4	1E-3	1E-3	6E-4	4E-5	3E-4	1E-3	7E-4	2E-3	7E-3	9E-3	0E+0	2E-5	1E-3	3E-3	9E-4
ELEC.EQUIP	6E-4	6E-4	1E-5	3E-5	8E-4	4E-5	1E-4	1E-4	0E+0	1E-4	1E-4	1E-4	1E-4	9E-4	3E-3	9E-3	2E-3	2E-4	8E-4	2E-3	1E-3	8E-3	9E-3	0.03	0E+0	4E-5	0.02	9E-3	-1E-3
MACHINERY	7E-4	1E-3	5E-5	1E-4	1E-3	9E-5	4E-4	3E-4	0E+0	2E-4	2E-4	5E-4	1E-4	1E-3	3E-4	8E-4	3E-3	3E-4	1E-3	2E-3	9E-4	4E-3	0.01	9E-3	2E-4	1E-4	0.04	0.01	8E-4
VEHICLES	1E-5	2E-5	9E-7	2E-6	2E-5	2E-5	7E-6	3E-6	0E+0	7E-6	3E-6	7E-6	0E+0	2E-5	3E-6	4E-5	6E-5	2E-4	3E-5	1E-5	1E-5	9E-5	8E-4	1E-3	0E+0	2E-5	0.02	1E-3	-1E-2
TRANSP$_{OTH}$	2E-3	7E-4	2E-5	5E-5	7E-4	6E-5	3E-4	2E-4	0E+0	2E-4	1E-4	3E-4	2E-4	6E-4	1E-4	3E-4	5E-4	2E-5	7E-3	1E-3	6E-4	2E-3	0.01	9E-4	0E+0	7E-3	0.02	0.01	-1E-3
MANUFOTH	6E-3	3E-3	8E-5	2E-4	3E-3	1E-3	1E-3	1E-3	0E+0	1E-3	5E-4	2E-3	8E-4	2E-3	7E-4	1E-3	2E-3	2E-4	2E-3	7E-3	3E-3	1E-2	0.03	0.02	0E+0	7E-4	0.02	0.02	4E-3
UTILITIES	0.02	0.02	8E-4	2E-3	0.02	4E-3	8E-3	9E-3	2E-5	0.01	6E-3	0.01	7E-3	9E-3	2E-3	4E-3	5E-3	4E-4	3E-3	7E-3	0.09	0.02	0.27	0.11	2E-4	0.01	0E+0	0.08	0.04
CONSTRUC	0.02	0.03	1E-3	3E-3	0.06	9E-3	9E-3	8E-3	3E-4	0.02	6E-3	0.01	3E-3	0.02	3E-3	8E-3	1E-2	6E-4	7E-3	0.02	0.07	0.65	0.90	0.98	9E-4	0.49	0E+0	0.66	9E-3
SERVICES	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0.92	2.32
DE	3.29	0.52	0E+0	5.74	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0						
IMP	0.12	0.25	5E-3	0.01	0.18	0.02	0.05	0.06	7E-3	0.14	0.05	0.18	0.04	0.12	0.01	0.05	0.04	5E-3	0.03	0.05	0.46	0.51	0.60						
EMISSIONS	-5E-2	-3E-2	-1E-3	-3E-3	-3E-2	-5E-3	-1E-2	-1E-2	-2E-5	-1E-2	-9E-3	-2E-2	-8E-3	-1E-2	-2E-3	-5E-3	-6E-3	-5E-4	-4E-3	-9E-3	-1E-1	-3E-2	-4E-1						
WASTE	-9E-2	-1E-3	-1E-4	-7E-2	-2E-2	-4E-3	-1E-2	-1E-2	-5E-3	-5E-3	-4E-3	-4E-3	-4E-3	-2E-2	-1E-3	-6E-3	-4E-3	-6E-4	-3E-3	-8E-3	-1E-1	-2E-1	-1E-1						

Table 9.28 - PIOT for the UK in 2015.

	AGRICUL	$MINING_{FF}$	$MINING_{MM}$	$MINING_{NM}$	FOOD	TEXTILES	WOOD	PAPER	$PETROL_{PROD}$	CHEM&PHARM	PLASTICS	OTH_{NM}	$METALS_{BASIC}$	$METAL_{PROD}$	ELECTRONICS	ELEC.EQUIP	MACHINERY	VEHICLES	$TRANSP_{OTH}$	MANUFOTH	UTILITIES	CONSTRUC	SERVICES	HFCE	NPISH	GGFC	EXP	GFCF	INVNT
AGRICUL	0.21	8E-4	4E-5	1E-4	0.81	6E-3	0.02	9E-4	1E-4	3E-3	2E-3	6E-4	2E-3	1E-3	6E-4	4E-4	1E-3	1E-3	1E-3	1E-3	3E-3	0.03	0.11	1.02	2E-5	0.01	0.09	7E-3	0.03
$MINING_{FF}$	7E-4	0.02	1E-4	4E-4	8E-3	4E-4	4E-4	2E-3	0.17	0.03	7E-4	2E-3	5E-3	1E-3	5E-4	5E-4	8E-4	1E-3	1E-3	1E-3	0.25	0.01	0.09	0.11	4E-5	0.03	0.74	3E-3	0.03
$MINING_{MM}$	1E-5	1E-6	3E-5	9E-5	2E-5	7E-7	8E-7	2E-5	9E-7	3E-4	3E-6	0E+0	6E-4	2E-6	2E-6	1E-6	1E-6	4E-6	4E-6	2E-5	3E-5	0E+0	2E-4	8E-5	4E-8	1E-5	2E-3	3E-4	0.02
$MINING_{NM}$	9E-3	6E-4	0.02	0.06	0.01	4E-4	5E-4	1E-2	6E-4	0.19	2E-3	0.53	0E+0	1E-3	9E-4	6E-4	9E-4	2E-3	3E-3	0.01	0.02	1.66	0.14	0.05	2E-5	8E-3	0.14	9E-4	4E-3
FOOD	0.01	1E-4	1E-5	5E-5	0.09	4E-4	1E-4	8E-4	1E-4	6E-3	8E-4	3E-4	4E-4	5E-4	3E-4	3E-4	5E-4	7E-4	5E-4	4E-4	1E-3	3E-3	0.11	0.57	3E-4	0.01	0.12	3E-3	0.11
TEXTILES	7E-6	2E-6	3E-7	1E-6	3E-5	2E-4	4E-6	2E-5	7E-7	3E-5	2E-5	8E-6	6E-6	7E-6	5E-6	4E-6	1E-5	3E-5	2E-5	8E-5	1E-5	8E-5	4E-4	5E-3	8E-8	2E-5	0.02	6E-4	-7E-3
WOOD	1E-4	2E-4	1E-5	5E-5	4E-4	8E-5	8E-3	3E-4	3E-6	2E-4	9E-5	2E-4	6E-5	6E-4	1E-4	1E-4	2E-4	7E-4	4E-4	2E-3	7E-5	0.01	3E-3	5E-3	4E-7	6E-5	0.01	8E-4	0.02
PAPER	2E-4	1E-5	5E-6	1E-5	1E-3	7E-5	6E-5	3E-3	1E-5	3E-4	2E-4	1E-4	3E-5	1E-4	5E-5	7E-5	1E-4	8E-5	6E-5	1E-4	1E-4	3E-4	9E-3	3E-3	2E-7	5E-5	0.10	2E-3	-9E-2
$PETROL_{PROD}$	4E-3	1E-3	2E-4	7E-4	2E-3	3E-4	3E-4	4E-4	7E-3	3E-3	6E-4	1E-3	2E-3	8E-4	3E-4	2E-4	1E-3	4E-4	8E-4	6E-4	3E-3	3E-3	0.06	0.16	0E+0	9E-6	0.39	3E-3	4E-3
CHEM&PHARM	3E-3	9E-4	1E-4	4E-4	5E-3	3E-3	7E-4	4E-3	6E-4	0.05	0.01	3E-3	3E-3	2E-3	1E-3	2E-3	1E-3	6E-3	2E-3	2E-3	2E-3	8E-3	0.04	0.09	4E-5	0.04	0.18	4E-3	-3E-2
PLASTICS	3E-4	4E-5	2E-5	5E-5	2E-3	2E-4	1E-4	3E-4	8E-6	8E-4	2E-3	2E-4	2E-4	4E-4	2E-4	2E-4	7E-4	2E-3	8E-4	6E-4	1E-4	6E-3	7E-3	3E-3	9E-7	7E-5	0.03	2E-3	-2E-2
OTH_{NM}	4E-3	2E-3	8E-4	3E-3	0.02	9E-4	3E-3	7E-4	8E-5	6E-3	6E-3	0.05	6E-3	4E-3	6E-3	3E-3	2E-3	0.01	5E-3	2E-3	4E-3	0.30	0.07	0.08	1E-5	2E-3	0.03	2E-3	7E-3
$METALS_{BASIC}$	1E-5	5E-5	1E-6	4E-6	8E-5	7E-6	7E-6	5E-5	5E-6	6E-5	5E-5	4E-5	1E-3	2E-3	1E-4	3E-4	8E-4	7E-4	4E-4	3E-4	2E-4	2E-3	7E-4	7E-4	8E-7	9E-5	0.25	2E-3	-7E-2
$METAL_{PROD}$	2E-4	4E-4	2E-5	6E-5	1E-3	8E-5	2E-4	1E-4	1E-4	4E-4	6E-4	3E-4	9E-4	5E-3	6E-4	8E-4	4E-3	4E-3	1E-3	1E-3	7E-4	6E-3	5E-3	4E-3	3E-6	6E-5	0.01	2E-3	4E-3
ELECTRONICS	4E-5	1E-4	5E-6	2E-5	3E-4	3E-5	3E-5	4E-5	1E-5	1E-4	8E-5	5E-5	2E-4	2E-4	2E-3	2E-4	5E-4	5E-4	2E-4	1E-3	5E-4	1E-3	3E-3	4E-3	5E-6	2E-4	5E-3	6E-4	2E-3
ELEC.EQUIP	5E-5	8E-5	4E-6	1E-5	2E-4	2E-5	2E-5	3E-5	7E-6	6E-5	6E-5	3E-5	1E-4	2E-4	1E-3	5E-4	5E-4	7E-4	3E-4	1E-3	3E-3	1E-3	3E-3	4E-3	1E-6	5E-5	0.01	1E-3	1E-3
MACHINERY	6E-5	3E-4	2E-5	7E-5	4E-4	7E-5	5E-5	1E-4	2E-5	1E-4	1E-4	9E-5	3E-4	3E-4	3E-4	3E-4	2E-3	1E-3	5E-4	7E-4	4E-4	2E-3	3E-3	2E-3	3E-6	1E-4	0.03	5E-3	-1E-3
VEHICLES	6E-5	4E-5	3E-6	9E-6	8E-5	1E-5	2E-5	2E-5	5E-6	4E-5	4E-5	3E-5	3E-5	1E-4	5E-5	6E-5	8E-4	6E-3	1E-4	2E-4	2E-4	4E-4	4E-3	9E-3	5E-6	5E-5	0.06	1E-2	8E-4
$TRANSP_{OTH}$	8E-5	2E-4	9E-6	3E-5	4E-4	5E-5	4E-5	6E-5	2E-5	1E-4	1E-4	6E-5	3E-4	3E-4	2E-4	2E-4	7E-4	5E-4	5E-3	6E-4	3E-4	2E-3	8E-3	4E-3	1E-5	2E-3	3E-3	7E-3	8E-3
MANUFOTH	2E-4	5E-4	2E-5	8E-5	1E-3	1E-4	2E-4	3E-4	5E-5	3E-4	3E-4	2E-4	9E-4	5E-4	7E-4	7E-4	2E-3	2E-3	6E-4	3E-3	9E-4	4E-3	6E-3	0.01	1E-6	3E-4	0.01	4E-3	1E-3
UTILITIES	4E-3	5E-3	4E-4	1E-3	0.01	2E-3	9E-4	7E-3	4E-3	0.01	5E-3	0.01	0.01	6E-3	2E-3	2E-3	6E-3	5E-3	2E-3	2E-3	0.31	1E-2	0.14	0.17	1E-5	0.06	2E-7	0.02	-5E-1
CONSTRUC	7E-3	3E-3	2E-4	8E-4	2E-3	5E-4	7E-4	2E-3	3E-3	3E-3	1E-3	2E-3	2E-3	2E-3	7E-5	4E-4	2E-3	2E-3	9E-4	3E-3	0.02	0.65	0.61	0.02	9E-6	1E-3	0E+0	0.66	-1E+0
SERVICES	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0.63	0.29
DE	2.11	1.42	2E-5	3.07	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0	0E+0						
IMP	0.05	0.07	6E-3	7E-3	0.15	8E-3	0.04	0.04	0.47	0.16	0.02	0.04	0.20	0.05	9E-3	0.02	0.04	0.05	0.02	0.03	0.67	0.25	0.52						
EMISSIONS	-4E-2	-1E-2	-2E-3	-4E-3	-2E-2	-4E-3	-2E-3	-1E-2	-1E-2	-1E-2	-9E-3	-2E-2	-2E-2	-1E-2	-3E-3	-3E-3	-1E-2	-8E-3	-6E-3	-5E-3	-3E-1	-2E-2	-4E-1						
WASTE	-9E-3	-8E-4	-5E-4	-3E-1	-6E-2	-9E-4	-4E-3	-3E-2	-8E-4	-2E-2	-1E-2	-4E-3	-2E-2	-7E-3	-4E-4	-7E-4	-1E-3	-4E-3	-1E-3	-3E-3	-6E-1	-2E+0	-6E-1						

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